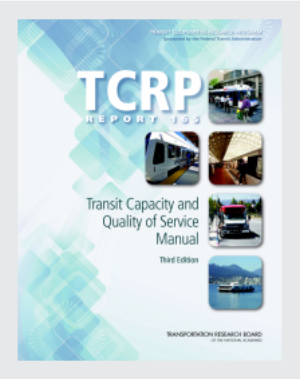
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TRANSIT COOPERATIVE RESEARCH PROGRAM
Sponsored by the Federal Transit Administration

TCRP REPORT 165







Transit Capacity and Quality of Service Manual

Third Edition





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TRANSIT COOPERATIVE RESEARCH PROGRAM

TCRP REPORT 165

Transit Capacity and Quality of Service Manual

Third Edition

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TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions,* published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transportation Association (APTA), Transportation 2000, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA, the National Academies, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time. It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel, appointed by the Transportation Research Board. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

Because research cannot have the desired impact if products fail to reach the intended audience, special emphasis is placed on disseminating TCRP results to the intended end users of the research: transit agencies, service providers, and suppliers. TRB provides a series of research reports, syntheses of transit practice, and other supporting material developed by TCRP research. APTA will arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by urban and rural transit industry practitioners.

The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

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The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

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Each edition of the TCQSM builds on the material developed for previous editions. The full set of contributors to the 1st and 2nd editions is too numerous to list here, but can be viewed in the acknowledgments sections of those editions. The original authors of material that has been retained between editions are acknowledged below.

The Introduction and Concepts chapters (Chapters 1–4) were written by Paul Ryus, with contributions from Buffy Ellis and Linda Cherrington (demand-response transit, Chapter 2), Daniel Fisher of Arup (value of time, Chapter 4), and Jamie Parks of KAI (bicycle access, Chapter 4). Some rail transit concepts material (Chapter 2) originally written for previous editions by Tom Parkinson has been retained, along with ferry transit concepts (Chapter 2) and park-and-ride material (Chapter 4) originally written by Miranda Blogg. Ferry vessel descriptions were updated based on comments provided by William Hockberger, a member of the TRB Committee on Ferry Transportation.

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Chapter 5, Quality of Service Methods, was written by Paul Ryus (fixed-route transit and calculation examples), and Buffy Ellis and Linda Cherrington (demand-responsive transit). Material on quality of service applications is derived from a Florida Department of Transportation guide written by KAI. Some material on transit service coverage originally developed by Peter Haliburton for the 2nd edition has been retained.

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Chapter 8, Rail Transit Capacity, was written by Foster Nichols, updating Tom Parkinson's work from the 1st edition and adding the section on applications. Ian Hood of Arup and several members of TRB committees related to rail transit provided input during chapter development. The core rail capacity methods were originally developed by Tom Parkinson and Ian Fisher through TCRP Project A-8, "Rail Transit Capacity."

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Chapter 10, Station Capacity, was written by Mark Walker. Contributions to the chapter were also made by James Anderson of PB, Daniel Fischer and Eric Rivers of Arup, and Jonathan Brooks of TTI. In addition, David Haase and Jeremy Parnes of New York City Transit contributed data and analysis referenced in the chapter. A major source for Chapter 10 was John Fruin's *Pedestrian Planning and Design*.

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Additional contributors to the development of the TCQSM 3rd edition include Kelly Blume (literature review), Kathryn Coffel and Jessica Horning (focus groups and survey), Jamie Parks and Alison Tanaka (spreadsheet tool development), Kyle Meyer (review website development), Matt Broughton (graphics assistance), and Jackie Olsommer and Dorret Oosterhoff (administrative assistance).

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FOREWORD

By Dianne S. Schwager
Staff Officer
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TCRP Report 165: Transit Capacity and Quality of Service Manual, 3rd edition (TCQSM) is a reference document that provides current research-based guidance on transit capacity and quality of service issues and the factors influencing both. The manual contains background, statistics, and graphics on the various types of public transportation, and it provides a framework for measuring transit availability, comfort, and convenience from the passenger and transit provider points of view. The manual contains quantitative techniques for calculating the capacity and other operational characteristics of bus, rail, demand-responsive, and ferry transit services, as well as transit stops, stations, and terminals. Example calculations are included. The TCQSM and the accompanying CD-ROM are intended for use by a range of practitioners, including transit planners, transportation planners, traffic engineers, transit operations personnel, design engineers, management personnel, teachers, and university students.

HISTORY OF THE TCQSM

The TCQSM, 3rd edition updates and improves the prior manuals. Much of the new content and revised presentation in the TCQSM, 3rd edition is a result of outreach in which users and potential users of TCQSM manual identified new or updated content that would make the manual more relevant to their work.

- **The 1st edition, *TCRP Web-Only Document 6,* was produced in 1999**, assembling for the first time in one place a set of methods for evaluating the capacity of bus and rail transit services and facilities, and introducing a framework for evaluating the quality of service from the passenger point of view. A portion of the material in this edition also formed the basis for the transit chapters in the *Highway Capacity Manual 2000.*
- **The 2nd edition, *TCRP Report 100,* was published in late 2003**. A major focus of this edition was on filling gaps in knowledge. This edition introduced material on ferry transit capacity, expanded coverage of demand-responsive transit (DRT) and Americans with Disabilities Act (ADA) issues, and added guidance on transit preferential treatments and park-and-ride access to transit. This edition tested and enhanced the TCQSM's transit quality of service framework.
- **The 3rd edition of the TCQSM** incorporates the results of new research on transit capacity and quality of service that has occurred in the ten years since the 2nd Edition was developed, including original research conducted as part of the production contract for the manual.

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ORGANIZATION OF THE TCQSM 3RD EDITION

The TCQSM 3rd edition consists of twelve chapters, divided into four main topic areas:

- **Introduction.** The introductory chapter provides a concise guide to the TCQSM. It describes how to use the manual; presents the manual's purpose, scope, and intended users; describes the contents of each chapter; highlights the changes made in the 3rd edition; and describes companion documents to the TCQSM.
- **Concepts Chapters.** The three concepts chapters present concepts, define important terms, and provide illustrations of the extent to which various factors inside and outside a transit agency's control influence transit capacity, speed, reliability, and quality of service.
- **Methods Chapters.** The six methods chapters provide a combination of mode-specific concepts information, computational methods for evaluating a variety of performance measures related to transit operations and quality of service, guidance on potential applications of the methods, and worked examples of performing calculations. These chapters address capacity for bus, DRT, rail transit, ferry transit, and stops and stations.
- **Reference Chapters and Supporting Material.** Two chapters at the end of the manual provide reference material supporting the rest of the manual, including a comprehensive transit glossary, a list of the variables used in the TCQSM's computational methods, and an index to the manual.

The CD-ROM that accompanies the TCQSM provides PDF versions of all the TCQSM chapters for use on tablets and computers; links to all of the TCRP reports referenced in the TCQSM; spreadsheets that help perform the calculations used in the bus, ferry, and rail transit capacity methods; and presentations that introduce the manual and its core material.

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CONTENTS

1-i **Chapter 1** User's Guide
1-1 1. INTRODUCTION
1-1 How to Use the Manual
1-5 How to Find Material of Interest
1-6 Five Key Concepts
1-9 2. PURPOSE AND SCOPE
1-9 Purpose and Objectives
1-9 Scope
1-9 Intended Users
1-9 Potential Applications
1-11 International Use
1-13 3. WHAT'S NEW IN THE THIRD EDITION
1-13 Organizational Changes
1-14 Content Changes
1-18 4. COMPANION DOCUMENTS
1-18 Highway Capacity Manual
1-18 Americans with Disabilities Act (ADA) Standards for Transportation Facilities
1-18 National Fire Prevention Association (NFPA) 130 Standard
1-19 5. REFERENCES

2-i **CHAPTER 2** Mode and Service Concepts
2-1 1. INTRODUCTION
2-1 How to Use This Chapter
2-1 Other Resources
2-2 2. TRANSIT MODES
2-2 Bus Transit
2-6 Demand-Responsive Transit
2-13 Vanpool
2-13 Rail Transit
2-27 Ferry Transit
2-31 3. OPERATING ENVIRONMENTS
2-31 Mixed Traffic
2-32 Semi-exclusive
2-34 Exclusive
2-35 Grade Separated
2-36 4. SERVICE PATTERNS
2-36 Fixed Route
2-42 Demand Responsive
2-48 5. REFERENCES

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3-i **CHAPTER 3** Operations Concepts
3-1 1. INTRODUCTION
3-1 How to Use This Chapter
3-2 Other Resources
3-3 2. CAPACITY, SPEED, AND RELIABILITY
3-3 Overview
3-4 Capacity Concepts
3-10 Speed Concepts
3-13 Reliability Concepts
3-15 3. PASSENGER DEMAND CHARACTERISTICS
3-15 Transit Passenger Demand Patterns
3-18 Demand Related to Demographics
3-18 Demand Related to Land Use
3-21 Demand Related to Transportation Demand Management Strategies
3-23 4. DWELL TIME
3-23 Definition
3-23 Dwell Time Components
3-24 Dwell Time Variability
3-24 Illustrative Impacts of Dwell Time on Capacity
3-27 Illustrative Impacts of Dwell Time on Speed
3-28 5. OPERATING ENVIRONMENT
3-28 Guideway Type and Design
3-29 Traffic and Transit Vehicle Effects
3-30 Illustrative Impacts of Operating Environment on Capacity
3-35 Illustrative Impacts of Operating Environment on Speed
3-37 Impact of Operating Environment on Reliability
3-38 6. STOP AND STATION CHARACTERISTICS
3-38 Vehicle–Platform Interface
3-38 Vehicle Characteristics
3-39 Fare Collection
3-39 Stop Spacing
3-39 Illustrative Impacts of Stops and Stations on Capacity
3-41 Illustrative Impacts of Stops and Stations on Speed
3-44 7. REFERENCES

4-i **CHAPTER 4** Quality of Service Concepts
4-1 1. INTRODUCTION
4-1 Overview
4-2 Roles of Transit
4-4 Performance Points of View
4-7 2. QUALITY OF SERVICE FACTORS
4-7 Customer Satisfaction Research
4-9 Value of Time Research
4-15 3. QUALITY OF SERVICE FRAMEWORK
4-15 Transit Trip Decision-Making Process
4-17 Framework Outline
4-17 Transit Availability
4-32 Transit Comfort and Convenience
4-37 4. QUALITY OF SERVICE, RIDERSHIP, AND SERVICE COSTS
4-37 Quality of Service and Ridership
4-40 Quality of Service and Service Costs

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4-42 5. REFERENCES
4-48 APPENDIX A: EXHIBITS IN METRIC UNITS

5-i **CHAPTER 5** Quality of Service Methods
5-1 1. INTRODUCTION
5-1 How to Use This Chapter
5-2 Other Resources
5-3 2. FIXED-ROUTE QUALITY OF SERVICE
5-3 Overview
5-3 Measures of Availability
5-22 Measures of Comfort and Convenience
5-39 Multimodal Level of Service
5-47 3. DEMAND-RESPONSIVE QUALITY OF SERVICE
5-47 Overview
5-47 Availability Measures
5-56 Comfort and Convenience Measures
5-71 4. APPLICATIONS
5-71 Comprehensive Planning
5-71 Long-Range Transportation Planning
5-75 Statewide Transportation Planning
5-75 Comprehensive Operational Analysis
5-76 Transit Development Plans
5-77 Service Planning
5-77 Corridor Planning
5-78 Demand-Responsive Transit Operations
5-79 5. CALCULATION EXAMPLES
5-79 Calculation Example 1: Service Coverage Analysis (Planning Level)
5-85 Calculation Example 2: Service Coverage Analysis (Detailed)
5-89 Calculation Example 3: Reliability
5-93 Calculation Example 4: Multimodal Transit LOS
5-101 6. REFERENCES

6-i **CHAPTER 6** Bus Transit Capacity
6-1 1. INTRODUCTION
6-2 How to Use This Chapter
6-2 Other Resources
6-3 2. FUNDAMENTALS
6-3 Sources of Bus Delay
6-15 Factors Determining Bus Capacity
6-20 Planning-Level Capacity Values
6-24 3. PREFERENTIAL TREATMENTS
6-24 Overview
6-26 Busways and Freeway Managed Lanes
6-31 Urban Street Bus Lanes
6-40 Transit Signal Priority (TSP)
6-46 Site-Specific Priority Treatments
6-51 Summary
6-53 4. OPERATIONAL TOOLS
6-53 Overview
6-53 Bus Stop Placement
6-55 Bus Stopping Patterns

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6-57 Route Design
6-58 Yield-to-Bus Laws
6-59 Summary
6-60 5. BUS CAPACITY METHODOLOGY
6-60 Introduction
6-61 Step 1: Define the Facility
6-61 Step 2: Gather Input Data
6-63 Step 3: Set a Design Bus Stop Failure Rate
6-66 Step 4: Determine Dwell Time
6-70 Step 5: Determine Loading Area Capacity
6-77 Step 6: Determine Bus Stop Capacity
6-80 Step 7: Determine Facility Bus Capacity
6-84 Step 8: Determine Facility Person Capacity
6-86 6. BUS SPEED METHODOLOGY
6-87 Step 1: Define the Facility
6-87 Step 2: Gather Input Data
6-87 Step 3: Determine Section Maximum Capacity
6-87 Step 4: Determine Base Bus Running Time Rate
6-91 Step 5: Adjust for Skip-Stop Operation
6-92 Step 6: Adjust for Bus Congestion
6-93 Step 7: Determine Average Section Speed
6-94 Step 8: Determine Average Facility Speed
6-95 7. BUS RELIABILITY
6-95 Factors Influencing Bus Reliability
6-96 Scheduling and Holding Strategies
6-96 Relationships of Service Characteristics to Reliability
6-97 Applications of AVL Data
6-97 Forecasting Reliability
6-98 8. APPLICATIONS
6-98 Alternative Mode, Facility, and Service Comparisons
6-98 Fare Collection Technology Changes
6-99 Assessing the Impact of Transit Preferential Treatments
6-100 Diagnosing and Treating Capacity Issues
6-100 Sizing BRT Facilities for a Given Demand
6-102 9. CALCULATION EXAMPLE
6-102 The Situation
6-102 The Question
6-103 Bus Capacity
6-110 Bus Speed
6-112 Options Assessment
6-119 Comments
6-120 10. REFERENCES
6-125 APPENDIX A: EXHIBITS IN METRIC UNITS
6-126 APPENDIX B: DWELL TIME DATA COLLECTION
6-126 Introduction
6-126 Passenger Service Times
6-127 Dwell Times
6-129 APPENDIX C: BUS BUNCHING AND PERSON CAPACITY
6-130 Reference

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7-i **CHAPTER 7** Demand-Responsive Transit
7-1 1. INTRODUCTION
7-1 How to Use This Chapter
7-1 Other Resources
7-3 2. DRT CAPACITY
7-3 Capacity Factors
7-6 Capacity Calculation Procedures
7-8 Importance of Ridership Demand for Estimating DRT Capacity
7-10 3. REFERENCES

8-i **CHAPTER 8** Rail Transit Capacity
8-1 1. INTRODUCTION
8-1 How to Use This Chapter
8-2 Other Resources
8-3 2. RAIL CAPACITY FUNDAMENTALS
8-3 Overview
8-3 Line Capacity
8-9 Person Capacity
8-13 Design Capacity
8-15 Speed
8-16 Positive Train Control
8-16 Reliability
8-18 3. TRAIN CONTROL AND SIGNALING
8-18 Overview
8-18 Fixed-Block Systems
8-19 Cab Signaling
8-19 Moving-Block Systems
8-20 Hybrid Systems
8-21 Automatic Train Operation
8-21 Automatic Train Supervision
8-21 On-Street Preferential Treatments
8-24 4. TRAIN OPERATIONS
8-24 Overview
8-24 Doorway Flow Rates
8-27 Operating Margins
8-31 Skip-Stop and Express Operation
8-31 Passenger-Actuated Doors
8-32 Train and Platform Screen Doors
8-32 Fare Payment
8-33 Station and Platform Design
8-34 Wheelchair Accommodations
8-40 System Design
8-44 5. RAIL SYSTEM CAPACITY METHODOLOGIES
8-44 Introduction
8-44 General Methodology
8-67 Commuter Rail Capacity
8-75 Automated Guideway Transit Capacity
8-77 Ropeway Capacity
8-81 6. APPLICATIONS
8-81 Designing for Future Growth
8-81 Planning-Level Analysis

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8-89 Transit Operations Planning
8-91 Role of Simulation
8-99 Application of Simulation
8-102 Sketch-Planning Tools
8-105 Best Practices for the Use of Simulation Models and Sketch-Planning Tools
8-108 7. CALCULATION EXAMPLES
8-108 Calculation Example 1: High-Capacity Heavy Rail
8-111 Calculation Example 2: Heavy Rail Line with Junction
8-112 Calculation Example 3: Heavy Rail with Long Dwell
8-115 Calculation Example 4: Light Rail with Single-Track Section
8-117 Calculation Example 5: Commuter Rail with Limited Train Paths
8-118 Calculation Example 6: AGT with Short Trains
8-119 Calculation Example 7: AGT with Off-Line Stations
8-120 Calculation Example 8: Aerial Ropeway
8-124 8. REFERENCES
8-126 APPENDIX A: EXHIBITS IN METRIC UNITS

9-i CHAPTER 9 Ferry Transit Capacity
9-1 1. INTRODUCTION
9-1 How to Use This Chapter
9-2 Other Resources
9-3 2. FERRY SERVICE AND FACILITIES
9-3 Ferry Service
9-5 Ferry Terminals
9-14 3. FERRY SCHEDULING AND SERVICE PLANNING
9-14 Port Dwell Time
9-16 Departure Clearance Time
9-16 Transit Time
9-17 Arrival Time
9-17 Operating Margin
9-18 Pedestrian Movements
9-18 Service Planning
9-21 4. VESSEL CAPACITY
9-22 Berth Capacity
9-27 Dock Capacity
9-28 5. PASSENGER AND AUTO CAPACITY
9-30 6. CALCULATION EXAMPLES
9-30 Calculation Example 1: Vessel Service Time (Passengers)
9-32 Calculation Example 2: Vessel Service Time (Automobiles)
9-33 Calculation Example 3: Berth Capacity
9-35 7. REFERENCES

10-i CHAPTER 10 Station Capacity
10-1 1. INTRODUCTION
10-1 Chapter Overview
10-1 How to Use This Chapter
10-2 Other Resources
10-2 Station Design Capacity
10-2 Access for Persons with Disabilities

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10-3 Emergency Evacuation
10-4 Security
10-5 2. STATION TYPES AND CONFIGURATIONS
10-5 Overview
10-5 Bus Stops
10-6 Transit Centers
10-7 Busway and BRT Stations
10-8 Light Rail and Streetcar Stations
10-8 Heavy Rail and AGT Stations
10-9 Commuter Rail Stations
10-10 Ferry Docks and Terminals
10-10 Intermodal Terminals
10-10 Passenger Amenities in Stations
10-13 3. PASSENGER CIRCULATION
10-13 Introduction
10-13 Pedestrian Level of Service
10-15 Station Access
10-20 Horizontal Circulation
10-24 Vertical Circulation
10-29 Platforms and Waiting Areas
10-31 4. VEHICLE CIRCULATION AND STORAGE
10-31 Transit Vehicles
10-34 Private Vehicles
10-38 5. STATION ELEMENTS AND THEIR CAPACITIES
10-38 Introduction
10-39 Station Access
10-43 Horizontal Circulation
10-48 Vertical Circulation
10-55 Platforms and Waiting Areas
10-58 Interactions Between Station Elements
10-58 Alternative Performance Measures for Sizing Station Circulation Elements
10-62 6. APPLICATIONS
10-62 Alternative Mode and Alignment Comparisons
10-63 Alternative Station Location and Features Comparisons
10-63 Remodeling an Existing Station
10-64 Addressing a Specific Capacity Issue in an Existing Station
10-64 Comprehensive Analysis of Passenger Circulation
10-67 Pedestrian Microsimulation
10-73 7. CALCULATION EXAMPLES
10-73 Calculation Example 1: Suburban Transit Center Design
10-76 Calculation Example 2: Stairway Sizing
10-79 Calculation Example 3: Platform Sizing
10-81 Calculation Example 4: Escalator Queuing Area
10-83 Calculation Example 5: Multiple Pedestrian Activities in a Facility
10-85 Calculation Example 6: Complex Multilevel Station
10-88 Calculation Example 7: Application of Pedestrian Microsimulation Software
10-91 8. REFERENCES
10-94 APPENDIX A: EXHIBITS IN METRIC UNITS

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11-i **CHAPTER 11** Glossary and Symbols
11-1 1. GLOSSARY
11-1 A
11-4 B
11-8 C
11-14 D
11-16 E
11-17 F
11-20 G
11-21 H
11-22 I
11-23 J
11-24 K
11-24 L
11-27 M
11-29 N
11-30 O
11-32 P
11-36 Q
11-36 R
11-40 S
11-47 T
11-56 U
11-58 V
11-59 W
11-59 Y
11-60 Z
11-61 2. LIST OF SYMBOLS
12-1 **CHAPTER 12** Index

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Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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CHAPTER 1
USER'S GUIDE

1. **User's Guide**
2. *Mode and Service Concepts*
3. *Operations Concepts*
4. *Quality of Service Concepts*
5. *Quality of Service Methods*
6. *Bus Transit Capacity*
7. *Demand-Responsive Transit*
8. *Rail Transit Capacity*
9. *Ferry Transit Capacity*
10. *Station Capacity*
11. *Glossary and Symbols*
12. *Index*

CONTENTS

1. INTRODUCTION 1-1
How to Use the Manual 1-1
How to Find Material of Interest 1-5
Five Key Concepts 1-6

2. PURPOSE AND SCOPE 1-9
Purpose and Objectives 1-9
Scope 1-9
Intended Users 1-9
Potential Applications 1-9
International Use 1-11

3. WHAT'S NEW IN THE THIRD EDITION 1-13
Organizational Changes 1-13
Content Changes 1-14

4. COMPANION DOCUMENTS 1-18
Highway Capacity Manual 1-18
Americans with Disabilities Act (ADA) Standards for Transportation Facilities 1-18
National Fire Prevention Association (NFPA) 130 Standard 1-18

5. REFERENCES 1-19

LIST OF EXHIBITS

Exhibit 1-1 TCQSM Chapter Organization..... 1-2
Exhibit 1-2 Measurement Unit Abbreviations Used in the TCQSM 1-11

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1. INTRODUCTION

The *Transit Capacity and Quality of Service Manual* (TCQSM, *1*) was initially published in 1999 as a comprehensive reference resource for public transit practitioners and policy makers. It assembled for the first time in one place a set of methods for evaluating the capacity of bus and rail transit services and facilities, and introduced a framework for evaluating the quality of transit service from the passenger point of view.

Whereas the 1st Edition was primarily a synthesis document, with the quality of service framework its main contribution, the 2nd Edition (*2*) sought to fill gaps in knowledge. This edition introduced material on ferry transit capacity, expanded coverage of demand-responsive transit (DRT) and Americans with Disabilities Act (ADA) issues, and added information about transit preferential treatments and park-and-ride access to transit. It also made changes to the quality of service framework based on user testing and additional research, including adding pedestrian environment considerations to the assessment of transit service coverage and adding a new measure of transit reliability, headway adherence. The 2nd Edition, published in late 2003 as *TCRP Report 100,* went on to become TCRP's best-selling report.

This 3rd Edition of the TCQSM incorporates new research on transit capacity and quality of service topics published since the 2nd Edition was developed, including original research conducted as part of the production contract for the manual. This edition is also significantly reorganized in response to user feedback. The "What's New" section of this chapter describes the major changes from the 2nd Edition.

The TCQSM is a reference work that provides current research-based guidance on the following topics:

- **Evaluating quality of service,** reflecting how passengers perceive the quality of the transit service offered and provided, while also considering the transit provider's needs and objectives.
- **Measuring transit capacity, speed, and reliability,** and the factors that influence them—these are important operational concepts that ultimately affect the cost of providing transit service and the demand to use the service.
- **Sizing elements of transit stops and stations**—for example, platform areas, fare collection elements, and passenger and vehicle circulation elements.
- **Guidance on ways to positively influence all of the above,** including their potential effects on operations, operating costs, and existing ridership demand.

HOW TO USE THE MANUAL

The TCQSM has a relatively broad scope and is written to satisfy the information needs of a variety of audiences. As a result, it contains a lot of information and its size may be intimidating to first-time readers. However, once familiar with basic capacity and quality of service concepts, most users will only need to use individual chapters, or portions of chapters, for any given application. This section describes how the manual is organized and how to quickly find information.

Organization of the Manual

The TCQSM 3rd Edition consists of twelve chapters, divided into four main topic areas: (*a*) introduction, (*b*) concepts, (*c*) methods, and (*d*) reference material, as illustrated in Exhibit 1-1.

Introduction Chapter

This introduction chapter (Chapter 1) provides a guide to the rest of the manual:

Organization of Chapter 1.

- Section 2 presents the manual's purpose, scope, and intended users.
- Section 3 describes the contents of each chapter.
- Section 4 highlights the changes made since the 2nd Edition.
- Section 5 describes companion documents to the TCQSM that may need to be consulted when performing certain types of analyses.

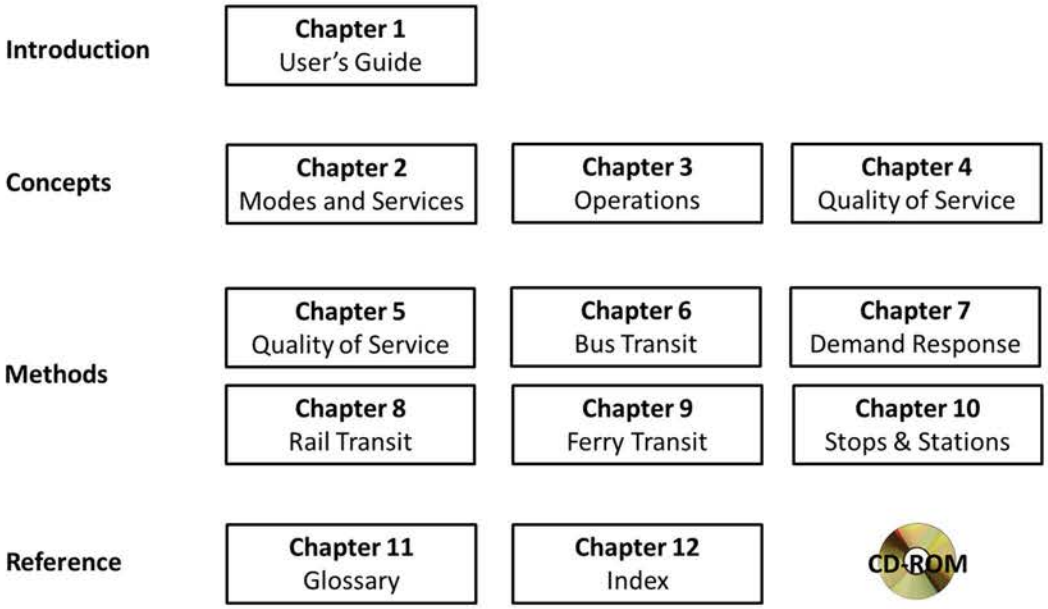


Exhibit 1-1
TCQSM Chapter Organization

Concepts Chapters

The three concepts chapters present concepts, define important terms, and provide illustrations of the extent to which various factors inside and outside a transit agency's control influence transit capacity, speed, reliability, and quality of service.

Fixed-route transit service operates on a defined route according to a defined schedule. Demand-response transit has a flexible route, schedule, or both.

- *Chapter 2, Mode and Service Concepts,* introduces the major transit modes addressed by the TCQSM—bus transit, DRT, rail transit, and ferry transit—along with their submodes (e.g., light rail, heavy rail, commuter rail) and the types of vehicles used for service. The chapter also describes route and network service patterns for fixed-route and DRT services. This chapter provides a useful introduction to public transit to those who have not worked in the area or studied it before.
- *Chapter 3, Operations Concepts,* is all about transit speed, capacity, and reliability and how various factors in and out of a transit agency's control influence them. The chapter defines speed, capacity, and reliability; describes how passenger

demand patterns, dwell time, operating environment (right-of-way type), and stop and station characteristics affect them; and presents a series of graphs illustrating the relative impacts of various factors on transit capacity and speed. Ideally, readers will be familiar with this chapter's contents prior to using any of the methods presented in the mode- and facility-specific capacity chapters (Chapters 6–10).

- *Chapter 4, Quality of Service Concepts,* describes the many roles transit plays within a community and the different perspectives that different stakeholders bring when considering the performance of transit service. *Quality of service focuses on the passenger perspective.* This chapter presents the important quality of service factors that have been identified by research, introduces the quality of service framework that is the focus of Chapter 5, and describes the relationship of changes in quality of service to both ridership and service costs. Readers will ideally be familiar with this chapter prior to applying Chapter 5's methods, but a broader audience will be interested in the topic from the standpoint of why quality of service is important to customer satisfaction and, ultimately, ridership generation and retention.

Methods Chapters

The focus of the methods chapters is on providing computational methods for evaluating quality of service, a specific transit mode or facility's capacity, and related performance measures. Engineers and planners who wish to perform capacity and quality of service analyses will find step-by-step instructions within the Methodology sections of these chapters. Worked problems illustrating the calculation process are provided within the chapters' Calculation Examples sections.

Most chapters also provide supporting material that will be of interest to broader audiences. The first few sections of most capacity-focused chapters (Chapters 6–10) provide *mode-specific concepts* information that supplements the general concepts material in Chapter 3, Operations Concepts. This information will be useful for staff, consultants, and students working with or learning about a specific transit mode or transit passenger facilities. Most chapters also provide *applications* sections that show how a chapter's methods can be incorporated into common transit planning and operations activities.

There are six methods chapters:

- *Chapter 5, Quality of Service Methods,* provides methods, applications, and examples of evaluating fixed-route and demand response transit availability, comfort, and convenience from the passenger perspective. The chapter also presents a method for evaluating transit level of service as part of a multimodal evaluation.
- *Chapter 6, Bus Transit Capacity,* presents factors specific to bus transit that impact bus capacity, speed, and reliability, and describes the infrastructure treatments and operational measures that can improve bus performance in one or more of these areas. Individual sections provide computational methods for evaluating bus capacity and speed, while a section on bus reliability presents more general information on the causes of bus unreliability, as research has not yet developed computational methods for forecasting reliability.

- *Chapter 7, Demand-Responsive Transit*, describes the factors that influence DRT capacity, presents four potential approaches for estimating the number of vehicles and vehicle service hours required to serve a given demand for DRT service, and points readers to several sources for estimating DRT demand.
- *Chapter 8, Rail Transit Capacity,* begins with sections on rail-specific capacity concepts and primers on train control and signaling and train operations. Computational methods are provided for estimating the capacity of various modes and configurations of rail transit systems, including guidance on measuring or estimating input values used by the methods.
- *Chapter 9, Ferry Transit Capacity,* starts with sections describing the aspects of ferry service, facilities, scheduling, and service planning that are unique to the mode. Computational methods are provided for estimating the number of ferry vessels per hour that a dock or berth can accommodate, along with the number of passengers and autos that can be carried onboard vessels.
- *Chapter 10, Station Capacity,* begins by discussing three themes that appear throughout the chapter: access for persons with disabilities, emergency evacuation, and security. The chapter describes the range of transit stops and stations that exist and their typical features, the variety of passenger circulation features found within stations, and methods for evaluating and sizing those features. The chapter also describes options for transit vehicle, private vehicle, and bicycle circulation and storage outside of stations.

Reference Chapters and Supporting Material

Glossary and Index

Two chapters at the end of the manual provide reference material supporting the rest of the manual. *Chapter 11, Glossary and Symbols,* provides a comprehensive transit glossary along with a list of the variables used in the TCQSM's computational methods. *Chapter 12, Index,* as its name suggests, provides an index to the manual.

CD-ROM

The CD-ROM that accompanies the manual provides supplemental material that supports the printed manual:

- **PDF chapter files.** The CD-ROM provides PDF versions of each TCQSM chapter that can be copied to computers, tablets, and other devices for easier portability. Users may also wish to print out the chapter(s) they use most often as an alternative to the larger book. The PDF versions of the chapters also include hyperlinks that allow readers to jump directly to a cross-reference or a document referenced by the manual.
- **Computational spreadsheets.** To assist TCQSM users in applying the methods presented in the bus, rail, and ferry capacity chapters, the CD-ROM provides Microsoft Excel spreadsheets that automate these modes' computational methods. *Neither TRB nor the research team that developed the TCQSM provide support for these spreadsheets.* Other chapters' methods are either readily performed by hand or are better suited for other types of software tools, such as GIS software.

- **Reference library.** The CD-ROM provides links to PDF versions of all of the TCRP reports referenced in the manual.
- **Training material.** To assist new users in applying TCQSM methods, the CD-ROM provides a series of narrated PowerPoint presentations ranging from a half-hour to an hour in length that introduce the main quality of service and capacity concepts and methods provided in the TCQSM. The CD-ROM also provides an executive summary of the manual in PDF format, particularly designed to educate transit agency management and board members about how the manual can be used to help improve agency activities.

Website

TRB's Committee on Transit Capacity and Quality of Service maintains the www.tcqsm.org website on a volunteer basis. At a minimum, the website is anticipated to provide links to major new research relevant to the TCQSM that is released prior to the next major TCQSM update, any errata or clarifications for the manual that the committee develops, and links to the electronic version of the manual and supporting material. Other features may also be provided on the website, depending on committee member interest and time availability.

HOW TO FIND MATERIAL OF INTEREST

There are a variety of ways to quickly find material of interest within the manual:

- **Tables of Contents.** The manual's front matter provides a master table of contents, and individual chapters provide a table of contents and list of exhibits (tables and figures) specific to that chapter. Readers can browse the section heads to identify which sections are of interest to them.
- **"How to Use" sections.** The preceding "How to Use the Manual" section provides an overview of the manual's organization. Each chapter also provides an Introduction section that outlines the chapter's contents, provides a "How to Use This Chapter" section, and points to related material in other chapters and on the CD-ROM.
- **Index.** The index (Chapter 12) identifies where key material is discussed in different sections of the manual.
- **PDF chapters.** The PDF versions of individual chapters can be searched for specific words or phrases. The PDF file's bookmarks list all of the subsections within a given chapter, not just the main subsections listed in the chapter table of contents. All hyperlinks in the PDF files are active at the time of this printing and can be used to quickly get to supporting information.
- **Reference library.** Links to all of the TCRP reports referenced by the TCQSM are included on the CD-ROM. These reports provide background about how TCQSM methods were originally developed and—for topics tangential to the TCQSM's scope—provide details not covered in the TCQSM.

- **Hyperlinks.** A number of other documents referenced by the TCQSM were available on the Internet at the time of writing. Hyperlinks to these documents are provided in each chapter's References section.
- **Margin notes.** Margin notes, like the one to the left about the changeable nature of hyperlinks, are used to highlight key points of interest.

Hyperlinks, like all Internet content, are subject to change. If a link no longer works, try searching for the document name in an Internet search engine.

FIVE KEY CONCEPTS

Five key concepts appear throughout the manual. While these concepts are fleshed out in Chapters 3 and 4, they are introduced here because they are so fundamental to understanding and applying the manual.

Quality of Service

Quality of service is the overall measured or perceived performance of transit service from the passenger's point of view.

While there are many valid perspectives for assessing transit performance, the TCQSM focuses on the passenger or customer point-of-view, while acknowledging that transit operators must strike a balance between the quality of service that passengers would ideally like and the quality of service that a transit agency (*a*) can afford to provide or (*b*) would reasonably provide, given the demand for transit service.

The performance measures used to describe quality of service are different from the financial and output-focused performance measures that have traditionally been used in the transit industry. Quality of service focuses on two areas:

1. *Transit availability*—Is transit service an option for a given trip?
2. *Transit comfort and convenience*—If transit service is an option, how attractive is it to potential passengers?

The quality of service provided depends on the operating decisions made by a transit agency within the constraints of its budget, particularly decisions as to where transit service should be provided, how often and how long it is provided, and how it is provided. These decisions in turn, are often guided by the agency's goals and objectives.

Capacity

Capacity reflects the maximum number of transit vehicles, persons, or both, that can travel past a particular location in a given period of time under specified conditions. There are several types of capacity discussed in the TCQSM:

- *Maximum (theoretical) capacity* reflects the greatest number of persons or transit vehicles that can be served *under any circumstance*. Maximum capacity is an unstable—and thus unreliable—form of operation. In the case of persons, maximum capacity is achieved under crush loading conditions, when as many people are squeezed onto a vehicle as is physically possible—a condition that North American passengers will only accept under exceptional circumstances. Consequently, maximum capacity should not be used for typical planning and operations applications.

Unless the TCQSM specifically states "maximum capacity," design capacity is meant.

- *Design (achievable, practical) capacity* reflects the number of persons or transit vehicles that can be served *at a specified quality of service* (e.g., design loading level, design reliability level). The TCQSM estimates design capacity, except when the term "maximum capacity" is specifically used. Greater volumes of persons or transit vehicles than the design capacity may be served on occasion, but not on a regular basis.
- *Vehicle (bus, train, vessel) capacity* is measured in vehicles per hour and expresses how many transit vehicles can pass a point in an hour.
- *Passenger capacity* is measured in persons per vehicle and expresses how many persons a transit vehicle can carry at a design passenger loading level.
- *Person capacity* is measured in persons per hour and expresses how many persons can pass a point in an hour. It is the product of vehicle and passenger capacity.

Speed and Reliability

Because speed and reliability are not included in the TCQSM's title, they can be easily overlooked amid all of the manual's other content. Furthermore, because capacity is not an issue for many transit agencies, it can be easy to assume that the manual's capacity chapters have no application to small- and mid-sized transit agencies. However, that assumption would be a mistake.

Speed (or, more accurately, travel time) and reliability are important quality of service attributes to passengers and thus influence transit ridership. At the same time, speed and reliability directly influence the time scheduled for a transit vehicle on a route. The scheduled travel time, in turn, determines the number of vehicles required to operate the route at a given service frequency and thus the route's operating and capital costs. Ridership and the cost of providing service are issues that affect all sizes of transit agencies.

The same factors that affect transit capacity also affect transit speed and reliability. Therefore, speed and reliability are addressed side-by-side with capacity in the manual's concepts and methods chapters. Although determining transit capacity may not be the ultimate goal of an analysis, calculating it allows other useful information, such as speed and reliability, to be determined.

Definitions

The transit industry, like many others, has developed its own vocabulary over the years. To someone new to public transit, these terms may be unfamiliar. To help these readers, the TCQSM uses *italics* in the text to identify terms and phrases as they are defined for the first time. The manual also includes a transit glossary (Chapter 11) that compiles all of these terms, plus many others used in transit planning and operations outside the areas of capacity and quality of service.

Complicating matters, the use of terminology is not consistent across the industry. Many transit systems have their own specific, historically derived, terminology: a motorman and guard on one system can be an operator and conductor on another. Modal definitions can be confusing. What is clearly light rail by definition may be termed streetcar, semi-metro, or rapid transit in a specific city. It is recommended that in these cases local usage should prevail. However, it is important to be aware of the

TCQSM's definition of a particular term when applying TCQSM methods, as it may differ from local usage.

Local Data

The TCQSM has compiled data and methods from a variety of sources and produces estimates that reflect average conditions. However, the manual recommends that for the best results, *local data should be used whenever possible,* as every location will have its own unique characteristics that may not reflect North American averages. When local data are not available, the TCQSM's default values may be substituted. In these cases, it is recommended that the sensitivity of important results to changes in assumptions be tested. The series of illustrative exhibits in Chapter 3, Operations Concepts that show the impacts of various factors on speed and capacity can be used to identify which assumptions may be particularly important to check.

2. PURPOSE AND SCOPE

PURPOSE AND OBJECTIVES

The *Transit Capacity and Quality of Service Manual* (TCQSM) provides transportation practitioners with a consistent set of techniques for evaluating the quality of service and capacity of transit services, facilities, and systems. The manual's objectives include providing the latest research results on estimating and assessing the capacity, speed, reliability, and quality of service transit services, facilities, and systems; providing methods for performing these estimates and assessments; and presenting computational examples illustrating the application of the manual's methods.

SCOPE

The TCQSM is the primary source document incorporating research findings on transit capacity, speed, reliability, and quality of service. A companion document, the *Highway Capacity Manual 2010* (*3*), presents methods for evaluating the quality of service of roadway, pedestrian, and bicycle facilities.

The TCQSM is not a standards document. The methods contained within the TCQSM, while representing the best available knowledge at the time of publication, do not set policies regarding a desirable or appropriate quality of service or capacity of a transit service, facility, or system.

The TCQSM does not provide tools for directly estimating the ridership generated by a particular transit service or system, although it does provide guidance on changes in ridership that might be expected to accompany changes in quality of service, and also provides information on the relative contributions of land use, demographic, and transportation demand management (TDM) to ridership. Readers are encouraged to refer to texts on travel demand modeling for more information on transit ridership estimation.

INTENDED USERS

The TCQSM is intended for use by a range of practitioners, including transit planners, transportation planners, traffic engineers, transit operations personnel, design engineers, management personnel, teachers, and university students. To use the manual effectively and to apply its methodologies, some technical background is desirable, typically university-level training or technical work in a public agency or consulting firm.

POTENTIAL APPLICATIONS

The TCQSM has many potential applications, and provides "Applications" sections within its methodological chapters that describe how the methods can be applied to address real-world transit operations, planning, and design needs. Example applications include:

- **Training.** The manual's concepts chapters provide an introduction to transit modes, operations, and quality of service to readers new to the transit industry. Potential users include new agency employees in their first job in the transit

agency, new transit agency board members, consulting staff who have not previously worked on transit projects, and university students and professors.

- **Reference.** The manual is filled with useful information that can be looked up as needed. Examples include service times associated with different fare-collection methods, areas taken up by persons carrying large objects, ridership responses to changes in quality of service, and a comprehensive transit glossary.
- **Guidance.** The manual provides guidance on a number of topics within its scope, including potential applications and effects of transit preferential treatments and operational tools (for example, transit signal priority, curb extensions, and stop consolidation), the role of simulation in operations analysis, and ways to design transit systems to accommodate future growth.
- **Service Standards Development.** The TCQSM's quality of service material is presented in a manner that facilitates the development of passenger-focused service standards. Quality of service tables for different factors (service frequency, passenger loading, etc.) describe both the passenger and transit operator perspectives associated with different service levels, and the accompanying text describes the potential ridership and operating cost implications of changes in quality of service.
- **Service Evaluation.** TCQSM methods can be used to diagnose and treat operational issues. The manual also provides standard definitions of quality of service–related performance measures that can be used for one-time service evaluations, incorporated into an agency performance-measurement program, or used as a part of a peer review process.
- **What-If Questions.** The manual's methods can be used to evaluate the transit operations and quality of service impacts of potential changes (e.g., introducing a new fare-collection system or developing a bus lane on a street). The manual's concepts material can be used to support an agency's response to service-related questions (e.g., from passengers, board members, or the media); it can also be used by transit and planning agencies to identify issues to consider when contemplating introducing new transit modes or service types.
- **Planning.** The manual's contents support both sketch-planning applications, providing quick, approximate answers about the expected operational performance and quality of service of a particular mode or alternative (via graphs and tables), or more precise answers, using the manual's computational methods. Potential uses include transit development plans, long-range transportation plans, and alternatives analyses.
- **Design.** The TCQSM's computational methods can be used to support a variety of transit design activities, including sizing transit centers (e.g., number of bus bays to provide), designing BRT service (e.g., platform length needed to meet a given ridership demand using a particular type of vehicle while providing a specified quality of service), and sizing passenger circulation elements of new and remodeled transit stations.

INTERNATIONAL USE

Applications

In producing the TCQSM with metric units, TRB has taken a step toward making these methods and procedures more applicable to international work. However, the user of the manual is cautioned that the majority of the research base, the default values, and the typical applications are from North America, particularly the United States. Although there is considerable value in the general methods presented, their use outside of North America will likely require calibrating the inputs to TCQSM methods to local conditions, particularly in regard to (*4*):

- Differences in passenger sizes and tolerances for crowding, which may lead to higher design loads than would be accepted in North America;
- Differences in transit vehicles from those used in North America, including vehicle types, sizes, number of doors, and interior layouts;
- Differences in the composition of traffic on streets used by transit vehicles, particularly the amount of 2- and 3-wheeled vehicles on the road and the number of pedestrians crossing the road;
- Differences in driving cultures with respect to obeying the rules of the road;
- Differences in ability to convert roadway space to transit lanes; and
- Differences in labor costs compared to North America, which may make transit service feasible under different conditions than in North America.

The World Bank has published a reference document (*4*) that highlights these differences and provides capacity procedures for developing cities that are modeled on TCQSM methods, but which use inputs typical of the conditions found in those cities.

Measurement Units

This edition of the TCQSM has been published in dual units, U.S. customary and metric. In general, U.S. customary units are presented first, with metric units as supplemental units, except in cases where the source material used metric units as the primary units, in which case metric units are presented first. Exhibit 1-2 provides common measurement unit abbreviations used in the TCQSM.

Exhibit 1-2
Measurement Unit Abbreviations Used in the TCQSM

Measurement Type	US Customary Units	Metric Units
Length, width, depth, distance	inches (in.) feet (ft) miles (mi)	millimeters (mm) meters (m) kilometers (km)
Area	acres (acre)	hectares (ha)
Time	seconds (s) minutes (min) hours (h)	seconds (s) minutes (min) hours (h)
Speed, travel time rate	miles per hour (mi/h) minutes per mile (min/mi)	kilometers per hour (km/h) minutes per kilometer (min/km)
Acceleration	feet per second squared (ft/s^2)	meters per second squared (m/s^2)
Capacity	vehicles per hour (veh/h) passengers per hour (p/h)	vehicles per hour (veh/h) passengers per hour (p/h)
Space	passengers per square foot (p/ft^2)	passengers per square meter (p/m^2)

When converting between measurement units, an equivalent level of precision is used. For example, the range of subway platform lengths of 300 ft to more than 1,000 ft is presented as 90 m to more than 300 m (i.e., rounded to a comparable level of precision). The 40-ft standard bus is given as 12 m in metric units. A maximum train speed of 50.1 mi/h (i.e., presented with one decimal of precision) would be shown as 80.6 km/h in metric units.

3. WHAT'S NEW IN THE THIRD EDITION

Each edition of the TCQSM builds on the foundation laid by the preceding edition, while adapting the presentation to meet current user needs and incorporating the latest research findings. The work of TCRP Project A-15C, which developed this edition of the TCQSM, included an extensive user outreach effort (including focus groups in six locations in the U.S. and Canada and an online survey) to obtain user feedback on the 2nd Edition. This feedback helped shape the 3rd Edition's organization and content. In addition, TCRP Project A-15C reviewed new research performed since the development of the 2nd Edition to identify areas where existing content could be updated. The results of this work can be seen in the changes to the manual's organization and content that are described in this section.

ORGANIZATIONAL CHANGES

The user outreach effort identified that the TCQSM has a variety of users who possess a range of backgrounds, both technical and non-technical. The latter group of users wants to know about transit capacity and quality of service concepts and about the relative impacts of various factors on capacity and quality of service, but does not need to perform specific calculations. To help this group of users, the 3rd Edition provides a clear separation between concepts and computational methods both through the presentation of chapters within the overall manual and through the presentation of material within individual chapters. This approach provides non-technical users with the information they need while lessening the perception that the TCQSM is solely an engineering reference. At the same time, the TCQSM still provides a full range of material for technical users, and all of the information that might be used in a computation (e.g., default values) is now provided alongside the methods they are used in, rather than being split between concepts and methods. Calculation examples are still provided, and the manual's computational spreadsheets have been updated.

Another significant change is that background material that ages rapidly (e.g., ridership statistics) has been removed from the TCQSM and replaced with references to sources for the latest information. This was done in response to user feedback that the material made the TCQSM seem dated as time passed after its publication date, even though the manual's core concepts and methods were still up-to-date.

Finally, the outreach revealed that, in the absence of other comprehensive reference works, many users look to the TCQSM for information that lies outside the TCQSM's scope. While the TCQSM cannot be everything to everybody, this edition takes particular care to refer readers to references tangentially related to the TCQSM that may provide the information they are looking for. Thus, the TCQSM provides the framework for capacity and quality of service analysis and identifies the necessary inputs to computational methods, but does not necessarily provide the tools for estimating every input to a method, possibly relying instead on references to other specialty documents.

CONTENT CHANGES

This section summarizes important content changes—both concepts and methods—by chapter. All chapters have many other small changes, mainly designed to improve the presentation of material or to update statistics and examples.

Chapter 2: Mode and Service Concepts

This chapter incorporates much of the material from Part 2, Transit in North America, in the 2nd Edition. New trends that appeared in the first decade of the 2000s in transit vehicle types (e.g., low-floor vehicles, different power sources) and their resulting impacts on transit speed and capacity are discussed. The demand-response transit material has been updated with information about the impacts on technology on service provision and the latest ADA requirements. The latest trends in North American fixed-guideway transit are described, such as the growing number of bus rapid transit (BRT) and modern streetcar services, and an expansion in the number and size of light rail systems. A new section has been added describing transit service patterns and their potential quality of service impacts. Finally, guidance has been added on transitioning demand-response service types to ones providing more or less flexibility.

Chapter 3: Operations Concepts

Chapter 3 incorporates the transit capacity and speed concepts material that previously appeared in Parts 4–6 (Bus, Rail, and Ferry Capacity, respectively) in the 2nd Edition. The presentation of these concepts in the 3rd Edition is intended to be mode-neutral to the extent possible, as several different modes are often capable of providing a desired capacity, speed, or both. Many new figures appear in the chapter that illustrate the relative impact of specific factors on transit capacity and speed, to help readers better understand which factors have the greatest influence.

Based on user feedback, a new section has been added on passenger demand characteristics, summarizing the latest research on the relative influence of demographics and transportation demand management (TDM) strategies on ridership. In addition, guidance on land use densities capable of supporting a given level and type of transit service has been updated and expanded. Other new material includes a section on the influence of transit operating environment (right-of-way) on capacity, speed, and reliability.

Chapter 4: Quality of Service Concepts

Concepts material that previously appeared in Part 3, Quality of Service, in the 2nd Edition is presented in Chapter 4 in the 3rd Edition. A new section has been added on passenger perceptions of value of time at different stages of their trip and under different conditions. Information on average walking distances to transit has been updated based on new research, and material on pedestrian, bicycle, and park-and-ride access to transit has been expanded. A new section is provided on how passengers schedule their trips to compensate for unreliable service and the resulting impacts on overall passenger travel time.

In response to user feedback on the 2nd Edition, additional information is provided on ridership responses to changes in quality of service, based on new research. Also, a

new section has been added that discusses the potential operating and capital cost implications of improving quality of service.

Chapter 5: Quality of Service Methods

Chapter 5 incorporates the remainder of the material found in Part 3, Quality of Service, in the 2nd Edition. The biggest change in this section is the elimination of level of service (LOS) letters associated with the transit quality of service measures. This was done in response to user feedback (primarily from transit agencies) that the LOS letters were an impediment to adopting and using the manual's quality of service framework because the letters were too closely associated with school grades. Eliminating the letters has also allowed the quality of service tables to show more or fewer service levels, as appropriate, rather than being forced to fit the levels to the six letters, as before. Furthermore, the quality of service tables now include a column presenting the transit agency point of view alongside the passenger point of view, to better illustrate the trade-offs involved in moving from one service level to another. In combination, these changes are designed to make it easier for transit agencies to develop service standards that incorporate quality of service, while balancing an agency's goals regarding service delivery with its budgetary constraints.

At the same time, recognizing that other users (primarily metropolitan planning organizations [MPOs] and roadway agencies) use LOS to evaluate other modes and are generally comfortable with the LOS concept, transit LOS has not been completely removed from the manual. The multimodal transit LOS measure developed by NCHRP Project 3-70, "Multimodal Level of Service Analysis for Urban Streets," has been added to meet the needs of transportation planners and engineers. This measure provides a single transit LOS letter as its output, while incorporating most of the factors included in the manual's transit quality of service framework. This measure can also be incorporated into an overall evaluation of the quality of service provided to all roadway users—transit passengers, pedestrians, bicyclists, and motorists. The multimodal transit LOS measure also addresses another user concern with the TCQSM's LOS system, specifically, that interpreting and reporting six different LOS measures was difficult.

The fixed route quality of service framework has also changed in that the stop, route, and system elements of the framework have been removed. (Previously, each quality of service measure was associated with either stop, route, or system evaluation.) Instead, guidance is provided for each element of the framework on its application to stop, route, and system evaluation, as appropriate. In addition, the demand-responsive transit framework has been completely updated.

The final major change is that a new section on applications has been added, demonstrating the potential usage of the TCQSM's quality of service measures in a variety of planning and operations analysis contexts.

A number of other smaller changes have also been made. Additional information is provided on evaluating transit access at a stop level, particularly bicycle access to transit. Information about the space consumed by transit passengers and their items has been updated. An additional measure of transit reliability, *excess wait time,* is introduced. The basis of the transit–auto travel time measure has changed from the absolute difference in travel times to a ratio of travel times, to allow it to be applied more easily in different sized communities. A section has been added on safety and security performance measures. Finally, the computational examples have been

updated to reflect the changes to the quality of service framework and to add an example of evaluating multimodal transit LOS.

Chapter 6: Bus Transit Capacity

Chapter 6 incorporates the majority of the fixed route bus material previously found in Part 4 of the 2nd Edition, Bus Transit Capacity. The section on transit preferential treatments has been split into two sections: one on infrastructure treatments (updated based on new research) and one on operations strategies. The bus capacity method, previously separated into separate busway, bus lane, and mixed traffic methods, is now presented as a unified method, with a set of step-by-step instructions. The bus speed method is now also presented step by step, and the calculation of base bus speed has been updated to allow the speed to be calculated directly for any combination of bus stop spacing, dwell time, posted speed, and bus acceleration characteristics. Material on bus reliability has been moved into a new section in the chapter and updated based on the latest research. Finally, a new section on applying the bus methods to real-world planning and design applications has been added.

Smaller changes to the chapter include a new table on bus performance characteristics, updates to the table of passenger service times associated with different fare collection methods, and introduction of a *boarding lost time* factor that accounts for the time required for boarding passengers to make their way to a bus at bus stops with more than one loading area.

Chapter 7: Demand-Responsive Transit

The DRT material previously found in Part 4, Bus Transit Capacity, in the 2nd Edition has been moved into its own chapter in the 3rd Edition. This material has been completely updated and includes a discussion of the factors that influence DRT capacity, a discussion of available methods for estimating DRT capacity in different operating environments, and a discussion of the importance of ridership demand in estimating DRT capacity.

Chapter 8: Rail Transit Capacity

The majority of the material that previously appeared in Part 5, Rail Transit Capacity, in the 2nd Edition now appears in Chapter 8. Significant new material has been added on the respective roles of simulation and sketch planning tools in evaluating rail capacity. Other new material includes a discussion of the role of the vehicle–platform interface in influencing capacity, along with a discussion of platform screen doors. The discussions of design capacity and on-street rail preferential treatments have been updated. The capacity equations, while producing the same results as before, have been adjusted to (*a*) match the way percentages are entered elsewhere in the manual (e.g., 0.75 instead of 75) and (*b*) clarify the units embedded in conversion factors.

Chapter 9: Ferry Transit Capacity

Ferry transit material formerly found in Part 6, Ferry Transit Capacity, in the 2nd Edition has moved to Chapter 9 in the 3rd Edition. The basic methodology is the same as before, but additional material has been added throughout the chapter, particularly related to the flow of passengers through ferry terminals and impacts of security procedures on overall capacity.

Chapter 10: Station Capacity

Material from Part 7, Stop, Station, and Terminal Capacity, in the 2nd Edition now appears in Chapter 10. Information relating to ADA and fire code (NFPA 130) requirements has been updated to reflect the standards in effect at the time of writing.

Although many of the procedures for sizing individual station elements are unchanged, there have been some significant additions to the chapter. These include a supplemental method for estimating stairway capacity based on the number of pedestrian lanes provided (as opposed to the width-based method) and new sections on platform clearance analysis and alternative performance measures. A new section on applications includes an extensive discussion of the role of simulation in evaluating station pedestrian circulation and the computational examples include new examples of sizing transit centers and applying microsimulation software.

Other changes include expanded descriptions of the various transit station types. A new section devoted to vehicle circulation and storage at stations includes new material on estimating the number of bus berths at off-street bus stops, typical amounts of automobile parking provided at transit stations, and bicycle parking provisions. Finally, updated information on fare purchase and fare control is provided.

Chapter 11: Glossary and Symbols

The glossary has been updated to reflect changes to definitions and new terms that have been added to the 3rd Edition. The list of symbols has been updated to reflect their usage in the 3rd Edition.

4. COMPANION DOCUMENTS

This section describes important documents that cover topics outside the TCQSM's scope, and which may need to be consulted when performing a TCQSM analysis.

HIGHWAY CAPACITY MANUAL

The *Highway Capacity Manual 2010* (HCM 2010, *3*) provides methods for estimating vehicle capacity on urban streets. The volume-to-capacity ratio of the curb lane (and possibly the adjacent lane) is an input to the TCQSM's bus capacity method, when buses operate in mixed traffic or in exclusive lanes. The HCM's procedures for estimating bus speeds on urban streets can also be used as an alternative to the TCQSM's procedures, when the specific signal timing used on the street is important to the analysis. Finally, the HCM provides methods for estimating multimodal bicycle, pedestrian, and automobile LOS on urban streets that complement the TCQSM's multimodal transit LOS method.

AMERICANS WITH DISABILITIES ACT (ADA) STANDARDS FOR TRANSPORTATION FACILITIES

The *ADA Standards for Transportation Facilities* (*5*) "apply to the construction or alteration of transportation facilities covered by the ADA." The standards may specify minimum dimensions for transit stop or station elements that are greater than the dimensions determined by Chapter 10 methods as the minimum needed to provide a desired passenger circulation capacity or quality of service.

NATIONAL FIRE PREVENTION ASSOCIATION (NFPA) 130 STANDARD

NFPA 130 (*6*) provides standards for emergency evacuation that must be considered as part of station design. When the minimum size for a station passenger circulation element specified by NFPA 130 is greater than the minimum size determined by TCQSM methods as being needed to provide a desired quality of service, the larger size required for emergency evacuation should be used.

5. REFERENCES

Links to the TCRP reports listed here can also be found on the accompanying CD-ROM.

1. Kittelson & Associates, Inc.; Texas Transportation Institute; and Transport Consulting, Ltd. *TCRP Web-Only Document 6: Transit Capacity and Quality of Service Manual,* 1st Edition. Transportation Research Board, National Research Council, Washington, D.C., January 1999. http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_webdoc_6-a.pdf
2. Kittelson & Associates, Inc.; KFH Group, Inc.; Parsons Brinckerhoff Quade & Douglass, Inc.; and K. Hunter-Zaworski. *TCRP Report 100: Transit Capacity and Quality of Service Manual,* 2nd Edition. Transportation Research Board of the National Academies, Washington, D.C., 2003. http://www.trb.org/Main/Blurbs/153590.aspx
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4. Reilly, J. and H. Levinson. *Public Transport Capacity Analysis Procedures for Developing Cities.* The International Bank for Reconstruction and Development/The World Bank, Washington, D.C., 2011. http://siteresources.worldbank.org/INTTRANSPORT/Resources/336291-1239112757744/5997693-1294344242332/Public-Transport-Capacity-Analysis-Procedures.pdf
5. U.S. Department of Transportation. *ADA Standards for Transportation Facilities.* http://www.access-board.gov/ada-aba/ada-standards-dot.cfm, accessed January 22, 2013.
6. National Fire Protection Association. *NFPA 130 Standard for Fixed Guideway Transit and Passenger Rail Systems.* Washington, D.C., 2010.

CHAPTER 2
MODE AND SERVICE CONCEPTS

1. *User's Guide*
2. ***Mode and Service Concepts***
3. *Operations Concepts*
4. *Quality of Service Concepts*
5. *Quality of Service Methods*
6. *Bus Transit Capacity*
7. *Demand-Responsive Transit*
8. *Rail Transit Capacity*
9. *Ferry Transit Capacity*
10. *Station Capacity*
11. *Glossary and Symbols*
12. *Index*

CONTENTS

1. INTRODUCTION 2-1
How to Use This Chapter 2-1
Other Resources 2-1

2. TRANSIT MODES 2-2
Bus Transit 2-2
Demand-Responsive Transit 2-6
Vanpool 2-13
Rail Transit 2-13
Ferry Transit 2-27

3. OPERATING ENVIRONMENTS 2-31
Mixed Traffic 2-31
Semi-exclusive 2-32
Exclusive 2-34
Grade Separated 2-35

4. SERVICE PATTERNS 2-36
Fixed Route 2-36
Demand Responsive 2-42

5. REFERENCES 2-48

LIST OF EXHIBITS

Exhibit 2-1 Trends in U.S. Bus Sizes 2-2
Exhibit 2-2 Trends in U.S. Bus Vehicle Power Sources 2-2
Exhibit 2-3 Bus Vehicle Type Examples 2-4
Exhibit 2-4 Bus Submodes Illustrated 2-5
Exhibit 2-5 Examples of Vehicles Used in Demand-Responsive Transit 2-6
Exhibit 2-6 Heavy Rail Transit Examples 2-14
Exhibit 2-7 Light Rail Examples 2-17
Exhibit 2-8 Commuter Rail Examples 2-19
Exhibit 2-9 AGT Examples 2-22
Exhibit 2-10 Monorail Examples 2-22
Exhibit 2-11 Funicular and Elevator Examples 2-23
Exhibit 2-12 Aerial Ropeway Examples 2-25
Exhibit 2-13 Cable Car Examples 2-26
Exhibit 2-14 Ferry Vessel Types 2-29
Exhibit 2-15 Mixed-Traffic Operation Illustrated 2-32
Exhibit 2-16 Semi-exclusive Operation Illustrated 2-32
Exhibit 2-17 Potential Enforcement Issues with Semi-exclusive and Exclusive Lanes 2-33
Exhibit 2-18 Exclusive Transit Operation Illustrated 2-34
Exhibit 2-19 Grade-Separated Operation Illustrated 2-35
Exhibit 2-20 Fixed-Route Stopping Patterns Illustrated 2-36
Exhibit 2-21 Trunk-and-Branch LRT Route Design (Portland) 2-38
Exhibit 2-22 Trunk-and-Branch BRT Route Design (Brisbane) 2-39
Exhibit 2-23 BRT Feeder Service via Grid Network (Los Angeles) 2-40
Exhibit 2-24 Examples of Fixed-Route Networks 2-41
Exhibit 2-25 Examples of DRT Trip Patterns 2-42
Exhibit 2-26 DART Criteria for Fixed-Route and DRT Service 2-47

1. INTRODUCTION

Chapter 2 of the *Transit Capacity and Quality of Service Manual* (TCQSM) is the first of three chapters that presents basic concepts that are applied in later chapters presenting capacity and quality of service methods. This chapter introduces the transit modes used in the U.S. and Canada and discusses how service using these modes can be developed.

Organization of Chapter 2.

- Section 2 describes and illustrates each of the transit modes—bus, demand responsive, vanpool, rail, and ferry transit—and their submodes.
- Section 3 describes the operating environments (rights-of-way) that transit service can operate in, along with general descriptions of their impacts on capacity, speed, and reliability.
- Section 4 describes the service patterns applied by fixed route and demand-responsive transit services and the situations in which they are typically used.
- Section 5 is a list of references used to develop the material in this chapter.

HOW TO USE THIS CHAPTER

This chapter introduces the various transit modes and how they operate. While readers who are new to the transit industry will get the most benefit out of this chapter, other readers may find value in the summaries of industry trends in vehicle design, propulsion, and transit agency usage; technology; and service types. Because industry terminology is not standardized, this chapter also serves as a reference that defines the transit modes and operating environments presented in subsequent chapters.

Unlike previous editions of the TCQSM, no lists of transit agencies operating particular modes are provided, nor are lists of ridership and other details of specific agencies or transit lines provided. This material ages rapidly and readers are referred instead to the up-to-date information available through the National Transit Database (NTD) and the American Public Transportation Association's (APTA's) annual *Public Transportation Fact Book.*

www.ntdprogram.gov
www.apta.com

OTHER RESOURCES

Other TCQSM material related to this chapter includes:

- The "What's New" section of Chapter 1, User's Guide, which describes the changes made in this chapter from the 2nd Edition;
- Chapter 3, Operations Concepts, which describes the effects of operating environment on achievable transit vehicle speeds and capacities; and
- The manual's CD-ROM, which provides links to of all of the TCRP reports referenced in this chapter.

2. TRANSIT MODES

BUS TRANSIT

Overview

The bus is the most commonly used form of public transport in North America. In 2011, it accounted for 52% of all U.S. passenger trips by transit and 56% of transit trips on larger Canadian transit systems that reported to APTA. There were estimated to be more than 1,200 bus systems in operation in the U.S. in 2010 (*1*). The bus mode is highly flexible in that service can be provided by many different types of vehicles (discussed below), can operate on many different types of rights-of-way (discussed in Section 3), and can implement a variety of stopping patterns (discussed in Section 4).

Vehicle Types

Bus service can be provided by vehicle types ranging from minibuses to articulated and double-deck buses, allowing the type of bus used to be matched to the type and quality of service desired to be operated and the required capacity. The standard 40-ft (12-m) bus has historically been the most widely used type of bus in the U.S., but its share of the total bus fleet dropped noticeably during the first decade of the 2000s, as shown in Exhibit 2-1, as usage of both larger and smaller buses increased.

Exhibit 2-1
Trends in U.S. Bus Sizes

	Share of U.S. Bus Fleet	
Bus Size	**2001**	**2010**
Articulated bus (60-ft/18-m length)	3.0%	5.7%
Standard bus (non-articulated, >35 seats)	71.1%	59.9%
Small bus (25–35 seats)	11.6%	16.5%
Minibus (<25 seats)	14.3%	17.9%

Source: Federal Transit Administration (*2*).

Diesel fuel has historically been the most common power source for transit buses in the U.S., but the use of alternative fuels increased noticeably during the first decade of the 2000s (Exhibit 2-2). Reasons for choosing alternative fuels can include environmental benefits (e.g., reduced or eliminated bus exhaust emissions), noise concerns (e.g., quieter operation with hybrid or electric-only buses), ride comfort (e.g., electric-only buses have no transmission), improved hill-climbing ability (electric trolleybuses), and operating cost savings (e.g., reduced fuel costs).

Exhibit 2-2
Trends in U.S. Bus Vehicle Power Sources

	Share of U.S. Bus Fleet	
Power Source	**2001**	**2010**
Diesel	90.1%	65.8%
Natural gas (CNG, LNG, and blends)	9.0%	18.6%
Biodiesel	0.0%	7.7%
Electric and hybrid	0.1%	7.0%
Gasoline	0.4%	0.7%
Other	0.3%	0.2%

Source: American Public Transportation Association (*1*). Totals may not sum to 100% due to rounding.
Note: CNG = compressed natural gas, LNG = liquefied natural gas.

The combination of vehicle size and power source affects a bus' acceleration characteristics, which impacts how quickly a bus can reach its cruising speed and its overall average speed. Chapter 6, Bus Transit Capacity, provides information about the acceleration characteristics of selected bus types in Exhibit 6-2.

Low-floor buses, which allow easier boarding for all passengers by eliminating the need for steps and wheelchair lifts, are becoming the predominant type of bus used in transit service, increasing from 20% of all bus orders in 1997 (*3*) to 90% of bus orders in 2010 (*4*). As discussed in Chapter 6, the lack of steps on low-floor buses speeds up the passenger boarding and alighting process, which can benefit bus speeds and bus stop capacity. At the same time, low-floor buses offer fewer seats than high-floor buses of comparable length, which affects the bus' person-carrying capacity and, potentially, the quality of service offered to passengers.

Partial low-floor designs, where only the area from the rear door forward is low floor, typically provide 3–5 fewer seats than a comparable high-floor bus, as the front wheelwells protrude into the seating area. Buses with 100% low-floor designs provide even fewer seats than comparable partial low-floor designs, as both the front and rear wheelwells replace seating area. The wheelwheel space is not necessary wasted, as it can be used for other purposes, such as a cabinet for the bus' electronics (passenger counting, vehicle location, video camera recorders, etc.), or storage space for larger items that would otherwise block the aisle.

In addition to constraints posed by the vehicle's floor height, the number of seats provided on a given bus also reflects trade-offs in seat orientation (e.g., facing forward, facing the aisle, facing each other), seat pitch (i.e., distance between seats), number and width of doors provided, and accommodations for users with strollers, bicycles, luggage, or other large objects. These factors can influence passenger capacity, boarding and alighting time, quality of service, or a combination of these.

Exhibit 2-3 illustrates some of the different types of buses used in North American bus service, describes typical applications for these buses, and discusses their associated capacity and quality of service considerations.

Bus Type	Typical Applications	Capacity/Quality of Service Factors
(a) Standard low-floor 	• Typical local bus service	• Faster boarding times, particularly for mobility devices • Fewer seats than comparable high-floor bus • Prefer streets developed with curbs for ramp deployment
(b) Standard high-floor 	• Local bus service on streets without curbs or sidewalks • Routes requiring a little more capacity than what a low-floor bus offers	• Wheelchair lift works better than ramps in areas without curbs and sidewalks • Typically provides 3–5 more seats than a comparable low-floor bus • Longer boarding times (stairs)
(c) Community bus 	• Bus service on lower-volume routes • Bus service that operates on neighborhood streets with tight turning radii	• Can allow bus service to be provided in areas difficult to serve with a standard-size bus • Most or all passengers will be seated
(d) Articulated bus 	• Routes where added capacity is desired without adding more buses • Routes where reduced number of buses, but same capacity, is desired	• 50% more seats and standing capacity than standard bus • High or low floor • Reducing frequency may increase passenger service times and overall travel times
(e) Motor (over-the-road) coach 	• Commuter bus service • Intercity passenger service • Heavier-duty bus for high-speed running • Can carry luggage or bicycles in compartments underneath bus	• Larger, more comfortable seats • May offer internet service, tray tables, overhead storage, and other amenities • Typically no standees allowed • High floor

(f) Special purpose bus 	• Custom designed for a particular application, for example:
	  ○ Doors on both sides for BRT routes with center stations
	  ○ Minimal seats for downtown circulator/distributor routes
		• Doors on both sides provide operating flexibility
		• Replacing seats with standing area provides greater passenger capacity

(g) Double-deck bus 	• Similar capacity/headway reasons as articulated buses • Tall bus stands out • Tourist-oriented or high-volume routes	• Potentially longer boarding/ alighting times due to stairs needed to access upper deck • Good views from upper deck • More capacity than a standard bus
(h) Replica trolley 	• Tourist-oriented circulator service • Special event service (e.g., city festival, county fair)	• Distinctive vehicle reassures passengers this is their bus • Increases transit service visibility • Seats may be less comfortable • High floor

Exhibit 2-3
Bus Vehicle Type Examples

Photo locations:
(a) Victoria, B.C.
(b) Tallahassee
(c) San Jose
(d) Edmonton
(e) Cleveland
(f) Eugene
(g) Victoria, B.C.
(h) Albuquerque

Bus Submodes

Bus transit is operated by rubber-tired passenger vehicles that operate over roadways with fixed routes and schedules. For the purposes of NTD reporting, the Federal Transit Administration (FTA) defines four submodes of bus transit on the basis of operating characteristics and technology (*5*):

- *Electric trolleybus*—rubber-tired vehicles that are powered by electric current from overhead wires;
- *Commuter bus*—bus service that provides at least 5 mi (8 km) of closed-door service, typically connecting outlying areas to a limited number of central city stops and typically using motorcoach (over-the-road) buses;
- *Bus rapid transit*—separately branded bus service that either (*a*) operates primarily on fixed guideways (other than high-occupancy vehicle or shoulder lanes) or (*b*) operates frequent service with substantial transit stations, traffic signal priority or pre-emption, and low-floor vehicles or level boarding; for NTD purposes, the FTA defines frequent service as being at least 10-min peak and 15-min off-peak headways for at least 14 h per day; and
- *Bus*—all other types of bus transit service not covered by one of the other submodes.

Exhibit 2-4 illustrates vehicles used by the four bus submodes.

Exhibit 2-4
Bus Submodes Illustrated



(a) Electric trolleybus (Vancouver)



(b) Commuter bus (San Francisco Bay Area)



(c) Bus rapid transit (Brisbane)



(d) Bus (Washington, D.C.)

DEMAND-RESPONSIVE TRANSIT

Overview

Demand-responsive transit (DRT) is a form of public transportation characterized by flexible routing and scheduling of small to medium-size vehicles (Exhibit 2-5) operating in shared-ride mode between pick-up and drop-off locations according to passengers' needs. Historically, DRT has been referred to as dial-a-ride service—passengers call the transportation operator, who then dispatches a vehicle to pick up the passengers and transport them to their destinations. However, in more recent years, DRT has evolved to include a range of user-oriented forms of public transportation that have been referred to as "flexible transit services," which share attributes of pure DRT and fixed-route service.



(a) DRT van (Chillicothe, Missouri)



(b) Small bus (Northern Virginia)

Exhibit 2-5
Examples of Vehicles Used in Demand-Responsive Transit

DRT and its related flexible services share a common element of a trip reservation. The reservation may be made once when an individual books the initial trip for subscription service, reservations may be made each time an individual requests a trip, or the reservation may be made by a passenger on board a vehicle requesting a specific stop. However, a passenger's personal request for a reservation or service consideration is one of the service characteristics that make DRT and its variants distinct from traditional fixed-route, fixed-schedule service (*6*).

A defining attribute of DRT is its flexibility, and this has generated variations of DRT, ranging from DRT as a specialized transportation service for human service agencies and their clients, to DRT as a feeder to fixed-route bus and rail, to flexible-route segments and route deviation service (also known as flex route). There is a wide range of DRT variants, sharing the common attributes that they are *not* fixed-route and fixed-schedule and include some form of individual trip request. Beyond this, the services differ in their degree of flexibility, the rider groups they serve, and their operational and performance attributes.

Development of DRT as a Mode

Origins of DRT

DRT emerged as a distinct transportation mode in the 1960s and 1970s, based on early work done by MIT, Northwestern University, Ford Motor Company, and GM Motors Research Laboratories (*7*). DRT services were implemented in a variety of communities, providing "many-to-many" or "few-to-few" service, as well as feeder

DRT trip patterns (e.g., many-to-many) are discussed in more detail in Section 4.

service to other transit modes ("many-to-one"). By the early 1970s, about 25 DRT systems were known to exist in North America. Most of these used small buses or vans and several were taxi-based (*7*).

In the later 1970s and the 1980s, the DRT mode spread to many communities across the U.S. as a way to provide community-based public transportation service to either the general public or to older adults and persons with disabilities, as a mode better suited in lower-density areas than traditional fixed-route bus. DRT became particularly popular in a number of states, including Michigan and California. Some of these early DRT services continue to operate today.

DRT service gained attention in the 1970s with the U.S. Congress' passage of Section 504 of the Rehabilitation Act (in 1973) and DOT-implementing regulations (in 1979). This law required federally assisted transportation programs to be accessible to persons with disabilities, including wheelchair users. To meet this requirement, public transportation agencies had some flexibility in the way each agency approached serving the transportation needs of people with disabilities. Some transit systems bought accessible buses for fixed-route services, some provided *paratransit* services only, and some provided a combination of accessible buses and paratransit services. Progress towards meeting Section 504 requirements was mixed, and more agencies opted to provide paratransit rather than accessible fixed-route.

DRT and the Americans with Disabilities Act

Passage of the Americans with Disabilities Act (ADA) in 1990 and implementing regulations the following year eliminated the flexibility that had been available under Section 504. The ADA established the requirement that all transit vehicles used for fixed-route service must be accessible to people with disabilities. For people who cannot access or use accessible fixed-route service because of their disability, the ADA mandates a DRT service known as *ADA complementary paratransit*. The ADA requires transit agencies that provide fixed-route service to also provide *paratransit* that *complements* the fixed routes, and this complementary paratransit service is highly prescribed by the federal regulations. The term *paratransit,* originally coined to refer to the wide range of services that fall between traditional fixed-route/fixed-schedule service and the private car, is used by some to refer just to the required ADA complementary paratransit service, although its original definition reflects a more comprehensive perspective.

Emergence of Flexible Transit Services

The 1980s and 1990s also saw the emergence of new types of flexible transit service, variants of traditionally-defined DRT. As communities responded to new growth patterns and economic trends, they implemented services that combined attributes of fixed-route, fixed-schedule service and DRT. *TCRP Synthesis 53: Operational Experiences with Flexible Transit Services* categorized these flexible services into six types: demand-response connector service (also known as feeder service), zone routes, point deviation, route deviation (also called flex route), flexible-route segments, and request stops (*8*). The most common of these six types are route deviation, request stop, and demand-response connector (*9*).

These flexible services generally operate in limited service areas that are considered difficult to serve because of the demographics, land development pattern, or street

layout. Transit agencies may operate DRT or other flexible services during low-demand time periods, substituting for fixed-route transit when ridership levels do not justify fixed-route/fixed-schedule service. DRT service may be the only transit in small and low-density areas, particularly rural communities and some suburban areas. Transit agencies that operate flexible services attempt to balance efficiency and flexibility, using strategies that reduce the inefficiency of pure DRT service. This means there are typically limits to the degree of pure DRT service that is provided (*8*).

Types of DRT Service

General Public DRT

Description and Applications

General public DRT provides flexibly routed, shared ride service that responds to requests from the general public. The flexible routing is typically "many-to-many," providing trips from many different origins to many destinations within the defined service area as well as "many-to-few," with trips from many origins to a small number of frequented destinations. Scheduling may be immediate response, similar to taxi service, or it may be advance reservation, so that trip requests are required a day to several days or more in advance. Alternatively, the policy on scheduling may allow for both immediate and advance requests.

General public DRT may be an appropriate transportation service in a low-density community with a geographic dispersion of trip generators, or in a rural community with limited demand for public transportation. Where population densities exceed about 1,000 persons per square mile and where there is some linear pattern to trip demand, transit planners generally look beyond DRT to service that incorporates some aspect of fixed-route or fixed-schedule service.

Performance

The performance of general public DRT varies in terms of its productivity (passenger trips per revenue hour) and depends on numerous factors, particularly the size of the service area, locations of trip generators, and nature of trip demand. Data from representative general public DRT systems in urban areas show productivity ranging from 2.9 to 4.7 passenger trips per revenue hour (*10*). Some transit agencies modify general public DRT to incorporate some aspects of fixed-route transit to achieve higher productivity. These DRT variants are discussed later in this chapter.

General public DRT is commonly provided in rural communities. Based on 2009 research, 86 percent of the more than 1,300 rural transit providers provide DRT service (*11*). Rural DRT productivity varies considerably by the size of the service area. An analysis of Rural NTD data from 2007 shows that rural DRT systems serving smaller, municipal-only areas had an average productivity of 4.4, those serving single-county areas had an average productivity of 3.1, and those serving multi-county areas had an average productivity of 2.9 (*6*). Many rural DRT providers, whether community-based or serving larger county and multi-county areas, serve long-distance trips to medical facilities in urban areas as part of their service mix. These long trips result in lower productivity and higher vehicle mileage, affecting performance as well as operating cost.

Technology

The technology used by transit agencies that provide DRT service includes traditional information technology, defined as computer-based information systems, communications technology such as the Internet and cell phones, as well as advanced systems designed specifically for demand-responsive transportation. These technology applications may help improve service on the street, enable an increase in productivity, and improve customer service. Examples of advanced technology include software that automates scheduling and dispatching functions from a central control center and on-vehicle technology that identifies the vehicle location in real-time.

Technology enhancements have enabled a new model of DRT that eliminates the need for a control center to handle trip reservations, scheduling, and dispatch, generally for DRT in a limited service area. For example, the Denver Regional Transportation District provides general public DRT in a number of lower-density service areas within its larger transit district. The DRT service, marketed as "Call-n-Ride," uses a mobile device for vehicle drivers to handle trip requests (and subsequent scheduling) from prospective riders via cell phone or online booking. GPS-enabled tablet computers with a mobile application, Web-based software, wireless access, and cell phone technology make this new model possible.

Limited Eligibility DRT

Description and Applications

Limited eligibility DRT operates similarly to general public DRT except that only defined rider groups are served, often older adults and people with disabilities. Limited eligibility DRT services may be referred to as *specialized transportation* and may serve as a supplement to fixed-route service, recognizing that some residents of a community have difficulty using traditional transit service and benefit from a more flexible and personalized service.

Some limited eligibility systems restrict not only the rider groups they serve, but also trip purposes. Where funding is constrained, the system may prioritize trips, with preference for trips to medical appointments, work, school, grocery shopping, and other life-sustaining trips. Other trip purposes, such as those for social purposes and other quality-of-life trips, may be served only if space is available, or may not be served at all.

Many rural DRT services have their origins as specialized transportation, expanding to serve general public riders once they receive funding from federal Section 5311, Formula Grants for Other than Urbanized Areas.

Productivity

Productivity for limited eligibility DRT services ranges from 1.5 to 4.35 passenger trips per revenue hour, based on representative data from urban systems (*10*). DRT providers that group trips to common destinations such as senior centers and human service agencies, using many-to-one scheduling, tend to have higher productivity.

ADA Paratransit

Description

In urban areas with fixed-route service, ADA complementary paratransit is the predominant public DRT service. The ADA requires any public transit agency—urban or rural—that provides fixed-route service to also provide ADA complementary paratransit to "ADA paratransit eligible individuals," defined as individuals whose disabilities, permanent or temporary, prevent their access to and/or independent use of the fixed-route service. Transit agencies must establish an eligibility process to determine which individuals qualify for ADA paratransit service.

Regulatory Requirements

ADA regulations stipulate that six service criteria must be met, ensuring that paratransit service is comparable to service by fixed route. These service criteria state that the ADA complementary paratransit service must, at a minimum:

1. Operate in the same service area as the fixed-route system, which generally includes a ¾-mile corridor on either side of bus routes and around rail stations.
2. Have a comparable response time as fixed route, where response time is defined as the elapsed time between a request for service and the provision of service. Comparability is defined as accommodating trip requests for ADA paratransit-eligible individuals at any requested time on a particular day in response to a request for service made during normal business hours on the previous day.
3. Have comparable fares as fixed route. Comparability is defined as fares that are no more than twice the base, non-discounted adult fare for fixed-route services. Companions of the ADA rider may be charged the same fare as the ADA rider, but personal care attendants must ride free.
4. Meet requests for any trip purpose, that is, there may be no trip purpose restrictions.
5. Operate during the same days and hours as the fixed-route service.
6. Operate without capacity constraints for ADA trips requested by ADA-eligible passengers, meaning no waiting lists, trip caps, or patterns and practices of a substantial number of trip denials, untimely pick-ups, or excessively long trips.

This last requirement has been one of the more difficult mandates of the ADA for transit agencies required to provide ADA complementary paratransit. According to ADA regulations and subsequent interpretations, *capacity constraints* means the transit agency cannot deny trips for eligible riders, as long as the trips are within the prescribed service area and service hours of the fixed-route service; the only exceptions are an insubstantial number of trips that are beyond the control of the transit agency. The prohibition of capacity constraints also means that the transit provider must ensure its ADA paratransit service achieves high standards for on-time performance, onboard trip length (measured by travel time), and telephone availability for trip reservations.

While the ADA essentially defines several service measures related to capacity constraints (e.g., on-time performance) and requires high standards of performance related to those measures, policies related to the measures (such as the length and definition of the on-time window) and the specific standards for achievement (e.g., on-time performance standard might be 90%, 92%, 93%, 95%, etc.) are determined locally.

http://www.fta.dot.gov /12325_3891.html

ADA guidance has been provided since the regulations were first published to clarify aspects of service provision. This guidance has clarified, for example, the requirement that ADA paratransit must be origin to destination. According to the guidance, a transit agency may establish the ADA paratransit service policy as either *curb-to-curb* or *door-to-door*, but the agency must ensure that riders can actually get from their origin point to their destination point. This means the transit provider will need to go beyond the curb to assist some riders to or from their doors if the established policy is curb-to-curb.

Significantly, the ADA-established six service criteria, as well as the service measures and requirements for high standards of performance related to the prohibition of capacity constraints, mean that transit agencies have less latitude to make operational changes to their ADA paratransit services to affect service and performance.

Premium Service

Transit agencies with an ADA paratransit obligation must meet the minimum requirements set out in the regulations, as outlined above, but they may chose to go beyond these requirements. For example, a transit agency may serve an area larger than the ¾ mile corridors, serve individuals who do not meet the ADA's disability definition (such as older adults without disabilities), or exceed other ADA paratransit mandates. These beyond-ADA paratransit services are referred to as *premium services.* Some transit agencies have chosen to offer service to a larger area than required, such as to the entire city or county, rather than just the ¾-mile corridors around fixed routes, essentially establishing two tiers, with the first tier being the required service area and the second extending to the jurisdictional limits. While the fare in the first tier can be no more than twice the fixed route fare in keeping with ADA regulations, fares for tier two trips can be higher, more than twice the fixed route fare. The transit agency can also adopt differing policies for the premium second tier, such as more limited service hours, denials of service once capacity is reached, and so forth.

Productivity

ADA paratransit productivity levels are generally lower than other types of DRT services, in part because trip patterns of ADA paratransit tend to be many-to-many. Representative data from urban systems show that the largest city transit agencies achieve productivity levels from 1.3 to 2.3 passenger trips per revenue hour, with most below 2. Transit agencies in large cities have productivities ranging from 1.8 to 2.7 and, in small cities, from 1.8 to 3.8 passenger trips per revenue hour (*10*).

Productivity is impacted by various factors and these should be considered when assessing productivity data. Such factors include, among others, the size of the service area and trip demand density, the nature of travel patterns, the length of the on-time window, the number of no-shows, and the level of traffic congestion. In major metropolitan regions, for example, ADA paratransit productivity may be as low as 1 passenger trip per hour, impacted by a large service area, many-to-many travel

patterns, and traffic-congested streets with limited curbside parking for passenger boarding and alighting.

Human Service Transportation

Description and Applications

Human service transportation is shared-ride, advance-scheduled transportation for users and clients of human service programs. This type of DRT allows older adults, persons with disabilities, lower-income persons, disadvantaged children, and others with social service needs to access health care, adult day care, job training, pre-kindergarten enrichment programs, and other non-profit and public human service programs as appropriate for their needs.

Human service transportation is an ancillary service provided by many human service agencies, offered so that their clients can access the agency's primary mission, whether that is healthcare, job training, or another human service. These agencies may purchase transportation services from public or private providers, may purchase vehicles that they operate directly to transport their own clients, or may facilitate their clients' use of public transportation, both fixed-route and DRT. Human service agencies may establish formal agreements for client transportation from the public transit agency, or clients of human service agencies may use the public transit services as unaffiliated riders to access their needed programs.

Shifts in Demand from Human Service Transportation to ADA Paratransit

In some cities, human service transportation has been a factor in the large growth in demand for public transit agencies' ADA paratransit service, as human service agencies may shift their clients to the ADA paratransit program because of their own agency funding constraints or with the intent of better integrating their clients into *public*, albeit specialized, transportation. Since many of those clients have disabilities, public transit agencies must absorb this growth within their ADA paratransit programs (assuming the passengers meet ADA paratransit eligibility criteria), because of the ADA prohibition on capacity constraints. This growth in demand for ADA paratransit service stemming from trip-shifting from human service agencies to public transit agencies, coupled with the beginning of the *age wave*, with a projected 79% increase in people aged 65 and above between 2010 and 2030 (*12*), has become a significant issue for some public transit agencies.

Coordinated Transportation

Human service transportation is noteworthy as the object of industry efforts to coordinate transportation for more than 30 years. Research has identified more than 60 different federal programs that fund some type of human service transportation, with the largest number funded through the federal Health and Human Services Department, resulting in myriad different transportation services at the local level.

Efforts to coordinate human service transportation stem from requirements of the FTA's funding programs that support specialized transportation. The FTA now requires a *locally developed, coordinated public transit-human services transportation plan* as a prerequisite for Section 5310 (Formula Grants for Enhanced Mobility of Seniors and Individuals with Disabilities) funding and for funding to support access to jobs under

the Section 5307 (Urbanized Area Formula Grants) and Section 5311 (Formula Grants for Other than Urbanized Areas) programs. Resulting experience with the coordinated plans, which have been developed at the local, regional, and statewide level, has been mixed, although participants have reported enhanced transportation access for the target populations (*13*).

Jitney

The jitney is a demand-responsive transit mode open to the general public for which passenger cars or vans are operated on fixed routes without fixed schedules or stops, often by private owner-operators or small companies. In many developing countries, they are the primary form of public transportation, but are banned in many U.S. cities due to competition with regulated taxicab and public transit service (*14*). (Jitneys may compete for riders on the most heavily used—and productive—transit routes, resulting in reduced revenue for the transit system and a reduction in its ability to provide service on less-productive routes.) Where they are allowed in the U.S., they may be regulated on the basis of:

- Insurance, safety, and ADA requirements only, with no restrictions on service area or number of vehicles operated, as was the case in Hudson County, New Jersey in 2010 (*15*);
- A franchise or permit, with defined routes or service areas, as in Houston (*16*);
- An association, with limits on the number of vehicles operated, as in Atlantic City, New Jersey (*17*);
- A privately owned and operated, publicly regulated (e.g., routes, fares) public transit service, as with the *público* systems in Puerto Rico (*5*); or
- Some combination of the above.

VANPOOL

ADA requirements for vanpools can be satisfied by having a stand-by, wheelchair-accessible vehicle available to serve a person who wishes to join a vanpool and who requires a wheelchair-accessible van. Not all vans need be wheelchair-accessible.

Vanpools provide shared rides in vans or buses between homes or a central location (e.g., a park-and-ride lot) to a regular destination. The same group of riders uses the vehicle each day; driving duties may be assigned to one of the riders (possibly in exchange for a reduced or eliminated fare or limited after-hours use of the vehicle) or rotated among the riders. In a public transit context, the service is available and promoted to the general public, is not restricted *a priori* to a particular employer, provides seven or more seats per van, and meets ADA requirements (*5*). Vans used in public transit service are typically owned by the public transit agency and riders are charged a weekly or monthly fare, sometimes on the basis of the number of vanpool participants relative to the van's seating capacity. Some of the larger public vanpool programs in U.S. in 2010 were located in the Seattle, Los Angeles, Houston, San Diego, and Chicago areas, each of which had more than 600 vanpools sponsored by a single transit agency (*18*).

RAIL TRANSIT

Overview

Rail transit systems in the U.S. and Canada carry more than 5.4 billion passengers each year. As of 2010, a total of 91 systems were in operation for the four major rail

transit submodes—heavy rail, light rail, commuter rail, and automated guideway transit (AGT). Minor rail submodes include monorails, funicular railways (inclined planes), aerial ropeways, and cable cars. Collectively, as part of public transit operations, minor rail submodes served more than 14 million annual unlinked passenger trips in 2011 (*1*).

The New York region dominates U.S. rail transit usage. The largest operator is MTA–New York City Transit, which carried over 2.4 billion passengers in 2010, 54% of the U.S. rail total. Adding all rail operators together in the New York City area, more than 2.8 billion passengers were carried, or more than 62% of the U.S. total (*18*). In Canada, the Toronto and Montréal systems dominate, with a combined 747 million annual rail passengers in 2010, or about two-thirds of the Canadian rail total (*19*).

Intercity passenger rail service, including Amtrak and future high-speed passenger rail services, is not considered public transit and is not addressed in this manual.

Rail Transit Submodes

Heavy Rail

Definition and Applications

Heavy rail transit (Exhibit 2-6) is characterized by fully grade-separated rights-of-way, high-level platforms, and high-speed, electric multiple-unit cars. Power is generally collected from a third rail, but can also be received from overhead wires as in Cleveland and a portion of the Blue Line in Boston. Third-rail power collection, frequent service, and high operating speeds generally necessitate the use of grade-separated pedestrian and vehicular crossings. A small number of grade crossings is an unusual feature of the Chicago system.

Heavy rail is also known as subway, elevated, rapid transit, metro, and rapid rail.



(a) Chicago



(b) Toronto



(c) Cleveland



(d) San Francisco Bay Area

Exhibit 2-6
Heavy Rail Transit Examples

Using trains of up to 11 cars running frequently, heavy rail systems can serve very high volumes of passengers, and are thus the dominant transit mode in the largest metropolitan areas in North America and in many other metropolises worldwide. Loading and unloading of passengers at stations is rapid due to level access and multiple double-stream doors.

U.S. and Canadian heavy rail systems generally fall into two groups according to their time of initial construction. Pre-war systems are often characterized by high passenger densities and closely spaced stations, although the postwar systems in Toronto and Montréal also fall into this category. The newer U.S. systems that opened primarily in the 1970s and 1980s tend to place a higher value on passenger comfort and operating speed, as expressed by a greater usage of interior railcar space for seating and a more distant spacing of stations, especially in suburban areas.

Most U.S. cities with the necessary population and job density to support heavy rail already have at least a starter system in place; therefore, only one new U.S. system has opened since the mid-1990s (in San Juan, Puerto Rico). Looking forward, all of the heavy rail projects in the New Starts pipeline as of 2012 consist of extensions to existing systems, except for a new automated heavy rail line proposed for Honolulu (*20*).

Relationship to Other Rail Submodes

Some overlap exists between heavy rail and other rail submodes:

- Some postwar heavy rail systems extend far into the suburbs and have long outer station spacings more typical of commuter rail systems—BART in the San Francisco Bay Area being a prime example. Because of their completely grade-separated nature and steel-wheel-on-rail technology, this manual treats these systems as heavy rail.
- Some newer heavy rail systems worldwide, such as Vancouver's SkyTrain and the Copenhagen Metro, have had fully automated operation (a characteristic of AGT), shorter trains and, in some cases, proof-of-payment fare collection (characteristics often associated with light rail). Some have termed these types of systems *advanced light rail transit.* Again, because of their completely grade-separated nature and steel-wheel-on-rail technology, this manual treats these systems as heavy rail.
- Philadelphia's Norristown high-speed line is entirely grade-separated, uses the third rail, and has high platforms (characteristics often associated with heavy rail), but uses one or two-car trains, makes many stops only on demand, and has onboard fare collection (characteristics often associated with light rail). Southeastern Pennsylvania Transportation Authority (SEPTA), the FTA, and this manual classify it as heavy rail.

Operating Characteristics

Regardless, operating characteristics are of much greater interest than the label given to a particular transit service. As discussed in Sections 3 and 4, the operating environment and service pattern are key to determining a service's capacity and quality of service. Heavy rail services using short trains and operating at relatively long headways can provide less capacity and (in some respects) poorer quality of service than more frequent light rail or bus rapid transit services. On the other hand, long

heavy rail trains operating at short headways provide capacity unmatched by any other rail transit mode, providing the means to develop and serve the extremely dense downtowns of the largest cities.

Light Rail

Definition and Applications

Light rail transit, often known simply as LRT, began as an evolutionary development of the streetcar to allow higher speeds and increased capacity. Light rail transit is characterized by its versatility of operation, as it can operate separated from other traffic below grade, at-grade, or on an elevated structure, or can operate together with motor vehicles on the surface. Service can be operated with single cars or multiple-car trains. Electric traction power is typically obtained from an overhead wire, thus eliminating the restrictions imposed by having a live third rail at ground level. (At the time of writing, Washington, D.C. was investigating options to allow streetcars to operate wirelessly over short segments to preserve viewsheds). This flexibility helps keep construction costs low in comparison to heavy rail and helps explains the popularity this mode has experienced since the late 1970s.

Types of Light Rail Operations

Three major types of light rail operations exist (Exhibit 2-7):

- *Light rail,* with relatively frequent service along mostly exclusive or segregated rights-of-way, using articulated cars and up to four-car trains.
- *Streetcars,* operating along mostly shared or segregated rights-of-way, with one-car (or rarely, two-car) trains. Vehicle types and ages can vary greatly.
- *Vintage trolleys* provide mainly tourist- or shopper-oriented service, often at relatively low frequencies, using either historic vehicles or newer vehicles designed to look like historic vehicles.

Light rail and streetcar systems in a few cities—Boston, Cleveland, New Orleans, Newark, Philadelphia, Pittsburgh, San Francisco, and Toronto—survived the general trend of replacing streetcars with bus service in the middle of the 20th century. Most of those systems date from the 19th century, although most now operate with modern light rail vehicles.

The modern North American LRT era began in 1978 in Edmonton. These newer LRT systems have adopted a much higher level of segregation from other traffic than earlier streetcar systems enjoyed, with most having extensive stretches of grade-separated or exclusive right-of-way with minimal interference from automobile traffic. As of 2011, 20 modern LRT systems were operating in the U.S. and Canada, all in larger cities, an increase of six systems from 2000.

The modern streetcar was introduced in Portland in 2001, using a European-built low-floor design. As of 2010, modern streetcar lines were also operating in Tacoma and Seattle. These initial lines serve downtown circulation or distribution functions, and were developed in conjunction with redevelopment plans along the lines. Other cities have also included streetcars as part of redevelopment plans, but have chosen to operate these lines with vintage trolleys. Six such lines were in operation in 2010, an increase of three from 2000.

Exhibit 2-7
Light Rail Examples



(a) High-floor light rail (Denver)



(b) Low-floor light rail (Portland)



(c) High-floor streetcar (Philadelphia)



(d) Modern low-floor streetcar (Seattle)



(e) Vintage trolley (Memphis)



(f) Diesel light rail (San Diego County)

Diesel Light Rail (Hybrid Rail)

Another recent trend is the introduction of diesel light rail cars, with three lines in operation as of 2010 in the U.S. and Canada. These vehicles do not meet the strict definition of light rail, as they are not electrically operated (the FTA now terms them *hybrid rail*), nor do they meet the strict definition of commuter rail, due to short trains and (often) lack of direct service to a central city. The TCQSM's rail capacity procedures can be applied to diesel light rail, with suitable modifications to reflect differences in vehicle performance and train signaling. The vehicles are designed to be operated on existing railroad tracks without the need to add electrical infrastructure. As the vehicles do not meet Federal Railroad Administration carbody strength standards with respect to collisions with other trains, passenger service on the tracks can only occur during times of the day when there is no freight service (and vice versa). None of the three lines is a traditional downtown-focused light rail line; two of the lines (Ottawa and northern San Diego County) do not serve the center city at all and the third (southern New Jersey)

resembles an old-style interurban line in route structure, with a few closely spaced stops in Trenton and Camden and more widely spaced stops at the towns in between. All three connect with high-capacity transit services at one or both ends of the line.

Wheelchair Access

Providing wheelchair access to LRT and streetcar vehicles is an important design consideration, with both capacity and quality-of-service implications. When the first modern LRT systems came into operation, high-floor vehicles were the only vehicle type available. With an entirely off-street system, as in Edmonton, high-level platforms could be provided, allowing level boarding into the vehicles. However, most LRT systems and all streetcar systems involve some on-street operation. Some light rail systems with street running, such as in Calgary, use high platforms throughout, but this is not applicable for streetcar service. As discussed in Chapter 8, Rail Transit Capacity, a number of systems have been devised to overcome the elevation difference, all of which take some time to operate. Newer light rail systems have adopted the low-floor vehicle technology that has entered the market, and some older systems have added low-floor vehicles to their fleet. Slide-out ramps allow wheeled mobility device users to roll directly onto the train, with minimal impacts on dwell time.

Commuter Rail

Definition and Applications

Commuter rail (Exhibit 2-8) is generally a long-distance transit mode using trackage that is part of the general railroad system, although portions may be used exclusively for passenger movement. A few commuter rail operations, such as the Long Island Rail Road and the New Canaan branch of MTA Metro-North's New Haven line, were built solely for passenger movement. Short portions of in-street trackage are rare, such as on the South Shore Line in Michigan City, Indiana. Track may be owned by the transit system or access may be by agreement with a freight railroad. Similarly, train operation may be by the transit agency, the track owner, or a third-party contractor. Service is heavily oriented towards the peak commuting hours, particularly on the smaller systems. All-day service is operated on many of the mainlines of the larger commuter rail systems and the term *regional rail* is more appropriate in these cases.

As of 2011, 27 commuter rail services were in operation in the U.S. and Canada (not including intercity services), an increase of seven from 2000.

Exhibit 2-8
Commuter Rail
Examples



(a) Bi-level car (Toronto)



(b) Bi-level gallery car (Chicago)



(c) Bi-level car (San Francisco Bay Area)



(d) Single-level car (Baltimore)

Scheduling

Commuter rail scheduling is often tailored to the peak travel demand rather than operating consistent headways throughout the peak period. Where track arrangements and signaling permit, operations can be complex with the use of local trains, limited-stop express trains, and zoned express trains. Zoned express trains are commonly used on busy lines with many stations where express trains serve a group of stations then run non-stop to the major destination station(s). Service is typically focused toward the downtown of a major city (e.g., New York, Chicago) or between major cities within a region (e.g., Baltimore–Washington, San Francisco–San Jose, Dallas–Ft. Worth). Metrolink's Inland Empire–Orange County service in the Los Angeles area is an exception, connecting major cities of suburban counties to each other. The FTA considers a few intercity passenger trains (e.g., Harrisburg–Philadelphia and Portland, Maine–Boston) to be commuter rail operations because more than 50% of the ridership uses the service at least 3 days a week (*5*); however, these services are outside the scope of this manual.

Power Sources

Diesel and electric power are both used for traction on commuter rail lines. Electric traction is capital intensive but permits faster acceleration while reducing noise and air pollution. It is used mainly on busy routes, particularly where stops are spaced closely together or where long tunnels are encountered. Both power sources can be used for locomotive or multiple-unit operation. All cars in a multiple-unit train can be powered,

Multiple-unit cars are self-propelled, as opposed to needing a locomotive to provide power.

or some can be unpowered "trailer" cars that must be operated in combination with powered cars. Electric multiple-unit cars are used extensively in the New York, Philadelphia, and Chicago regions, and the entire SEPTA regional rail system in Philadelphia is electrified. The Trinity Railway Express between Dallas and Ft. Worth operates diesel multiple-unit cars during off-peak periods and TriRail in South Florida also supplements its service with diesel multiple-unit cars.

Locomotive-hauled commuter trains are standard for diesel operation. They have also been used to serve lines where different voltages are used on different track sections (e.g., New Jersey Transit's Midtown Direct service) and to supplement electric locomotives when the diesel locomotives' slower acceleration does not unduly impact operations (e.g., certain peak-period express trains operated by SEPTA). Other systems, such as SEPTA, Metra's Electric District (Chicago), and the South Shore Line (Indiana–Chicago), value the flexibility of multiple-unit cars in varying train length. Montréal's STCUM commuter rail system replaced a mixed fleet with a standard electric multiple-unit design.

Train Length

Commuter rail train length can be tailored to demand with cars added and removed as ridership dictates. This is particularly easy with multiple-unit equipment and can result in trains of anywhere from one to twelve cars in length. Where train length is constant all day, unneeded cars can be closed to passengers to reduce staffing needs and the risk of equipment damage.

Passenger Comfort and Car Design

Commuter rail is unique among the rail transit modes in that a high priority is placed on passenger comfort, as journeys are often long and the main source of competition is the automobile. All lines operate with a goal of a seat for every passenger except for the busy inner portions of routes where many lines funnel together and frequent service is provided. Such is the case for the 20-min journey on the Long Island Rail Road between Jamaica and Penn Stations. Service between these points is very frequent (trains on this four-track corridor operate as close as 1 min apart in the peak hours) as trains from multiple branches converge at Jamaica to continue to Manhattan.

Railcar Access

Passenger access to commuter rail trains can be from platform (high) or ground level (low). High-level boarding is commonly used on busy lines or at major stations to speed passenger movements. Standard railway type "traps" in the stepwells allow cars to use both types of platform but require the train crew to raise and lower the trap door above the steps. The electric multiple-unit cars used by the South Shore Line employ an extra set of doors at the center of the cars that are used exclusively at high platform stations while the car end doors are fitted with traps in the conventional manner for use at high and low platform stations. This arrangement is also used on the electric multiple-unit cars used on Montréal's Deux-Montagnes tunnel line. Commuter rail cars can be designed with passenger seating on one or two levels, with the bi-level designs offering more seats per car and thus greater passenger capacity.

Automated Guideway Transit

Definition and Applications

As their name indicates, AGT systems are completely automated (vehicles without drivers), with personnel limited to a supervisory role. Their automated nature requires the guideways to be fully grade-separated. Because a number of other rail modes are also capable of being automated when grade-separated, the National Transit Database narrows the definition of AGT to exclude steel-wheel-on-rail technologies (*5*). AGT technologies in use vary widely and include rubber-tired electrically propelled vehicles, monorails, cable-hauled vehicles, belt-driven systems, air levitation, and magnetic levitation (*21, 22*). Cars are generally small and service is frequent—the name "people mover" is often applied to these systems, which can take on the role of horizontal elevators.

AGT systems operate in four types of environments, as illustrated in Exhibit 2-9:

- Airports;
- Institutions (universities, shopping malls, government buildings);
- Leisure and amusement parks; and
- Public transit systems.

Airport Systems

AGT use in the airport environment is increasing markedly. Nine new airport systems opened in the U.S. and Canada in the first decade of the 2000s, along with 11 others elsewhere in the world (*22*). Some of these airport systems—for example, the AirTrain at New York's JFK Airport and the MIA Mover at Miami International Airport—connect to regional transit systems. Although the TCQSM's capacity concepts are applicable to airport AGT systems, special attention must be given to the highly peaked passenger flows associated with flight arrivals and passengers' luggage needs, which differ from normal transit operations. *ACRP Report 37: Guidebook for Planning and Implementing Automated People Mover Systems at Airports* (*22*) provides guidance on estimating airport AGT capacities.

Institutional and Other Systems

As of 2003, nine institutional AGT systems operated in the U.S., along with 10 leisure systems (*23*). One of the largest institutional systems is located at the West Virginia University campus in Morgantown. This 3-mi (5-km) line features off-line stations that enable close headways, down to 15 s, and permit cars to bypass intermediate stations. The cars are small, accommodating only 21 passengers, and are operated singly. On-demand service is possible during off-peak hours. As of 2010, three public transit AGT systems operated in the U.S. (unchanged from 2000), serving the downtown areas of Detroit, Jacksonville, and Miami.



(a) Airport shuttle (Newark)



(b) Downtown people mover (Miami)



(c) Institutional (Honolulu)



(d) Leisure (Memphis)

Exhibit 2-9
AGT Examples

Monorail

Although often thought of as being relatively modern technology, monorails (Exhibit 2-10) have existed for over 100 years, with the first monorail, in Wuppertal, Germany, having opened in 1901 (*24*). Monorail vehicles straddle or are suspended from a single rail. Driverless monorails, such as the Jacksonville Skyway, fall into the category of AGT.

The 0.9-mi (1.5-km) Seattle Center monorail, originally constructed for the 1962 World's Fair, is the only existing U.S. example of a non-automated public transit monorail. About one dozen privately operated monorails are in use at North American zoos and amusement parks. Outside the United States, a number of monorails are used for public transit service similar to an elevated heavy rail line. Examples include seven systems in Japan (*25*).



(a) Straddle (Seattle)



(b) Suspended (Wuppertal, Germany)

Exhibit 2-10
Monorail Examples

Funiculars, Inclines, and Elevators

Funicular railways (Exhibit 2-11), also known as *inclined planes* or simply *inclines*, are among the oldest successful forms of mechanized urban transport in the United States, with the first example, Pittsburgh's Monongahela Incline, opening in 1870 and still in operation today. Funiculars are well suited for hilly areas, where most other transportation modes would be unable to operate, or at best would require circuitous routings. The steepest funicular in North America operates on a 100% (45°) slope, and a few international funiculars have even steeper grades.

Exhibit 2-11
Funicular and Elevator Examples



(a) Passenger incline (Pittsburgh)



(b) Vehicle incline (Johnstown, PA)



(c) Passenger incline (Mürren, Switzerland)



(d) Inclined elevator (Ketchikan, Alaska)

Historical Usage

Early funiculars were used to transport railroad cars and canal boats in rural areas, as well as to provide access to logging areas, mines, and other industrial sites. Funiculars have played a role in many transit systems, moving not just people, but cars, trucks, and streetcars up and down steep hillsides. An example of a remaining vehicle-carrying incline that is part of a transit system is in Johnstown, Pennsylvania. Nearby, in Pittsburgh, the Port Authority owns the two remaining inclines from a total of more than 15 that once graced the hilly locale.

Current Applications

The number of remaining inclined planes in North America is small, but they are used extensively in other parts of the world to carry people up and down hillsides in both urban and rural environments. Switzerland alone has over 50 funiculars, including urban funiculars in Zürich and Lausanne. Many other cities worldwide have funiculars, including Barcelona, Budapest, Haifa, Heidelberg, Hong Kong, Paris, Prague, and Valparaíso, Chile (which has 15). In addition, funiculars are still being built for access to

industrial plants, particularly dams and hydroelectric power plants, and occasionally, ski resorts. New funiculars, primarily in Europe, also provide subway or metro station access. New designs rarely handle vehicles and make use of hauling equipment and controls derived from elevators.

Design

Most typical design involves two cars counterbalancing each other, connected by a fixed cable, using either a single railway-type track with a passing siding in the middle or double tracks. Single-track *inclined elevators* have just one car and often do not use railway track—see, for example, the Ketchikan example in Exhibit 2-11(d). When passing sidings are used, the cars are equipped with steel wheels with double flanges on one set of outer wheels per car, forcing the car to always take one side of the passing siding without the need for switch movement. Earlier designs used a second emergency cable, but this is now replaced by automatic brakes, derived from elevator technology, that grasp the running rails when any excess speed is detected. Passenger compartments can either be level, with one end supported by a truss, or sloped, with passenger seating areas arranged in tiers.

To minimize wear-and-tear on the cable, and make the design mechanically simpler, an ideal funicular alignment is a straight line, with no horizontal or vertical curves. To achieve this design, a combination of viaducts, cuttings, and/or tunnels may be required, as illustrated in Exhibit 2-11(c). However, many funiculars have curved alignments.

Public Elevators and Escalators

Public elevators or escalators are occasionally used to facilitate pedestrian movement up and down steep hillsides where insufficient pedestrian volumes exist to justify other modes. These services allow pedestrians to bypass stairs or long, out-of-direction routes to the top or bottom of the hill.

Aerial Ropeways

Definition

Aerial ropeways (Exhibit 2-12) encompass a number of modes that transport people or freight in a *carrier* suspended from an aerial rope (wire cable). The carrier consists of the following components:

- A device for supporting the carrier from the rope: either a *carriage* consisting of two or more wheels mounted on a frame that runs along the rope, or a *fixed* or *detachable grip* that clamps onto the rope;
- A unit for transporting persons or freight: an enclosed *cabin,* a partially or fully enclosed *gondola,* or an open or partially enclosed *chair*; and
- A *hanger* to connect the other two pieces.

Exhibit 2-12
Aerial Ropeway Examples



(a) Aerial tramway (Portland)



(b) Detachable-grip gondola (Queenstown, N.Z.)

The rope may serve to both suspend and haul the carrier (*monocable*); or two ropes may be used: a fixed track rope for suspension and a moving haul rope for propulsion (*bicable*); or multiple ropes may be used to provide greater wind stability. Carriers can operate singly back-and-forth, or as part of a two-carrier shuttle operation, or as part of a multiple-carrier continuously circulating system.

Common Aerial Ropeway Types

The common aerial ropeway types are the following:

- *Aerial tramways,* which are suspended by a carriage from one or two stationary track ropes, and propelled by a separate haul rope. Tramways have one or, more commonly, two relatively large (20 to 180 passenger) cabins that move back and forth between two stations. Passenger loading occurs while the carrier is stopped in the station.
- *Detachable-grip aerial lifts,* consisting of a large number of relatively small (six to 15 passenger) gondolas or two to eight passenger chairs that travel around a continuously circulating ropeway. The carriers move at higher speeds along the line, but detach from the line at stations to slow to a creep speed (typically 0.8 ft/s or 0.25 m/s) for passenger loading.
- *Fixed-grip aerial lifts,* which are similar to detachable-grip lifts, with the important exception that the carriers remain attached to the rope through stations. Passenger loading and unloading either occurs at the ropeway line speed (typical for ski lifts), or by slowing or stopping the rope when a carrier arrives in a station (typical for gondolas). Some fixed-grip gondolas are designed as pulse systems, where several carriers are attached to the rope in close sequence. This allows the rope to be slowed or stopped fewer times, as several carriers can be loaded or unloaded simultaneously in stations.
- *Funitels* are a variation of detachable-grip aerial lifts, with the cabin suspended by two hangers from two haul ropes, allowing for longer spans between towers and improved operations during windy conditions.

Applications

Aerial ropeways are most often associated with ski areas, but are also used to carry passengers across obstacles such as rivers or narrow canyons, and as aerial rides over zoos and amusement parks. Two aerial tramways are used for urban public transportation in the U.S.—New York City's Roosevelt Island Tram and the Portland Aerial Tram—and gondola systems are used internationally in such cities as Medellín, Caracas, Rio de Janeiro, and Algiers (*26*). A gondola system in Telluride, Colorado, transports residents, skiers, and employees between the historic section of Telluride, the ski area, and the Mountain Village resort area, reducing automobile trips between the two communities and the air pollution that forms in the communities' box canyons. Several North American ski areas use aerial ropeways for site access from remote parking areas, as an alternative to shuttle buses.

Route Alignment

Aerial ropeway alignments are typically straight lines, but allow changes in grade (vertical curves) over the route. Intermediate stations are most often used when a change in horizontal alignment is required, resulting in two or more separate ropeway segments—detachable-grip carriers can be shuttled between each segment, but passengers must disembark from other types of carriers and walk within the station to the loading area for the next segment. Gondola systems and chair lifts can have changes in horizontal alignment without intermediate stations, but this kind of arrangement is much more mechanically complex and is rarely used.

Cable Car

Application

Cable cars (Exhibit 2-13) now operate only in San Francisco, where the first line opened in 1873. Although associated with San Francisco's steep hills, more than two dozen other U.S. cities, including relatively flat cities such as Chicago and New York, briefly employed this transit mode as a faster, more economical alternative to the horse-drawn streetcar. Most cable lines were converted to electric streetcar lines between 1895 and 1906 due to lower operating costs and greater reliability, but lines in San Francisco, Seattle, and Tacoma that were too steep for streetcars continued well into the 20th century (*27*).



(a) Cable car (San Francisco)



(b) Cable-hauled APM (Boston)

Exhibit 2-13
Cable Car Examples

Design

San Francisco's cable cars are pulled along by continuous underground cables (wire ropes) that move at a constant speed of 9 mi/h (15 km/h). A grip mechanism on the car is lowered into a slot between the tracks to grab onto the cable and propel the car. The grip is released from the cable as needed for passenger stops, curves, and locations where other cables cross over the line. This system is not very efficient, as 55 to 75% of the energy used is lost to friction. However, cars can stop and start as needed, more or less independently of the other cars on the system, and a large number of cars can be carried by a small number of ropes (*27*).

Relationship to Modern Automated People Movers

Cable-hauled automated people movers often use technology adapted from cable cars and aerial ropeways.

Modern automated people movers (APMs) that use cable propulsion have retained many of the original cable car technological concepts, albeit in an improved form. Modern cable-hauled APMs often include gripping mechanisms and, in some cases, turntables at the end of the line. Some of these APMs can be accelerated to line speed out of each station, in a similar manner as detachable-grip aerial ropeways. Once at line speed, a grip on these APMs attaches to the haul rope, and the vehicle is moved at relatively high speed along the line. At the approach to the next station, the vehicle detaches from the rope, and mechanical systems brake the vehicle into the station. This technology addresses two of the major issues with the original cable cars: (*a*) having only two speeds, stop and line speed, which caused jerky, uncomfortable acceleration for passengers and (*b*) rope wear each time cars gripped the cable, as the cable slid briefly through the slower-moving grip before the grip took hold and caught up to the cable's speed. The airport shuttle at the Cincinnati-Northern Kentucky Airport is an example of a detachable-grip APM, while the Mystic Transit Center APM (Exhibit 2-13b) is an example of an APM with a permanently attached cable.

FERRY TRANSIT

Description and Applications

Ferry transit provides a water connection between or among points where land routes are interrupted by water, and effectively forms part of the longer land route. Ferry services play a role in the transit systems of a number of North American cities, providing pedestrian, bicycle, and—in some cases—vehicle transport across waterways where transportation connections are desirable but conditions do not justify a bridge or tunnel, or where alternative bridges and tunnels are congested.

The Staten Island Ferry carries more passengers per day than many rail lines.

The busiest ferry route in North America, New York's Staten Island Ferry, carries more passengers per day (65,000) than all but the busiest light rail and commuter rail lines, and more than many heavy rail lines (*18*). In addition, several private operators provide a variety of commuter services into Brooklyn and Manhattan, as well as special services to New York's major league baseball stadiums.

Other services carry more modest numbers of passengers, but still play vital roles in their area's transportation system. Vancouver's SeaBus ferry, for example, operates high-speed vessels between North Vancouver and downtown Vancouver and connects to Vancouver's rapid transit, commuter rail, and bus systems. As of 2012, eight commuter-oriented passenger ferry routes operated on San Francisco Bay and twelve

routes with significant commuter ridership operated on Puget Sound. Many of the Puget Sound routes also carry vehicles, including King County Metro buses on one route.

Internationally, ferries play an important role in providing cross-harbor transportation, as in Sydney and Hong Kong, and along rivers, as in Brisbane and London.

Ferries offer flexible routing, subject only to dock availability, and services can be implemented relatively quickly. This adaptability has helped two metropolitan areas cope with emergencies in the past. For example, when the 1989 Loma Prieta earthquake closed the Bay Bridge between Oakland and San Francisco for 1 month, new ferry routes from three East Bay communities were open within 1 week, with a fourth route open within 2 weeks. The combination of the four new routes, plus one existing route, carried an average of 20,000 passengers per weekday while the bridge was closed (*28, 29*). Following the World Trade Center attack in New York in 2001, new trans-Hudson ferry routes were opened to replace the lost capacity resulting from damage to the PATH heavy rail station at the World Trade Center. In the first 6 months following the attacks, trans-Hudson ferry ridership nearly doubled to 67,000 passengers per day (*30*).

Ferries have quickly provided needed capacity during emergencies.

Service Types

Many different types of ferry services exist, and the vessels used tend to be custom-built to meet the specific needs of the service to be operated. Considerations include passenger and vehicle demand, dock configurations, speed, and environmental issues (e.g., wake and exhaust). The TCQSM focuses on urban scheduled ferry transit services; however, other types of ferry services are described here for completeness.

Urban Services

Urban ferry services provide trips into or within major cities, and experience similar peaks in passenger demand as other urban transportation modes. Typical travel times range from a few minutes to 45 to 60 min, and service is often provided once per hour or more frequently. There are four major types of urban services:

- *Point-to-point services,* typical of most urban ferry services, crossing harbors or major rivers;
- *Linear multiple-stop services,* either along a river (e.g., the East River service in New York) or a waterfront;
- *Circulators,* with fixed routes but often not fixed schedules, that serve destinations around the edge of, or a designated portion of, a harbor or riverfront via a loop route; and
- *Water taxis,* which have fixed landing sites, but pick up passengers on demand, similar to a regular taxi service.

Some harbor circulator and multiple-stop services also call themselves "water taxis," although they operate on fixed routes and sometimes with fixed schedules.

Because ferries can only take passengers to the water's edge, intermodal transfers are usually required at one, and often, both ends of the ferry trip. Options for providing this transfer include park-and-ride lots; feeder bus service; roll-on, roll-off bus service (for auto ferries); and terminals located close to rail service (as in New York and San Francisco).

Coastal Services

Coastal ferries provide intercity and interisland trips on salt water and large freshwater lakes, such as the Great Lakes. Travel times are typically in the range of one to a few hours, but can be fairly short for service to nearby islands, or more than 1 day (e.g., some of the Alaska Marine Highway routes). Service frequencies range from several trips per day to one trip per week. Vehicles are often also transported on these ferries, in a roll-on, roll-off mode (or rarely, as cargo, in a lift-on, lift-off mode).

Rural Services

Rural ferries cross rivers and narrow lakes in areas where traffic volumes do not justify constructing a bridge. Routes are short and are often operated on demand. Vessels tend to be small (a capacity of six to 12 automobiles is common). Walk-on passengers and bicycles are generally infrequent.

Vessel Types

Three main vessel types—monohulls, catamarans, and hovercraft—are used for ferry service, although only the first two of these (Exhibit 2-14) are currently used in North America (*31*).

Exhibit 2-14
Ferry Vessel Types



(a) Monohull passenger ferry (San Francisco)



(b) Monohull vehicle/passenger ferry (Seattle)



(c) Catamaran passenger ferry (Vancouver)



(d) Catamaran passenger ferry (San Francisco)

Monohulls have a single hull. They tend to have lower operating and construction costs and are the most common ferry type; large passenger and vehicle ferries are often monohulls. Several types of hulls are used:

- A *displacement hull* always rides in the water at the same waterline or depth in the water (i.e., propulsion does not raise the hull) with the same freeboard

(height of the main deck above the water). This type of hull is appropriate for low-speed operation.

- A *semi-planing hull* is designed for somewhat higher speeds than a displacement hull. It provides a degree of dynamic lift that causes it to ride up the water and have somewhat greater freeboard.
- A *planing hull* is designed for even higher speeds, with enough dynamic lift to raise the hull significantly up in the water and provide still greater freeboard. The dynamic lifting effect reduces the power required to attain higher speeds; nevertheless, the required propulsion power increases rapidly with speed.

Catamarans have two hulls connected by cross-structure, with passengers and vehicles (if any) mainly accommodated in the superstructure above. They provide relatively greater deck area and volume for their weight and generally enable higher speeds than monohulls for a given propulsive power. They can have better maneuverability and a shallower draft (distance from the waterline to the bottom of the keel) than monohulls. An important characteristic is the height of the cross-deck above water, which reduces wave impacts. As with monohulls, catamarans can be designed with displacement, semi-planing, or planing hulls.

Hovercraft are designed for high speed. They are raised entirely above the water surface by a cushion of pressurized air formed beneath it and enclosed by a flexible skirt all around. In exchange for the moderate power required to produce the cushion, the power required for forward movement is greatly reduced, and with sufficient power, high speeds can be attained. Since none of the craft is immersed in the water, an air propulsion system (air propellers) is required. Hovercraft are able to cross dry land and even clear small obstacles. They are useful as ferries where consistently deep-enough water is lacking or where sandbars must be crossed. They have high capital and operating costs as a result of their relative complexity and use of less rugged materials and equipment.

3. OPERATING ENVIRONMENTS

This section introduces the different operating environments—or rights-of-way—that are used by the various public transit modes, followed by a discussion of their impacts on transit capacity, speed, and reliability. Capacity refers to how many transit vehicles can be operated over a particular section of roadway or track in an hour, speed refers to how fast the vehicles can operate, and reliability refers to how well the transit service can keep to its schedule. More precise definitions of these terms are given in Chapter 3, Operations Concepts.

There are four types of operating environments discussed in this section:

- *Mixed traffic*—shared lane operation with general traffic;
- *Semi-exclusive*—a lane partially reserved for transit use, but also available for other use at certain times or in certain locations;
- *Exclusive*—a lane, portion of a roadway (e.g., the median), or right-of-way reserved for transit use at all times, but still subject to some external traffic interference (e.g., intersections, grade crossings); and
- *Grade separated*—a facility dedicated to the exclusive use of transit vehicles, without at-grade crossings.

MIXED TRAFFIC

In mixed-traffic operation, transit vehicles share their lanes with other vehicles—in particular, automobiles, trucks, and bicycles—using the same roadway. Transit vehicles are subject to the same kinds of traffic control (e.g., signals, signs) that other vehicles are subject to, although transit may be given preference at some locations. Transit vehicles are also subject to delays caused by turning vehicles, pedestrian crossings, high traffic volumes, parking activities, etc.

One mile of street, roadway, or tracks with transit service in two directions equals two directional route miles (regardless of the actual number of routes operated over the section). A revenue mile is one mile operated by one transit vehicle while in passenger service.

Mixed-traffic operation is the most common operating scenario in North America for bus and trolleybus service, with more than 98% of directional route miles operated in mixed traffic in 2010 (*1*). Similar records are not kept for demand-responsive service, but the nature of the service, typically with flexible origins and destinations, requires that nearly all revenue miles occur in mixed traffic, even though demand-responsive vehicles may use exclusive lanes or facilities where these are provided for buses. Among rail modes, only streetcar and light rail can operate in mixed traffic and, in practice, only streetcar has significant amounts of operation in mixed traffic.

Exhibit 2-15 illustrates bus and rail operations in mixed traffic.



(a) Bus (Los Angeles)



(b) Streetcar (Portland)

Exhibit 2-15
Mixed-Traffic Operation Illustrated

SEMI-EXCLUSIVE

A semi-exclusive facility (Exhibit 2-16) is partially dedicated to transit use, but allows certain classes of vehicles to use the facility or allows general traffic use at specific locations or at certain times of the day. As with mixed-traffic facilities, semi-exclusive facilities are primarily used by the bus and streetcar modes. Examples include:

- *Freeway managed lanes* used by buses, and shared with carpools, automobiles that have paid a toll, or both;
- *Bus lanes* on urban streets that allow other vehicles to enter the lane to make right turns at intersections or driveways;
- *Parking lanes* that transform into bus-only lanes during peak periods.



(a) Part-time bus lane (Seattle)



(b) Bus lane allowing right turns (San Antonio)



(c) Bus mall shared with bicycles (Minneapolis)



(d) Light rail line with ped access (Portland)

Exhibit 2-16
Semi-exclusive Operation Illustrated

Restricting non-transit use of a facility to certain classes of vehicles—typically carpools, taxis, or bicycles—often reflects a political compromise, where priority is given to certain desired travel modes, with the intent to use the lane as efficiently as possible, without having too much effect on transit operations. Restricting general traffic use to specific locations (e.g., right turns) reflects a compromise on allocating roadway space among modes, with the result that transit service receives some preference, but not to the detriment of other modes. Restricting transit-only use to peak periods gives transit priority when most needed to provide high levels of transit capacity and quality of service, and allows others to use the lane during lower-volume periods when transit can operate in mixed traffic without serious problems.

The intent of each of these restrictions is to reduce or eliminate certain types of general traffic interference that can slow down transit service, make it less reliable, or reduce its capacity. For the bus mode, 2,173 directional route miles (representing 0.9% of the national total) were on semi-exclusive facilities in 2010 (*1*).

Exhibit 2-16(a) represents an extreme case of trying to balance the use of a downtown lane: parking is allowed outside the peak periods of 6 to 9 a.m. and 3 to 6 p.m. weekdays, bicycles are allowed at all times, and general traffic right turns are allowed during the periods the lane operates as a bus lane. While better than nothing, the preference given to transit in this situation is not particularly high.

Enforcement is an issue whenever semi-exclusive and exclusive transit facilities are accessible by other vehicles:

The dynamic envelope is the space that may be occupied by a rail vehicle due to, among other things, its lateral motion.

- Delivery trucks may park illegally in the lane (Exhibit 2-17[a]);
- Parked vehicles may encroach into a streetcar's dynamic envelope (Exhibit 2-17[b]);
- Parked vehicles may not be moved from the lane by the time a parking lane converts to a bus lane;
- Pedestrians may jaywalk across the facility; and
- Taxis or other unauthorized vehicles may use the lane illegally.

Any of these issues can create unanticipated delays to transit vehicles that result in transit service running behind schedule. As most transit agencies do not have police powers themselves, a good working relationship with local police agencies is necessary to ensure that restrictions are enforced so that transit receives the intended priority.



(a) Stopped delivery vehicle (New York)



(b) Parking encroachment (Seattle)

Exhibit 2-17
Potential Enforcement Issues with Semi-exclusive and Exclusive Lanes

EXCLUSIVE

Exclusive transit facilities (Exhibit 2-18) are reserved for the exclusive use of transit vehicles, but allow other travel modes to cross the facility at controlled locations. Examples of such facilities include:

- On-street lanes reserved for the exclusive use of transit vehicles at all times and locations;
- Bus lanes and light rail tracks in a street median, with vehicle access across the tracks limited to signalized intersections;
- Light rail and commuter rail operating on their own rights-of-way, with at-grade crossings provided where roadways cross the tracks; and
- Bus rapid transit operating on its own right-of-way, with traffic signals used to control at-grade crossings.



(a) Transit mall (Denver)



(b) BRT on private right-of-way (Los Angeles)



(c) Light rail on private right-of-way (Los Angeles)



(d) Light rail in street median (Los Angeles)

Exhibit 2-18
Exclusive Transit Operation Illustrated

Restricting facility use to transit vehicles eliminates many of the potential external factors that can interfere with transit operations, and allows transit preferential treatments (e.g., signal priority or preemption, grade crossings) to address most of the rest. As a result, exclusive facilities offer many of the benefits of fully grade-separated facilities at a significantly lower cost. Nevertheless, some issues can remain when exclusive facilities are used, mainly related to potential safety concerns (e.g., speed restrictions at signal-controlled intersections on busways, potential conflicts between left-turning vehicles and transit vehicles operating in a street median). In addition, particularly with exclusive transit lanes, unauthorized facility use or crossings can pose an enforcement challenge.

GRADE SEPARATED

Grade-separated transit facilities (Exhibit 2-19) are reserved for the exclusive use of transit vehicles. All other travel modes (e.g., automobiles, pedestrians) cross over or under the facility. Delays due to traffic signals and potential conflicts with other traffic are eliminated, allowing higher-speed, more-reliable transit operations, but with significantly higher capital costs to construct. Examples of grade-separated facilities include:

- Facilities located at grade, where other modes cross over or under the facility;
- Below-grade facilities, such as subways and bus tunnels; and
- Elevated facilities.

Exhibit 2-19
Grade-Separated Operation Illustrated



(a) Grade-separated busway (Brisbane)



(b) Bus/light rail tunnel (Seattle)



(c) Subway (New York)



(d) Elevated tracks (Chicago)

4. SERVICE PATTERNS

FIXED ROUTE

Fixed-route services are provided along a designated route and are operated at set times or headways. This section introduces the main types of stopping patterns and route network designs associated with fixed-route service and their impacts on passenger quality of service. More information is available in a number of sources (for example, *32–34*).

Stopping Patterns

Exhibit 2-20 illustrates the main types of stopping patterns that can be offered along a fixed route. Although this exhibit shows different types of services sharing the same stop, it is also possible for operational or branding purposes to locate different services' stops close to each other, but in separate locations.

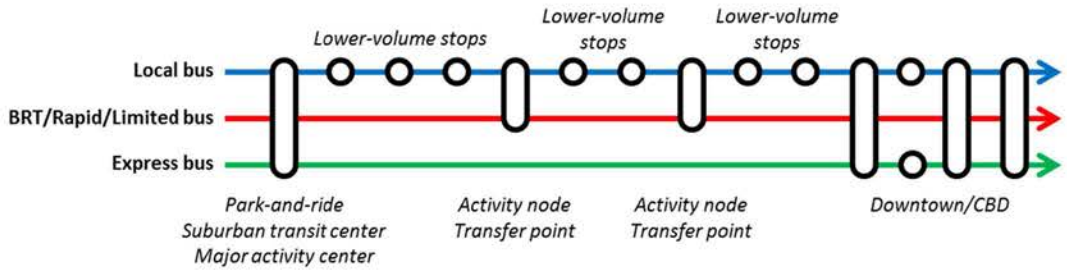


Exhibit 2-20
Fixed-Route Stopping Patterns Illustrated

Local

A local route serves all stops along the route, emphasizing transit access over speed. It can be offered by any fixed-route mode. In small cities, "flag stops" may be used in lieu of designated bus stops, allowing passengers to be picked up and dropped off at any safe location upon request. As ridership increases, flag stop operation tends to create schedule reliability problems, as the effective stop spacing becomes very short (sometimes with stops at each end of a city block) and bus speeds become too slow to maintain the schedule. Flag stop operation can also be offered at night as a passenger security measure, allowing passengers to be dropped off closer to their destination.

Limited Stop

This type of service balances access with speed. Transit vehicles serve only high-volume stops (e.g., major destinations, transfer points), providing many passengers with a faster trip as a result of the fewer stops between passengers' origins and destinations. This type of service can also potentially be operated with fewer vehicles than a local service (offering lower operating costs), as a vehicle can complete a round trip faster, resulting in fewer vehicles needed to operate the route, compared with local service. BRT routes are frequently limited-stop routes. Limited-stop bus services can be offered in conjunction with local service on a street. Limited-stop rail service typically requires multiple-track corridors (as with New York's express subway lines) or—at a minimum and with potential scheduling difficulty—passing sidings within a corridor, such as at shared stations.

Express

Express services emphasize speed over access and are often used for longer-distance trips. Transit vehicles provide local service near the end points of the route (sometimes with only one pickup point, as with park-and-ride based commuter bus service) and operate non-stop over the majority of the route. As with limited-stop rail service, express rail service typically requires multiple-track corridors. A variant of express rail service can also be offered when only one track per direction exists. In this case, an express train leaves the starting point just before a local train and runs non-stop until it catches up to the local train in front, at which point it must serve all stops again as it cannot overtake the train in front. The ability to run non-stop on the line is a function of the headway—the shorter the headway, the shorter the distance between trains and the shorter the non-stop section will be.

Route Network Designs

Facility-based Designs

The construction of a new transit facility—anything from bus lanes on an urban street to a new rail line—offers improved transit capacity, speed, and reliability characteristics that had not previously existed in the corridor served by the facility. It also provides an opportunity to consider changes to the broader bus network using or feeding the facility. As one source puts it, an approach focused on improving and branding a single route sends the message that *this route* provides better service, while an approach focused on improving and branding a facility sends the message that *all routes on this facility* provide better service (*35*).

In outlying areas, a new facility can open opportunities to provide high-quality bus service to areas relatively remote from major destinations, as they allow a transit trip to be made in less time, particularly when combined with some form of express or limited-stop service. In downtown areas, a facility offers the opportunity to consolidate multiple services onto a single street. This improves the ease of understanding of the system to users (passengers know where to go to find transit service) and supports a greater level of infrastructure improvements than might otherwise be possible if only one route was affected.

There are two main types of facility-based route designs: (*a*) trunk-and-branch and (*b*) feeder service, which are discussed in the following subsections.

Trunk-and-Branch

In a trunk-and-branch design, the bus or rail facility supports several transit lines on the inner portion of the facility. Moving out along the facility, individual lines branch off from the trunk to serve more localized market areas. The trunk portion provides a higher effective frequency than could be supported by an individual line within the corridor, which creates the potential for additional ridership generation as a result of the higher frequencies.

The branches provide local, readily accessible service in the outer portions of the routes. They work well when a feeder route would already be full or nearly full when it reaches the corridor and when most of the passengers have destinations along the corridor. This pattern can also support an all-stops route that serves all stations along the corridor (*35*).

Exhibit 2-21 shows an example of this model in a light rail context. Three light rail lines from Portland's eastern suburbs and the region's airport converge into a trunk corridor that proceeds west toward downtown. The trunk receives more service than any of the branches—three times as frequent service, if each branch operates at the same headway as the others (not a requirement). This type of pattern is also used in light rail systems based on older streetcar systems, such as Boston, Philadelphia, and San Francisco, where multiple routes converge on underground light rail subways. Because light rail facilities are typically constructed with only one track in each direction, all trains operating on the trunk must serve all stations. In a rail context, this pattern also requires reliable operations on the branches, with trains entering the trunk at their scheduled time, so that following trains from other branches are not delayed.



Source: TriMet.

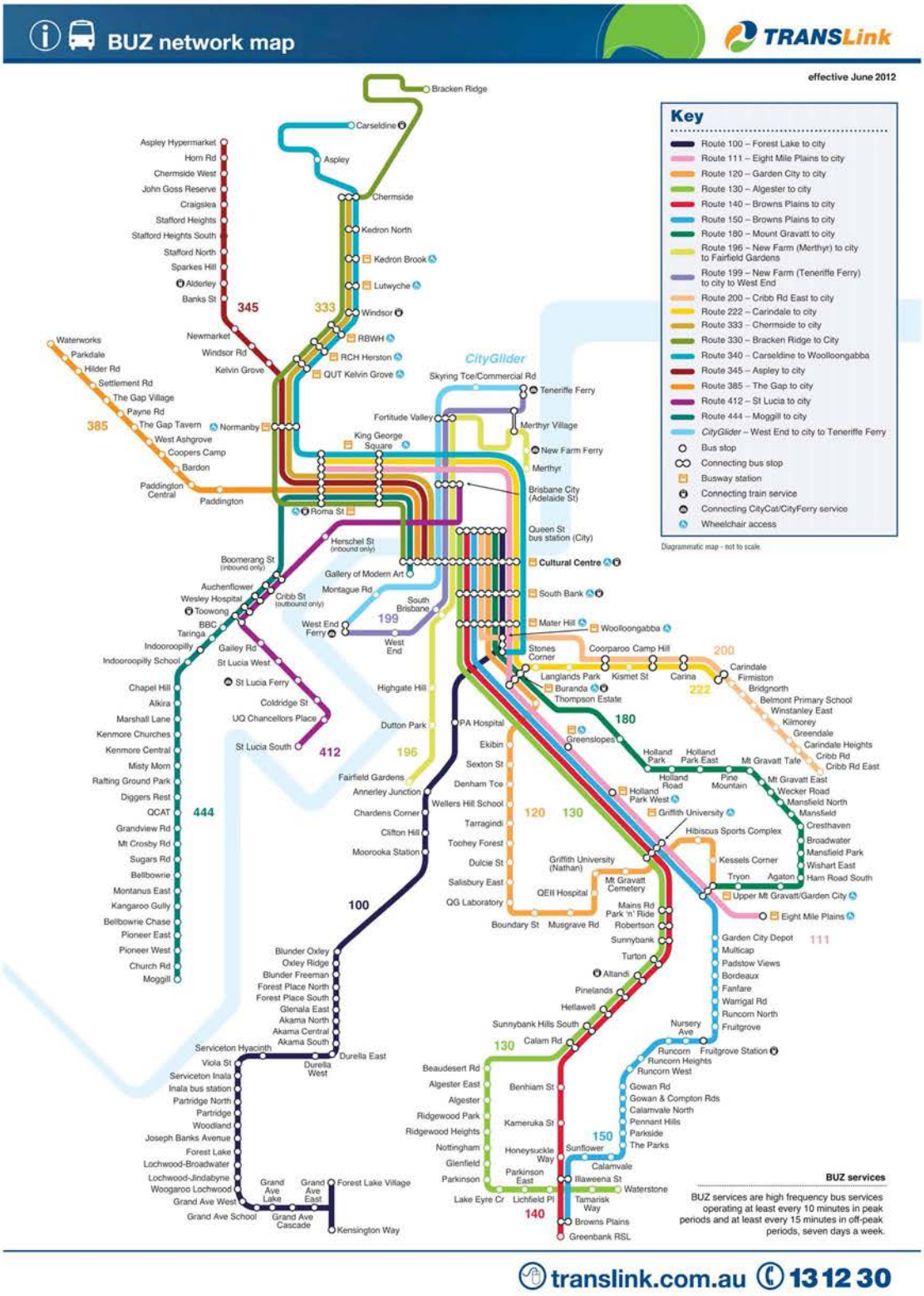
Exhibit 2-21
Trunk-and-Branch LRT Route Design (Portland)

Exhibit 2-22 shows a trunk-and-branch design in a BRT context. Multiple bus services converge on BRT facilities in Brisbane. Because passing opportunities are provided at stations—in contrast to a light rail line—different stopping patterns can be used for different bus lines. Some lines operate non-stop to downtown (express), others serve major stations only (limited-stop), and some serve all stations (local). The speed and level of transit access offered on a given route can be better matched to the origins and destinations of that route's passengers. This model is also used, for example, on the Ottawa and Pittsburgh busway systems, and on the Columbia Pike corridor in Northern Virginia.

Feeder

In a feeder pattern, local transit routes bring passengers to a corridor served by a high-frequency bus or rail line. Passengers must transfer to continue their trip along the corridor, but do not have to wait long for connecting service on their inbound trip. In a rail corridor served by buses or other modes, this is the only possible model. In a bus facility context, feeder service can be appropriate where buses are not full when they arrive at the facility (the buses can be used more efficiently by keeping them within their local service area) or when smaller buses are used on the local route.

Exhibit 2-22
Trunk-and-Branch BRT Route Design (Brisbane)



Source: TransLink.

A variation of feeder service is a grid route network where, for example, a series of north-south routes intersect an east-west corridor. The north-south routes serve destinations along the street, as well as providing connections to the east-west corridor and to other east-west routes. Los Angeles' Orange Line BRT is example of local and rapid bus service feeding a trunk BRT line (Exhibit 2-23). The Orange Line itself is a feeder to the Red Line subway.

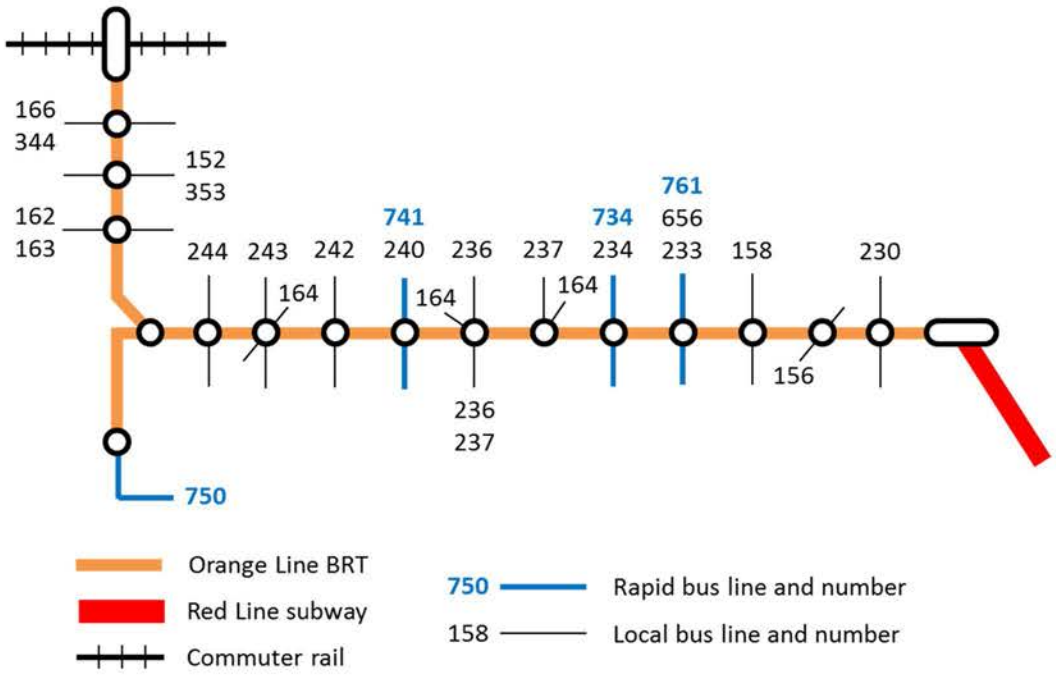


Exhibit 2-23
BRT Feeder Service via Grid Network (Los Angeles)

Rail services typically rely on feeder bus service to some degree—less so for urban subway and AGT systems supplemented by surface bus routes and more so for light rail and commuter rail lines, particular in suburban areas. Many South American BRT systems use a feeder service pattern (*36*).

System Design

As discussed in more detail in Chapter 4, Quality of Service Concepts, planning transit service involves trade-offs between the area served by transit (service coverage), service frequency, and the time required to make a trip, given a fixed amount of resources for service. Except in the smallest communities, where a loop route can provide (slow, circuitous) service to all major origins and destinations, at least some—and often many—transit trips will require a transfer. The way that transfers are facilitated via the transit system design has quality of service implications. Common system designs in larger communities with multiple transit routes consist of (*32–34*):

- *Radial* networks, where all routes focus on the downtown area, due to its role as a major source of trip destinations and—often—its central location. Major corridors can be served with high-capacity transit routes. One-seat rides can be provided to downtown, as well as to selected other destinations when routes extend through and past downtown (*interlining*). Interlining can create schedule reliability problems on the outbound trip when the inbound trip is delayed, as

Examples of radial networks include Philadelphia's regional rail lines and the bus networks in Providence and Hartford.

schedule recovery opportunities are only available at the outer ends of the route. All other trips with origins and destinations outside the central area require a transfer and a potentially out-of-direction trip through downtown.

Portland, Oregon is an example of a hybrid network.

- *Hybrid* networks overlay key *crosstown* routes that directly connect selected major non-downtown origins and destinations and provide connection opportunities to radial routes. Faster, more direct trips are possible for trips involving non-downtown locations.

Edmonton and Omnitrans (San Bernardino area) are examples of hub-and-spoke networks.

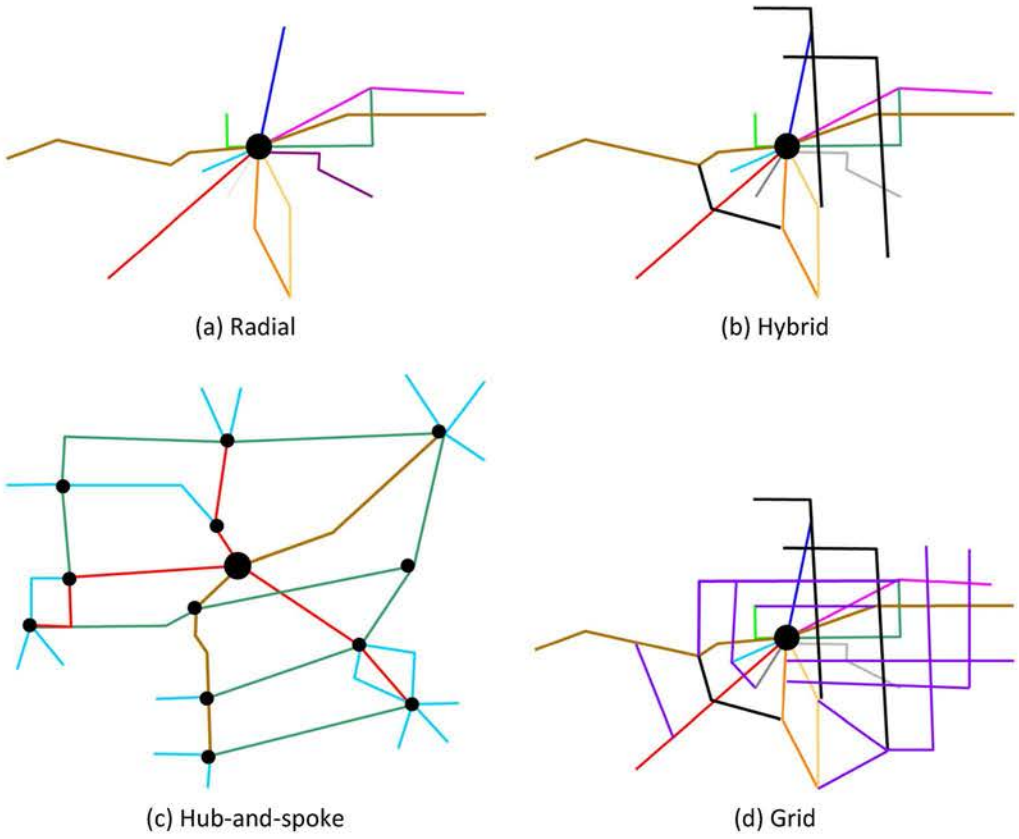
- *Hub-and-spoke* networks focus local bus service around transit centers, where buses meet on a *timed transfer* (*pulse*) basis to transfer passengers, minimizing the time required to make a connection. Other, potentially high-capacity, routes connect transfer centers and the downtown to each other. This design offers relatively direct connections to a variety of locations within a region, but requires good reliability when local service is infrequent, so that passengers do not miss their connection.

Chicago, Los Angeles, and Vancouver are examples of grid networks.

- *Grid* networks provide frequent service along major streets and cover a large portion of the region. Many trips require a transfer, but transfer times are minimized due to the frequent service.

Exhibit 2-24 illustrates these types of route networks. A region's network will often begin with a radial design when fixed-route service is introduced, but will evolve over many years into one of the other forms, if the region continues to grow. The region's growth provides new areas in which to operate fixed-route service and potentially greater resources for operating the service.

Exhibit 2-24
Examples of Fixed-Route Networks



DEMAND RESPONSIVE

DRT and its related flexible services are provided in response to a passenger request for a trip. DRT services—such as those discussed earlier in this chapter—provide flexible scheduling along with flexible routing within the constraints of the trip pattern (e.g., many-to-few) established for the service. Flexible transit services combine elements of DRT and fixed-route service. This section illustrates the types of trip patterns commonly used for DRT service, describes the service attributes of various flexible transit services, and gives examples of transit agency approaches to transitioning a service type to one providing more or less flexibility.

DRT Trip Patterns

DRT service can be operated using a variety of trip patterns, including many origins to many destinations, many origins to few destinations, few origins to many destinations, few origins to few destinations, and many origins to one destination. These trip patterns are illustrated in Exhibit 2-25:

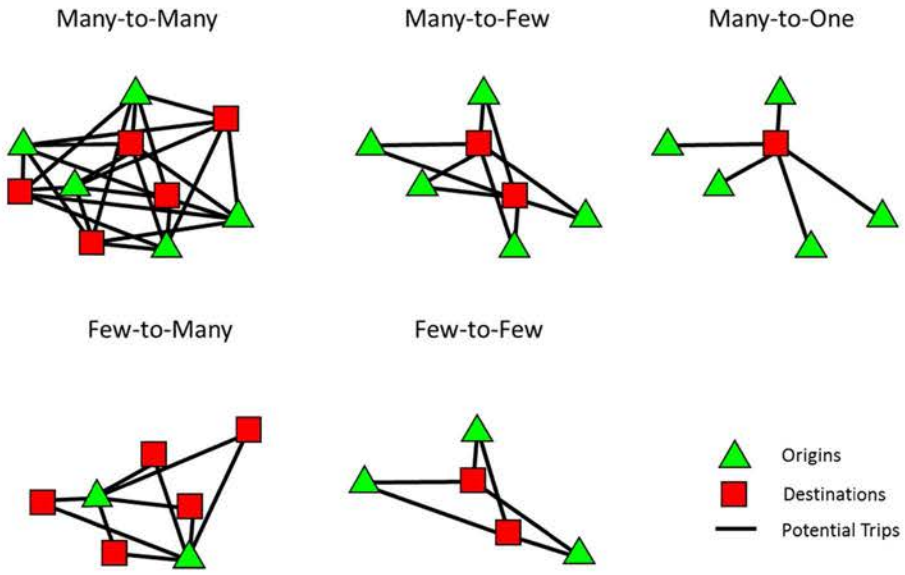


Exhibit 2-25
Examples of DRT Trip Patterns

Flexible Transit Services

Beyond the types of demand-responsive transit discussed earlier in this chapter, other DRT variants have evolved with service designs that build on the inherent flexibility of DRT but include elements of more traditional fixed-route and fixed-schedule transit to increase productivity.

DRT Connector/Feeder Service

Definition

DRT connector, also referred to as "feeder" service, provides demand-responsive service within a defined zone that has one or more scheduled transfer points to fixed-route transit. The transfer points may be a bus stop for peak-period express or other bus service, or a rail station. The service is designed primarily to offer connections to

the fixed-route network, but also provides local transportation within the defined zone. Generally, a large percentage of DRT connector trips begin or end at the designated transfer points. Performance data for several feeder services report productivity figures from about two to eight passenger trips per vehicle revenue hour (*10*).

Applications

Several large transit agencies, including those in Denver, Dallas, and San Diego, have implemented DRT connector services in low-density parts of their service areas to connect with fixed-route bus and light rail service. The transit agency in Denver, for example, provides DRT connector service —called Call 'n Ride—in 21 different defined parts of its large service area, ranging from a mountain community to office campus areas to old and new suburban developments. The Call 'n Ride service areas range from very small (2.2 mi^2 or 5.7 km^2) to considerably larger (10, 12, and 30 mi^2, equivalent to 26, 31, and 78 km^2). The agency's first DRT connector service replaced a poor-performing fixed-route bus service in 1999 that carried 1.6 passengers per hour at a $78.46 subsidy per passenger trip. One year after implementation, the Call 'n Ride replacement service served 4.3 passengers per hour for a subsidy of $9.84 per passenger trip. Based on data from 2011, the median Call 'n Ride productivity for an average weekday is 3.9 passenger trips per revenue hour (*37*).

In Dallas, the transit agency initiated its first DRT zone—branded On-Call—in 1999 in areas where population density was too low to support fixed routes. As of 2012, there are eight On-Call zones. On-Call services are neighborhood circulators that also connect to Dallas Area Rapid Transit (DART) fixed-route or light rail services, depending on the zone. Passengers may board an On-Call transit vehicle at one of its regular stops, may book a curb-to-curb pickup in advance, or may call in on the same day of travel (usually at least an hour in advance) to request a pickup. On-Call vehicles operate flexible service during all service hours; during peak commute hours, each On-Call vehicle provides connector service only to and from local transit centers, while midday service also makes other regular stops at shopping centers, medical offices, grocery stores, and similar destinations (*38*).

Potential Integration with ADA Paratransit

For those transit agencies with DRT connector services, there is an opportunity to integrate the general public DRT service with required ADA paratransit in the same service zone. If the two services are fully integrated, the agency does not provide ADA paratransit service as separate from the DRT service, allowing the transit agency to reduce service hours to serve the two rider groups. In such case, the effectiveness of the general public DRT service is measured by comparing the performance of the DRT service to the combined performance of both the fixed-route and ADA services operating concurrently in the same area. This is a positive consideration in favor of general public DRT service in low-density parts of a community as it can be an effective substitute for traditional fixed-route service and its required ADA paratransit in low density environments (*10*).

Zone Routes

Zone routes combine DRT service within defined zones along a corridor with scheduled departure and arrival times at one or more end points. This type of flexible

service is one of the least common. One application is in rural Washington State, where the service involves one trip per day that leaves the main small city in the county and provides drop-offs and pick-ups within a demand-response corridor that is defined by the road network and natural barriers. Most of the passengers are traveling to or from the small city (*8*).

A more urban example is the nighttime service operated in Charleston, S.C. To serve suburban and some urban areas during lower-demand nighttime hours from 9:30 p.m. to 1:00 a.m., the transit agency operates four flexible zone routes. The vehicles serving the four defined zones all meet at a designated downtown stop at scheduled times, and the routes take 60 to 90 min to operate, depending on the specific route. Riders can board at the downtown stop or make a reservation in advance for a pick-up at any established bus stop in the defined route/zone area. Drop-offs are at bus stops on an on-demand basis. The transit agency reports a productivity of three passenger trips per hour on its zone routes (*9*). This service is designed to provide coverage within lower-density areas during periods of lower demand.

Point Deviation

Point deviation service, also called checkpoint dial-a-ride, operates within a defined area or zone, providing demand responsive service as well as scheduled service to a limited number of designated stops, without any regular route between the stops. Point deviation services allow considerable time within their schedules for demand responsive trips because of the service design. The time allotted for DRT service for point deviation systems averages 30 min for each service hour (*8*).

Reported productivities for point deviation service range from about 2.5 to 4 passenger trips per vehicle revenue hour. As one example, the transit agency in Oklahoma City uses point deviation service as a substitute for fixed-route service during night hours and Sundays in five zones of the city and for all-day service in one suburban area. The vehicles provide demand-responsive service within each zone, with a limited number of scheduled stops at fixed locations within each defined zone (*8*).

Route Deviation

Definition and Applications

Also called flexible-route or flex-route service, route deviation is actually one of the less flexible DRT variants, sharing more with fixed-route service than with DRT. Route deviation vehicles operate along a regular route, with or without marked bus stops, and deviate off that route to serve demand-response trips within a zone around the route. The width of that zone, or extent of the deviation, may be precisely defined, for example ½ mi, or it may be flexible. Formal deviations typically range from ¼ to 1½ mi. Less-formal deviation policies may allow the driver to deviate farther, particularly in very rural areas, with deviations of up to several miles or more allowed, assuming the driver maintains the route schedule.

The number of deviations allowed depends on the schedule for the route and the extent of the deviation, although the service needs some limits so that travel times for riders boarding and alighting at bus stops are not overly long. Based on TCRP research on flexible services, the time allowed for deviation in schedules varied from 20 min each

hour, which allows for considerable deviation capability, to only 2.5 min each hour, which gives very limited time for deviations (*8*).

Route deviation is the most common of the DRT variants, often deployed in lower density and rural areas. According to 2009 Rural NTD data, close to 30 percent of rural transit systems operate route deviation services (*11*).

Performance

Performance data for route deviation shows a wide range of productivity, ranging from 2.5 to 20 passenger trips per revenue hour, with the high productivity systems providing very limited deviations from the route.

Route deviation, as well as other DRT variants, can serve the general public as well as those who need more personalized service, eliminating or reducing the need to operate two separate services—fixed route and DRT. Where funding is very limited, operation of a combined service, such as route deviation, may be the only viable way to provide transit service in a community.

ADA Requirements

Route deviation is considered demand-responsive service according to the ADA and is not subject to the requirements for ADA complementary paratransit, as long as the service accepts route deviation requests from the general public. However, transit agencies operating such route deviation service do have to provide service to riders with disabilities that is *equivalent* to the service provided to other passengers, as defined by the ADA. If deviations are limited to persons with disabilities, then the deviation service becomes the transit agency's ADA complementary paratransit and must meet the six ADA service criteria, including that the vehicles deviate at least ¾ mile either side of the route, that fares for the deviation be no more than twice the base fare, and so forth.

Flexible Route Segments

Flexible route segment service is predominately fixed-route service but converts to DRT for a limited and defined portion of the route. For example, the Corpus Christi transit agency operates a route connecting two rural communities to downtown Corpus Christi. The route has one scheduled stop in one community and two in the second, and also provides demand-responsive service within each of the two communities. After its scheduled stops and any requested demand-responsive trips, the service heads to its terminus in Corpus Christi. This service is reversed for trips outbound from Corpus Christi (*8*).

Research on flexible transit services found that that this type is not among those commonly in service. The limited data on performance report productivity at approximately 2.5 to 3 passenger trips per revenue hour (*8*).

Request Stop

Request stop service is predominately traditional fixed-route/fixed-schedule service but which also provides service to a limited number of defined stops close by the route at the request of a passenger. This is different from flag stop service in that the request stops are not directly on the route. In one application, the transit agency serves several stops only by passenger requests; these stops are major destinations with poor

pedestrian accessibility from the main transit route. The request stop flexibility allows the transit system to better serve those destinations, with more direct service for the riders. Request stop service may also be honored only during specific time periods, for example, during night service to provide the passenger direct access to the final destination.

Productivity information for request stop service is limited, with data for one system, which reported approximately six passenger trips per revenue hour (*8*).

Transitioning DRT to More or Less Flexibility

As more and more DRT variants are placed into service, transit agencies need criteria or guidelines to determine when to consider implementation of flexible transit and when to transition to more, or less, flexibility in the type of transportation service offered. While research documenting these criteria is limited, the experiences of transit agencies that operate DRT variants provide insight and guidance for planning and transitioning among DRT and its variants.

Three transit agencies that have implemented general public DRT and other flexible services as strategies to provide cost-effective transit in lower density areas are the Regional Transportation District (RTD) in Denver, DART, and King County Metro in Seattle. Examples of the types of flexible services implemented by the three agencies include the following:

- Zoned, neighborhood demand-responsive service for many-to-few trips within a limited service area,
- Feeder/connector service for many-to-one transit from residential areas to rail stations or transit centers,
- Point deviation with scheduled checkpoints,
- Route deviation (flexible routes), and
- Other hybrid services that reflect combinations of DRT or DRT services blended with fixed route.

King County Metro

King County Metro emphasizes productive services to control costs. A key strategy to controlling Metro's cost is to develop and implement alternative public transportation, including demand-responsive services where land uses and travel demand patterns do not support fixed-route service. Metro uses two performance metrics to measure the transit performance of all its services: rides per platform hour and passenger miles per platform mile (platform hours and miles include service, layover, and deadhead—non-revenue—miles and hours). Fixed-route services that are in the bottom 25% of both measures become candidates for change that could include conversion to demand-responsive service. Metro service guidelines provide for variable routing where demand is dispersed and fixed route service is unlikely to be successful (*40*).

Denver RTD

Denver RTD has developed a family of transit services suited to a variety of travel markets. The goal of this approach is to match the type and level of service to the

demand in a given service area, thus improving performance and sustainability. RTD operates a variety of DRT services. According to the RTD experience, DRT is not a service with a fixed capacity. Variations on DRT service can make it possible for a transit agency to carry more passengers for a specified amount of resources. Characteristics of RTD's approach include:

- The transit agency can maintain the initial level of service for many-to-many DRT and carry more passengers (improve productivity) as demand increases.
- If demand increases beyond the initial capacity (trip requests are turned away), the transit agency can add a vehicle to increase the level of service.
- At higher levels of demand, the transit agency can convert many-to-many DRT services to structured DRT or flex-route services with higher productivity.
- DRT services can also be blended with fixed-route operations via route segments that can deviate when needed.

The RTD has shown that structured DRT is able to generate higher productivity than pure demand-responsive transit. RTD reports that most DRT services that are predominantly many-to-many achieve a productivity of 3 to 4.5 passenger trips per vehicle service hour. On the other hand, productivity for more structured services, such point deviation or flexible routes, can achieve 5 to 9 passenger trips per service hour (*41*).

DART

Dallas Area Rapid Transit (DART) strives to "right-size" service based on ridership. Exhibit 2-26 illustrates DART criteria to match transit mode to levels of productivity or riders per revenue hour.

Exhibit 2-26
DART Criteria for Fixed-Route and DRT Service

Mode	Ridership Demand Level	Typical Riders per Revenue Hour
Fixed-Route Transit Bus	High	>20
Fixed-Route Small Bus	Low to medium	10–20
Flex-Route	Moderate	5–12
On-Call Demand Responsive	Insufficient ridership to support fixed-route	3–7
Shared-Ride Taxi	Very sparse ridership that cannot be cost-effectively served through other modes	<3

Source: Dallas Area Rapid Transit (*42*).

DART sponsors several flex-route services with an average productivity of 8 passengers per hour. When demand reaches 10 passengers per hour for three consecutive performance reporting periods (four reporting periods per year), the agency begins an analysis of the potential for converting the flex route to fixed route (*42*).

Cost-effective flexible services balance efficiency and flexibility, using strategies that reduce the inefficiency of pure DRT service and typically limit the degree of pure DRT that is provided. As demand increases and the need for structure (defined bus stops, scheduled times, and greater frequency of service) increases, DRT variants transition toward more traditional fixed-route, fixed-schedule transit service.

5. REFERENCES

Links to the TCRP reports listed here can be found on the accompanying CD-ROM.

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CHAPTER 3
OPERATIONS CONCEPTS

1. User's Guide
2. Mode and Service Concepts
3. **Operations Concepts**
4. Quality of Service Concepts
5. Quality of Service Methods
6. Bus Transit Capacity
7. Demand-Responsive Transit
8. Rail Transit Capacity
9. Ferry Transit Capacity
10. Station Capacity
11. Glossary and Symbols
12. Index

CONTENTS

1. INTRODUCTION 3-1
How to Use This Chapter 3-1
Other Resources 3-2
2. CAPACITY, SPEED, AND RELIABILITY 3-3
Overview 3-3
Capacity Concepts 3-4
Speed Concepts 3-10
Reliability Concepts 3-13
3. PASSENGER DEMAND CHARACTERISTICS 3-15
Transit Passenger Demand Patterns 3-15
Demand Related to Demographics 3-18
Demand Related to Land Use 3-18
Demand Related to Transportation Demand Management Strategies 3-21
4. DWELL TIME 3-23
Definition 3-23
Dwell Time Components 3-23
Dwell Time Variability 3-24
Illustrative Impacts of Dwell Time on Capacity 3-24
Illustrative Impacts of Dwell Time on Speed 3-27
5. OPERATING ENVIRONMENT 3-28
Guideway Type and Design 3-28
Traffic and Transit Vehicle Effects 3-29
Illustrative Impacts of Operating Environment on Capacity 3-30
Illustrative Impacts of Operating Environment on Speed 3-35
Impact of Operating Environment on Reliability 3-37
6. STOP AND STATION CHARACTERISTICS 3-38
Vehicle–Platform Interface 3-38
Vehicle Characteristics 3-38
Fare Collection 3-39
Stop Spacing 3-39
Illustrative Impacts of Stops and Stations on Capacity 3-39
Illustrative Impacts of Stops and Stations on Speed 3-41
7. REFERENCES 3-44

LIST OF EXHIBITS

Exhibit 3-1 Factors Influencing Person Capacity 3-7
Exhibit 3-2 Average Weekday Passenger Traffic Densities (2010) 3-10
Exhibit 3-3 Factors Influencing Transit Speed 3-11
Exhibit 3-4 Average System Speeds by Mode (2010) 3-12
Exhibit 3-5 Factors Influencing Transit Reliability 3-14
Exhibit 3-6 Illustrative Time-of-Day Variations in Transit Demand 3-15
Exhibit 3-7 Illustrative Variation in Peak-Hour Demand 3-17
Exhibit 3-8 Minimum Land Densities Supporting Transit Service at Various Frequencies 3-20
Exhibit 3-9 Illustrative Change in Transit Demand with Density 3-20
Exhibit 3-10 Illustrative Impact of Dwell Time on Bus Facility Capacity 3-25
Exhibit 3-11 Illustrative Impact of Bus Dwell Time Variability on Capacity 3-25
Exhibit 3-12 Illustrative Impact of Dwell Time on Rail Line Capacity 3-26
Exhibit 3-13 Illustrative Impact of Operating Margin on Rail Line Capacity 3-26
Exhibit 3-14 Illustrative Impact of Dwell Time on Average Bus Speed 3-27
Exhibit 3-15 Illustrative Impact of Dwell Time on Average Train Speed 3-27
Exhibit 3-16 Impacts of Other Modes on Transit Speed and Capacity 3-29
Exhibit 3-17 Interactions of Transit with Other Modes 3-30
Exhibit 3-18 Illustrative Impact of Traffic Signalization on Bus Facility Capacity 3-31
Exhibit 3-19 Illustrative Impact of Train Signaling System and Station Approach Speed on Line Capacity 3-32
Exhibit 3-20 Illustrative Impact of Curb Lane Traffic Congestion on Bus and Streetcar Capacity 3-32
Exhibit 3-21 Illustrative Impact of Station Approach Grade and Speed on Line Capacity 3-33
Exhibit 3-22 Illustrative Impact of Operating Environment on Facility Capacity 3-34
Exhibit 3-23 Illustrative Impacts of Traffic Signals on Bus Speeds 3-35
Exhibit 3-24 Illustrative Impact of Bus Congestion on Bus Speeds 3-36
Exhibit 3-25 Illustrative Impact of Operating Environment on Average Transit Speed 3-37
Exhibit 3-26 Illustrative Impact of Bus Passenger Service Time on Capacity 3-40
Exhibit 3-27 Illustrative Impact of Floor Height and Door Availability on Light Rail Line Capacity 3-40
Exhibit 3-28 Illustrative Impact of Number and Type of Loading Areas on Bus Facility Capacity 3-41
Exhibit 3-29 Illustrative Impact of Fare Collection on Average Bus Speed by Facility Type 3-42
Exhibit 3-30 Illustrative Impact of Stop Spacing on Average Transit Speed 3-43

1. INTRODUCTION

Organization of Chapter 3.

Chapter 3 of the *Transit Capacity and Quality of Service Manual* (TCQSM) presents the basic transit capacity, speed, and reliability concepts that form the basis for many of the computational methods found in later chapters:

- Section 2 defines transit capacity, speed, and reliability, and highlights the key factors influencing each. Later sections in this chapter focus in more detail on these factors and their specific effects on capacity and speed.
- Section 3 provides an overview of transit passenger demand patterns and the external factors (i.e., factors not under the control of a transit agency) that influence demand.
- Section 4 discusses dwell time's significant impact on transit capacity and speed and the factors that contribute to dwell time.
- Section 5 reviews the characteristics of transit operating environments (rights-of-way) that influence capacity, speed, and reliability.
- Section 6 covers factors related to transit stops and stations (e.g., fare collection, stop spacing, passenger service time) that affect capacity and speed.
- Section 7 is a list of the references that provided material used in the chapter.

HOW TO USE THIS CHAPTER

This chapter provides a basic set of capacity and quality of service definitions used throughout the TCQSM; all readers will ideally be familiar with Section 2 before applying the computational methods presented later in the manual (Chapters 5–10).

Although the TCQSM's scope does not include ridership estimation, changes in ridership demand can nevertheless affect transit speed and capacity by changing dwell time. Section 3 summarizes current research on external influences on ridership demand, including time-of-day demand patterns, land use density, demographic patterns, and travel demand management (TDM) programs. This material will be of interest to readers wanting to know more about the relative impacts of various external factors on ridership. (Ridership changes related to changes in quality of service are discussed in Chapter 4, Quality of Service Concepts.)

Sections 4–6 examine in detail the influence of various factors related to dwell time, operating environment, and stops and stations, respectively, on transit capacity and speed. These sections are recommended reading for those new to transit operations analysis. In addition, these sections provide a series of "illustrative exhibits" that depict the relative impact of these factors on capacity and speed. These exhibits will be useful to readers who want to quickly identify areas to consider prioritizing or studying in detail when speed or capacity improvements are desired.

Because exact values of speed and capacity are highly dependent on the specific conditions existing on a particular transit route or facility, these exhibits deliberately do not present specific capacity and speed values. Readers desiring such values can apply the speed and capacity methods presented by mode in Chapters 6–9.

While an effort has been made to select representative conditions when developing the illustrative exhibits, all relationships presented in the exhibits apply only to the set of assumptions used to create the exhibit (and listed with each exhibit). It is not expected that changing these assumptions will change the overall trends or relationships; however, it is not recommended that these exhibits be used as a substitute for calculations when an exact answer is required.

OTHER RESOURCES

Other TCQSM material related to this chapter includes:

- The "What's New" section of Chapter 1, User's Guide, which describes the changes made in this chapter from the 2nd Edition;
- Chapter 2, Mode and Service Concepts, which introduces the operating environments that are addressed in more detail in this chapter;
- The initial sections of Chapters 6 (Bus Transit Capacity), 8 (Rail Transit Capacity), and 9 (Ferry Transit Capacity), which provide mode-specific operations concepts that build upon this chapter's more broadly applicable material; and
- The manual's CD-ROM, which provides links to electronic versions of all of the TCRP reports referenced in this chapter.

2. CAPACITY, SPEED, AND RELIABILITY

OVERVIEW

Transit agencies may consider themselves fortunate when they have capacity problems—it indicates a strong demand for their service. However, for the majority of small and mid-size transit systems, capacity constraints are usually not an issue—sufficient demand exists to provide service only once or twice per hour on most routes and perhaps more frequently on the busiest routes. However, even smaller systems may experience capacity issues in downtown areas where a number of routes may converge.

Why, then, should transit agencies and transportation planners be concerned with transit capacity? There are a number of reasons:

Factors influencing capacity also influence speed and reliability.

Recovery time is time included in the schedule between vehicle runs to allow late-arriving vehicles to start their next runs on time.

- **Improving speed and reliability.** The same factors that influence transit capacity also influence speed and reliability. Faster, more reliable service is more attractive to passengers. Speed improvements reduce the time required for a transit vehicle to travel its route, while reliability improvements may allow reductions in the scheduled recovery time. In the best-case scenario for a transit operator, the combined reduction in running and recovery time would be greater than or equal to one headway. This result allows the route to be operated with one fewer bus or, alternatively, to be operated at a higher frequency than before at the same operating cost. More typically, the time saved postpones the need to add more service to maintain a particular headway, due to delays arising from traffic congestion. This result is nevertheless a positive outcome, as it results either in (*a*) costs postponed to future years or (*b*) the need to cut service postponed to future years, in situations where the budget cannot accommodate increased costs (*1*).
- **Managing passenger loads.** Capacity plays a role in determining how many buses, trains, or railcars are needed to provide a desired quality of service with respect to passenger loading.

Changing the fare collection method or vehicle type can have unanticipated impacts on running time and crowding that may entail additional costs to correct.

- **Forecasting the effects of changes** in fare collection procedures, vehicle types, or other agency decisions. Dwell time, the time a vehicle spends stopped to load and unload passengers, is often the key determinant of speed and capacity. Changes that impact passenger service times may create unanticipated impacts on running times, passenger loads, or vehicle bunching, which may entail additional costs to correct. Changes in vehicle types (e.g., switching from standard to articulated buses, or high-floor to low-floor buses) may also have dwell time and passenger capacity impacts.
- **Planning for the future.** Planning studies may suggest more than one possible mode or service type to meet a particular travel demand. Knowledge of the speed and capacity provided by each option is essential for making an informed decision. New light rail and bus rapid transit (BRT) systems are sometimes developed with built-in capacity constraints to help reduce initial costs. Knowing how much of a constraint will exist is important for comparing short-term savings with long-term costs.
- **Analyzing the operation of major bus streets** in large cities and the areas around transit centers in all sizes of communities. Small cities that operate a

small number of buses will often have all of the buses meet at a central location. Because delays in bus arrivals will often result in delays to the other bus departures (to avoid missing transfer connections), efficient bus access into and out of the transit center is important. Larger cities will often have a number of routes converge on a small number of downtown streets, and the TCQSM's capacity procedures can be used to analyze the operation of those streets.

- **Special event service.** Bus services are sometimes required to bring a portion of the demand for community festivals, county fairs, sporting events, and the like to the event site from remote parking areas. The procedures in this manual can be used to help size passenger waiting areas at the event site and to help determine the appropriateness of temporary transit preferential treatments (e.g., temporary bus lanes).
- **Transportation system management.** Transit vehicles can carry many more passengers than automobiles. As a result, an increase in transit vehicle capacity will increase the person capacity of a facility by more than a corresponding percentage increase in automobile vehicle capacity (*2*).

Readers who are familiar with the *Highway Capacity Manual* (*3*) will find that transit capacity is different than highway capacity: transit capacity deals with the movement of *both* people and vehicles; depends on the size of the transit vehicles and how often they operate; and reflects interactions between transit vehicles, passengers, and other travel modes. Transit capacity also depends on the transit agency's operating policies, which normally specify service frequencies, allowable passenger loading, and the type of vehicle used to carry passengers. Accordingly, the traditional concepts applied to highway capacity need to be adapted and broadened (*2*).

The remainder of this section introduces the basic capacity, speed, and reliability concepts common to all public transit modes. Subsequent sections discuss the impacts of specific factors on capacity, speed, and reliability. Chapters 6 through 10 apply these concepts to the development of mode- and facility-specific calculation procedures. Many of these concepts also relate to the quality of service perceived by transit passengers; these issues are discussed further in Chapters 4 and 5.

CAPACITY CONCEPTS

Public transit service focuses on moving people from one place to another. Consequently, transit capacity is focused more on the number of people that can be served in a given amount of time (*person capacity*) than on the number of transit vehicles served by a transit facility (*facility* or *line capacity*). However, determining vehicle capacity is often a necessary first step in determining person capacity.

Person Capacity

The number of people that can be served by a particular transit facility depends on a number of factors, some under the control of the transit operator and some not. At its most basic level, person capacity (persons per hour) is the product of facility capacity (vehicles per hour) and vehicle passenger capacity (persons per vehicle).

Person capacity defined.

The person capacity of a given transit route or facility is defined as follows:

> The maximum number of people that can be carried past a given location during a given time period under specified operating conditions; without unreasonable delay, hazard, or restriction; and with reasonable certainty.

This definition is not absolute, and it is instructive to look at the meaning of specific pieces of the definition:

- *"A given location"*: Capacity is determined at a specific location, typically the segment of a route or facility that carries the most people, known as the maximum load segment. The number of boardings over the length of a route over the course of an hour may be considerably greater than the value of capacity, depending on how often passengers get on and off; capacity represents the maximum number of passengers that can be carried past a given location.
- *"Specified operating conditions"*: The number of people that can be carried depends on the number of vehicles operated and the size of those vehicles. It should be specified whether a reported capacity reflects scheduled capacity (how many people *can* be served under the current schedule), design capacity (how many people *could* be served with no limits on vehicle availability), or some other condition.
- *"Without unreasonable delay"*: Person capacity is maximized when a constant queue of passengers exists to fill all available passenger spaces each time a vehicle arrives, as happens with amusement park rides, for example. Achieving this theoretical capacity requires that some or all passengers be passed up by the first vehicle to arrive, and often by subsequent vehicles. Transit passengers generally dislike pass-ups, particularly when there is a long wait involved for the next vehicle, although they may tolerate it for special event service, when they know another vehicle will be along shortly. Consequently, person capacity for transit must allow some slack to accommodate potential surges in demand, when it is desired that virtually all passengers will be able to board the first vehicle that goes to their destination.
- *"Without…hazard or restriction"*: A key assumption in determining person capacity is the passenger capacity of each vehicle. Person capacity will be greatest when people are assumed to be packed in as tightly as possible (*crush loading*), but in practice, North Americans will not tolerate such conditions and will wait for another vehicle. Therefore, person capacity should be based on the maximum level of crowding that persons will normally tolerate. Similarly, many longer-distance transit services design for all passengers being seated, both for passenger comfort and (with freeway operations) liability reasons.
- *"With reasonable certainty"*: Capacity should reflect the number of people that can be carried on a sustained basis day after day, considering variations in passenger demand, traffic congestion, and other factors not under the control of the transit operator. More people than the design capacity may sometimes be carried, but not most or all of the time.

Vehicle Capacity

Vehicle capacity defined.

The vehicle capacity of a given transit route or facility is defined as follows:

> The maximum number of transit vehicles (buses, trains, vessels, etc.) that can pass a given location during a given time period at a specified level of reliability.

Different transit modes have historically referred to vehicle capacity by different names.

Vehicle capacity is known by different names in the modal capacity chapters of this manual (Chapters 6 through 9)—for example, bus capacity, line capacity, and vessel capacity—but all of these names relate back to the number of transit vehicles that can pass a point during a given period of time, typically 1 h. Ultimately, vehicle capacity depends on the minimum possible headway (time spacing) between individual transit vehicles. This minimum headway is dependent on control systems (e.g., traffic or train signals), passenger boarding and alighting demand at busy stops, the number of transit vehicles that can use a stop or station simultaneously, and, often, interactions with other vehicles (transit or non-transit).

An important part of the vehicle capacity definition is "at a specified level of reliability." Vehicle capacity is maximized when a route or line is operated at the minimum headway, so that the next vehicle is ready to arrive at a stop or station when the vehicle ahead of it pulls out (and, in the case of rail operations, is a safe distance down the line). However, this is an unstable form of operation. The moment that one vehicle's dwell time exceeds the value used to develop the minimum headway, all subsequent transit vehicles will be delayed until the end of the peak period, when headways increase again. The result is that the actual number of transit vehicles that can be reliably served will be less than the theoretical maximum capacity.

Operating margins.

The TCQSM uses the concept of an *operating margin* to allow the analyst to specify a desired level of reliability. The operating margin is added to the minimum headway as an allowance for longer-than-average dwell times. The sum of dwell time and operating margin represents the longest dwell time that can occur without one transit vehicle impeding the following transit vehicle. Although the value of capacity that is obtained will be lower when an operating margin is used, achieved speeds will be higher, as vehicles will not have to stop and wait for the preceding vehicle as often, and overall reliability will be better.

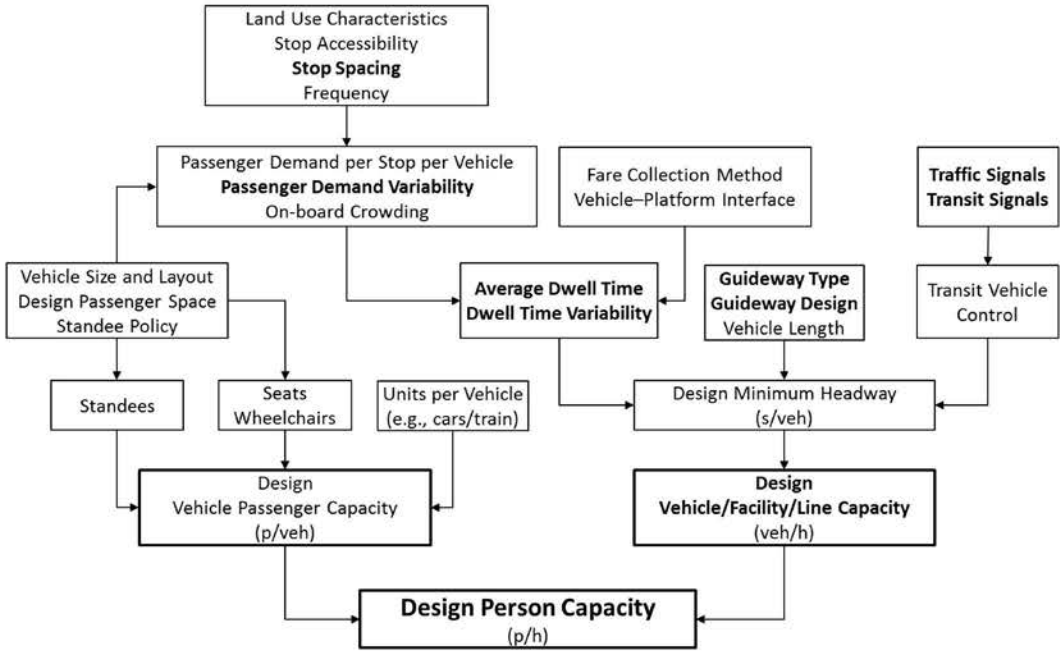
Factors Influencing Transit Capacity

Exhibit 3-1 lists the major factors that influence person capacity—the number of people that can consistently be transported past a given point. It can be seen that factors from every category in the list above are shown as influences in the exhibit. Some of these factors, shown in bold, also influence speed, reliability, or both.

Unless stated otherwise, all capacities given in the TCQSM are design capacities that can be regularly achieved. They are less than maximum (theoretical) capacities.

Exhibit 3-1 also shows person capacity as a *design* capacity. As explained further in Section 7, Capacity Concepts, all capacities given in the TCQSM are design capacities, unless stated otherwise. Design capacities are capacities that can be sustained day after day, accounting for small irregularities in service and variations in passenger demand and arrival patterns. Design capacities are less than the maximum (*theoretical*) capacities that could be achieved if service was 100% reliable, passenger demand never varied, passengers filled every available space on every trip, and so on.

Exhibit 3-1
Factors Influencing Person Capacity



Note: Inputs to design person capacity shown in bold also influence transit speed, reliability, or both.

Exhibit 3-1 shows that person capacity depends on both how many transit vehicles can pass by a point in an hour (*vehicle, facility,* or *line capacity*) and the number of passengers that can be carried on those vehicles (*passenger capacity*).

Factors influencing vehicle passenger capacity.

Passenger capacity is influenced by the number of units per vehicle (e.g., cars per train), the size of the vehicle, and how the space inside each transit vehicle is allocated between seats and standees. Agency policies or government regulations may determine whether standees are allowed and the number of wheelchair positions that must be provided. Agency policy will also determine a design space per standing passenger which, in turn, determines how many standees can be accommodated.

Factors influencing dwell time.

Vehicle size and layout also influence dwell time, because they affect the likelihood of a vehicle arriving at a stop already crowded with passengers, some of whom will need to make their way to and out of the door(s) before other passengers can board. The fare collection method, the height of the platform relative to the vehicle floor, the location of waiting passengers relative to boarding doors, and the number and width of boarding doors all influence the average boarding time per passenger. Finally, various land use, pedestrian infrastructure, and transit service characteristics influence the demand to use transit at a given stop or station. Thus, dwell time is the product of the number of boarding passengers at the critical (typically busiest) door multiplied by the time to serve each passenger, plus the time required to serve alighting passengers through the same door.

The minimum operable headway controls vehicle (bus facility, rail line, ferry vessel) capacity.

Dwell time, guideway characteristics (e.g., mixed traffic operation vs. exclusive guideway operation, platform lengths at stations), and traffic and transit signals influence the minimum headway that can be operated, which in turn controls vehicle capacity.

Other Capacity Considerations

The following considerations are also important (*2*):

1. Operations at vehicle capacity tend to strain transit systems, resulting in vehicle bunching, slower speeds, and passenger delays. These operations do not represent desirable operating conditions. Most North American transit systems operate at vehicle capacity for relatively short periods of time, if at all.
2. Person capacity relates closely to system performance and service quality in terms of speed, comfort, and service reliability. A single fixed number for capacity can often be misleading. The concept of *productive capacity*, the product of person capacity and speed, provides a useful measure of system performance that incorporates both the passenger (speed) and operator (capacity) points of view (*4*).
3. Capacities obtained by analytical methods or simulation must be checked against actual operating experience for reasonableness.

Illustrative Transit Capacities

Difficulty of Providing Representative Capacities

The capacity offered by a given mode can vary widely, depending on the circumstances.

It is difficult to provide representative transit capacities by mode, because of the range of factors that enter into the determination of capacity. For example, heavy rail person capacity can range from around 12,000 persons per hour per direction (p/h/dir) with short trains and a combination of train signaling and critical station dwell time that allows 25 trains per hour, to around 48,000 p/h/dir with long trains and the ability to operate 32 trains per hour. Both of these values assume maximum design load conditions—sufficient space to allow passengers to stand without touching while the vehicle is in motion. When trains are more tightly packed, higher capacities can be achieved, with a resulting poorer passenger quality of service.

Influence of stopping patterns on capacity.

Stopping patterns also play a role in determining capacity. For example, when buses operate non-stop on freeway managed lanes or on some grade-separated busways, a very high volume of buses can be served: for example, up to 735 bus/h/dir on the New Jersey approach to the Lincoln Tunnel (*5*) and 280 bus/h/dir on the busiest portions of Bogotá's TransMilenio BRT system (*6*). In these cases, the facility acts like a pipe, transporting buses to their ultimate destinations, and the capacity of the bus terminal(s) receiving the buses ultimately constrains the facility capacity. Rail corridors can be constructed with multiple tracks, allowing a variety of stopping patterns to be provided and increasing the number of trains that can be accommodated in the corridor.

To obtain an apples-to-apples comparison of the capacities achievable by different combinations of modes, rights-of-way, and stopping patterns, it is necessary to calculate the capacity of each combination using a common set of assumptions (e.g., passenger demand, design space per passenger, right-of-way type). The procedures given in Chapters 6–9 can be used to determine these capacities. The results should be reported for the maximum load segment. When not every transit service stops at every station, evaluating the vehicle capacity of individual stations may also be important to an analysis.

Passenger Traffic Density

As an illustration of the relative abilities of different modes to carry large numbers of passengers, the concept of *passenger traffic density* (passenger miles per directional route mile) is employed. Passenger traffic density measures how many passengers are carried on average over a given mile of a route. When applied to a facility's maximum load segment and peak hour, traffic density can directly express capacity in terms of the maximum number of passengers that can be carried through the maximum load segment during the peak hour.

When measured over longer distances and timeframes, passenger traffic density values are influenced not only by capacity (the greater the capacity, the more passengers that *can be* carried on a section of a route), but also by demand over the timeframe (the greater the demand, the more passengers that *are* carried) and by loading levels (the greater the average load, the more passengers on board in a given section of the route). The data available from the National Transit Database (NTD, *7*) usable for determining passenger traffic density are system-level by mode on weekdays. As a result, NTD-based passenger traffic density values reflect more than just capacity. They are nevertheless useful for comparing relative amounts of passenger service by mode, particularly at the higher end of the traffic density range for each mode.

Exhibit 3-2 shows the range of weekday passenger traffic densities and the median (50th-percentile) value by mode from all U.S. transit systems reporting to the NTD in 2010. Definitions of each mode and system size are provided with the exhibit. Note that the chart uses a logarithmic scale.

Several observations can be made about this exhibit:

- The modes with the highest passenger traffic densities typically provide the highest-capacity vehicles, the most frequent service, or both.
- There is considerable overlap in the passenger density ranges between modes, suggesting that more than one mode is often feasible from a capacity standpoint for accommodating a particular passenger demand.
- The ferry range includes New York's Staten Island Ferry as an outlier at the high end. This ferry serves a role closer to a subway line in terms of its passenger-carrying characteristics (almost 33,000 passenger-miles per route mile on an average weekday). The second-highest ferry system, Washington State Ferries, carried 2,170 passenger-miles per route mile on weekdays.
- The commuter bus mode has relatively high passenger densities because commuter buses tend to be highly loaded for most or all of their route and service can be operated frequently.
- Passenger traffic density values in the lower half of the ranges for each mode are more reflective of demand than of capacity.

BRT does not appear in the exhibit, as the NTD did not include it as a separate mode in 2010 and no independent source of passenger-mile data for BRT was available. Given the range of possible BRT operation (e.g., freeways, busways, on-street), a relatively large range of passenger traffic densities would be expected, likely in the range of large bus systems up to the upper end of the commuter bus range for mature systems.

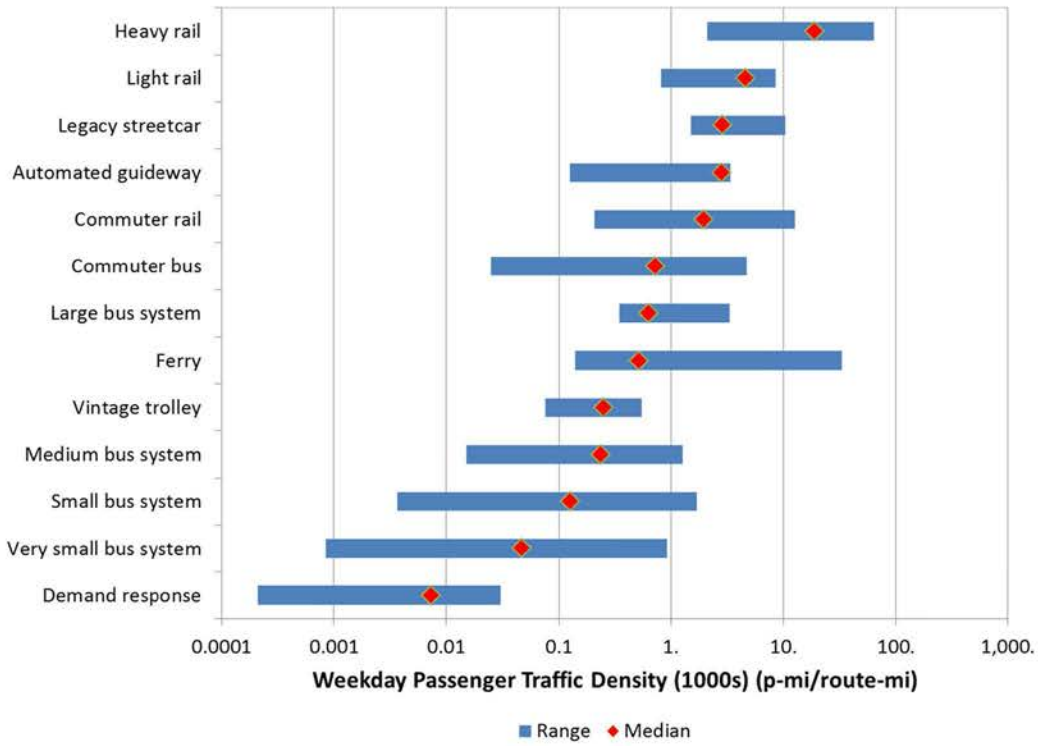


Exhibit 3-2
Average Weekday Passenger Traffic Densities (2010)

Source: Derived from NTD data (*7*).

Notes: Light rail = modern light rail systems built in the 1970s or later.
Legacy streetcar = light rail systems built before the 1970s.
Vintage trolley = non-legacy streetcar systems using historic or historic-looking vehicles.
Insufficient data available to separate modern streetcar from light rail.
Commuter bus = motorbus data from NTD reporters that primarily operate commuter bus service.
Large bus system = motorbus data from NTD reporters with >50 million annual boardings.
Medium bus system = motorbus data from NTD reporters with 10–50 million annual boardings.
Small bus system = motorbus data from NTD reporters with 1–10 million annual boardings.
Very small bus system = motorbus data from NTD reporters with <1 million annual boardings.
Bus rapid transit was not reported as a separate NTD mode in 2010 and thus is not shown.
Equivalent route miles for demand response calculated as (average passenger trip length [passenger miles per unlinked trip]) × (number of vehicles operated in maximum service) × 2.

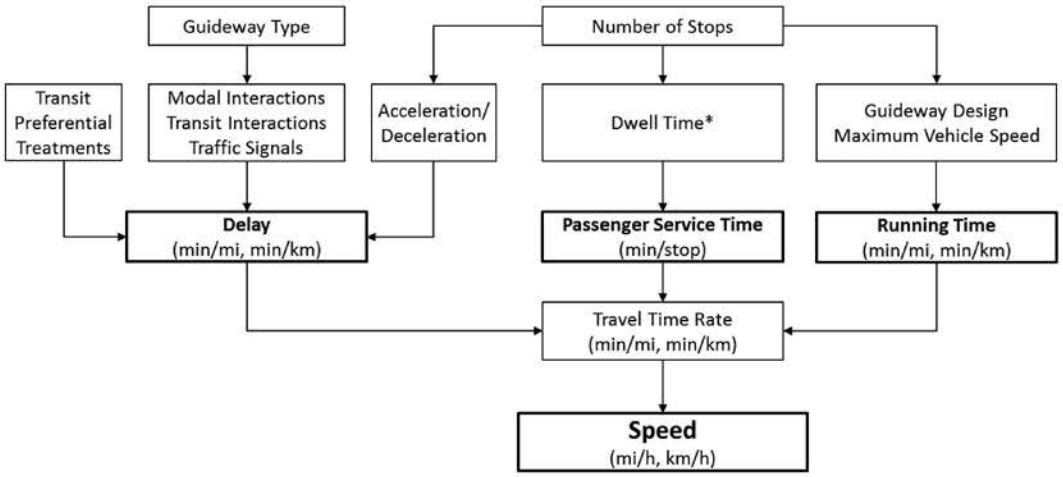
SPEED CONCEPTS

Speed is important to passengers, as it directly impacts the time required to make a trip. The more competitive that transit travel time is with competing modes, in particular the automobile, the more attractive transit service is to potential passengers. Attracting ridership is of course important to transit operators, but speed also impacts the cost of operating a route. The number of transit vehicles required to operate a service at a given frequency depends on the route's cycle time—the time required to make a round-trip on the route, plus driver layover time and any additional schedule recovery time required beyond layover time. The cycle time (in minutes) divided by the headway (in minutes per vehicle) gives the required number of vehicles to serve the route. If a route's cycle time can be reduced sufficiently to reduce the required number of vehicles, cost savings result. Alternatively, the saved vehicle can be used to increase frequency on this or another route, with no net change in operating costs.

Factors Influencing Transit Speed

Exhibit 3-3 shows the major factors that influence transit speed. As was the case with capacity, factors from nearly all of the categories listed at the start of this section contribute to transit speed (keeping in mind that a number of factors, not shown here, but shown in Exhibit 3-1, influence dwell time).

Exhibit 3-3
Factors Influencing Transit Speed



Note: *Factors influencing dwell time are shown in Exhibit 3-1.

Running time, passenger service time, and delay are the main components of transit speed.

Exhibit 3-3 shows that there are three main components of transit speed (shown in bold in the exhibit): *running time* (time spent at constant speed following acceleration), *passenger service time* (boarding and alighting time), and *delay* (external factors that impede transit vehicles). These times can be expressed as a travel time rate (time required to travel a given distance); the inverse of the travel time rate is speed.

The number of stops along a route influences transit speed in several ways.

Exhibit 3-3 also shows that the number of stops influences all three components of transit speed. The more frequently that transit vehicles stop, the more time they spend decelerating and accelerating, compared to time that could have been spent at running speed. More-frequent stops spreads passenger demand among stops, reducing the average boarding volume at any given stop and thus dwell time; however, acceleration and deceleration delays typically more than offset any dwell time benefits. Finally, when stops are frequent, transit vehicles may never reach the maximum speed they are capable of before they must begin decelerating again to the next stop.

Factors influencing running time, passenger service time, and delay.

Running time is typically constrained by the guideway design (e.g., maximum allowed operating speed, vehicle passing provisions), the characteristics of the vehicles being operated (e.g., acceleration, maximum vehicle speed), and stopping frequency (constraining the achievable running speed). Passenger service time is directly related to the number of stops made to serve passengers and the average dwell time at each stop. Delay is primarily related to the type of guideway (e.g., mixed traffic operation vs. exclusive guideway), which determines how much transit vehicles are impeded by other modes (i.e., automobile, pedestrian, bicycle) that use or cross the guideway. The number of transit vehicles using a guideway relative to its capacity also influences delay (the closer a guideway is operated to its capacity, the more likely that transit vehicles will impede each other). Transit vehicles operating on roadways are also subject to traffic signal delays, which can be considerable. Transit preferential treatments can help offset some of mixed-traffic operation's negative impacts on transit speed.

Illustrative Transit Speeds

Exhibit 3-4 shows ranges of average system speeds (revenue miles per revenue hour) by mode in 2010, along with median speeds, based on all transit agencies reporting to the NTD (*7*). Exceptions are BRT, which is based on 2008 conditions and includes Canadian BRT data (*8*), and modern streetcar, which is based on mid-2012 operator data for the three lines in operation at the time. Average system speeds are based on all portions of all lines of a given mode operated by a given transit agency during all service hours. Actual operating speeds during peak hours, particularly in downtown locations, may be lower. Modes may be capable of higher average speeds than suggested by the U.S. operating data used to develop the exhibit. Nevertheless, the exhibit provides a reasonable comparison of relative differences in speed by mode.

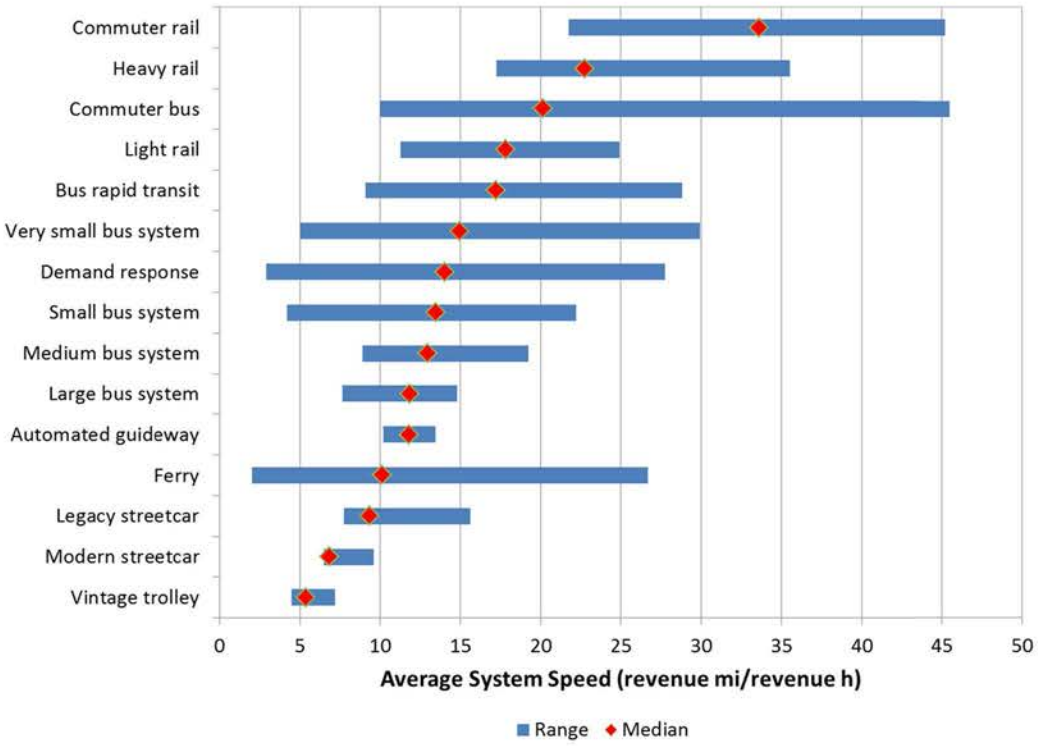


Exhibit 3-4
Average System Speeds by Mode (2010)

Source: Derived from NTD data (*7*), Diaz and Hinebaugh (*8*), and modern streetcar operator data.

Notes: Light rail = light rail systems built in the 1970s or later.
Legacy streetcar = light rail systems built before the 1970s.
Modern streetcar = streetcar system using modern vehicles (2012 data).
Vintage trolley = non-legacy streetcar systems using historic or historic-looking vehicles.
Commuter bus = motorbus data from NTD reporters that primarily operate commuter bus service.
Large bus system = motorbus data from NTD reporters with >50 million annual boardings.
Medium bus system = motorbus data from NTD reporters with 10–50 million annual boardings.
Small bus system = motorbus data from NTD reporters with 1–10 million annual boardings.
Very small bus system = motorbus data from NTD reporters with <1 million annual boardings.
Bus rapid transit data reflect 2008 conditions and include Canadian systems.

A number of observations can be made about Exhibit 3-4:

- Higher speeds, regardless of mode, typically reflect long stop or station spacings and relatively high operating speeds.
- The modes with the highest median speeds also tend to operate in environments that provide some degree of separation from other traffic.
- A relatively wide range of speeds exists for most modes, reflecting differences in stop spacing and operating environment among different systems operating that mode (e.g., on-street vs. freeway operation for BRT).
- The larger the bus system in terms of annual boardings, the lower the average system speed, as larger systems tend to be found in larger cities with higher levels of traffic congestion.
- Ferry systems at the low end of the ferry speed range operate short crossings, where passenger service time and vessel docking time constitute a majority of the time spent in revenue service.

RELIABILITY CONCEPTS

As will be discussed in greater detail in Chapter 4, Quality of Service Concepts, reliability is important to passengers from the standpoints of arriving at one's destination on time and not having to wait too long at a stop or station for one's transit vehicle to arrive. From the operator's perspective, reliability impacts the schedule recovery component of cycle time (discussed above in the Speed Concepts subsection), and thus can be a contributor to increased operating costs when recovery time needs require that one or more extra vehicles be used to operate a route at a given frequency. Unreliable operations on frequent-service transit lines can result in vehicle bunching, with more passengers experiencing crowded onboard conditions.

Factors Influencing Transit Reliability

Exhibit 3-5 lists the major factors that influence transit reliability, divided into *internal* (under a transit agency's control) and *external* (not under a transit agency's control) factors. As can be seen from the exhibit, many different functions within a transit organization contribute to providing a reliable service for passengers. Most of these functions influence aspects of reliability under an agency's control; however, the capital projects function is responsible for projects that can help offset or even eliminate some external influences on reliability. Causes of and potential remedies for transit reliability issues are discussed in Chapter 4.

Exhibit 3-5 also shows that there are a number of interactions between the external and internal contributors to overall reliability. For example, although the scheduling and operations functions cannot control passenger and traffic demand variability, they can plan to control the effects of that variability. Passengers holding train doors open affect the reliability of that particular train and—if they jam the door mechanism in the process—also create a vehicle availability issue for the agency's maintenance and operations functions to address.

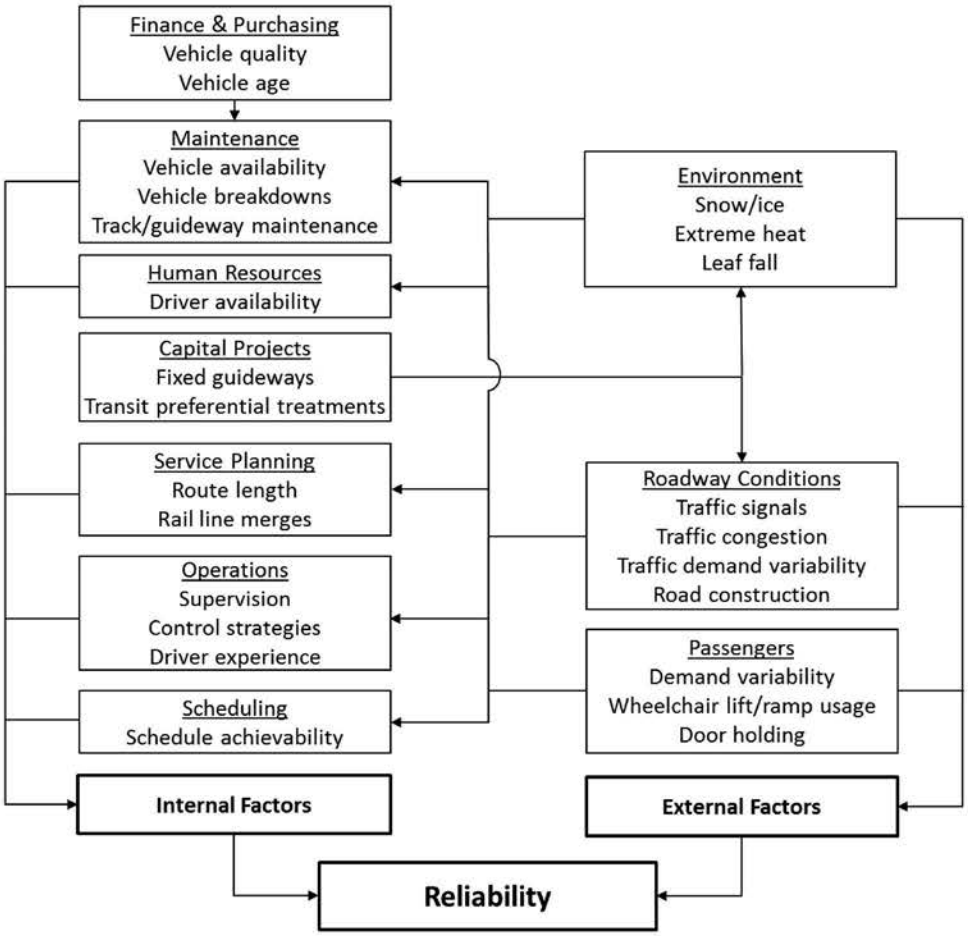


Exhibit 3-5
Factors Influencing Transit Reliability

3. PASSENGER DEMAND CHARACTERISTICS

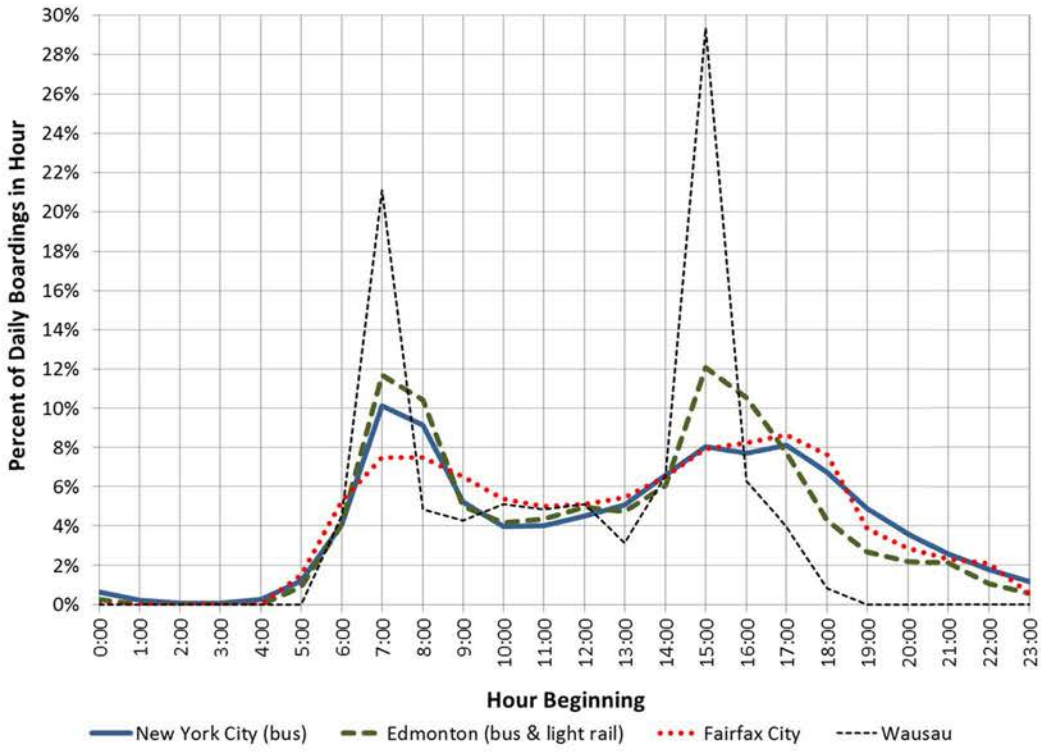
It is clear from the previous section that the demand to use transit, and variations in that demand, are important factors that influence transit capacity, speed, and reliability. As will be seen in Chapter 4, Quality of Service Concepts, demand also influences an transit operator's ability to provide a particular quality of service, as cost-effectiveness considerations enter into the decision-making process. Although the TCQSM is not a ridership forecasting manual, it is nevertheless useful to provide a high-level overview of some of the external factors that influence transit demand. Quality of service factors that influence ridership are discussed in Chapter 4.

TRANSIT PASSENGER DEMAND PATTERNS

Time-of-Day Demand Variation

Transit passenger demand has distinct peaking patterns, typically coinciding with peak commuting periods and—in many cases—school schedules. Exhibit 3-6 shows peaking patterns associated with four transit systems of various sizes: Wausau, Wisconsin (2011 population 39,000); Fairfax City, Virginia (suburban Washington, D.C., population 25,000); Edmonton, Alberta (bus and light rail service, population 812,000); and New York City (showing bus service only, population 8.2 million).

Exhibit 3-6
Illustrative Time-of-Day Variations in Transit Demand



Sources: Lu and Reddy (*9*), City of Edmonton (*10*), Connetics Transportation Group (*11*), and Urbitran Associates and Abrams-Cherwony & Associates (*12*).

Despite the wide range of population sizes and land use patterns represented by these locations, all share an a.m. peak that is highest in the 7:00–8:00 hour and (except for Wausau) an 8:00–9:00 hour that is nearly as high. All also share a midday period from 10:00 (and for all but Fairfax, 9:00) to 14:00 where hourly demands are relatively constant at around 4–5% of daily demand. Finally, all have a p.m. peak period that begins in the 15:00–16:00 hour and (except for Wausau) spreads out more than during the a.m. period.

There are also differences between the four agencies' demand patterns:

- Wausau has two very short, sharp peaks, corresponding to school start and end times, and relatively constant demand throughout the rest of its service day (which is shorter than that of the other systems). At the time the data were collected, peak demand was 5.75 times as high as off-peak demand, which required eight buses (most making just one a.m. and one p.m. trip) to supplement the nine regular buses (*12*).
- Fairfax City's off-peak demand, in contrast, is much closer to its peak demand and it has the most spread out peak periods. At the time the data were collected, the city operated two bus routes connecting a Metrorail rapid transit station to the George Mason University campus, circulating through the city along the way. Thus, its demand patterns reflect both commuting patterns into the center of the region, and student travel to and from the university. Peak demand is only 1.7 times off-peak demand, which allowed the same service levels to be provided throughout the day (*11*).
- Edmonton's peak demand is high relative to its off-peak periods, with peak demand 2.6 times as high as off-peak demand. This pattern requires that a significant amount of peak-period-only service be provided, much of which connects lower-density neighborhoods in the outer parts of the city to downtown, the University of Alberta, or light rail (which serves both activity centers). The p.m. peak is highest relatively early, with the greatest demand occurring during the 15:00–16:00 hour. (This pattern does not hold for every route; for example, light rail peaks an hour later and has a mini-peak at 21:00 when night classes end at the university.) (*10*)
- New York City, which is extremely dense, has relatively high midday demand relative to peak demand, with peak demand about twice as high as off-peak demand and a broad p.m. peak. This demand pattern requires extra service during peak periods, but proportionately less than required by Edmonton. Unlike the other examples, New York's demand is highest in the a.m. peak.

These demand patterns illustrate several important points about linkages between demand, land use patterns, service patterns and costs, and quality of service. Extra service added during the peak often costs more to provide, due to contractual needs to provide part-time drivers a minimum amount of work (not all of which may be possible to fill with revenue service) or to pay drivers working split shifts at a higher rate because of the inconvenience of the work schedule. Extra service also requires more vehicles to provide the service (added capital costs) and extra staff to maintain those vehicles. Transit service in very dense areas, or transit service that serves several different trip purposes (as in the Fairfax example) has less peaking, making it more feasible to provide good all-day service on those routes. Otherwise, service between

Drivers working split shifts work both peaks, with time off in between.

low-density residential areas and major activity centers may only be feasible during peak periods or at a very low frequency (hourly or worse) during off-peak periods (*13*).

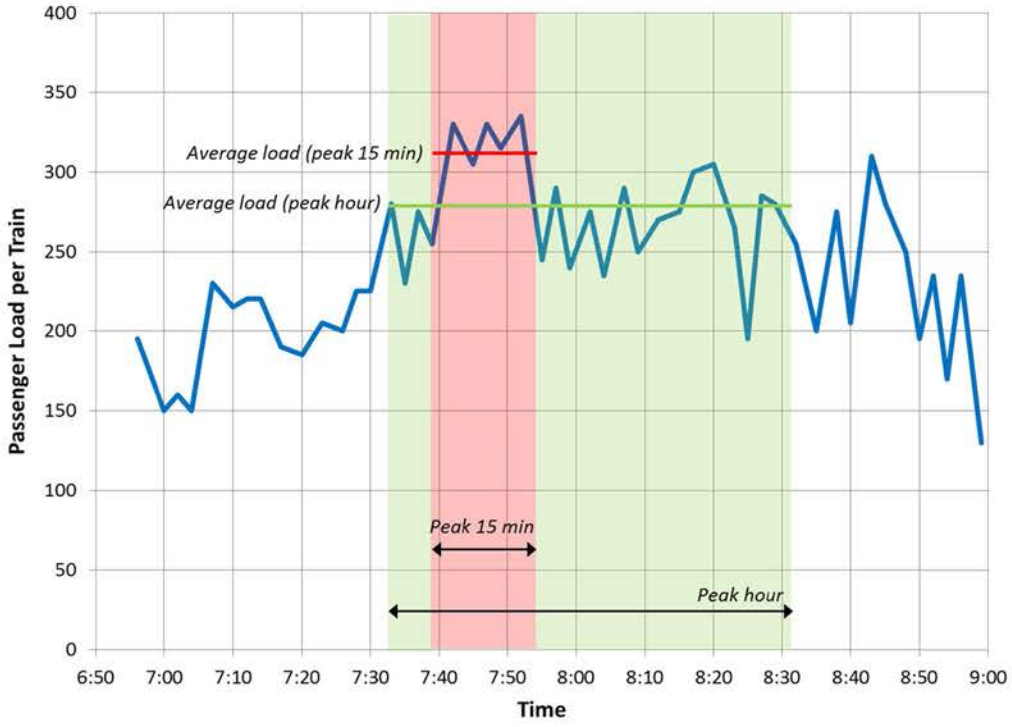
Peak-Hour Demand Variation

Passenger demand can also vary within the peak period. Some of this variation is attributable to people timing their trips to arrive at a destination (e.g., job, school) as close to the desired starting time as possible; other is due to day-to-day variations in people's activities that result in them taking different transit vehicles on different days. These variations have implications on the level of onboard crowding, as a service scheduled to accommodate average demand over the peak hour may experience overcrowded conditions during the peak of the peak.

The concept of a *peak hour factor* (PHF) is used to express this demand variation within the peak hour (or any other analysis hour). The PHF is defined as the demand during the hour divided by four times the demand during the peak 15 min of the hour. Thus a PHF of 1.00 indicates even demand in each 15 min period of the hour, while a PHF of 0.25 would indicate that all the demand occurs in one 15-min period. Typical transit PHFs range from 0.60 to 0.95 (*2, 14*).

Exhibit 3-7 shows actual train loading data for the a.m. peak period for one day at a peak load station on Vancouver's SkyTrain (*15*), with the peak hour and the peak 15 min indicated, along with the average passenger loads during those time periods. The PHF represented in the graph is 0.92, which is relatively high (i.e., relatively even loading by 15-min intervals) for transit service.

Exhibit 3-7
Illustrative Variation in Peak-Hour Demand



Source: Derived from *TCRP Report 13* (*15*).
Note: Vancouver, B.C., Broadway Station inbound, October 27, 1994.

Even though the average load throughout the peak hour, relative to the peak 15 min, is fairly even, it can be seen from the exhibit that there are considerable variations from one train to the next. Furthermore, the average load during the peak 15 min is 35 passengers per train higher than the average for the peak hour. If this agency had only peak-hour ridership totals to work with and had (hypothetically) a service standard of 300 passengers per train, it might appear to meet its standard based on the average peak hour load, while in actuality, peak 15-min loads would exceed the standard. In many cases, the proportional difference between peak-hour and peak-15-min demands will be much greater than shown in Exhibit 3-7.

Both Exhibit 3-6 and Exhibit 3-7 have illustrated the importance of being aware of demand patterns over both long and short periods of time. The use of automatic passenger counting (APC) equipment allows the collection of passenger demand data on a regular basis. *TCRP Report 113: Using Archived AVL-APC Data to Improve Transit Performance and Management* (*16*) provides guidance on collecting, archiving, and using APC data. *TCRP Report 135: Controlling System Costs: Basic and Advanced Scheduling Manuals and Contemporary Issues in Transit Scheduling* (*17*) describes the use of ridership data, in conjunction with transit agency loading standards and policy headways, when developing transit schedules.

DEMAND RELATED TO DEMOGRAPHICS

The *2009 National Household Transportation Survey* (NHTS, *18*) provides data on household travel patterns for all travel modes and trip purposes. The following are selected demographic factors that relate to transit use in the U.S. (*19*):

- *Gender.* Controlling for other factors that influence mode choice, males are 7% more likely to use transit for a given trip than females.
- *Age.* Compared to persons 16–24 years old, persons in the 25–44 and 45–64 age groups are about half as likely to use transit for a given trip (45–64 years olds are slightly less likely to use it than 25–44 year olds), and those 65 and older are one-fifth as likely to use it. (The NHTS did not ask about trips made by children.)
- *Employment.* Persons who are employed are 41% more likely to use transit for a given trip than those not in the workforce or unemployed.
- *Number of cars in household.* Compared to zero-car households, one-car households are 10% as likely, two-car households 3% as likely, and three-car households 2% as likely to use transit for a given trip.

DEMAND RELATED TO LAND USE

Land Use Densities Supporting Various Transit Service Modes and Levels

As indicated above, there are a number of factors that influence the ridership demand for a given transit line—for example, ease of access, demographic factors such as age and car ownership, cost and convenience of transit relative to competing modes—but the density of land uses along the line is a basic requirement. Simply put, the more people and the more jobs that are within easy access distance of transit service, the more potential customers there are to support high-quality service. Conversely, the more spread apart land uses are, the more difficult it is to develop a

transit line that can connect the relatively sparse population and can also provide the necessary travel speed to compete with driving an automobile.

Any guidance on the minimum land use density that can support a particular frequency or mode of transit service must come with the caveat that the answer depends on how much one is willing to subsidize service. In the case of fixed-guideway transit service, the answer also depends on how much grade separation is desired or required, as that greatly affects the capital cost of constructing the guideway.

Existing guidance on the minimum density required to support a particular frequency of service ultimately derives from one mid-1970s study (*20*). This study developed rates of transit trip-making at different land use densities and estimated the number of transit vehicles required to provide service per square mile at different land use densities, with the assumption that transit vehicles can travel faster in areas with lower density (i.e., areas with less activity and congestion). Given a transit vehicle requirement for a given land use density, the average transit ridership generated at a given land use density, and mid-1970s values for average bus operating costs and fares, the subsidy required for any given combination of land use density and desired frequency can be determined. The determination of whether a particular service frequency could be supported at a given land use density was made on the basis of the service being self-supporting (i.e., zero subsidy or profitable).

Average U.S. bus operating costs in 2010 were approximately 7 times higher ($120 per revenue hour) than the values used in the study ($15 to $20), while average fares were only 2.3 times as high ($1.44 per linked trip versus $0.50 to $0.75), based on National Transit Database data (*7*) and a ratio of unlinked to linked trips of 1.5 (*21*). This change in costs relative to farebox revenue means that either the study's recommended minimum densities need to increase by a factor of 3 (7 / 2.3) to meet the original target of zero subsidy, or that a subsidy needs to be provided so that fares only cover 33% (2.3 / 7) of operating costs, assuming no change in transit trip-making characteristics. Since fares covered approximately 27% of bus operating costs on average in 2010 (i.e., a higher level of subsidy) (*7*), the general relationships between density and frequency still hold if a transit agency and its stakeholders are comfortable with the average U.S. bus subsidy level. A smaller farebox subsidy would require higher densities to support a given frequency, while a greater farebox subsidy would allow a given frequency to be offered at lower densities.

Exhibit 3-8 presents residential densities based on net acres. The "transit-supportive area" definition used in Chapter 5 is based on gross acres.

Exhibit 3-8 presents minimum land use densities that can support a given frequency for a selection of modes. The exhibit assumes a service span of 20 hours per weekday; a shorter weekday service span would allow more frequent weekday service, service at a lower density threshold, some weekend service, or some combination of these for the same overall operating cost. All frequencies are directional. All residential densities are given as *net acres*, which count only the land actually developed as residential use. *Gross acres,* which represent total land area, including that used for streets or not developed, can be approximated by multiplying net acres by a factor of 1.5.

Exhibit 3-8
Minimum Land Densities Supporting Transit Service at Various Frequencies

Transit Service	Minimum Residential Density	CBD Commercial/Office Density
Local bus, 1 bus/h	4.5 dwelling units/net acre	5–8 million ft^2
Local bus, 2 bus/h	7 dwelling units/net acre	8–20 million ft^2
Local bus, 6 bus/h	15 dwelling units/net acre	20–50 million ft^2
Light rail, 5-min peak headway	9 dwelling units/net acre in 25–100 mi^2 corridor	35–50 million ft^2 (20 million ft^2 if 100% at-grade)
Rapid transit, 5-min peak headway	12 dwelling units/net acre in 100–150 mi^2 corridor	>50 million ft^2
Commuter rail, 20 trains/day	1–2 dwelling units/net acre	>100 million ft^2

Sources: Pushkarev and Zupan (*20*), Institute of Transportation Engineers (*22*), and Moore et al. (*23*).
Note: Assumes 20 h/weekday service span, 33% farebox recovery.

At the time of writing, TCRP Project H-42, "An Exploration of Fixed-Guideway Transit Criteria Revisited", was developing updated guidance on the conditions that are needed to support fixed-guideway transit systems, including considerations of land use patterns (*24*).

Density and Transit Use Relationships

Density has a double effect on the demand for transit service: (*a*) persons are more likely to use transit when they live in dense areas and (*b*) there are simply more people within walking distance of transit service as density increases. Exhibit 3-9 illustrates this concept, with the likelihood of transit use based on NHTS data (*18*):

Exhibit 3-9
Illustrative Change in Transit Demand with Density

Household Density		Multiplicative Change Relative to Base Condition		
(HH/acre)	(HH/ha)	Households	Likelihood of Using Transit	Overall Transit Demand
2.35	5.8	1.0	1.0	1
4.7	11.6	2.0	2.0	4
10.9	26.9	4.7	5.9	28
26.6	65.7	11.7	15.9	186
46.9	115.9	20.0	24.0	480

Source: Calculated for the TCQSM 3rd Edition from 2009 National Household Travel Survey data (*18*).
Note: HH = households. Base condition is 2.35 HH/acre (5.8 HH/ha). Household densities based on the densities of the census block groups of survey respondents.

Thus, as household density increases from 2.35 households per acre to 4.7 households per acre, transit demand from a given area would be expected to double, because there are twice as many people living in the area. Furthermore, a person living in the higher-density area is twice as likely to use transit for a given trip as a person living in the lower-density area. The combined effect is that transit demand would be expected to be four times as high at a density of 4.7 households per acre than at 2.35 households per acre.

Concentrations of employment, especially in city centers, also influence ridership. In concentrated areas such as Manhattan's business districts and the Chicago Loop, transit is the main means of travel to and from the area. In smaller, less concentrated centers, transit's mode share is much less.

Transit-Oriented Development

Transit-oriented developments (TODs) can be good generators of transit trips because many of the density and demographic characteristics that are indicative of higher propensities of transit use are found there. In addition, the mix of uses frequently found in TODs can generate reverse-direction and off-peak transit trip making. TODs can be described as developments close to high quality transit service (5–8 min peak headways, 15-min or better off-peak headways), with higher densities (minimum 12 residential units or 50 jobs per acre), parking management programs, and good walking environments (*25*).

TOD residents are 2–5 times as likely to commute by transit and to make non-work trips by transit as non-TOD residents. They are twice as likely not to own a car as non-TOD residents and own half as many cars on average. There may also be an element of self-selection involved: persons who would like to avoid owning a car may choose to live in TODs because the walking environment, transit access, and mix of uses allows them to go about their lives without relying on a car (*25, 26*).

DEMAND RELATED TO TRANSPORTATION DEMAND MANAGEMENT STRATEGIES

Transportation demand management (TDM) programs seek to reduce automobile trip making through a variety of means:

- Incentives to use alternative modes (e.g., preferential carpool parking, transit pass subsidies);
- Flexible employee work schedules (e.g., compressed work weeks, flexible arrival and departure times) or locations (e.g., telecommuting);
- Support infrastructure (e.g., pedestrian-friendly environments, bicycle lockers, shower facilities);
- Support programs (e.g., guaranteed ride home, carpool matching, carsharing);
- Disincentives for driving (e.g., parking charges, reduced parking supply); and
- Marketing programs that raise awareness of transportation options.

Chapter 19, Employer and Institutional TDM Strategies, of *TCRP Report 95: Traveler Response to Transportation System Changes* (*27*) provides information, summarized below, on the relationships between transit availability, transit-focused TDM strategies, and vehicle trip reductions (VTRs). The Environmental Protection Agency's COMMUTER model (*28*) and the Florida DOT's TRIMMS model (*29*) are two tools that can be used to estimate the impact of a specific set of TDM strategies on transit usage. The *Online TDM Encyclopedia* (*30*) incorporates new research findings about TDM strategy effects as they are published.

The results presented below are primarily based on three studies from the 1990s of 82 exemplary TDM programs for which detailed data were available. Because these programs were originally selected for study as potential role models of successful TDM programs, the results from these programs tend to be better than those of typical programs. In addition, VTRs resulting from a TDM strategy do not correspond one-to-one with transit trip additions, as other travel modes (particularly carpooling and walking) can be substituted for some trips, while other trips could be combined or simply not made as a work-based trip. As a result, these results should be considered an upper bound on the potential VTR effect of a particular TDM strategy (*27*):

- When transit availability at a site was high (in terms of frequency and number of routes, although the criteria are not specifically stated in *TCRP Report 95*), VTRs were 14 percentage points higher than when transit availability was medium or low—in other words, the presence of good transit service was correlated with better overall TDM program results.
- Programs with transit subsidies had VTRs that were 8 percentage points higher than programs without subsidies, and programs combining transit subsidies with parking restrictions or parking fees had VTRs 16 percentage points higher than programs without subsidies.
- A California study (*31*) found an average 3 percentage point increase in transit mode share when a parking cash-out program was offered.
- The level of support given to a program by employers had minimal effect (VTRs up to 4 percentage points higher) when transit availability was high, but had more of an effect when transit availability was medium or low (VTRs 7–12 percentage points higher).
- Programs providing transportation services (e.g., shuttles to transit stations, vanpools) had VTRs 5 percentage points higher than programs without such services, in areas with high transit availability.
- Programs offering any kind of alternative work schedule had VTRs no different than those that did not when transit availability was high, but programs offering flexible work schedules had VTRs 7–8 percentage points higher than those that did not, when transit availability was medium or low.

4. DWELL TIME

DEFINITION

For the purposes of the TCQSM, *dwell time* is defined as the time spent at a stop or station serving passenger movements, including the time required to open and close the doors. Time spent at a stop for any other reason—for example, waiting for a traffic signal, waiting for another transit vehicle to move, or waiting for a late-arriving passenger—is considered delay and is not counted as part of dwell time.

DWELL TIME COMPONENTS

Dwell time is among the most important factors determining transit capacity and average speed. Dwell time at a given stop is directly related to the following factors:

- *Passenger boarding and alighting volumes.* The more people that must be served, the longer it takes to serve them.
- *Fare payment method.* Some fare payment methods require more time than others. Minimizing fare payment time is a key factor in reducing dwell time.
- *Vehicle type and size.* Passengers spend less time boarding and alighting when boarding is level or near-level, particularly for passengers bringing items with them, older and younger passengers, and passengers with disabilities. Multiple or wide doors that allow several people to board or alight simultaneously also help expedite passenger movement. However, if the fare payment method requires all passengers to use a single door or door channel, then having multiple door channels only expedites alighting passenger movements.
- *In-vehicle circulation.* Boarding and alighting occurs more slowly when standees are present. The amount of space between standees, as well as the aisle width, also influences how easily passengers circulate within the vehicle. Passengers who exit buses through the front door rather than the rear door(s) delay the start of passengers boarding.

Dwell time is indirectly related to stop spacing. Assuming walkable distances and environments between stops and therefore a fixed passenger boarding demand, more stops over a given distance will spread out passenger volumes over a greater number of stops, resulting in smaller average dwell times at each stop. However, the greater number of stops will tend to slow down overall transit speeds, despite the shorter dwell times, as acceleration and deceleration delay is incurred with each stop. In addition, buses and streetcars may incur additional traffic signal delay with each stop, when stopping causes these vehicles to fall out of the progression band provided by the street's traffic signal timing. As a result, consolidating stops can be a productive way to improve transit speeds, even though average dwell times increase, as long as accessible routes are available from a consolidated stop to the next closest stop and walking distances are not excessive.

DWELL TIME VARIABILITY

Dwell time variability—the variation in dwell times between successive vehicles using a stop or station—is an important factor influencing both transit reliability and capacity. Dwell time variability can arise from, among other reasons:

- Variations in passenger demand for a particular route over the course of 15 min, 30 min, or an hour;
- Variations in passenger demand between different routes sharing the same stop;
- Irregularities in maintaining the planned schedule or headway, which can result in more passengers accumulating when a transit vehicle runs late, causing it to fall farther behind schedule;
- Crowded conditions on board a vehicle, which causes passengers to board and alight more slowly than normal;
- Wheelchair and lift deployment, and bicycle rack usage; and
- Driver interactions with passengers (e.g., answering questions, fare disputes).

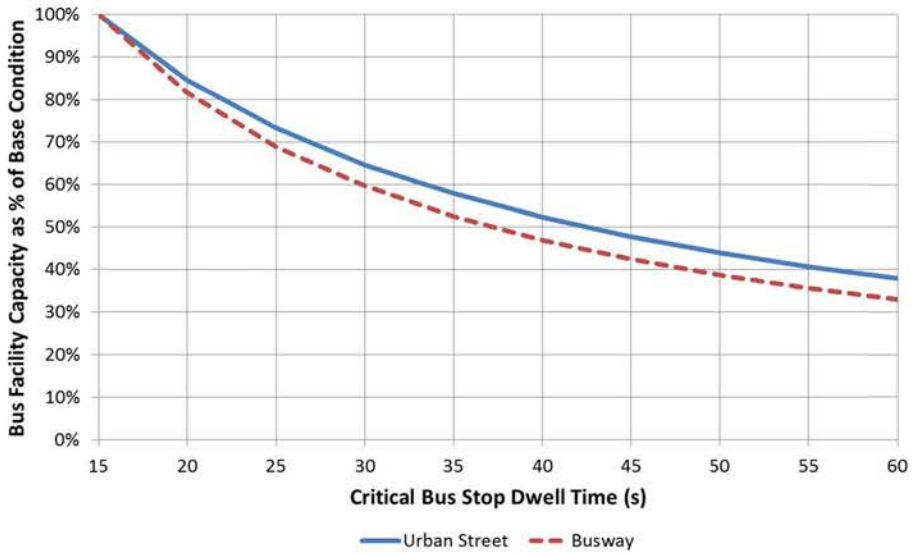
As was shown in Exhibit 3-1, dwell time variability influences the minimum headway between successive transit vehicles, which in turn controls the capacity of a transit facility. The TCQSM accounts for dwell time variability through the concept of an *operating margin,* additional time added to the minimum headway to account for longer-than-normal dwell times. The operating margin ensures that one transit vehicle does not delay following transit vehicles more than an analyst- or transit agency–specified percentage of time. The greater the dwell time variability, the greater the operating margin should be, with the result that the design capacity will be lower than it otherwise could be.

ILLUSTRATIVE IMPACTS OF DWELL TIME ON CAPACITY

Exhibit 3-10 illustrates how bus facility capacity (and by extension, person capacity) is influenced by dwell time at the critical bus stop along the facility (typically, the bus stop with the longest dwell time). It can be seen that capacity decreases as dwell time increases, with the effect strongest at lower dwell times. The capacity that can be achieved with a critical dwell time of 60 s is 50% that provided by a 30-s dwell time and approximately 75% that provided by a 45-s dwell time, for the conditions stated in the exhibit. Similarly, reducing dwell time from 30 s to 25 s improves the critical stop's capacity by (73% / 65%) or 12%, for the given conditions. Capacity drops somewhat more rapidly with increasing dwell time for busways than for urban streets, as there are fewer other things besides dwell time that influence the capacity of busway stations.

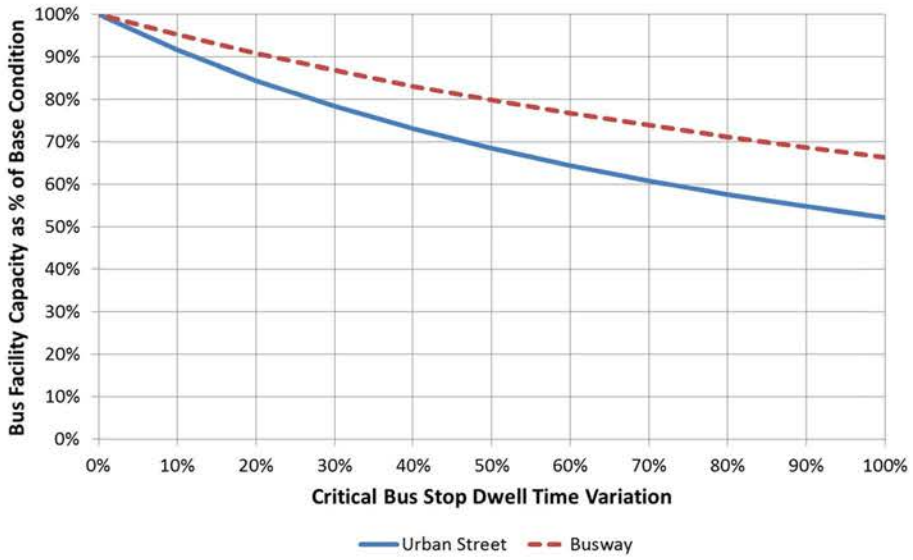
Exhibit 3-11 illustrates the impact of dwell time variability (standard deviation of dwell time divided by average dwell time) on bus facility capacity. By comparing the slopes of the lines to those in Exhibit 3-10, it can be seen that dwell time variability has less of an effect on capacity than dwell time itself (e.g., a 10% increase in the coefficient in variation reduces capacity less than a 10% increase in dwell time does). Nevertheless, the typical dwell time variability value of 60% for buses produces one-quarter to one-third lower capacity for the stated conditions than if bus dwell times were exactly the same (0% variability).

Exhibit 3-10
Illustrative Impact of Dwell Time on Bus Facility Capacity



Source: Calculated using TCQSM methods.
Note: Base condition assumes 15-s average dwell time, no traffic signals (busway) or 40% traffic signal green time for the bus' direction of travel (urban street), 10-s clearance time, and 60% dwell time variability. See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

Exhibit 3-11
Illustrative Impact of Bus Dwell Time Variability on Capacity



Source: Calculated using TCQSM methods.
Note: Base condition assumes 30-s average dwell time, no traffic signals (busway) or 40% traffic signal green time for the bus' direction of travel (urban street), 10-s clearance time, and 0% dwell time variability (i.e., all buses dwell exactly 30 s). See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

Exhibit 3-12 shows the impact of increasing dwell time on rail line capacity. In comparison to bus facility capacity, increases in dwell time have a smaller proportional impact on capacity, as other factors (in particular, the minimum train separation imposed by the train control system) also contribute significantly to the minimum train

headway. Exhibit 3-13 shows the impact of operating margin (an allowance for longer-than-average dwells and other irregularities) on capacity. In the typical range of 15–25 s recommended in Chapter 8, Rail Transit Capacity, for operating margin, line capacity is 14–21% lower for the stated conditions than if dwell times were exactly the same and service was otherwise perfectly reliable.

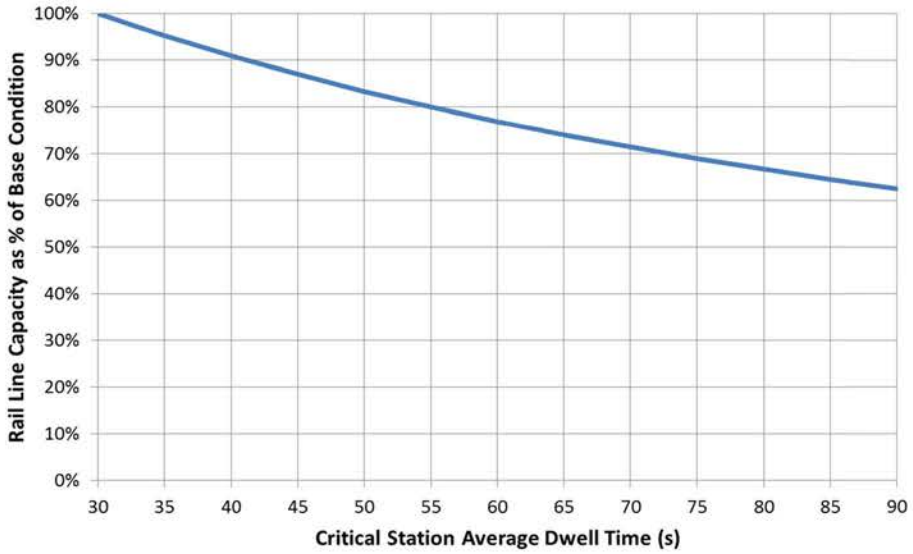


Exhibit 3-12
Illustrative Impact of Dwell Time on Rail Line Capacity

Source: Calculated using TCQSM methods.
Note: Base condition assumes 30-s average dwell time, 20-s operating margin, and 50-s minimum train separation time. See Chapter 8, Rail Transit Capacity, for explanations of these parameters.

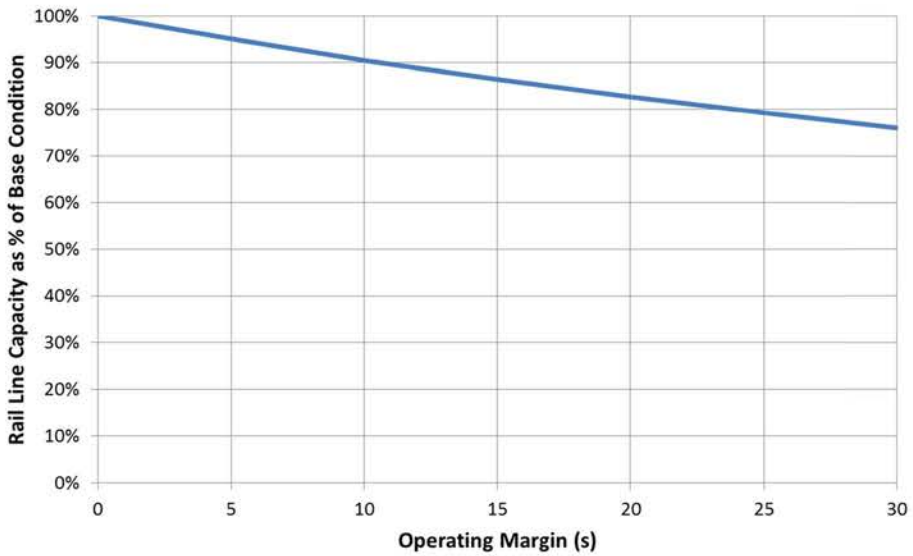


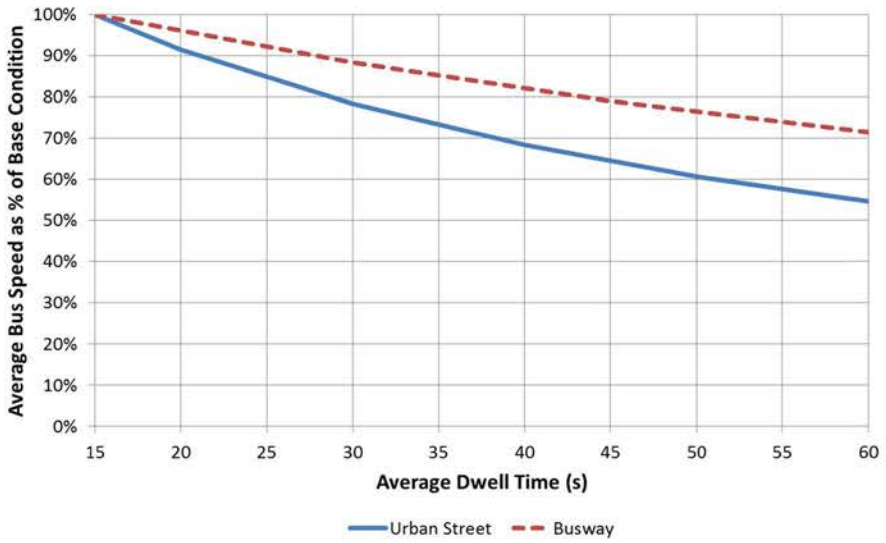
Exhibit 3-13
Illustrative Impact of Operating Margin on Rail Line Capacity

Source: Calculated using TCQSM methods.
Note: Base condition assumes 45-s average dwell time, 0-s operating margin, and 50-s minimum train separation time. See Chapter 8, Rail Transit Capacity, for explanations of these parameters.

ILLUSTRATIVE IMPACTS OF DWELL TIME ON SPEED

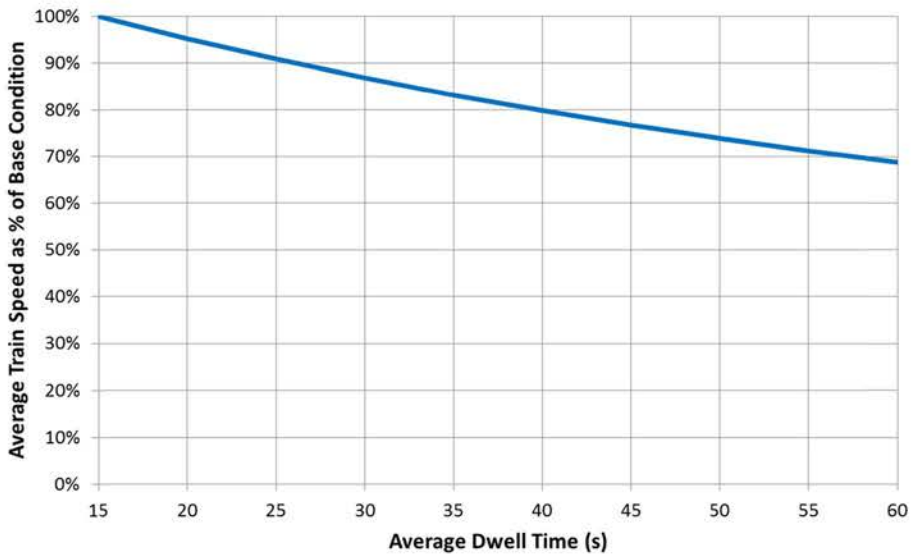
Exhibit 3-14 and Exhibit 3-15 illustrate the effects of increasing dwell time on bus and rail speeds, respectively, for the stated conditions. Dwell time has a smaller impact on busway speed than for urban street speeds due to the longer stop spacing typically found on busways.

Exhibit 3-14
Illustrative Impact of Dwell Time on Average Bus Speed



Source: Calculated using TCQSM methods.
Note: Base condition assumes 15-s average dwell time, 1 stop/mi (busway) or 8 stops/mi (urban street), and mixed traffic operation (urban street). See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

Exhibit 3-15
Illustrative Impact of Dwell Time on Average Train Speed



Source: Calculated using TCQSM methods.
Note: Base condition assumes 15-s average dwell time, 1 stop/mi, and 55 mi/h maximum train speed.

5. OPERATING ENVIRONMENT

Chapter 2, Mode and Service Concepts, introduced four main types of operating environments for transit vehicles. In order of increasing speed, capacity, and reliability, these are:

- *Mixed traffic*—shared lane operation with general traffic;
- *Semi-exclusive*—a lane partially reserved for transit use, but also available for other use at certain times or in certain locations;
- *Exclusive*—a lane, portion of a roadway (e.g., the median), or right-of-way reserved for transit use at all times, but still subject to some external traffic interference (e.g., intersections, grade crossings); and
- *Grade-separated*—a facility dedicated to the exclusive use of transit vehicles, without at-grade crossings.

This section discusses how these different operating environments affect transit speed, capacity, and reliability.

GUIDEWAY TYPE AND DESIGN

The more exclusive the right-of-way, the less interaction that occurs between transit vehicles and other transportation modes (e.g., automobiles, pedestrians, bicycles). This interaction can take the form of *traffic control* that regulates when transit vehicles can move; *traffic delays* that temporarily impede transit vehicles; and *speed restrictions* that prevent transit vehicles from moving as fast as they otherwise could.

Traffic control (e.g., traffic signals, STOP signs) influences capacity by restricting the time available for transit vehicles to pass through an intersection over the course of an hour. It affects speed as a result of the delay that transit vehicles incur while other traffic movements are being served. Train control systems impose a minimum safe separation distance between trains that directly influences minimum headways and thus capacity; this minimum safe separation distance increases as operating speeds increase.

Traffic signals can also be a source of travel time unreliability. Because of the relatively long delays that can be imposed by traffic signals, both schedule and headway reliability can be affected when some buses are able to make it through a signal on green, but other buses miss the green and are delayed a minute or two.

Traffic delay (e.g., delay waiting for a vehicle in front to make a turn or to park) influences capacity at signalized intersections by cutting into the amount of green time that transit vehicles can actually use to pass through an intersection. It influences speed both through the actual delay incurred and through the deceleration/acceleration delays that occur each time a transit vehicle has to stop or slow instead of proceeding at speed. The degree to which traffic delays cause transit vehicles to miss green lights they would have otherwise made affects transit speed and reliability.

Speed restrictions can take the form of posted speeds on roadways that transit vehicles must observe, policy speeds imposed by the transit agency for safety reasons at particular locations, and guideway design elements (e.g., curves, grades) that slow down transit vehicles. Speed restrictions generally do not affect capacity, except that rail line

capacity can be constrained when a sharp curve, downgrade, or policy speed restriction occurs just before a station, causing trains to enter the station more slowly or to begin to decelerate sooner than they would have otherwise.

Exhibit 3-16 summarizes the magnitudes of the traffic interactions associated with each guideway type.

Exhibit 3-16
Impacts of Other Modes on Transit Speed and Capacity

Guideway Type	Traffic Control	Traffic Delay	Speed Restrictions
Mixed traffic	Transit vehicles regulated by traffic signals [a]	Full exposure to potential traffic delays	Transit vehicle speeds regulated by roadway posted speed
Semi-exclusive	Transit vehicles regulated by traffic signals [a]	Partial exposure to potential traffic delays (typically right turns)	Transit vehicle speeds regulated by roadway posted speed
Exclusive (median)	Transit vehicles regulated by traffic signals [b]	Non-transit traffic prohibited on guideway, pedestrian crossing points may be provided	Transit vehicle speeds regulated by roadway posted speed
Exclusive (off-street)	Buses regulated by traffic signals at street crossings; [c] rail provided with gated crossings, train control signals	Non-transit traffic prohibited on guideway, pedestrian crossing points may be provided	Transit vehicle speeds constrained by vehicle performance and guideway design [c]
Grade-separated	No signal control for busways (unless shared with light rail); train control signals for rail lines	Non-transit traffic prohibited on guideway [d]	Transit vehicle speeds constrained by vehicle performance and guideway design [d]

Notes: (a) Transit signal priority may provide some benefit.
(b) Transit vehicles may be provided with signal priority (less feasible with high volumes of transit vehicles). Light rail may be allowed to preempt traffic signals.
(c) Bus signal priority or preemption may be provided. Bus speed restrictions typically imposed at signalized roadway crossings, due to safety issues with cross traffic not observing the traffic signals (*8*).
(d) Some busways allow pedestrian crossings at stations, in conjunction with bus speed restrictions for buses not stopping at the station.

TRAFFIC AND TRANSIT VEHICLE EFFECTS

The other transportation modes sharing or crossing a transit guideway affect transit operations and vice versa. Exhibit 3-17 lists some of the main interactions between transit vehicles and other transportation modes.

Transit vehicles can also impede each other. Bus speeds begin to decline when approximately half of a bus facility's capacity is used, as buses begin to interfere with other buses (e.g., blocking access into or out of bus stops, passing maneuvers). Trains operating under a train control system (as opposed to line-of-sight operation on a street) can interfere with each other. For example, if one train's dwell time at a station exceeds the average dwell time plus the operating margin, and the next train is following at the minimum headway, the following train will have to slow or stop until the leading train moves a safe distance down the line. Similarly, when one train arrives at a merge or crossing of two lines later than scheduled, the next train on the other line may be delayed.

When buses and light rail share a guideway, operating rules typically favor light rail service, potentially causing delays to buses on, or arriving at, the guideway at the same time.

Exhibit 3-17
Interactions of Transit with Other Modes

Interaction	Motorized Vehicles	Bicyclists	Pedestrians
Other modes on transit	• Traffic congestion delays transit vehicles operating in mixed traffic • Traffic may delay buses re-entering roadway from bus stops • Day-to-day variation in traffic volumes and delays affects transit travel time and reliability	• May delay buses sharing a lane with bicycles • Bicyclists delay buses re-entering roadway from bus stops • Bicycle environment quality influences ability of transit passengers to bike to transit service	• Traffic signal timing constrained by need to serve pedestrians crossing streets • May directly (crossing street) or indirectly (crossing parallel to street, with turning traffic yielding) delay buses • Pedestrian environment quality influences transit passenger ability to walk to transit service
Transit on other modes	• Buses are equivalent to 2 cars in terms of their effect on roadway capacity • Transit vehicles stopped in travel lane at bus stops reduce available roadway capacity and create delay • Transit signal priority reallocates green time, with potential capacity and delay impacts (both positive and negative)	• Heavy vehicle volume and speed in curb lane (including transit vehicles) negatively impacts bicycle quality of service • Stopped transit vehicles may delay bicyclists or force them to shift lanes • Bicyclists and buses have similar average speeds, creating leapfrog passing patterns when sharing lanes • Bicyclists can use transit to greatly extend the range of a bicycle trip, when bicycles can be brought aboard transit vehicles	• Traffic volume in curb lane (including transit vehicles) negatively impacts pedestrian quality of service • Waiting passengers may block pedestrian flow on sidewalk • Alighting passengers may create cross-flows that disturb pedestrian flow on sidewalk

Source: Derived from *Highway Capacity Manual 2010* (*3*).

ILLUSTRATIVE IMPACTS OF OPERATING ENVIRONMENT ON CAPACITY

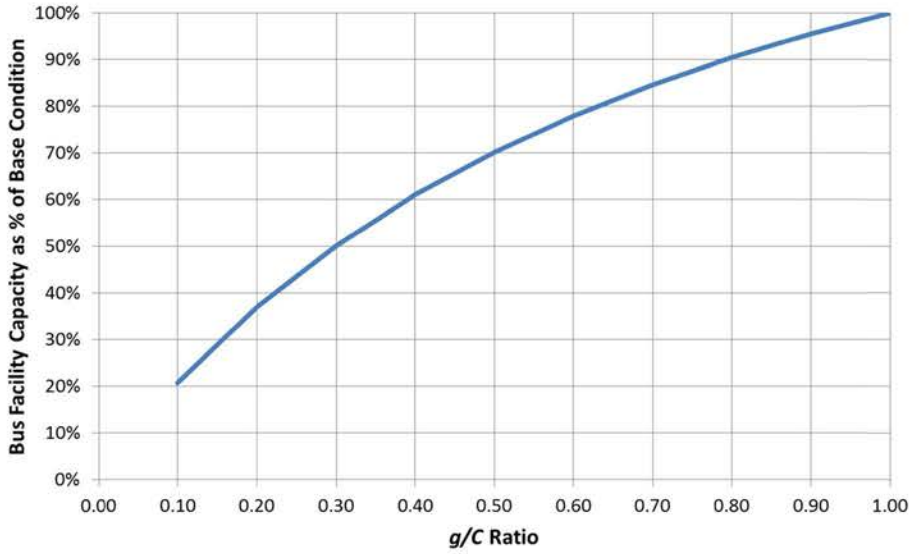
Traffic Control

Exhibit 3-18 demonstrates how bus facility capacity decreases as the amount of green time provided for bus movements at a bus stop decreases. This effect is measured by the *g/C ratio*, the amount of effective green time provided by the traffic signal for the bus' direction of travel *g*, divided by the traffic signal cycle length *C*. Illustrative *g/C* ratios are as follows:

- Through movement at an intersection of two roadways with similar volumes: 0.45 with no protected left-turn phasing (i.e., left-turn arrow) or 0.40 with protected left-turn phasing (*32*).
- Through movement on a major roadway intersecting a minor roadway: 0.50 to 0.70, depending on relative traffic volumes and use of protected left-turns (*33*).
- Through movement on a minor roadway intersecting a major roadway: 0.20 to 0.30, depending on relative traffic volumes and use of protected left-turns (*33*).
- Protected left-turn movement: 0.10.

The g/C ratio is 1.00 for bus stops not located in the vicinity of a traffic signal.

Exhibit 3-18
Illustrative Impact of Traffic Signalization on Bus Facility Capacity



Source: Calculated using TCQSM methods.
Note: Base condition assumes 30-s average dwell time, 10-s clearance time, 60% dwell time variability, and no traffic signal (g/C = 1.00). See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

Exhibit 3-19 shows the impacts of the train signaling system and station approach speed on line capacity. Chapter 8, Rail Transit Capacity, provides descriptions of the various train signaling systems; the systems that provide greater capacity know each train's position more precisely and thus allow trains to operate closer together. It can be seen in the exhibit that each signaling system has an optimal station approach speed that maximizes a given signaling system's capacity. However, the optimal speed from a capacity standpoint is not necessary optimal from a passenger travel time (quality of service) perspective.

Traffic Delay

Exhibit 3-20 depicts how bus and streetcar capacity declines when operating in mixed traffic or semi-exclusive guideways (e.g., transit lanes allowing right turns), as the volume of non-transit movements using the guideway increases relative to the guideway's capacity for serving those movements. It can be seen that far-side stops provide greater capacity than mid-block or near-side stops for a given general traffic volume-to-capacity (v/c) ratio, and that having the ability to move around (pass) stopped traffic also results in higher capacity for a given v/c ratio than being forced to remain in the curb lane. Streetcars do not have the ability to leave their lane, while buses may be able to do so if more than one lane is provided for their direction of travel and traffic volumes in that lane permit buses to change lanes.

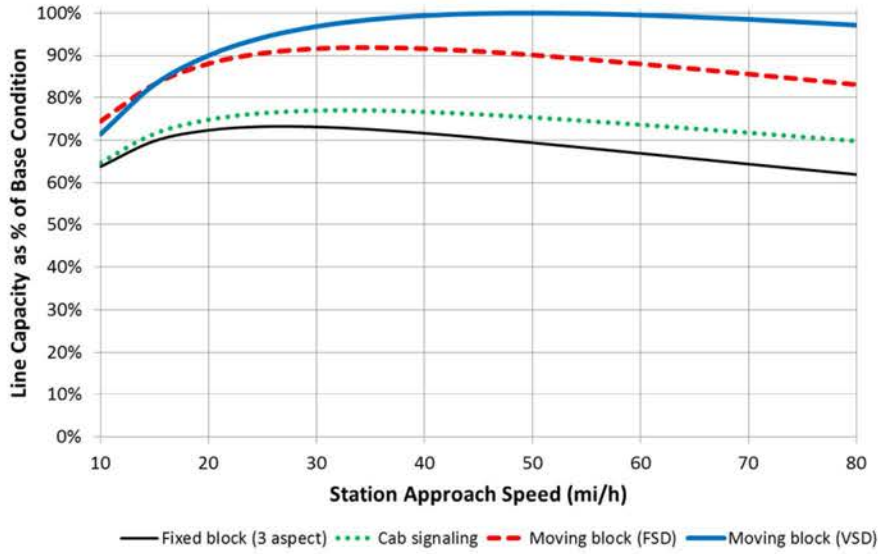


Exhibit 3-19
Illustrative Impact of Train Signaling System and Station Approach Speed on Line Capacity

Source: Calculated using TCQSM methods.
Note: FSD = fixed safety distance, VSD = variable safety distance.
Base condition assumes moving block signals with variable safety distances, 45-s average dwell time, and 20-s operating margin, and no grade entering station. See Chapter 8, Rail Transit Capacity, for explanations of these parameters.

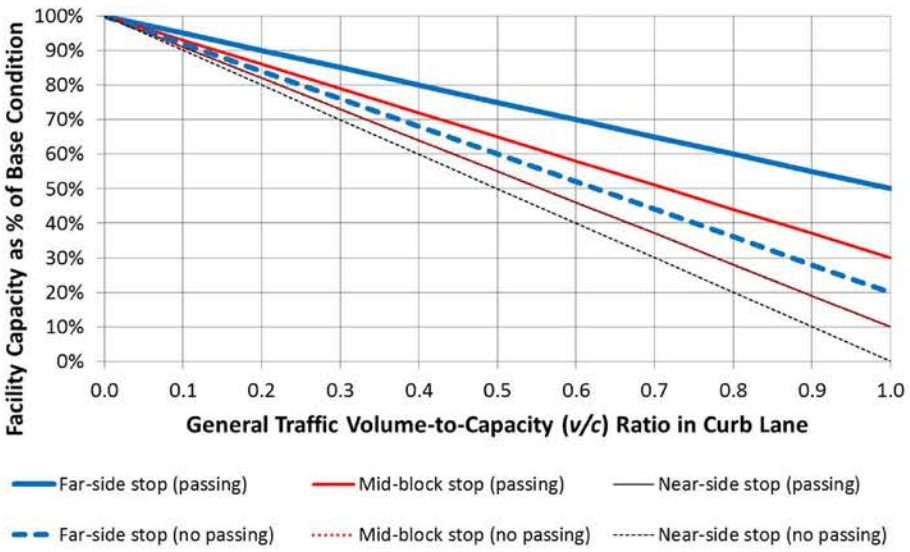


Exhibit 3-20
Illustrative Impact of Curb Lane Traffic Congestion on Bus and Streetcar Capacity

Source: Calculated using TCQSM methods.
Notes: Base condition assumes that only transit vehicles are allowed to use the curb lane.
"Passing" indicates ability of buses to leave the curb lane to pass stopped vehicles.
"Mid-block (no passing)" and "Near side (passing)" have the same characteristics.

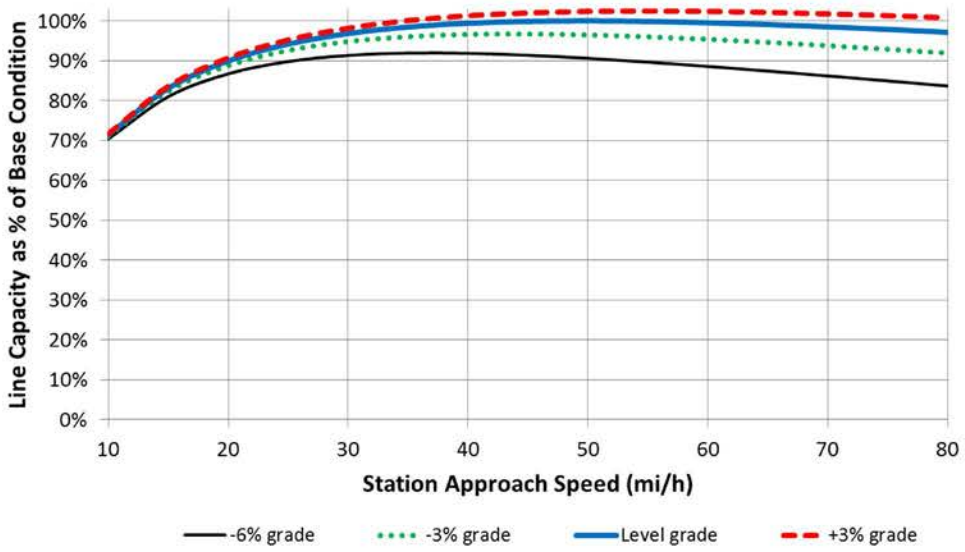
Capacities at or near 0% of base conditions are more theoretical than practical, as one or two vehicles (*sneakers*) will typically complete their turning movement at the end of the green signal phase, allowing the vehicles behind them to move forward. Nevertheless, high *v/c* ratios in the curb lane are undesirable for transit operations, as

they result in low capacities, low speeds, and poor reliability. Capacities are highest when only transit vehicles are allowed to use the curb lane (general traffic $v/c = 0$).

Speed Restrictions

Exhibit 3-21 shows the impact of station approach grade on rail line capacity at various station approach speeds. Trains take longer to decelerate from line speed when going downhill into a station, as gravity is working against them; this extra time adds to the required safe separation time between trains and thus decreases capacity. Gravity works with trains when deceleration occurs uphill into a station, resulting in a small decrease in the minimum headway and a corresponding small increase in capacity. However, this capacity effect is more theoretical than practical, as the total combined deceleration rate from the train's braking system and gravity should not exceed the maximum deceleration rate set for passenger comfort and safety reasons. Nevertheless, rapid transit systems—particularly underground systems—are often designed with uphill grades into stations and downhill grades out of stations as an energy conservation measure.

Exhibit 3-21
Illustrative Impact of Station Approach Grade and Speed on Line Capacity



Source: Calculated using TCQSM methods.
Note: Base condition assumes moving block signals with variable safety distances, 45-s average dwell time, 20-s operating margin, and level grade entering station. See Chapter 8, Rail Transit Capacity, for explanations of these parameters.

Overall Impact of Operating Environment on Capacity

Exhibit 3-22 illustrates the overall impact of transit vehicle control, traffic delay, and speed restrictions on the capacity of the bus and light rail modes. These modes are selected as they are ones most capable of operating in any environment. *All percentages shown in the exhibit are relative to the base condition for a particular mode*, expressed in vehicles per hour. Typical light rail line capacities (trains per hour) will be lower than bus facility capacities (buses per hour) because of the need to provide time separation between trains for safety reasons. However, in terms of person capacity (persons per hour), either mode is capable of providing the greater capacity, depending on the particular circumstances.

The exhibit shows that both modes are generally sensitive to the increased traffic control and traffic delay effects of less-exclusive operating environments, but there are a few differences. Bus operations at or near capacity in a street median, typically involving high volumes of buses, generally do not allow transit signal priority or preemption to be employed, as it would be too disruptive to cross-street traffic and pedestrian operations. In contrast, the number of light rail trains at capacity is much smaller, and can be often be accommodated with preemption or a traffic signal timing plan designed to progress light rail vehicles.

In an exclusive right-of-way environment, light rail trains may activate railroad crossing gates or preempt traffic signals near a station exit when passenger movements have ended. The extra time that a train spends in a station waiting for the gates to lower or the preemption sequence to complete results in a slightly lower line capacity when this occurs at a station with a long dwell time. When transit operates in the street median, stations may be located on the far-side of the intersection, avoiding the need for preempting traffic signals on exit. The need to serve very high cross-street traffic volumes may constrain the ability of exclusive operating environments to provide their maximum possible capacity.

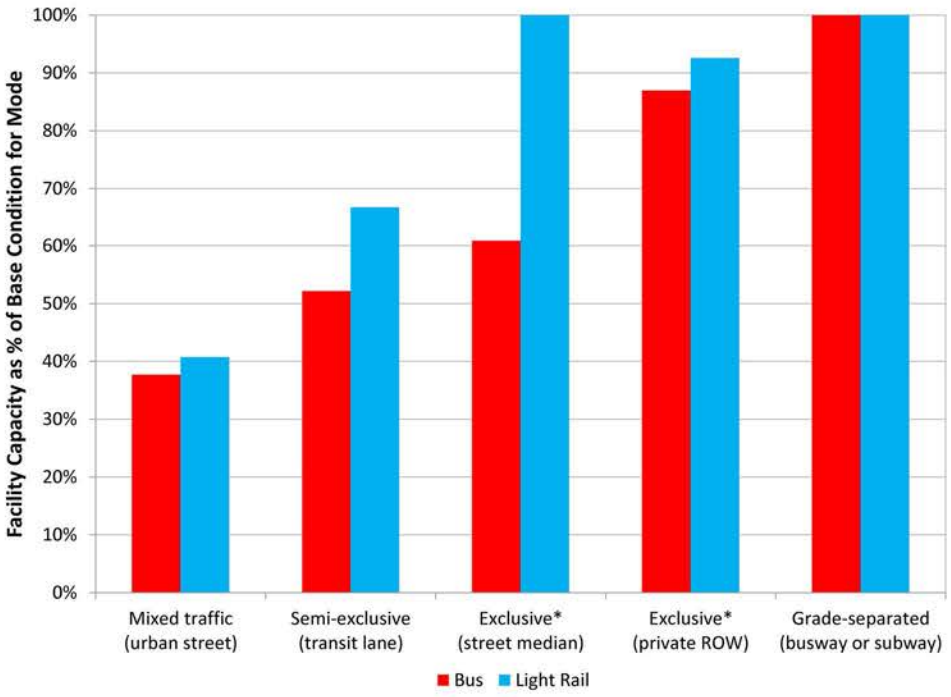


Exhibit 3-22
Illustrative Impact of Operating Environment on Facility Capacity

Source: Calculated using TCQSM methods.

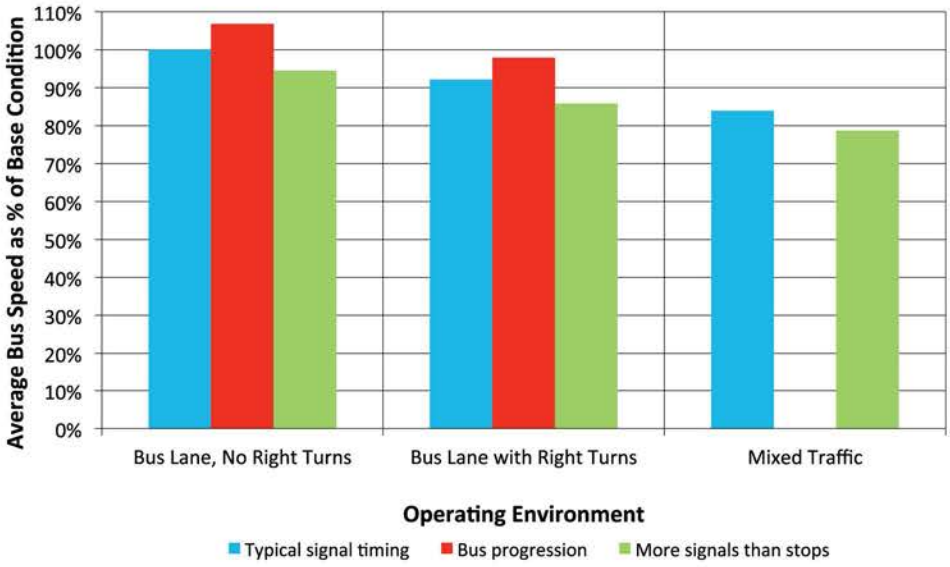
Note: *Capacity may be lower when very high cross-street volumes must be accommodated. Percentages calculated relative to the base condition for a given mode. Base condition for bus assumes grade separation, 30-s dwell time, no traffic signals, 10-s clearance time, and 60% dwell time variation (see Chapter 6, Bus Transit Capacity, for explanations of these terms). Base condition for light rail assumes 3-aspect train signals, 45-s dwell time, and 20-s operating margin (see Chapter 8, Rail Transit Capacity, for explanations of these terms). Exclusive light rail ROW assumes far-side stations when operating in street medians and a grade crossing on the exit to the critical station for private ROW. Semi-exclusive assumes 100-s signal cycle, g/C = 0.40, and (bus only) v/c = 0.25. Mixed traffic assumes g/C = 0.40 and v/c = 0.75 for both modes.
ROW = right-of-way.

ILLUSTRATIVE IMPACTS OF OPERATING ENVIRONMENT ON SPEED

Traffic Control

Exhibit 3-23 depicts the impact of traffic signals on bus speeds in semi-exclusive and mixed traffic environments. (Although calculated specifically for buses, streetcar operation would be similar.) The exhibit shows that timing signals to progress buses rather than motor vehicles provides the greater speeds, while operating on a street where signalized intersections are more frequent than bus stops results in lower speeds, compared to the base condition. In addition, the greater the opportunity for interactions with general traffic, the lower the overall speed. Light rail is usually provided with traffic signal preemption or signal timing to progress trains and thus is not delayed by traffic signals, except in unusual circumstances.

Exhibit 3-23
Illustrative Impacts of Traffic Signals on Bus Speeds

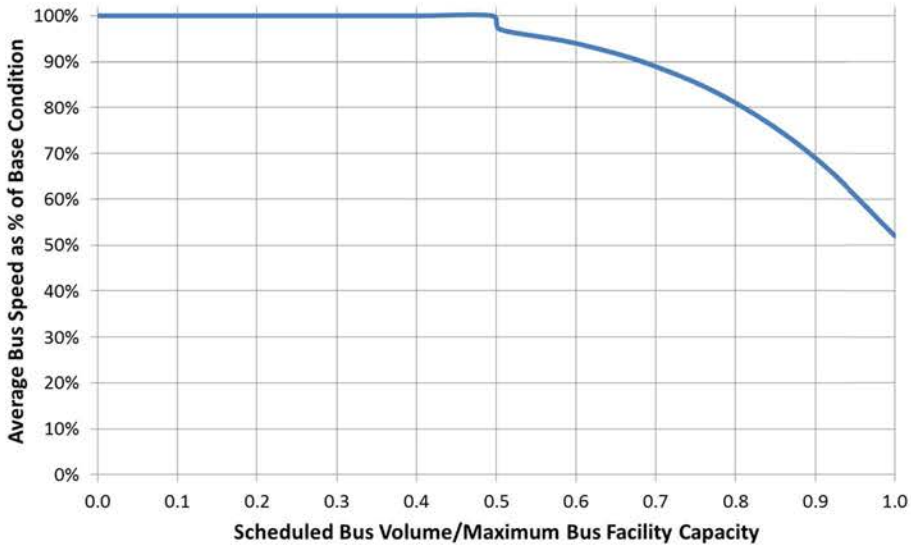


Source: Calculated using TCQSM methods.
Note: Base condition assumes 30-s average dwell time, 8 stops/mi, central business district location, and an exclusive bus lane not allowing general traffic right turns. See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

Transit Vehicle Interference

As the volume of buses on an urban street increases, the probability increases that one bus will delay another bus, either by blocking access into or out of a bus stop or by requiring passing maneuvers. These delays result in lower overall speeds. Exhibit 3-24 shows that until scheduled bus (or streetcar) volumes reach about half of the facility's maximum capacity (i.e., capacity without regard for reliability), these delays are negligible. When 50% of a facility's maximum capacity is in use, speeds begin to decline, and when all of a facility's capacity is used, speeds are approximately one-half what they would be without bus interference.

Exhibit 3-24
Illustrative Impact of Bus Congestion on Bus Speeds



Source: Calculated using TCQSM methods.
Note: Base condition assumes less than half the facility's maximum capacity in use.

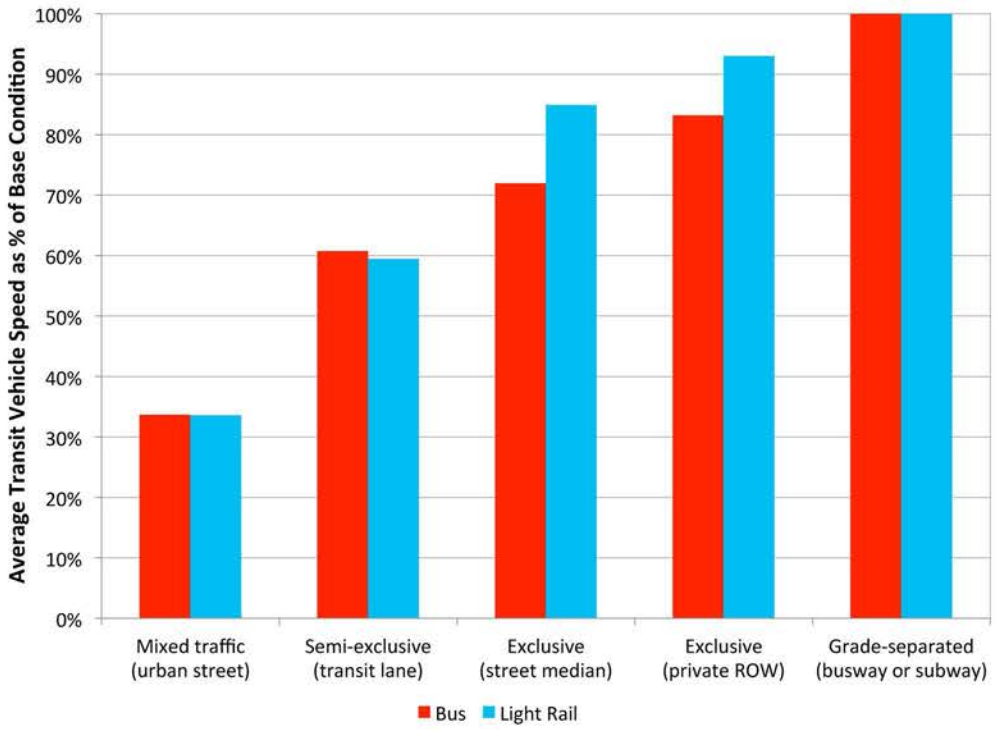
Because light rail trains are normally separated from each other by a train control system, interference effects typically occur at capacity, when one train's dwell time exceeds the scheduled dwell time plus operating margin, causing delays to the following trains. Capacity conditions can occur either because of normal scheduling or because of a disruption to service (e.g., track blockage) that causes a queue of trains to build up.

Overall Impact of Operating Environment on Speed

Exhibit 3-25 illustrates the overall impact of transit vehicle control, traffic delay, and speed restrictions on the average speed of the bus and light rail modes. *All percentages shown in the exhibit are relative to the base condition for a particular mode*, expressed in miles per hour.

As with the capacity relationships previously illustrated in Exhibit 3-22, this exhibit shows that both modes are sensitive to the increased traffic control, traffic delay, and speed restrictions associated with less-exclusive operating environments. Buses are more likely to be delayed at traffic signals than light rail in exclusive right-of-way types, but light rail may experience extra holding time in stations on private right-of-way while waiting for railroad crossing gates to be activated at a crossing near the station exit. Light rail speeds in street medians are typically restricted by policy to be no more than the posted speed for the street.

Exhibit 3-25
Illustrative Impact of Operating Environment on Average Transit Speed



Source: Calculated using TCQSM methods.
Note: Base condition assumes 30-s average dwell time, 2 stops/mi, and a grade-separated environment. Light rail values assume 55 mi/h maximum speed in private right-of-way (ROW) and grade-separated environments, 35 mi/h in street medians, and 20 mi/h otherwise.

IMPACT OF OPERATING ENVIRONMENT ON RELIABILITY

Reliability is discussed in more detail in Chapter 4, Quality of Service Concepts.

With grade-separated facilities, the potential sources of schedule unreliability are generally limited to (*a*) things under the transit agency's control, such as schedule achievability, vehicle maintenance, and route length and number of stops, and (*b*) variations in passenger demand, including randomness in the use of wheelchair lifts and ramps. The introduction of at-grade crossings introduces potential conflicts with other travel modes. On-street facilities introduce traffic signals (potential randomness in whether a transit vehicle receives a red or green signal when approaching an intersection), the potential for road construction, and the potential for unauthorized use of the facility (e.g., stopped or parked vehicles). Semi-exclusive facilities have greater potential for unauthorized usage, introduce potentially variable right-turning traffic delays, and introduce the potential for parking maneuvers. Finally, mixed-traffic operations introduces potential travel time variability due to traffic congestion and variability in traffic volumes from one hour or day to the next.

6. STOP AND STATION CHARACTERISTICS

VEHICLE–PLATFORM INTERFACE

Factors involving the vehicle–platform interface that affect transit speed and capacity include:

- Height differential between the vehicle floor and the platform,
- Platform position relative to the guideway, and
- Number of transit vehicles that can stop simultaneously.

The elevation difference between the vehicle floor and the platform influences how quickly passengers can board and alight. In addition, if the horizontal or vertical separation between vehicle floor and platform exceeds ADA standards, a bridgeplate, wheelchair lift, or similar device must be employed to provide access to passengers with disabilities. These devices take time to deploy and stow again after use, which affects dwell time. They can also potentially affect reliability when dwell times are significantly extended when these devices are used.

Stops and stations can be *on-line,* where the transit vehicle stops in the guideway (e.g., the travel lane on a street, the mainline tracks on a rail line) to serve passenger movements, or they can be *off-line,* where the transit vehicle stops out of the guideway (e.g., in a bus pull-out, in the parking lane, on a passing siding at a station) to serve passengers. In a mixed-traffic environment, on-line stops allow transit vehicles to proceed again as soon as passenger movements are finished, traffic control permitting, with no delay waiting for a gap in traffic to re-enter the street. Otherwise, when the guideway provides only one lane or track per direction of travel, off-line stops allow transit vehicles to pass each other at stations. This arrangement allows a mix of all-stop and limited-stop services to share the guideway, allowing higher speeds for the limited-stop services and often resulting in a greater vehicle throughput (capacity) on the guideway.

There are also safety and traffic operations considerations when deciding between on-line and off-line stops in mixed-traffic environments; these are discussed in Chapter 6, Bus Transit Capacity.

The number of transit vehicles that can stop simultaneously at a stop or station directly affects the facility capacity. This is primarily a consideration for bus transit, but short streetcars and light rail vehicles operating under line-of-sight control are also capable of sharing long platforms. The number of stopping positions provided, and their design (allowing independent movement in and out of each position, or not) determines capacity. Speed is indirectly affected, because (as was seen in Section 5), average bus speed is related to the amount of capacity in use; thus, increasing capacity without scheduling more vehicles to use it will decrease the number of interactions between vehicles and will improve speeds when more than half the facility's maximum capacity was in use prior to the increase in capacity.

VEHICLE CHARACTERISTICS

As was discussed in Section 4, the number of doors available for passenger use and their width influences how many passengers can simultaneously board or alight a transit vehicle, which in turn affects dwell time. However, even when several doors are provided, onboard fare collection needs may restrict boarding passengers to using the front door. In addition, the seating arrangement inside the bus (e.g., seats facing forward

vs. seats facing the aisle, number of seats per row) influences the width of the aisle and thus the ease with which passengers can circulate to and from the doors when standees are present.

FARE COLLECTION

With proof-of-payment fare collection, passengers purchase their fare prior to boarding and can be asked to show proof-of-payment during their trip, with a potential fine if they are traveling without a valid fare.

Fare collection affects dwell time in several ways. First, when fares are collected on board, each fare collection method has a passenger service time associated with it—some methods are faster than others. Second, the fare collection policy may require all passengers with pre-paid fares (e.g., passes) or smart cards to interact with the driver, or the policy may allow these passengers to board any door, with smart card holders tagging their cards at one of the rear doors. Finally, when fares are collected off-board (e.g., using faregates or proof-of-payment fare collection), passengers can use any door to board. Although proof-of-payment fare collection can significantly reduce dwell times (thus providing improved speeds and potential operating cost savings), and the cost of additional fare inspectors can be more than the additional fare revenue or fines collected, there has always been a tension between the operating efficiencies that the method provides and political and public perceptions that some people cheat the system by not paying their fare (and potentially are the source of more serious crimes).

STOP SPACING

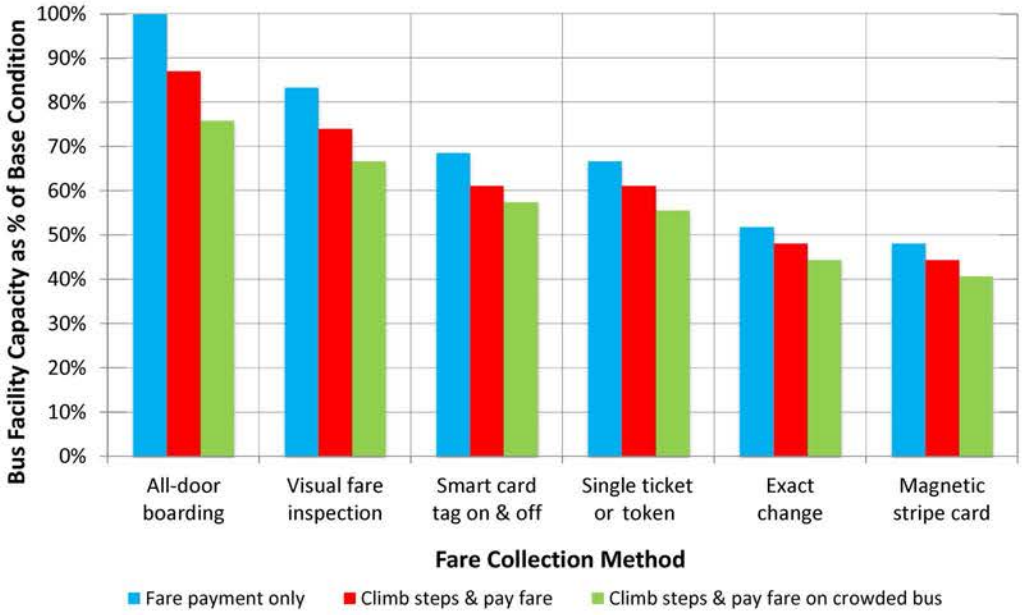
As was discussed in Sections 3 and 4, the more frequently that transit vehicles stop, the more time that is lost in decelerating and accelerating. In addition, when transit vehicles operate on street, each stop carries the risk that the vehicle will fall out of the progression band provided by the street's signal timing and will be further delayed at the next traffic light. Finally, when stops are too close together, a transit vehicle becomes incapable of reaching its maximum allowed speed before it has to decelerate again for the next stop.

ILLUSTRATIVE IMPACTS OF STOPS AND STATIONS ON CAPACITY

Passenger Service Time

Exhibit 3-26 and Exhibit 3-27 show the impact of fare collection method, level vs. non-level boarding, and bus crowding (collectively, passenger service time) on bus facility and light rail line capacity, respectively. Exhibit 3-26 shows that there are clear impacts on bus capacity with different fare collection methods, and that climbing steps or entering a crowded bus increases passenger service time and thus reduces capacity. The impacts of steps and crowding are more severe when fare collection times are low, as other factors play more of a role in determining overall capacity at higher dwell times. Exhibit 3-27 shows that passenger service times decrease and capacity increases as more door channels are available to serve passengers. A rail system that requires passengers to enter through the front door to pay fares cannot come close to the maximum capacity it is otherwise capable of providing.

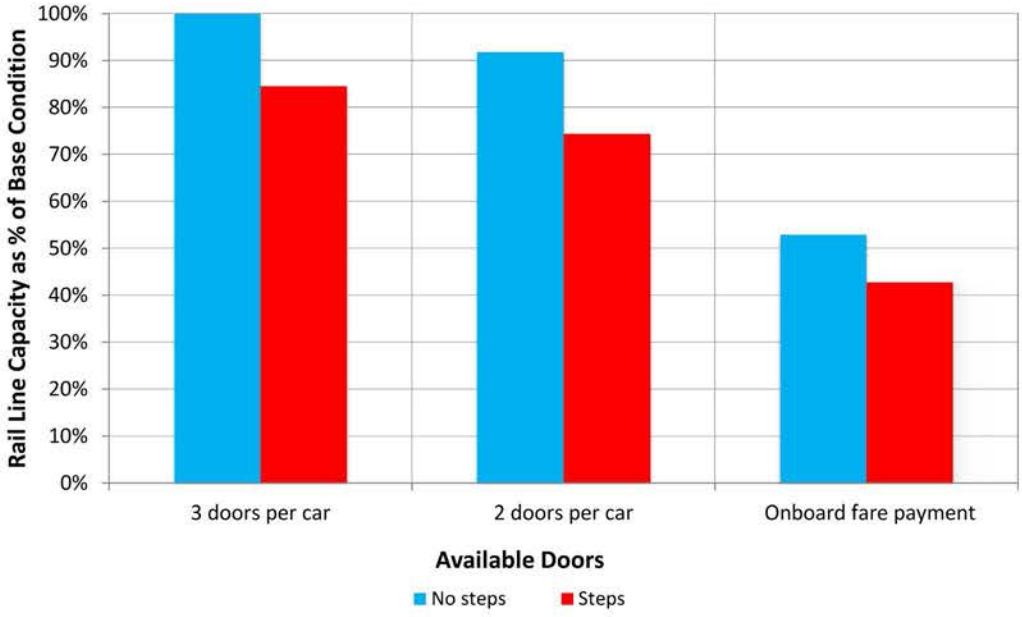
Exhibit 3-26
Illustrative Impact of Bus Passenger Service Time on Capacity



Source: Calculated using TCQSM methods, including default fare collection times from Chapter 6, Bus Transit Capacity.

Note: Base condition assumes 10 passengers boarding and 4 passengers alighting at the critical stop, level boarding, no standees, all-door boarding, 60% dwell time variation, 10-s clearance time, and 0.40 *g/C* ratio. See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

Exhibit 3-27
Illustrative Impact of Floor Height and Door Availability on Light Rail Line Capacity



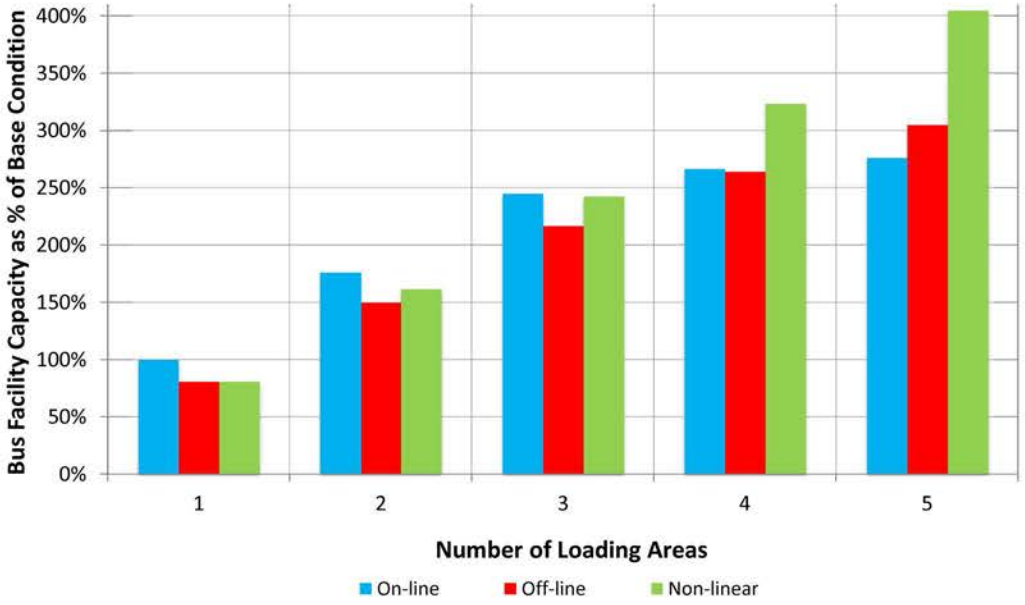
Source: Calculated using TCQSM methods.

Note: Base condition assumes 2-car light rail train with an average of 20 passengers boarding and 20 passengers alighting at the critical stop, level boarding, 20-s operating margin, and 50-s safe train separation time. See Chapter 8, Rail Transit Capacity, for explanations of these parameters.

Type and Number of Loading Areas

Exhibit 3-28 illustrates how bus facility capacity increases as the number of loading areas provided at the critical stop increase. With 1–3 loading areas, for the conditions used to develop the exhibit, on-line stops provide the greatest capacity, as buses are not delayed by other traffic when they are ready to continue after serving passengers. With 4–5 loading areas, off-line loading areas provide as much or more capacity as on-line loading areas, as the ability of buses to access unoccupied loading areas at the front of the stop overcomes the disadvantage of having to yielding to street traffic on departure. The incremental benefit of a fourth or fifth loading area is relatively low for either on-line or off-line loading area designs, compared to adding a second or third. Non-linear loading areas can be independently accessed by buses and thus add the same increment of capacity with each additional loading area. However, because of the extra curb space required to develop non-linear loading areas, they are more often used at off-street bus stops than at on-street stops.

Exhibit 3-28
Illustrative Impact of Number and Type of Loading Areas on Bus Facility Capacity



Source: Calculated using TCQSM methods.
Note: Base condition for the critical stop assumes 1 on-line loading area, 30-s average dwell time, 60% dwell time variability, 10-s clearance time, and 0.4 *g/C* ratio. Off-line and non-linear loading areas assume 18-s clearance time. See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

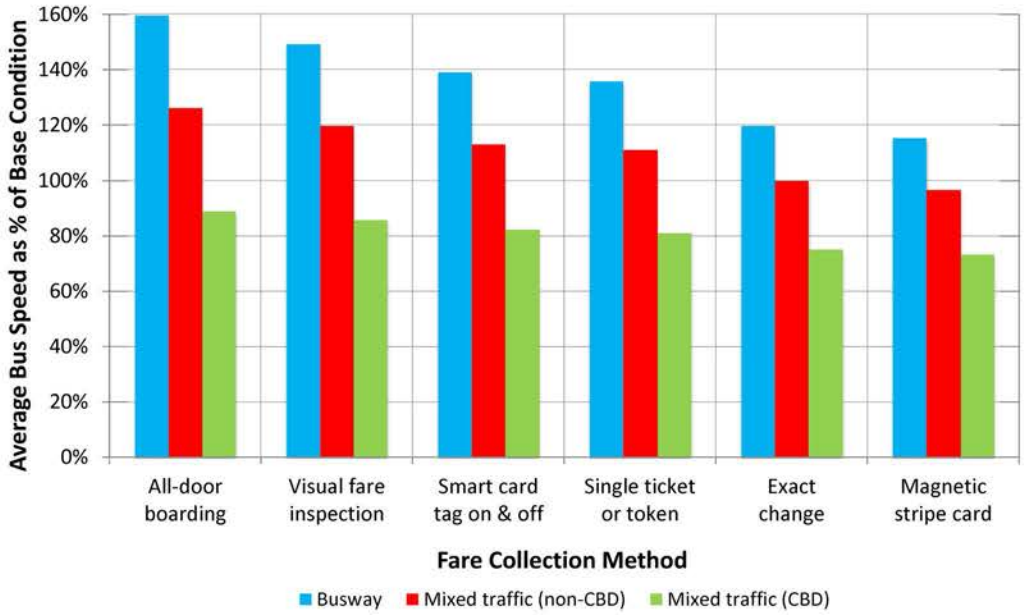
ILLUSTRATIVE IMPACTS OF STOPS AND STATIONS ON SPEED

Fare Collection

Exhibit 3-29 shows the impact of fare collection method on average bus speeds for busways, arterial streets outside central business districts (CBDs), and mixed-traffic operation within a CBD. The base condition is exact change fare payment and a bus facility consisting of a non-CBD arterial street. For the conditions used to develop the exhibit, it can be seen that visual inspection of pre-paid fares and all-door boarding both

result in average speeds 20% or more higher than with exact-change fare collection. However, the type of operating environment has a greater impact on speed than the choice of fare collection method.

Exhibit 3-29
Illustrative Impact of Fare Collection on Average Bus Speed by Facility Type

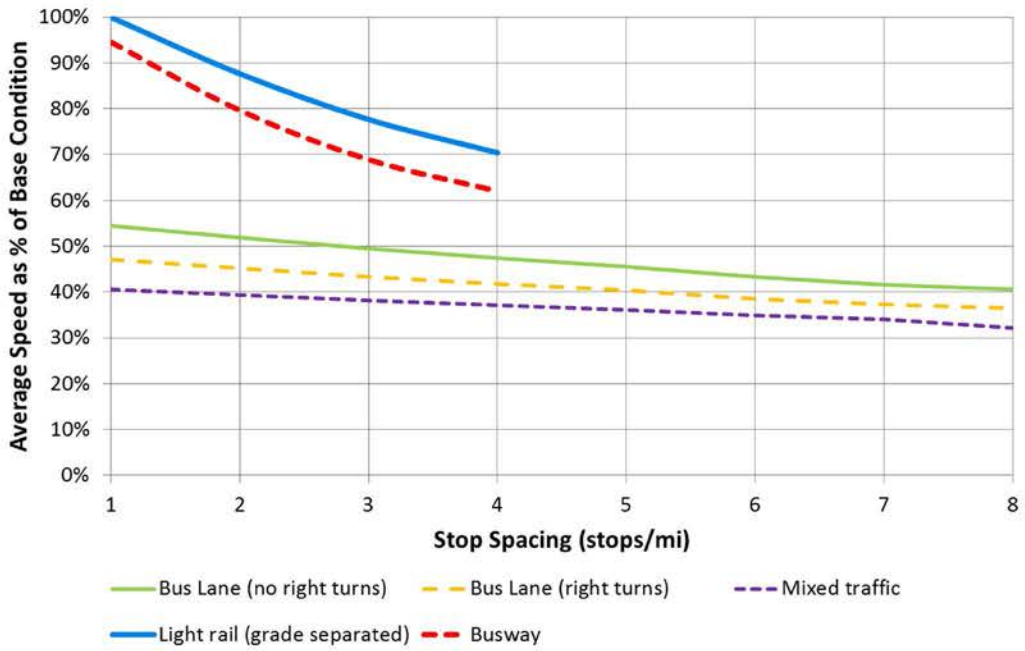


Source: Calculated using TCQSM methods.
Note: Base condition assumes 32-s dwell time, exact change fare payment, non-CBD mixed traffic operation, level boarding, no standees, 35 mi/h maximum speed, and 4 stops/mi. See Chapter 6, Bus Transit Capacity, for explanations of these parameters.

Stop Spacing

Exhibit 3-30 illustrates the impact of stop spacing on average transit speeds for different types of transit facilities. For the purpose of this exhibit, passenger demand is assumed to be unaffected by stop spacing; thus the average passenger service time at 1 stop/mi is assumed to be eight times the average passenger service time per stop at 8 stops/mi. Therefore, differences in speeds for a given facility type are due solely to deceleration and acceleration delays. Differences in speeds between facility types are due to differences in operating environment and, in the case of grade-separated light rail vs. busway, differences in vehicle acceleration characteristics (light rail vehicles can accelerate more quickly than buses and thus spend more time at their running speed). It can be seen from the exhibit that stop spacing impacts speed more severely when running speeds are high (e.g., on grade-separated facilities), as more time is spent decelerating and accelerating than at lower speeds.

Exhibit 3-30
Illustrative Impact of Stop Spacing on Average Transit Speed



Source: Calculated using TCQSM methods.
Note: Base condition assumes grade-separated light rail and 1 stop/mi. Assumed dwell time is 15 s at 8 stops/mi (10-s passenger service time and 5-s door opening and closing time), with the passenger service time component increasing proportionately as the number of stops decreases (e.g., 25-s dwell time at 4 stops/mi). Assumed running speed is 55 mi/h for light rail and busway and 25 mi/h otherwise.

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CHAPTER 4
QUALITY OF SERVICE CONCEPTS

1. User's Guide
2. Mode and Service Concepts
3. Operations Concepts
4. **Quality of Service Concepts**
5. Quality of Service Methods
6. Bus Transit Capacity
7. Demand-Responsive Transit
8. Rail Transit Capacity
9. Ferry Transit Capacity
10. Station Capacity
11. Glossary and Symbols
12. Index

CONTENTS

1. INTRODUCTION 4-1
Overview 4-1
Roles of Transit 4-2
Performance Points of View 4-4

2. QUALITY OF SERVICE FACTORS 4-7
Customer Satisfaction Research 4-7
Value of Time Research 4-9

3. QUALITY OF SERVICE FRAMEWORK 4-15
Transit Trip Decision-Making Process 4-15
Framework Outline 4-17
Transit Availability 4-17
Transit Comfort and Convenience 4-32

4. QUALITY OF SERVICE, RIDERSHIP, AND SERVICE COSTS 4-37
Quality of Service and Ridership 4-37
Quality of Service and Service Costs 4-40

5. REFERENCES 4-42

APPENDIX A: EXHIBITS IN METRIC UNITS 4-48

LIST OF EXHIBITS

Exhibit 4-1 Transit Performance Stakeholders, Interest Areas, and Performance Measure Examples 4-5
Exhibit 4-2 Factors Contributing Most to Stated Overall Satisfaction with a Transit Trip 4-8
Exhibit 4-3 Typical Values of Time for Different Types of Travel 4-9
Exhibit 4-4 Relative Urban Travel Values of Time 4-10
Exhibit 4-5 Relative Values of Time for Different Stages of a Trip 4-11
Exhibit 4-6 Relationship Between Platform Crowding and Perceived Walk and Wait Times 4-12
Exhibit 4-7 Relationship Between Vehicle Crowding and Perceived Travel Time 4-13
Exhibit 4-8 In-vehicle Time Equivalent of Bus Stop Amenities 4-13
Exhibit 4-9 Transit Availability Factors 4-16
Exhibit 4-10 Quality of Service Framework: Fixed-Route Transit 4-17
Exhibit 4-11 Quality of Service Framework: Demand-Responsive Transit 4-17
Exhibit 4-12 Walking Distance to Bus Stops 4-18
Exhibit 4-13 Effect of Grade on Distance Walked 4-19
Exhibit 4-14 Onboard Bicycle Facility Examples 4-23
Exhibit 4-15 Conceptual Illustration of Effect of Distance on Transit Access Mode Choice 4-24
Exhibit 4-16 Illustrative Park-and-Ride Market Areas 4-27
Exhibit 4-17 Components of a Long-Headway Transit Trip 4-29
Exhibit 4-12m Walking Distance to Bus Stops 4-48
Exhibit 4-13m Effect of Grade on Distance Walked 4-48

1. INTRODUCTION

OVERVIEW

Quality of service reflects the passenger's perception of transit performance.

Quality of service reflects the passenger's perception of transit performance. The performance measures used to describe this perception are different from the financial and output-focused performance measures typically reported by transit agencies to the National Transit Database (*1*) and from the automobile operations performance measures that are a major focus of the *Highway Capacity Manual* (*2*). Quality of service depends to a great extent on the operating decisions made by a transit agency within the constraints of its budget, particularly decisions on where transit service should be provided, how often and how long it is provided, and how it is provided.

Ultimately, quality of service reflects how well transit service meets the needs of its customers, which has ridership implications. However, a balance must be struck between the quality of service that passengers ideally would like and the quality of service that a transit agency (*a*) can afford to provide or (*b*) would reasonably provide, given a base demand for transit service. Better quality of service is more attractive to potential passengers and generates higher ridership than lower quality of service, but better quality of service often (but not always) also entails higher costs.

Chapter Organization

Organization of Chapter 4.

Chapter 4 of the *Transit Capacity and Quality of Service Manual* (TCQSM) explores the basic concepts of quality of service:

- The remainder of Section 1 discusses the roles of transit in North America and the different perspectives that different stakeholders provide when assessing the performance of transit service.
- Section 2 presents findings from research on the most important quality of service factors from the passenger perspective.
- Section 3 organizes these quality of service factors into a framework that includes (*a*) measures of *transit availability* that determine whether or not transit is an option for a given trip, and (*b*) measures of *transit comfort and convenience* that influence a potential customer's decision to use transit, for trips where transit is an available option.
- Section 4 presents the ridership and cost implications of making changes in quality of service.
- Section 5 is a list of the references that provided material used in the chapter.
- Appendix A provides metric versions of exhibits presented in U.S. customary units only within the chapter.

How to Use This Chapter

The remainder of Section 1 will be of greatest interest to those readers new to the transit industry, although the material on transit performance measurement needing to consider a variety of stakeholder perspectives will also be useful to transit agency managers, decision makers, and staff involved with measuring agency performance.

Section 2 provides reference information not needed to apply the TCQSM's methods but which nevertheless have some bearing on them. The material on customer satisfaction research is provided for those readers wanting additional support for the TCQSM's selection of service measures. The material on value of time provides the relative values that passengers place on different aspects of their transit trip; it is hoped that this material can be expanded in future editions of the manual to provide even more quantitative information about passengers' perspectives on quality of service.

Section 3 will be valuable for many readers. The section can be read by all users who intend to apply the quality of service methods found in Chapter 5, as the section presents the manual's framework for measuring quality of service. For other readers, this section describes the major factors that influence quality of service and their importance.

Finally, Section 4 will be useful for transit agencies wishing to evaluate the potential effects of making changes to quality of service, both in terms of ridership and in terms of operating and capital costs.

Other Resources

Other TCQSM material related to this chapter includes:

- The "What's New" section of Chapter 1, User's Guide, which describes the changes made in this chapter from the 2nd Edition;
- Chapter 5, Quality of Service Methods, which presents methods for evaluating the quality of service measures introduced in this chapter; and
- The manual's CD-ROM, which provides links to electronic versions of all of the TCRP reports referenced in this chapter.

ROLES OF TRANSIT

Transit plays two major roles in North America. The first role is to accommodate passengers who choose to use transit for their trip making even though they have other means of travel available to them, most likely a motor vehicle. The other role is to provide basic mobility for those unable to drive.

Choice Riders

Passengers who have more than one travel option available to them are often referred to as *choice* riders. These customers may choose transit for a given trip for a variety of reasons, including:

Choice riders choose to use transit even though other means of travel are available.

- Saving money (e.g., parking costs, fuel costs, tolls, insurance and registration costs associated with owning a car or multiple cars);
- Having the potential for a faster or more reliable trip compared to competing modes, particularly in large metropolitan areas and where natural barriers constrain the roadway network;
- Avoiding the need to drive in congested roadway conditions;
- Being able to use travel time more effectively (e.g., reading, working); and
- Helping the environment by not contributing to the negative impacts of automobile travel.

Choice riders use transit particularly during peak periods for work trips. In this role, transit is essential for mobility in the downtowns of some major cities— which could not survive without the existence of transit service—and in other concentrated employment centers. However, this peaked ridership demand also means that more vehicles and operators are needed to serve peak-period demand than off-peak demand. Peak-period transit demand is often highly directional—toward major employment centers in the morning and away in the afternoon—with unused capacity available in the off-peak direction. The more that ridership can also be attracted to the off-peak direction—for example, through the design of the transit route (e.g., having strong trip attractors, or *anchors,* at both ends of the route) or through fare incentives—the more productive the route will be, and the more cost effective it will be to provide a high quality of service.

Transit-dependent Riders

Transit-dependent riders rely on transit to meet basic mobility needs.

Transit also provides basic mobility for those segments of the population too young, too old, or otherwise unable to drive due to physical, mental, or financial disadvantages. In 2009, about 31% of the population in both the United States (*3*) and Canada (*4*) did not possess a driver's license. This portion of the population therefore depended on others to transport them (e.g., in autos, in taxis, or on transit), made trips by walking or bicycling, or used a combination of these. Such transit users have been called *captive* or *transit-dependent* riders. Transporting these riders is the principal role for those transit services provided specifically for persons with disabilities and is the dominant role in many smaller transit systems.

Role of Quality of Service in Attracting and Retaining Ridership

Although transit may be the best or only travel choice available at a given time for many types of trips made by transit-dependent riders, quality of service is still an important consideration for both riders and service providers. For riders, a poor quality of service can limit the options available for finding and holding a job, taking classes, or taking care of basic living needs. For transit providers, providing a good quality of service can help retain riders once they are no longer transit dependent.

In the major cities in North America, transit serves higher numbers of both choice and captive riders. The variation in transit mode share among urban areas reflects differences in population, downtown employment and parking costs, extent of bus and rail transit service, and geographic characteristics.

Transit trips can be both time and cost competitive to the auto under certain operating conditions, particularly where exclusive right-of-way operation, on-street transit lanes, or other forms of transit priority that provide significant time savings can be provided. Time or cost savings helps attract ridership from single-occupant vehicles, thereby reducing traffic congestion and improving air quality.

Importance of good pedestrian and bicycle connections to transit.

Transit passengers must of necessity be pedestrians or bicyclists at one, or usually, both ends of their trips. It is therefore important that the land uses along transit routes and around transit stations help support transit service by providing safe and direct linkages between transit stops and passengers' origins and destinations. Providing these linkages also helps develop a more walking- and bicycling-friendly environment that encourages the use of these modes for other trips, thereby creating a more active, and potentially more secure environment around transit stops. Providing transit-

supportive land uses around transit stops and stations also helps take full advantage of the quality of service provided at that location and can generate the ridership that supports even better quality of service.

PERFORMANCE POINTS OF VIEW

As the previous discussion suggested, transit service directly or indirectly affects many aspects of a community. As a result, there are a number of different stakeholders who are interested in transit performance. These stakeholders include:

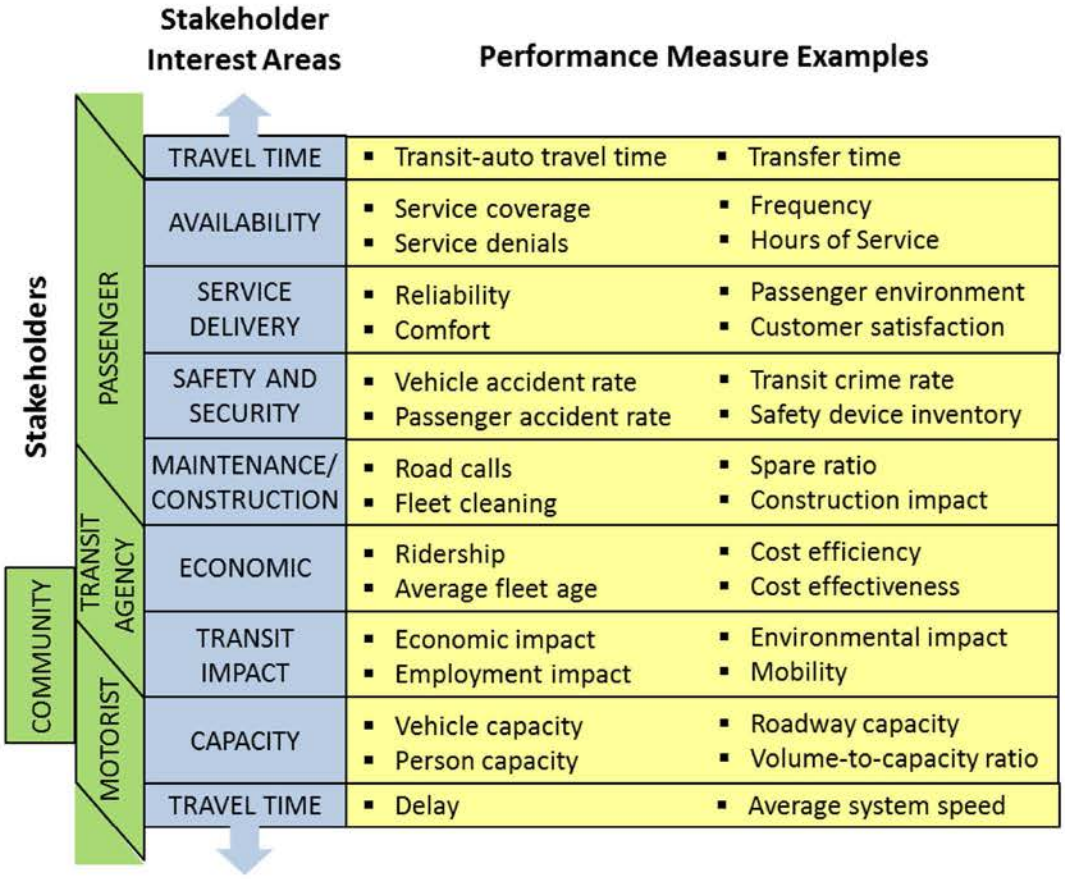
- *Transit passengers,* who have to decide which travel mode to use (when they have a choice of modes), or whose travel options may be constrained by the quality of the service (when they do not have a choice);
- *Transit agency staff and decision makers,* who have to make choices about how to allocate a finite amount of resources to best meet the agency's goals and objectives, and who also have to report on transit performance to other agencies providing funding support;
- *Motorists,* who interact with transit vehicles on the road and who may benefit when other motorists decide to use transit, and *roadway agency staff and decision makers,* who have their own sets of stakeholders, goals, and objectives, and need to become partners in order to implement roadway infrastructure improvements that can benefit transit; and
- *Community members and decision makers,* who may directly support transit service through taxes and who may indirectly benefit from the role that transit plays in the community (e.g., congestion relief, air quality, mobility, source of employment).

Each of these major stakeholder groups has its own sets of interests and priorities—a point of view. Some of these points of view overlap with those of other stakeholders and others are a primary focus of one set of stakeholders. Consequently, transit performance needs to be addressed in a way that addresses the points-of-view of multiple stakeholders. Exhibit 4-1 shows some of the primary interest areas of major stakeholder groups, along with potential performance measures for those interests.

Exhibit 4-1
Transit Performance Stakeholders, Interest Areas, and Performance Measure Examples

Transit performance measures can reflect passenger, transit agency, motorist, and community points of view.

Travel time overlaps the motorist and passenger points of view.



Source: Derived from *TCRP Report 88* (*5*).

Transit Agency

The transit agency point of view reflects transit performance from the perspective of the transit agency as a business. Although transit agencies are naturally concerned with all aspects of transit service provision, the categories listed under the transit agency point-of-view—particularly economic performance and maintenance and construction—are ones of greater interest to transit agencies than to the other stakeholders. Performance measures in these categories are also ones most likely to be tracked by transit agencies.

One reason that transit agency–oriented measures are more commonly tracked than others is that this category includes most of the measures routinely collected in the United States for the Federal Transit Administration's National Transit Database (NTD, *1*). Most NTD measures relate to cost and utilization. These measures are important to the transit agency—and indirectly to passengers—by reflecting the amount of service a transit agency can afford to provide on a route or the system as a whole. The utilization measures (e.g., ridership) indirectly measure passenger satisfaction with the quality of service provided. However, with a few exceptions related to safety and service availability (e.g., vehicle revenue hours per directional mile and vehicles operated in maximum service per directional mile), the NTD measures do not directly reflect the passenger point of view.

Motorist

The motorist point of view includes measures of vehicular speed and delay, such as those routinely calculated for streets and highways using the *Highway Capacity Manual* (*2*). This point of view also includes measures of roadway capacity in terms of the numbers of transit vehicles or total vehicles that can be accommodated. Because transit vehicles carry passengers, these measures also indirectly reflect the passenger point of view: passengers on board a transit vehicle traveling at an average speed of 12 mi/h (20 km/h) individually experience the same average travel speed as the vehicle. However, because these vehicle-oriented measures do not take passenger loading into account, the passenger point of view is hidden, as all vehicles are treated equally, regardless of the number of passengers in each vehicle. For example, while a single-occupant vehicle and a 40-passenger bus traveling on the same street may experience the same amount of delay due to on-street congestion and traffic signal delays, the person-delay experienced by the bus is 40 times as great.

Community

The community point of view measures transit's role in meeting broad community objectives. Measures in this area include measures of the *impact* of transit service on different aspects of a community, such as employment, property values, or economic growth. This viewpoint also includes measures of how transit contributes to community *mobility* and measures of transit's effect on the *environment.* Many of these measures reflect things that are important to passengers, but which may not be directly perceived by passengers or by others on an individual trip basis.

Passenger

Quality of service focuses on those aspects of transit service that directly influence how passengers perceive the quality of a particular transit trip. It is defined as follows:

Quality of service focuses on the passenger point of view.

> The overall measured or perceived performance of transit service from the passenger's point of view.

In contrast to transit capacity, where issues are mainly concentrated in larger cities, transit quality of service matters to communities of all sizes. The factors that influence quality of service are introduced in the next section.

2. QUALITY OF SERVICE FACTORS

Two important ways of identifying the quality of service factors that are most important to existing and potential passengers are (*a*) to ask them directly through customer satisfaction surveys and (*b*) to observe how they react when given actual or hypothetical choices between transit services or travel modes with different characteristics. This section explores how these techniques have been used to identify the factors most important to passengers.

CUSTOMER SATISFACTION RESEARCH

Several large-scale customer satisfaction studies appear in the literature that help identify quality of service factors important to passengers.

TCRP Project B-11, "Customer-Defined Service Quality"

This TCRP project developed guidance for transit agencies on conducting customer satisfaction surveys to allow agencies to identify the most important customer-service issues that affect, or could potentially affect, their system. The project's surveying techniques were pilot tested at three transit agencies—an urban rail system, a suburban bus system, and a small city bus system—and more than 13,000 surveys were distributed, with response rates of 33 to 46 percent. These surveys asked passengers to rate 46 transit system attributes on a scale of 1 to 10 and to identify whether they had experience a problem with that attribute within the last 30 days (*6*).

For ease of comparison, the 46 surveyed attributes can be grouped into the following nine categories: comfort, nuisances, scheduling, fares, cleanliness, in-person information, passive information, safety, and transfers. Attributes relating to scheduling were the top area of existing concern, followed by comfort and nuisances (e.g., rowdy passengers). When potential problems (areas not currently a problem but still of concern to passengers) were analyzed, fares and scheduling were the top concerns, followed by comfort and safety. Nuisances was the category with the least potential for high levels of concern among passengers who had not experienced a problem in that area in the previous 30 days.

Florida Department of Transportation

The Florida Department of Transportation (FDOT) commissioned a survey of customer satisfaction factors for six larger Florida transit systems (*7*). As with the TCRP B-11 survey, the FDOT survey sought to identify both existing problems and potential problems. A total of more than 14,500 surveys were returned from the six systems, representing response rates of up to 28%. The surveys covered 22 factors, including hours of service, frequency of service, convenience of routes, on-time performance, travel time, transferring, cost, information availability, vehicle cleanliness, ride comfort, employee courtesy, perception of safety, bus stop locations, and overall satisfaction.

Existing problems of greatest significance to Florida customers were hours of service, routes, and headways. Potential problems of greatest significance were routes and headways, hours of service, bus ride comfort, printed schedules, and safety and cleanliness.

NCHRP Project 3-70, "Multimodal Level of Service for Urban Streets"

As part of the work to develop a transit level of service (LOS) measure for urban streets that could be directly compared to similar measures for the automobile, bicycle, and pedestrian modes, onboard surveys were conducted on bus routes with varying service characteristics (e.g., frequency, loading, reliability, amenity provision) operated by five different transit agencies around the U.S. Customers were asked to rate their overall satisfaction with their trip, along with their satisfaction about specific aspects of their trip (e.g., frequency, reliability) and—in the first phase of the survey effort—to select the service quality factors contributing most to their overall satisfaction, out of a list of 17 factors. More than 2,600 surveys were returned. In addition, as the starting and ending points of the customer's trip on the transit vehicle were known, customer responses could be compared to the conditions actually experienced (*8*).

Bus passengers' stated overall satisfaction varied greatly, even when making identical trips—so much so that no relationships could be drawn between overall satisfaction and various contributing factors to satisfaction. The researchers theorized that transit passengers surveyed on board are to some degree self-selected and that their trip must have already met some minimum threshold of satisfaction for them, otherwise they would not have been on board the transit vehicle. This threshold likely varies by individual, depending on the other travel choices available (*8*).

It was possible, however, to develop relationships between satisfaction with specific quality of service factors (e.g., frequency) and the conditions that surveyed passengers experienced. It was also possible to identify factors that passengers consistently stated as most contributing to their overall satisfaction. As shown in Exhibit 4-2, passengers consistently identified frequency as being the most important factor, while reliability, wait time (which relates to frequency and reliability), access (close to home and destination), and service span were also consistently stated as being contributors to passengers' satisfaction (*9*).

	Route				
Rank	**A**	**B**	**C**	**D**	**E**
1	*frequency*	*frequency*	*frequency*	*frequency*	frequency
2	*wait time*	*reliability*	*close to home*	*reliability*	wait time
3	*reliability**	*wait time*	*reliability*	*close to home*	close to home
4	*close to home**	close to dest.	*wait time*	close to dest.	reliability
5	service span	close to home	close to dest.	wait time	service span
6	close to dest.	service span		service span	
7	friendly drivers				

Exhibit 4-2
Factors Contributing Most to Stated Overall Satisfaction with a Transit Trip

Source: Dowling et al. (*9*).

Notes: *tie.
Italics indicate factors mentioned by 50% or more of surveyed passengers. Other listed factors were mentioned by at least 33% of surveyed passengers.
Dest. = destination.

VALUE OF TIME RESEARCH

The Value of Quality: Transit Planning Context

Ask most transit passengers how much their journey cost them and they will quote the price of their ticket. However, passengers also place a value on travel time and journey quality. Before making their ticket purchase decision, most passengers consider these issues and select an optimal travel option. In short, for each available travel option, they will subconsciously make a personal assessment of what is termed the *generalized cost* of their trip.

Transportation planners typically associate generalized costs with the requirements of strategic modeling and network assignment exercises—big picture studies into how people choose to get around cities and regions. However, such costs also incorporate transit's quality of service attributes, which affect choice of route and mode. Quality is represented both by the speed of the journey (including potential delays) and the quality of the facilities used during various stages of the journey. The higher the perceived cost of a combination of route and mode (e.g., longer travel time, more crowded conditions), the less likely a person would choose it for a given trip.

The econometric framework is underpinned by in-vehicle value of time (VoT). It provides the central reference point for the valuation of access, wait, and transfer travel time, and also for the valuation of non-time quality attributes; it is the glue that binds the framework together. Practitioners typically use generic and simplified values of time, often by neccessity (e.g., lack of available data or the need to model geographically large and diverse areas with relatively standardized parameters). However, values may vary by local context and quality improvements can alter them.

In-Vehicle Values of Time

Single point estimates for in-vehicle VoT (or value of travel time saved) are often quoted as a dollar-per-hour rate. These estimates reflect the average value placed on saving one hour of time within the relevant population. Exhibit 4-3 shows typical VoT values from the literature.

Exhibit 4-3
Typical Values of Time for Different Types of Travel

Type of Travel	VoT (% of Prevailing Wage Rate)
Personal travel	50%
Commercial (on the clock) travel	100% + benefits
Transit (in vehicle, seated)	25%-35%
Transit (in vehicle, standing)	50%
Transit (in vehicle, crowded)	100%
Waiting (unpleasant conditions)	Up to 175%

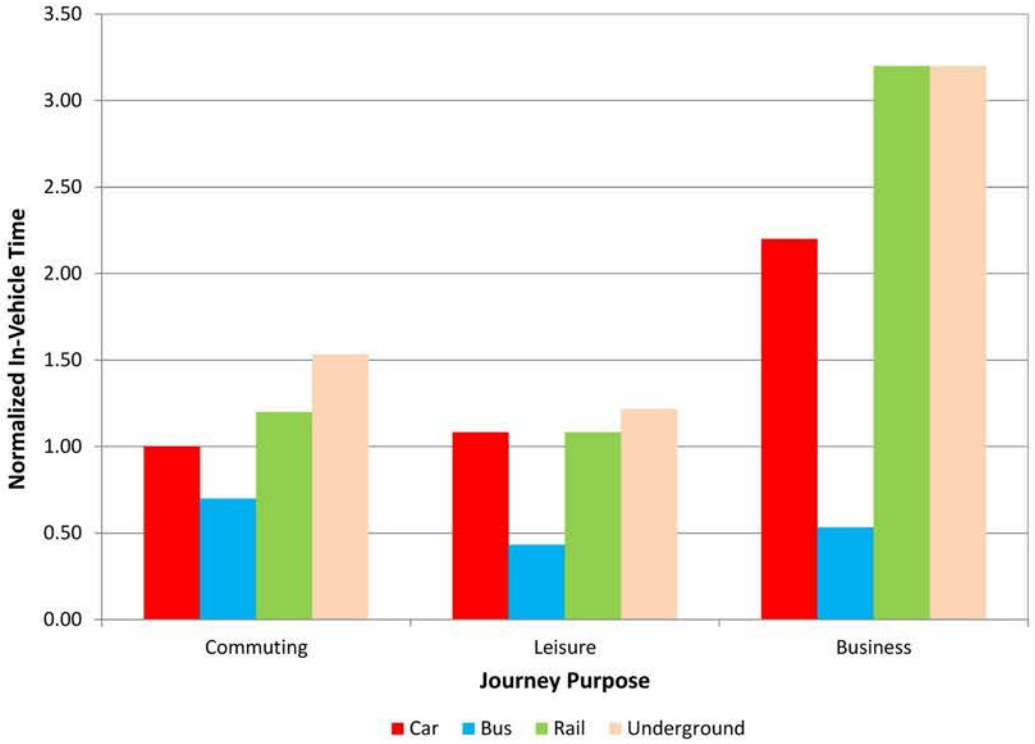
Source: Concas and Kolpakov (*10*).

The use of an average value or single-point estimate is by definition a simplification. The validity of using any such estimate will depend on the local circumstance, the context in which it is used, and the way in which the rate was calculated. For example, one source describes a range of British VoT ranging from £0.50 to £45.43 (*11*). The following subsections list some generally agreed reasons as to why VoT unit rates vary between sources.

Trip Purpose and Mode

As a general rule, modes that offer a higher speed or better quality of service attract passengers who value speed or quality more highly and are willing to pay a premium for those attributes. Trip purpose and mode of travel are key differentiators known to have an influence on in-vehicle VoT. Exhibit 4-4 shows the results of a review of over 200 British VoT studies (*12*), with values normalized to the commuting car driver valuation, which has been set to 1.0.

Exhibit 4-4
Relative Urban Travel Values of Time



Source: Derived from Wardman (*12*).

Exhibit 4-4 suggests that, for example, the average valuation for bus commuters is approximately half the average valuation for rail commuters—in other words, if the valuation for the average rail commuter was found to be $14/h, it could be inferred that the valuation for the average bus passenger may be in the region of $7/h. However, presenting summary data in this way can obscure some significant user type effects (*13, 14*). For example, although the average bus mode VoT is lower than the average rail mode VoT, individuals are likely to reveal a higher VoT when using bus because bus quality is generally perceived to be lower than rail quality.

Translating this to a real-world scenario, John Doe, who normally commutes by car to work, uses public transportation while his car is in the shop for repairs. His in-vehicle VoT when travelling by car is (hypothetically) $10/h, but because he perceives bus travel less positively, his in-vehicle VoT would be $15/h when travelling by bus. This means that only if John's bus journey time was two-thirds of his car journey time, would he perceive the in-vehicle portion of his bus and car options as being equivalent.

Trip Duration

Longer distance trips are generally agreed to attract a higher unit rate VoT. In other words, the longer the trip to be made, the more value the average passenger will place on reducing the travel time by a single unit of time. For example, the VoT values in Exhibit 4-4 were found to be higher for inter-urban travel by between 38% and 104% (*12*).

The American Association of State Highway and Transportation Officials (AASHTO) practice is to use non-linear, increasing unit rates for three time bands of 0–5 min, 5–15 min, and 15+ min. In the U.K., on the other hand, the normal practice is to apply VoT in fixed proportion to the average hourly rate, which is a pragmatic response to the reality of many transit preferential treatments, which deliver modest travel time savings, particularly when compared to projects designed to increase highway capacity (*15*).

One source (*16*) cites studies that indicate unit rate VoT increases for journeys above 40 min. Another source (*13*) describes a distance elasticity of 0.161 for in-vehicle transit time and 0.205 for in-vehicle auto time. These elasticities suggest that doubling the average trip duration will result in a VoT unit rate increase of between 16% and 20%.

Access, Transfer, and Wait Time

When compared to the in-vehicle component of a trip, the access, wait, and transfer elements typically require greater physical effort. Little or no productive use can be made of time during these stages of a trip and travelers may also encounter wayfinding difficulty and experience general anxiety associated with getting to a particular location on time. For these reasons, a unit of time spent during these stages of a transit trip is perceived as more onerous than a unit of in-vehicle time (*15*). This is a well-established principle. Exhibit 4-5 shows ranges of in-vehicle, walk, initial wait, and transfer time from eight U.S. studies from the 1960s to the 1990s reported in *TCRP Report 95* (*17*), along with a compilation of U.K. results, which suggest slightly lower average values (*12*).

Exhibit 4-5
Relative Values of Time for Different Stages of a Trip

	In-Vehicle Time	Walk Time	Initial Wait Time	Transfer Time
U.S. average	1.0	2.2	2.1	2.5
U.S. range	1.0	0.8–4.4	0.8–5.1[a]	1.1–4.4
U.K. average	1.0	1.7	1.8	N/A

Sources: *TCRP Report 95, Chapter 10* (*17*) and Wardman (*12*).

Note: N/A = not available. Values shown are multiples of the value of a unit of in-vehicle time.
(a) Two studies showed a sharp decrease in these values after the first 7–7.5 min of wait time.

In addition to these multipliers for in-vehicle time, some studies have identified transfer penalties in the range of 12–17 min of equivalent in-vehicle time. On the other hand, a bus re-restructuring in the Seattle area that moved from a relatively infrequent one-seat ride from suburbs to downtown Seattle to more-frequent service requiring a timed transfer at a transit center resulted in a 23% ridership gain over 2 years (*17*).

It can be seen from Exhibit 4-5 that there is considerable variability in reported VoT for a given stage of a transit trip. While some of this variability is the result of the type of study that generated the valuations (*12*), local context is also important and no universally applicable set of multiplier values exists.

Value of Quality

In some cases, the influence of specific aspects of quality has such a significant influence on passenger perception that mechanisms have been developed for directly manipulating the journey stage multipliers to reflect differences in quality of service. In particular, crowding has a significant effect on the perception of time. Other quality attributes have a more marginal impact.

Platform Crowding Effects

Exhibit 4-6 shows a relationship developed in Australia between rail platform crowd density and perceived walk and wait times.

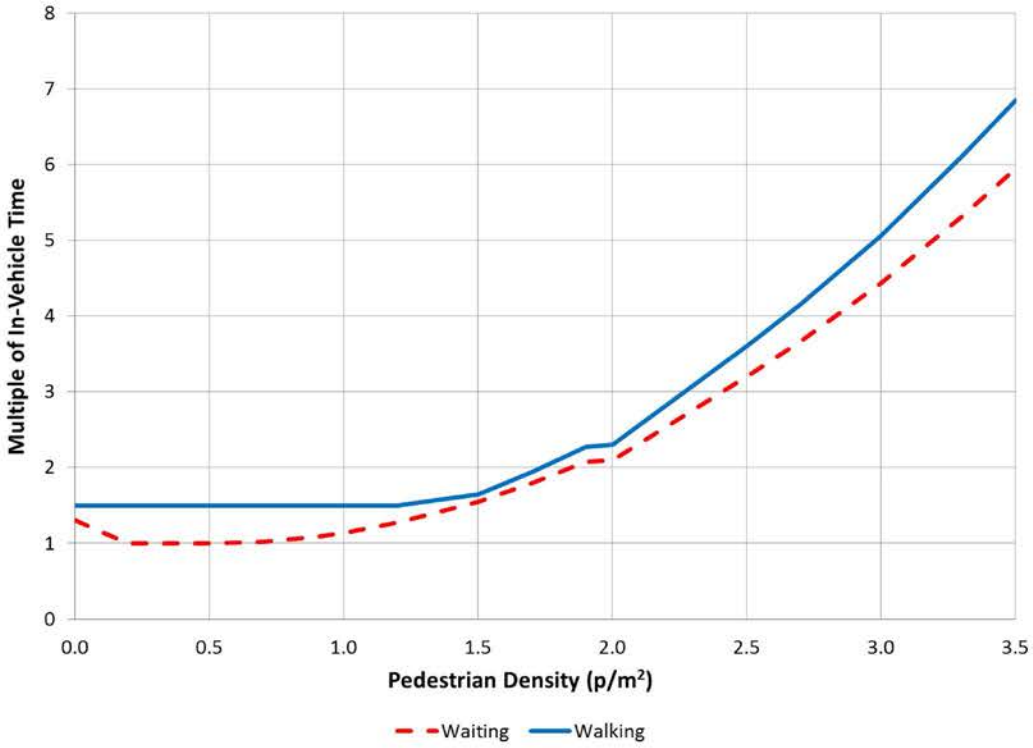


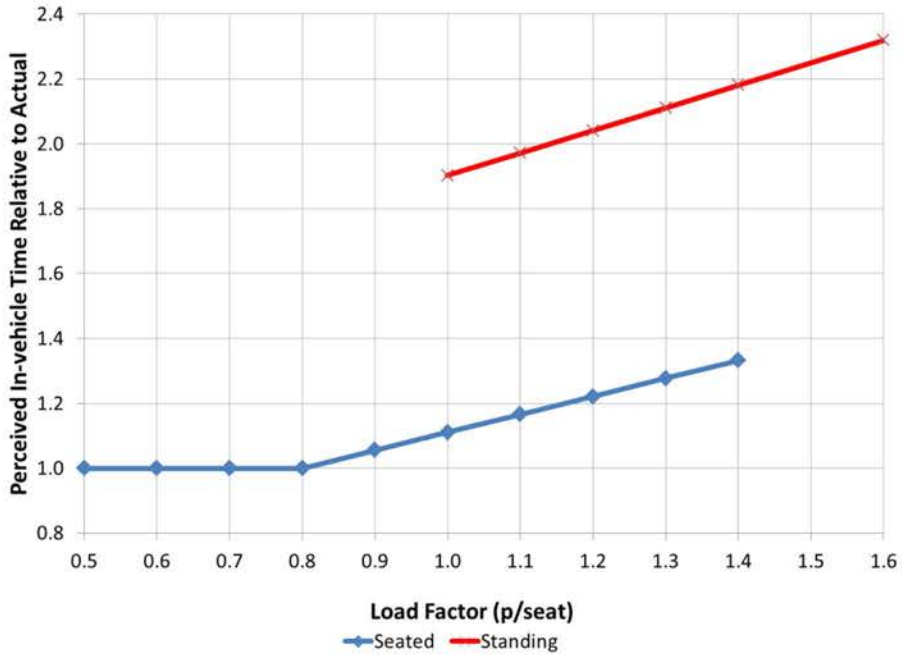
Exhibit 4-6
Relationship Between Platform Crowding and Perceived Walk and Wait Times

Source: Douglas Economics (*18*), quoted in Litman (*16*).
Note: 2 p/m^2 = 5.4 ft^2/p.

In-vehicle Crowding

Exhibit 4-7 shows British values of perceived in-vehicle time for seated and standing passengers in railcars.

Exhibit 4-7
Relationship Between Vehicle Crowding and Perceived Travel Time



Source: Derived from Balcombe (*11*).

Reliability

Unreliable transit service will increase average waiting time. If the impact on waiting passengers is measured in terms of *excess wait time* (the difference between the actual and scheduled departure time when a transit vehicle is late), the resulting time values may be converted to a monetary valuation of service unreliability. A value of 2 to 3 times the normal unit rate for *waiting* is typical (*19*); a study of public transport users in Auckland and Wellington, New Zealand found values of 3 to 5 times *in-vehicle* time (*20*).

Bus Stop Amenities

Exhibit 4-8 lists examples of the in-vehicle time equivalent of various types of amenities at a bus stop, derived from British data and converted from pence to equivalent values of time.

Exhibit 4-8
In-vehicle Time Equivalent of Bus Stop Amenities

Amenity	In-vehicle Time Equivalent (min)
Shelter with roof and end panel	1.3
Basic shelter	1.1
Lighting	0.7
Molded seats	0.8
Flip seats	0.5
Bench	0.2
Dirty bus stop	-2.8

Source: Derived from Balcombe (*11*).

Note: Positive VoT values in the exhibit indicate a benefit (i.e., a reduction in perceived time).

Real-time Arrival Information

Real-time information—whether provided through a display at a transit stop, by calling or texting an information service, or via a smartphone app—helps reassure passengers that their transit vehicle is on the way and can help them use their waiting time more efficiently:

- A study of a transit information tool in the Seattle area (available by calling, texting, smartphone app, or online) found that, on average, users with real-time information reported wait times that were 30% lower than users without it. In addition, the actual wait time was lower for users with real-time information because the information enabled those users to better plan their arrival at the bus stop (*21*).
- A study of real-time information at stops on a tram line in The Hague, Netherlands found that perceived wait time decreased 20% (1.3 min) (*22*).
- London Underground users overestimated their wait time with and without real-time information; however, the real-time information reduced the overestimation by an average of 0.7 min (*23*).
- Passengers were surveyed after countdown displays were installed at bus stops in London: 65% reported shorter wait times, although bus frequency did not change; 83% felt that time passed more quickly; and 89% agreed that waiting time was more acceptable with the information (*23*).

Other Aspects of Service

Monetary values (which can be converted into equivalent values of in-vehicle time) can be developed for many aspects of service quality—for example, driver friendliness and clarity of stop announcements. There are a number of examples of British research on these aspects of VoT, both published (e.g., *11–13*) and internal to transit operators.

3. QUALITY OF SERVICE FRAMEWORK

TRANSIT TRIP DECISION-MAKING PROCESS

Urban transport involves millions of individual travel decisions. Some are made infrequently—to take a job in a particular location, to locate a home outside an area with transit service, or to purchase a second car. Other decisions—when to make a trip or which mode to use—are made for every trip.

Availability

Is transit service available to a potential passenger?

A key decision is determining whether or not transit service is even an option for a particular trip. Transit service is only an option for a trip when:

- Service is available at or near the locations and times that one wants to travel, and one can access it (*spatial availability*);
- Service is provided at the times one desires to travel—often including the return trip (*temporal availability*);
- One knows how to use the service (*information availability*); and
- Sufficient space is available on transit vehicles and, potentially, at supporting facilities such as park-and-ride lots (*capacity availability*).

When service is not available, other aspects of service quality do not matter for a given trip.

If any one of these factors is not satisfied for a particular trip, transit will not be an option for that trip—either a different mode will be used, the trip will be taken at a less convenient time, or the trip will not be made at all. When service is not available at the times one wants to travel, other aspects of transit service quality will not matter to that passenger for that trip, as the trip will not be made by transit (or at all), regardless of how good the service is in other locations or at other times of the day or week. Exhibit 4-9 depicts these availability factors in the form of a flowchart.

Comfort and Convenience

If transit service is available, will a potential passenger find it comfortable and convenient?

If transit service is available as described above, then transit becomes an option for a given trip. At this point, passengers weigh the comfort and convenience of transit against competing modes. Some of the things that a potential passenger may consider include the following:

- Is the service reliable?
- How long is the wait? Is shelter available at the stop while waiting?
- Are there security concerns—walking, waiting, or riding?
- How comfortable is the trip? Will I have to stand? Are there an adequate number of securement spaces? Are the vehicles and transit facilities clean?
- How much will the trip cost?
- Is a transfer required?
- How long will the trip take in total? How long relative to other modes?

Unlike the first decision—whether or not transit is an option for the trip—the questions listed above are not necessarily pass/fail. People have their own personal values that they apply to a given question, and each person will weight their answers to

these questions differently. Regular transit users familiar with the service may perceive transit service more favorably than non-users. In the end, the choice to use transit will depend on the availability of other modes and how the quality of transit service compares with that of competing modes. Exhibit 4-9 summarizes this decision-making process.

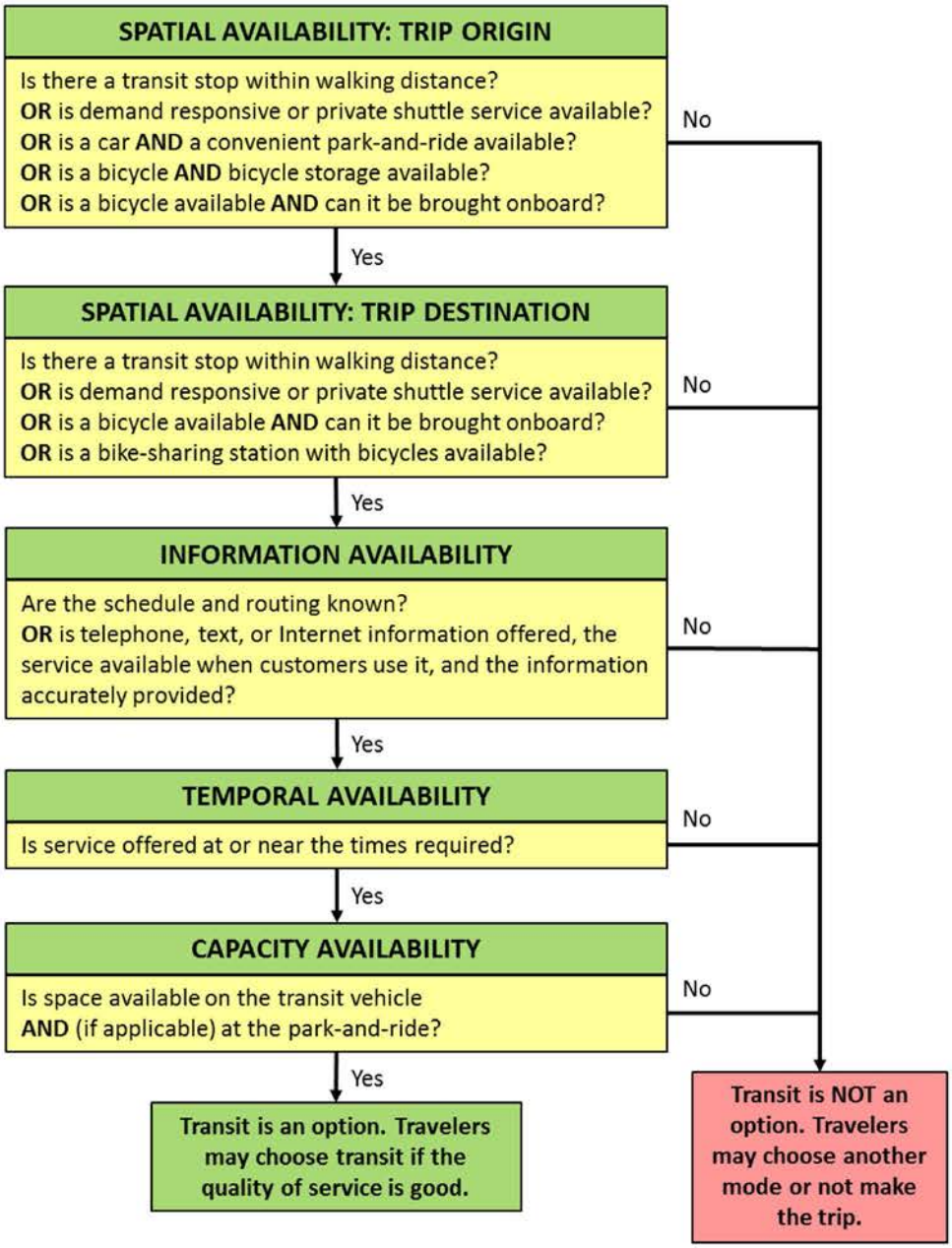


Exhibit 4-9
Transit Availability Factors

FRAMEWORK OUTLINE

Aspects of transit availability and transit comfort and convenience that are (*a*) important to passengers and (*b*) relatively easy to quantify and forecast are presented in the TCQSM in the form of *quality of service frameworks.* These frameworks—one for fixed-route service and one for demand-responsive service—focus on key performance measures that transit agencies can use to set service standards and to evaluate the quality of service they provide to their passengers.

Exhibit 4-10 presents the quality of service framework for fixed-route transit, while Exhibit 4-11 presents the framework for demand-responsive transit.

Exhibit 4-10
Quality of Service Framework: Fixed-Route Transit

Availability	Comfort and Convenience
Frequency	Passenger Load
Service Span	Reliability
Access	Travel Time

Exhibit 4-11
Quality of Service Framework: Demand-Responsive Transit

Availability	Comfort and Convenience
Response Time	Reliability
Service Span	Travel Time
Service Coverage	No-shows

Comparing the two exhibits, it can be seen that the two frameworks share a number of factors in common, but also have some differences specific to the type of service. As will be seen in Chapter 5, Quality of Service Methods, even where the frameworks do address similar factors, the performance measures used to evaluate fixed-route and demand-responsive service quality are almost always different.

Not every factor that affects quality of service can be included in the framework. For example, safety and security are areas that are important to passengers, but which are difficult to forecast. Therefore, it is important for analysts and decision makers not to lose sight of broader issues by focusing only on evaluating the factors that appear in the frameworks. The discussions in this chapter and the next help to highlight some of the other aspects of quality of service that may also be important to evaluate, depending on the needs of a given analysis.

The following sections describe the components of the quality of service frameworks in more detail.

TRANSIT AVAILABILITY

Spatial Availability

If transit service is located too far away from a potential passenger, transit use is not an option.

The presence or absence of transit service near one's origin and destination is a key factor in one's choice to use transit. Ideally, transit service will be provided within a reasonable walking distance of one's origin and destination. Alternatively, demand-responsive service will be available at one's doorstep for those unable to use fixed-route service. The presence of accessible transit stops, as well as accessible routes to transit stops, is a necessity for many persons with disabilities who wish to use fixed-route transit. Furthermore, upgrading existing facilities to meet Americans with Disabilities Act (ADA) requirements also results in a more comfortable walking environment for

everyone. When transit service is not provided near one's origin, driving to a park-and-ride lot or riding a bicycle to transit service may be viable alternatives.

Service coverage considers both ends of a trip.

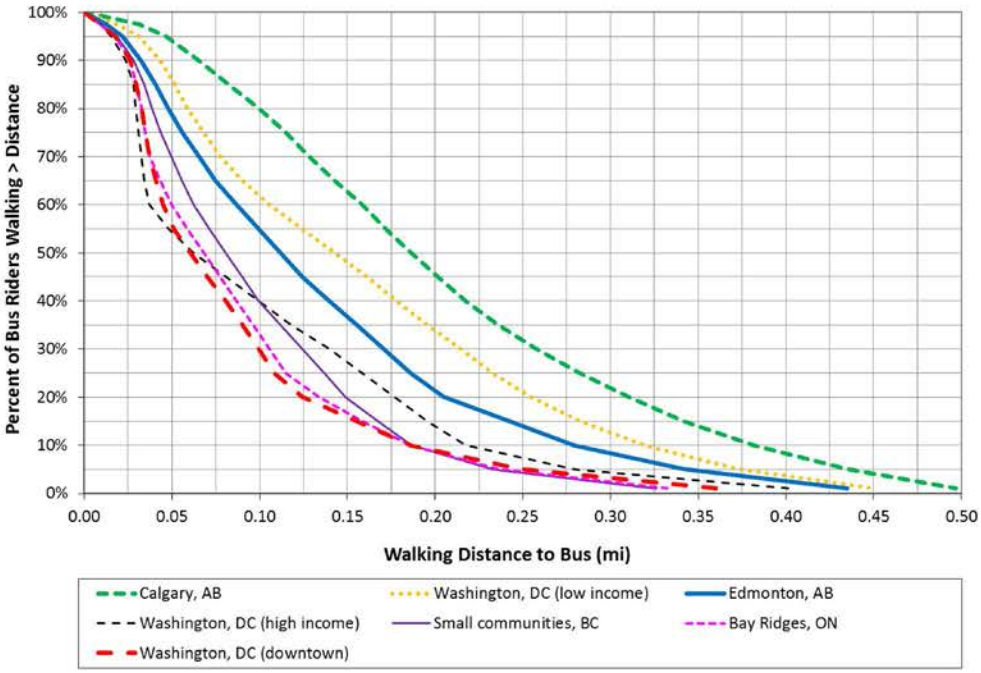
Service coverage considers both ends of a trip, for example, both home and work. Transit service at one's origin is of little use if service is not provided near one's destination. Options for getting from a transit stop to one's destination are more limited than the options for getting from one's origin to a transit stop. The car one drove to a park-and-ride lot will not be available at the destination, nor will a bicycle left behind in a storage facility. A bicycle carried on a bus-mounted bicycle rack or brought on board a train will be available at the destination, as long as space was available for the bicycle on the transit vehicle. In some cases, large employers may provide private shuttle service connecting transit stations to worksites.

Pedestrian Access

Walking Distance to Transit

The maximum distance that people will walk to transit varies depending on the situation. Exhibit 4-12 shows the results of several studies of walking distances to transit in North American cities from the late 1960s through the 1980s. Although there is some variation between cities and income groups among the studies represented in the exhibit, it can be seen that most passengers (75 to 80% on average) walked 0.25 mi (400 m) or less to bus stops. At an average walking speed of 3 mi/h (5 km/h), this is equivalent to a maximum walking time of 5 min. A 2010 study in Montréal found somewhat longer walking distances: about half of those walking to bus stops walked more than 0.25 mi (*24*).

Exhibit 4-12
Walking Distance to Bus Stops



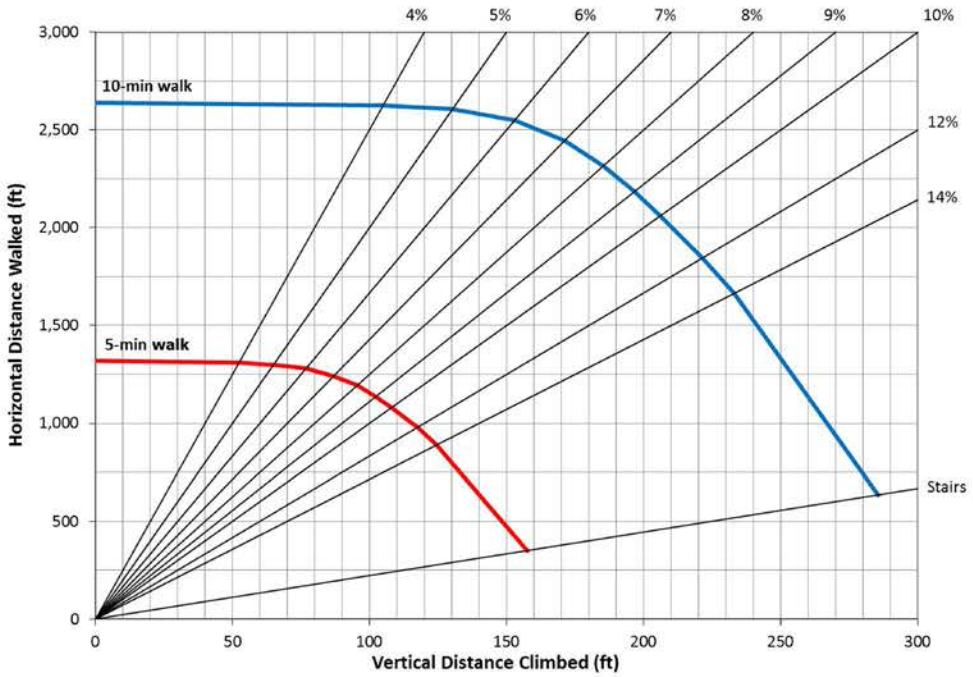
Sources: Atkinson (*31*), Lam and Morrall (*32*), Peterson (*33*), and Shortreed and Maynes (*34*).
Note: A metric version of this exhibit appears in Appendix A.

The walking times and distances to local bus stops can be at least doubled for rapid transit stations, where about 50% of walk-access passengers walk more than 0.5 mi (800 m) to the station (*24–28*). However, one study in the San Francisco Bay Area found that employment sites within 0.25 mi of a rail station had significantly higher transit usage rates than sites located between 0.25 and 0.5 mi, and that usage dropped precipitously after 0.5 mi. Many sites were in suburban areas with poor pedestrian environments, and it is unclear whether the results are due to the pedestrian environment or because passengers are more sensitive to access length at the destination end of their trip (*29*). A 2005 WMATA survey found that 35% of office workers on average used rapid transit for their commute trip when their office was located at a station entrance, with the percentage falling approximately 1% per 100 ft (30 m) of distance between the office and the station entrance (*30*).

BRT service that emulates the quality of rapid rail transit—frequent service throughout much of the day, relatively long stop spacing, distinct stations with a variety of passenger amenities, etc.—is expected to have the same walking access characteristics as other forms of rapid transit. However, at the time of writing, insufficient research had been conducted in the U.S. to confirm this expectation.

Other factors can reduce the distance that people will walk to transit stops. A poor pedestrian environment, discussed below, discourages pedestrian travel. The elderly typically do not walk as far as younger adults. Finally, people will tend to walk shorter distances in hilly areas, due to the effort involved. Exhibit 4-13 shows the results of a study in Pittsburgh on the relationship between walking speeds and grades. It can be seen that at grades of 5% or less (5 ft climbed for each 100 ft traveled horizontally), grades have little impact on travel speed, but that above 5%, the distance traveled within 5 or 10 min (0.25 mi/400 m or 0.5 mi/800 m on level terrain) goes down.

Exhibit 4-13
Effect of Grade on Distance Walked



Source: Municipal Planning Association (*35*).
Note: A metric version of this exhibit appears in Appendix A.

Pedestrian Environment

The built environment, ability to cross the street safely, and personal security concerns all influence passengers' ability to walk to transit service.

Even when a transit stop is located within a reasonable walking distance of one's origin and destination, the walking environment may not be supportive of transit. Studies of the relationship between urban form and walking have found that sidewalk availability, intersection density, and presence of retail are correlated with higher levels of walking to transit, while higher vehicle volumes and speeds and large parking lots around stations are associated with lower levels of walking (*36–38*).

Pedestrian safety is also an important factor. Wide or busy streets without safe and convenient crossing opportunities discourage pedestrian travel. Street-crossing difficulty poses particular difficulties for transit operators: an arterial street generally provides better transit speeds, but potential passengers using stops along the street must cross the street at some point during their round trip—either when they depart or when they return—and may not be able to easily access bus stops between signalized crossing points. One study found that the most important access factor for pedestrians after distance was safety. Approximately half of respondents rated it as "very important" to have traffic devices present and traffic driving at safe speeds, which was a higher rate than having sidewalks in good repair or aesthetic considerations (*28*).

Related to personal security, a study of access trips to light rail stations showed that higher crime levels at the station reduced the likelihood of walking to transit (compared to other access modes), particularly for female riders (*39*).

Street Patterns

Walking distances to transit may be considerably greater than straight-line ("air") distances.

A neighborhood's street pattern may affect transit access. A grid street pattern, such as those found in older cities, offers direct access between streets with transit service and the surrounding neighborhoods. When service is offered on parallel streets, some locations may have a choice of routes to use for a particular trip, resulting in a higher quality of service. On the other hand, subdivisions that back onto streets with transit service, with only one way in and out, will generally have a much smaller proportion of their residences located within a 0.25-mi (400-m) walking distance of a transit stop, even when the majority of the subdivision is located within 0.25 mi air distance of one or more transit stops.

Americans with Disabilities Act (ADA) Considerations

Coordination between transit agencies and public works agencies is desirable to make sure transit access is prioritized.

Passengers with disabilities often must have sidewalk facilities and curb cuts on their routes to and from transit stops to have the ability to access fixed-route transit service. Stops, stations, and transit vehicles must also be accessible. Without these facilities and provisions, passengers with disabilities must rely on paratransit service, which generally provides customers with fewer choices in travel times and usually costs substantially more for transit operators to provide.

Pedestrian Access Summary

TCRP Report 153 (*25*) lists the following issues as being essential in designing pedestrian access to transit service:

- *Directness and speed of route*—Pedestrians want direct walking routes, with minimum delays when crossing streets.

- *Safety and security*—Pedestrians need to perceive that their route is secure and visible to other road users, particularly in the evening. Highway safety is also important, particularly when crossing busy roadways.
- *Pedestrian-friendly design*—Lighting, building setbacks and orientations, and sidewalks are important determinants of whether pedestrian feel like "unwelcome guests" or perceive that the street is designed to meet their needs. Pedestrian facilities should be designed at a "human scale."
- *Information*—New, occasional, and visiting travelers particularly need wayfinding information to reach local destinations.

Bicycle Access

According to *TCRP Report 153* (*25*), bicycle access to rapid transit stations is an increasingly important concern for transit agencies. Moreover, transit agencies located in urban areas where cycling is rapidly increasing are more likely to be actively engaged in efforts to improve bicycle access to transit. Transit agencies typically wish to achieve two goals related to bicycle access: (*a*) increase total bicycle access to support transportation agency and community goals for higher bicycle ridership and (*b*) establish effective means of accommodating bikes within the transit system, whether through bicycle storage facilities at the station or on board transit vehicles. These two goals are not always compatible, as increasing bicycle access also has the potential to overwhelm transit system passenger capacity when passengers choose to bring their bicycles with them, and bus-mounted bicycle rack use can increase dwell times at stops.

Integrating Bicycles with Transit

TCRP Synthesis 62 (*40*) provides a comprehensive review of bicycle integration policies at transit agencies. The review determined several key factors in determining the effectiveness of bicycles serving as an access mode to public transit:

- Bicycle facility availability and maintenance;
- Bicycle parking security;
- Restrictions and rules with regard to bicycles on transit vehicles;
- Marketing, awareness, education, and public support;
- User demographics;
- Climate; and
- Transit system design.

Key conclusions and findings of *TCRP Synthesis 62* include:

- Bicycle services help attract more transit riders by extending the transit system's catchment area and by providing greater mobility to customers at the beginning and end of their transit trips.
- Several transit agencies believed that their bicycle services help decrease automobile traffic congestion, reduce air pollution, and improve the public image of transit.
- Compared with the capital costs of buses, rail cars, and automobile parking facilities, it is relatively inexpensive for transit agencies to purchase bicycle

equipment, such as bike racks on buses, bike hooks in rail cars, and bike racks and lockers at transit stations.

- Transit agencies have generally experienced few maintenance problems with their bicycle services. Problems reported included obtaining replacement parts for broken bus bike racks, abandoned bicycles in bicycle racks, bus bicycle racks interfering with windshield wipers, and the need to remove the bus bicycle rack when a bus is towed.

Bicycles on Transit

The predominant approach for integrating bicycles and transit in the U.S. is for bicyclists to bring their bicycle with them on board transit vehicles (Exhibit 4-14). In 2011, about 74% of new U.S. buses were equipped with exterior bicycle racks, up from 32% in 2001 (*41*). Bicycle racks have been popular with passengers, but they frequently run up against capacity constraints, typically two or three bicycles for each bus on a front rack, or three to four bicycles per light rail car interior (*42*).

Another consideration for higher-volume transit systems is that bicycles brought on board transit vehicles (BRT vehicles or rail cars) take up space on the station platform and in the vehicle that could be used by other passengers. A bicycle held horizontally occupies 11.8–16.6 ft² (1.10–1.54 m²) (*43*), which is roughly the space taken up by 5 to 7 large adult males with heavy clothing. Bicycle hooks inside rail cars (Exhibit 4-14[a]) allow bicycles to be stored vertically, which reduces their space requirements, but they still occupy multiple passengers' worth of space. For this reason, some rapid transit systems prohibit bicycles during peak hours, at least in peak directions. A number of European transit operators require the purchase of a separate ticket for bicycles brought on board commuter trains.

Alternatives to bringing bikes on board transit vehicles include providing bicycle storage at the boarding transit stop and bike-sharing programs. An analysis of (*a*) the travel behavior of individuals, (*b*) the accompanying urban form characteristics, (*c*) individual preferences related to cycle–transit facilities, and (*d*) economic costs and technological feasibility suggest that transit agency investment in more attractive bicycle storage facilities would prove most cost effective in many cases (*42*). Bicycle storage options at transit stops and stations are discussed in more detail in Chapter 10, Station Capacity (page 10-36).

Bicycle Access Trip Lengths

Typical bicycling speeds are approximately 12 to 15 mi/h (20 to 25 km/h), or about four to five times higher than walking speeds. This speed advantage allows bicyclists to access transit lines much farther away from their origin or destination than they could if they walked, as long as a safe bicycling environment exists. There are limited available data on bicycle access sheds. However, a study of commuter rail access suggests that bicycle access peaks at distances between 1.0 and 1.25 mi (1.6 to 2.0 km) (*36*).

Exhibit 4-14
Onboard Bicycle Facility Examples



(a) LRT bike hook (Portland)



(b) BRT interior bicycle storage (Eugene)



(c) Bus-mounted bicycle rack (Honolulu)



(d) Bikes on ferry (Larkspur, California)

Automobile Access

As distance from the trip origin to transit service increases, more passengers use automobiles as an access mode, as illustrated conceptually in Exhibit 4-15. In particular, the automobile is the primary access mode for transit modes such as commuter bus and commuter rail that serve lower-density areas and rely on park-and-ride lots to focus demand on a small number of locations.

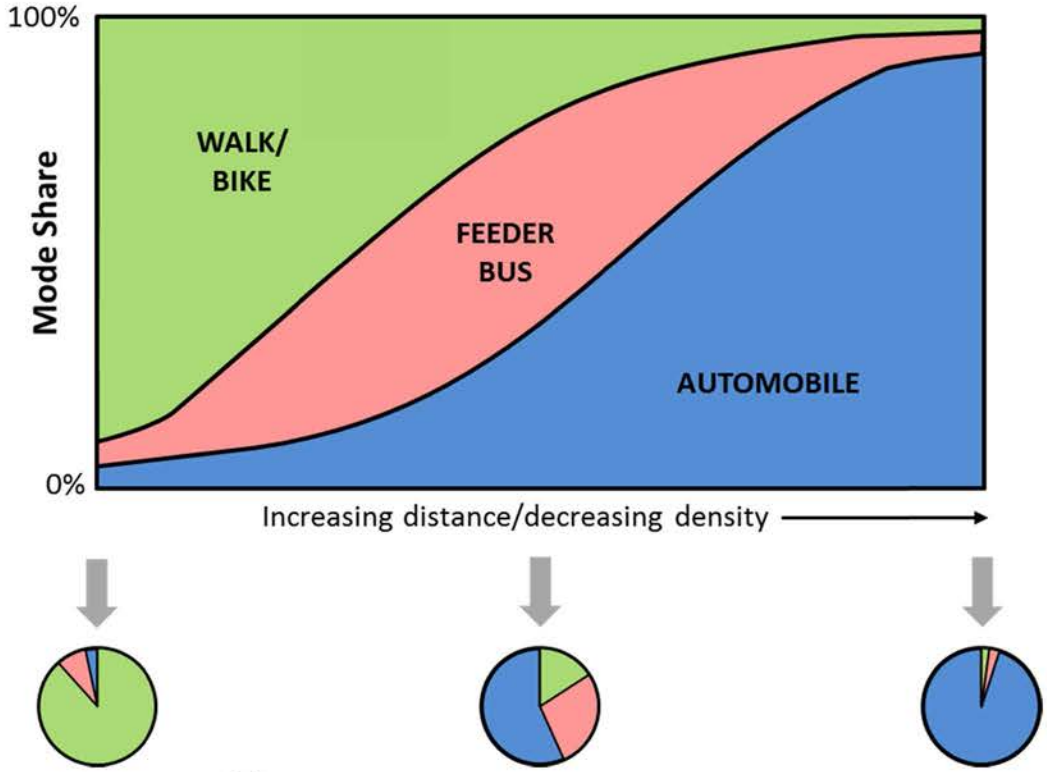


Exhibit 4-15
Conceptual Illustration of Effect of Distance on Transit Access Mode Choice

Source: *TCRP Report 153* (*25*).

An Overview of the Park-and-Ride User

Surveys of park-and-ride users in the Sacramento, Northern Virginia, Chicago, Seattle, and Phoenix regions identified the following characteristics of park-and-ride users at successful park-and-ride lots (*44*):

- Park-and-ride users are choice riders;
- Park-and-ride users have significantly higher incomes than local bus riders;
- The majority of park-and-ride users (more than 60%) travel to the CBD for work more than four times per week;
- Parking at the destination is expensive;
- Convenient, frequent bus service is offered; and
- Most riders find park-and-ride facilities because they can see them from their regular commute routes.

Characteristics of a Successful Rapid Transit–Focused Park-and-Ride Lot

TCRP Report 153: Guidelines for Providing Access to Public Transportation Stations (*25*) identifies the following characteristics of successful park-and-ride lots serving rapid transit stations:

- *Locate in advance of congestion.* Park-and-ride lots in combination with rapid transit lines generate the greatest use (and transit ridership) in travel corridors that experience the most intense traffic congestion (i.e., peak-hour peak-direction freeway speeds of less than 30–35 mi/h or 50–60 km/h). Park-and-

ride facilities should intercept motorists in advance of congestion and before points of major route convergence. Sites near junctions of radial transit lines and beltways or major arterial roads can tap a wide catchment area. Access to the lot should be upstream of major congestion points.

- *Locate sufficiently far away from the city center.* Park-and-ride facilities should be located as far from the downtown area as practical to remove the maximum number of travelers [and vehicle miles traveled (VMT)] from roadways during peak periods. They generally should be located at least 5 to 8 mi (8 to 13 km) from the city center. They should be far enough away to compensate for the time spent changing travel modes. Increasing parking space on the fringes of the downtown area is not desirable, as it could divert existing passengers from feeder transit service and non-motorized access modes.
- *Serve low-density residential areas.* In general, population densities in park-and-ride catchment areas should be less than 4,000 to 6,000 persons per square mile (1,500 to 2,300 persons per square kilometer) or about 4 to 5 dwelling units per net acre (10 to 12 dwelling units per net hectare).
- *Serve multiple markets.* Most rapid transit–focused park-and-ride lots serve downtown travelers. However, there is a growing tendency to also serve other large activity centers along the rapid transit lines. The lots should be located between their catchment areas and major activity centers. Motorists will use facilities that can be easily accessed en-route, but are less likely to backtrack.
- *Locate in safe areas.* Park-and-ride facilities should be placed in areas that are perceived as safe by patrons. They should not be located in high-crime areas, or in settings that are considered unattractive by users.
- *Complement and reinforce land development.* Park-and-ride facilities should be compatible with the surrounding environments. Large facilities—especially open-lot parking—should be limited or avoided in town centers, areas of high population and development density, and locations where transit-supportive uses are planned or encouraged around stations. Where garages are built, they should be carefully integrated with their surroundings.
- *Provide fast and frequent rapid transit service.* Rapid transit should operate at frequencies of 10 to 12 min or less during peak periods, while frequencies up to 20 min are acceptable during midday hours. Headways of 20 to 30 min are acceptable for commuter rail and commuter bus service during commute hours.
- *Provide good roadway access.* Facilities should be accessible and visible from nearby freeways and arterial roadways.

Types of Park-and-Ride Facilities

Park-and-ride facilities are a type of intermodal transfer facility. They provide a staging location for travelers to transfer between the auto mode and transit or between a single-occupant vehicle and carpools or vanpools. Park-and-ride facilities can be classified by location or function as follows (*45*):

- *Informal park-and-ride lots* are transit stops where motorists regularly drive their cars and leave them parked on the street or on an adjacent property. These are often more difficult to discern than lots officially connected with a transit stop.
- *Joint use lots* share the transit parking with another land use (e.g., church, theater, shopping mall, special events center) whose peak parking activity occurs outside regular commuting hours. The park-and-ride activity can be either the secondary or primary use of the facility, depending upon the desired orientation and opportunity provided.
- *Park-and-pool lots* are typically smaller lots that are intended exclusively for the use of carpool and vanpool vehicles. These can be joint use or may be part of a development plan where the developer dedicates a number of spaces.
- *Suburban park-and-ride lots* are typically located at the outer edges of the urban area.
- *Transit centers* are facilities where interchange between local and express transit service occurs.
- *Satellite parking lots* are generally placed at the edge of an activity center to provide inexpensive alternatives to on-site parking within the activity center itself and to reduce traffic congestion within the activity center.

Larger park-and-ride lots will also often provide *kiss-and-ride* areas with short-term parking where passengers can be dropped off and picked up.

Park-and-Ride Market Areas

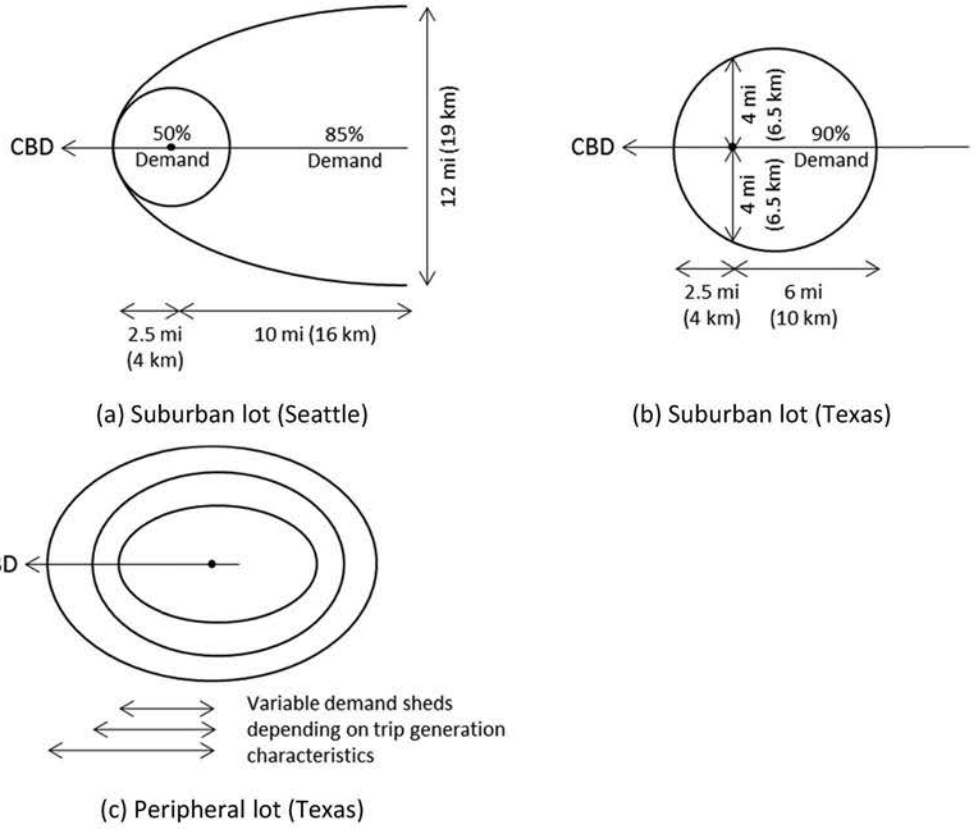
A standardized service shape for park-and-ride lots is not feasible.

Because of the different characteristics of metropolitan areas, a standardized service shape that describes the entire park-and-ride lot market area that is suitable for application throughout North America is not feasible. However, some common characteristics of park-and-ride lots can be described.

Patrons using a specific park-and-ride facility will be expected to come from a catchment area primarily upstream from the park-and-ride facility. Backtracking, the phenomenon of patrons who live between the park-and-ride lot and the employment destination who drive upstream to gain access to a lot for a downstream location is limited. However, where multiple major activity centers exist within an area and are served by a particular lot, passengers may arrive from all directions.

A study of Seattle-area park-and-ride lots found suburban lots generate about 50% of their demand from within a 2.5-mi (4-km) radius of the facility, and that an additional 35% comes from an area defined by a parabola extending 10 mi (16 km) upstream of the lot and having a long chord of 10 to 12 mi (16 to 20 km) (*46*). This market area is illustrated in Exhibit 4-16(a).

Exhibit 4-16
Illustrative Park-and-Ride Market Areas



Sources: Spillar (*45*); Parsons Brinckerhoff Quade & Douglass, Inc. (*46*); and North Central Texas Council of Governments (*47*).

Studies conducted in several Texas metropolitan areas suggest a parabolic model or an offset circular model would be appropriate for a park-and-ride service coverage area (*45*). This market area form is illustrated in Exhibit 4-16(b).

A study conducted for the North Central Texas Council of Governments found that the average market shed for "non-suburban" (i.e., peripheral) lots is typically more dispersed around a common center than the suburban park-and-ride types, as shown in Exhibit 4-16(c) (*47*). These findings were confirmed in a similar study from the Puget Sound region, which examined two lots that operate as peripheral park-and-ride facilities (*45*).

Finally, a study in Chicago found that approximately half of riders traveled less than 3 mi (5 km) from their origin to reach the parking facility, with only 30 percent traveling more than 6 mi (10 km). The length of the transit leg of the trip was greater than 10 mi (16 km) for nearly all trips (*48*).

Park-and-Ride Capacity

Where parking demand exceeds capacity, research shows that parking pricing and transportation demand management (TDM) measures can encourage auto drivers to switch to other access modes, but can run the risk of reducing ridership if not priced appropriately. While advanced parking management has not been shown to increase

ridership significantly in the short term, it does benefit customer satisfaction, which may have long-term benefits (*49*).

Chapter 10, Station Capacity, provides example ranges of park-and-ride lot sizes for rail transit modes. It also summarizes existing knowledge about conceptually designing park-and-ride lots. *TCRP Report 153: Guidelines for Providing Access to Public Transportation Stations* (*25*) provides more detailed guidance about planning and conceptually designing park-and-ride lots associated with transit stations.

Temporal Availability

Frequency and service span determine whether transit service is available when one wants to travel.

How often transit service is provided and when it is provided during the day are important factors in one's decision to use transit. The more *frequent* the service, the shorter the wait time when a bus or train is missed or when the exact schedule is not known, and the greater the flexibility that customers have in selecting travel times. The number of hours during the day when service is available (*service span*) is also highly important: if service is not provided at the times one desires to travel, transit will not be an option for that trip. These two factors in combination determine the temporal availability of transit service.

Frequency

As was discussed in Section 2, Quality of Service Factors, frequency was consistently reported as the top factor influencing overall trip satisfaction in a survey administered in several cities around the U.S. (9). As will be seen in Section 4, Ridership and Service Costs, passengers also respond strongly in the form of increased ridership when frequency is improved, particularly when the previous service was relatively infrequent (*50*). The longer the headway, the more inconvenient transit service becomes, both because passengers have to plan their trip around transit service and because they incur more unproductive time during their trip. With long-headway service, passengers budget extra time into their trip to ensure they do not miss their transit vehicle and, as a result, have to wait the length of one headway for the next departure. Increasing frequency is expensive for transit agencies, so it is important to consider whether the land uses served by a transit route are capable of supporting higher frequencies.

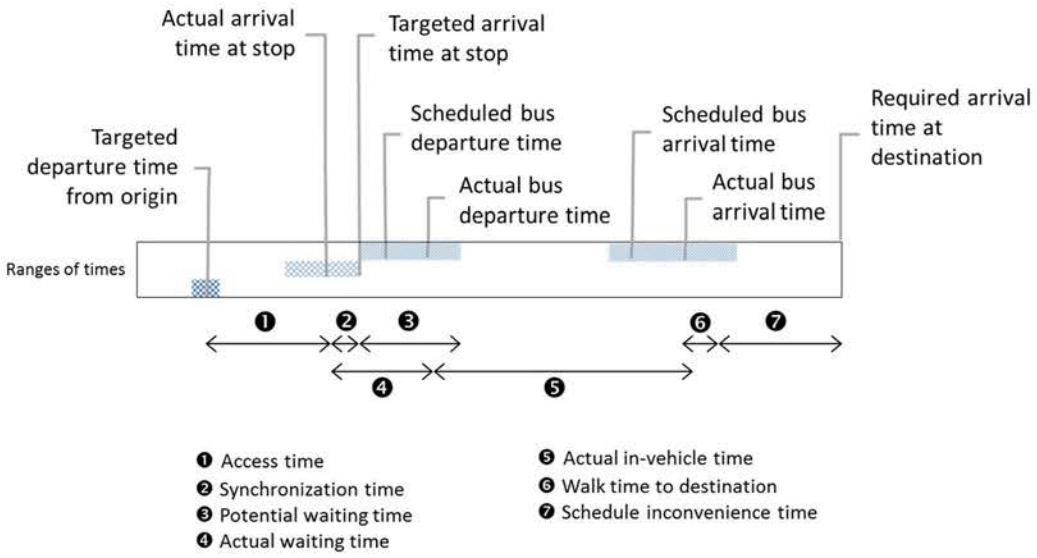
Passenger Arrival Patterns

Frequency affects when passengers arrive at a bus stop. When headways are short, passengers know a transit vehicle should arrive shortly, so they tend not to consult schedules and instead arrive randomly. When headways are long, passengers will tend to consult the schedule, so they can plan their activities such that they arrive at the stop or station shortly before the scheduled departure time. The dividing line between short- and long-headway arrival patterns is fuzzy and depends in part on local service characteristics (e.g., schedule reliability, onboard seating availability). However, at headways of 10 min or less, most passengers tend to arrive randomly, while most passengers tend to schedule their arrival at headways of 15 min or more. Given the increasing availability of real-time arrival information in readily accessible forms (e.g., by smartphone, by texting a message to the transit agency's trip planner), more passengers may schedule their arrivals in the future, even with short headways.

As noted above, when headways are long, passengers budget extra time into their trip to ensure that they actually catch their desired transit departure, which affects their

arrival time at a transit stop or station. Exhibit 4-17 depicts the different elements involved in a long-headway transit trip.

Exhibit 4-17
Components of a Long-Headway Transit Trip



During the first stage of her trip, the passenger leaves her trip origin (e.g., home) and travels to the transit stop or station. A passenger who makes the same trip regularly will be familiar with the reliability of the service and will try to arrive at the stop in time to catch even an early-departing vehicle. *TCRP Report 113* suggests that a reasonable passenger will target her arrival to catch a 2nd percentile departure time (*51*). Because a person's routine varies from day to day and because of day-to-day variability in the *access time* required to travel from the trip origin to the stop, there will be a range of times when the passenger will arrive and the passenger will arrive ahead of the targeted time on most days. The difference between the actual and targeted arrival times at the stop is known as *synchronization time* and is experienced as extra waiting time at the stop (*51*).

If the transit service is not perfectly reliable, there will be a range of times when the transit vehicle could depart on any given day. *TCRP Report 113* suggests that passengers' planned or *potential waiting time* is the time between their targeted arrival time at the stop and the 95th percentile departure time (thus assuming that passengers do not want to be late more than 5% of the time) (*51*). The actual departure time will usually be closer to the scheduled time, so the *actual waiting time* will be the difference between the arrival time at the stop and the departure time of the transit vehicle. With access to real-time information, a person can potentially plan around a late departure (e.g., by leaving his origin later or by running an errand on the way), making better use of the time than simply waiting at the transit stop.

In the next stage of the trip, the passenger rides on the vehicle to her destination. The *in-vehicle time* will vary from day to day, unless the service is perfectly reliable. Given the potential variation in departure times from the boarding stop and the potential variation in travel times to the destination, there is a range of potential arrival times at the destination stop. A passenger will pick the specific trip to travel on based on her knowledge of the *walk time* from the destination stop to the destination, her

knowledge of the trip's travel time reliability or the reliability of the transit agency's service in general, and the importance of arriving at the destination on time. This typically results in *schedule inconvenience time,* where the passenger arrives at the destination earlier than desired (*51*). This time may be used productively in some cases (e.g., starting work earlier) or it may not (e.g., sitting in the doctor's waiting room or waiting to transfer to the next transportation service used in the trip).

Compared to a long-headway trip, a short-headway trip eliminates synchronization time (because the passenger shows up at random) and schedule inconvenience time is reduced, because departures occur more frequently and passengers can choose trips that arrive closer to their desired time. As a result, the time required to make a trip is reduced with higher-frequency (shorter-headway) service.

Service Span

Service span determines the potential markets that transit serves. The longer the span, the greater the variety of trip purposes that can be served. A 12-hour weekday service span, for example from 6 a.m. to 6 p.m., serves traditional commute trips and midday trips (e.g., shopping, medical appointments, social visits). A longer span would allow additional types of trips to be served—for example, retail employees who work in the evening or students who take night classes. A longer span needed to serve a particular market (e.g., office workers) gives those customers travel flexibility, particularly for their return trip (e.g., to work late, to run errands after work).

Information Availability

Riders need to know where and when transit service is available and how to use it.

Passengers need to know how to use transit service, where to go to access it, how to pay their fare, where to get off near their destination, whether any transfers are required, and when transit services are scheduled to depart and arrive. Without this information, potential passengers will not be able to use transit service, even though it would otherwise be an option for their trip. Visitors to an area and infrequent transit users (e.g., people who use transit when their car is being serviced) particularly need this information, but they can be the most difficult people to get information to. Even regular transit users may require information about specific routes when they need to travel to a location they rarely visit.

Timely and correct information is also vital under other circumstances:

- When regular service adjustments are made, such as schedule changes or route modifications;
- When temporary service changes are required, for example, due to road construction or track maintenance; and
- When service problems arise, so passengers know the nature of the problem and have enough information to decide how to adjust their travel plans.

Information can be provided to passengers by a variety of means:

Information must be available in accessible formats.

- *Printed, distributable information,* such as timetables, maps, service change notices, rider newsletters, etc., preferably available at a number of locations;
- *Posted information,* such as system maps posted at stations or on vehicles, or notices of out-of-service elevators;

- *Audible announcements* of stops and stations, train directions, fare zone boundaries, etc., which assist not only passengers with visual impairments, but also passengers unfamiliar with the route or area;
- *Visual displays* to assist passengers with hearing impairments and to supplement onboard announcements that may be muffled by other noise;
- *Transit agency staff,* such as station agents at transit stations, or *tourist information staff* at visitor centers;
- *Telephone information*, which can be provided by voice calls to a transit agency information line during business hours, automated phone menus available 24 hours a day, or by texting a short message to receive schedule or fare information;
- *Online information,* available 24 hours per day to anyone with Internet access;
- *Smartphone apps,* which can provide trip planning functions, fare information, and other kinds of transit information based on a person's current location; and
- *Transit infrastructure,* such as shelters, signs directing motorists to park-and-ride lots, and bus stop signs that indicate the presence of service to people not currently using transit.

No matter how passengers obtain information, it should be correct and up to date. Schedule information posted at stops, for instance, should be updated each time the schedule is updated. Information provided to passengers by transit agency employees during service disruptions should be as accurate and complete as possible under the circumstances, but should avoid being too specific (e.g., the train will be underway in "X" minutes) when there is the possibility that the circumstances could change.

Real-time information reassures passengers and lets them make informed choices.

Real-time information is useful for reassuring passengers about when the next vehicle will arrive. For example, if a bus does not arrive at its scheduled time, a passenger arriving at the stop shortly before that time will not know whether the bus left early, is running behind schedule, or is not in service. In addition, knowing that there will be a wait until the next bus arrives allows passengers to decide whether to run an errand or take a different bus rather than wait at the stop. Finally, when vehicle bunching occurs, knowing when the following vehicles will arrive is also useful: when passengers know that another vehicle will arrive in 1 or 2 min, some will choose not to board the first, typically crowded, vehicle in favor of a later, less-crowded vehicle. This helps spread out passenger loads among the vehicles and may help keep the lead vehicle from falling further behind schedule.

Capacity Availability

Insufficient capacity can impact transit service availability. If a bus or train is full when it arrives at a stop, transit service is not available at that time to the people waiting there. The effective service frequency for these passengers is reduced from what is implied by the schedule, as they are forced to wait for the next vehicle or find another means of making their trip. Lack of available securement space, a non-functional wheelchair lift, or a non-functional station elevator will impact fixed-route service availability for persons with disabilities. In demand-responsive service, capacity constraints take the form of *service denials,* where a trip cannot be provided at the requested time, even though service is operated at that time. Courts have held that a

pattern of service denials is not allowed under the ADA for ADA service required as a complement to fixed route service. However, service denials can be and are used by general public demand-responsive transit providers as a means of rationing capacity to control costs.

TRANSIT COMFORT AND CONVENIENCE

Passenger Loading

The ability to find a seat on a transit vehicle is an important passenger comfort factor for longer trips.

Transit is less attractive when passengers must stand for long periods of time, especially when transit vehicles are highly crowded. When passengers must stand, it becomes more difficult for them to use their travel time productively, which eliminates a potential advantage of transit over the private automobile. Crowded vehicles also slow down transit operations, as it takes more time for passengers to get on and off. In addition, rail passengers may try to hold doors open in order to squeeze more passengers onto the train, which delays trains even more and, in a worst case, can cause the train to be taken out of service if the door jams.

Many transit agencies assess the degree of passenger crowding on a transit vehicle based on a design load or occupancy for the vehicle. This load, which may vary by time of day, reflects a compromise between passenger comfort and moving as many passengers as possible with the least number of vehicles. The design load is typically determined by the number of available seats, plus an assumed number of standees based on providing a desired level of comfort (space) per standee. Some types of transit service, including commuter bus and rail service that typically serve long trips, transit vehicles that operate in high-speed mixed-traffic operations, and demand-responsive service, will typically try to provide a seat for every passenger. Other types of transit service will typically design for some standees—at least during peak periods.

As discussed in Section 2, Quality of Service Factors, passengers perceive crowded in-vehicle conditions as being more onerous than non-crowded conditions, particularly when they have to stand.

Reliability

Reliability includes both on-time performance and the evenness of headways between transit vehicles.

Reliability affects the amount of time passengers must wait at a transit stop for a transit vehicle to arrive, as well as the consistency of a passenger's arrival time at a destination from day to day. As shown previously in Exhibit 4-17, reliability also affects a passenger's total trip time: if persons believe a transit vehicle may depart early, they may arrive earlier than they would otherwise to ensure not missing the bus or train. Similarly, if passengers are not confident of arriving at their destination on time, they may choose an earlier departure than they would otherwise, to ensure that they arrive on time, even if it means often arriving much earlier than desired.

Types of Reliability

Bus bunching has capacity impacts, as the offered capacity cannot be fully utilized.

Reliability encompasses both on-time performance and the regularity of headways between successive transit vehicles. Uneven headways result in uneven passenger loadings, with a late transit vehicle picking up not only its regular passengers but those passengers that have arrived early for the following vehicle, with the result that the vehicle falls farther and farther behind schedule and more passengers must stand. In contrast, the vehicles following will have lighter-than-normal passenger loads and will

tend to run ahead of schedule. With buses, this "bunching" phenomenon is irritating both to passengers of the bunched buses and to passengers waiting for other buses who see several buses for another route pass by while they wait for their own bus. With signaled rail operations, bunched trains often have to wait at track signals until the train ahead of them moves a safe distance forward. The resulting unscheduled waits are not popular with passengers, particularly when no onboard announcements are given explaining the delay.

Causes of Unreliability

Factors affecting the reliability of transit service.

Reliability is influenced by a number of factors, some under the control of transit operators and some not. These factors include:

- *Traffic conditions* (for on-street, mixed-traffic operations), including traffic congestion, traffic signal delays, parking maneuvers, incidents, etc.;
- *Road construction* and *track maintenance,* which create delays and may force a detour from the normal route;
- *Vehicle and maintenance quality*, which influence the likelihood that a vehicle will break down while in service;
- *Vehicle and staff availability*, reflecting whether there are sufficient vehicles available to operate the scheduled trips (some vehicles will be undergoing maintenance and others may be out of service for various reasons) and whether sufficient operators are available on a given day to operate those vehicles;
- *Transit preferential treatments*, such as exclusive bus lanes or conditional traffic signal priority that operates only when a bus is behind schedule, that at least partially offset traffic effects on transit operations;
- *Schedule achievability*, reflecting whether the route can be operated under usual traffic conditions and passenger loads, with sufficient layover time provided for operators and sufficient recovery time to allow most trips to depart on time even when the previous trip arrived late at the end of the route;
- *Line merges,* on rail systems, where one train arrives at a merge point behind schedule and creates a cascading series of delays to subsequent trains;
- *Evenness of passenger demand,* both between successive vehicles and from day to day for a given vehicle and run;
- *Differences in operator driving skills* (*52*), route familiarity, and adherence to the schedule—particularly in terms of early ("hot") running;
- *Wheelchair lift and ramp usage,* including the frequency of deployment and the amount of time required to secure wheelchairs;
- *Environmental conditions,* such as snow, ice, extreme heat or cold, or leaf fall;
- *Route length and the number of stops,* which increase a vehicle's exposure to events that may delay it—delays occurring earlier along a route result in longer overall trip times than similar delays occurring later along a route (*53, 54*); and
- *Operations control strategies* used to react to reliability problems as they develop, thus minimizing the impact of the problems (*55*).

Operational Control and Scheduling Measures to Improve Reliability

A study of a short-headway tram line in The Hague, The Netherlands (*56*) compared schedule-based and headway-based holding strategies. A schedule-based strategy holds early transit vehicles at a timepoint to maintain the schedule. A headway-based strategy holds transit vehicles as needed to maintain a desired spacing between vehicles. Schedule-based holding was found to be more effective when no maximum holding time was applied. With a maximum holding time of 60 s, there was no difference in the effectiveness of the two holding strategies. The improved reliability due to holding was found to reduce crowding or to allow a smaller capacity slack when scheduling trams.

Inserting slack into the schedule to improve a route's reliability does not necessarily increase a route's round-trip cycle time (a key determinant of vehicle needs for a route and thus operating costs) because time spent holding at timepoints can be subtracted from time spent holding on a layover (*57*).

Travel Time

As was seen previously in the section on value of time, passengers' travel time is an important convenience factor, and different portions of a trip may seem to pass more slowly or be more onerous than time spent in a transit vehicle. Total trip time includes access time from the trip origin to a transit stop or station, waiting time for a transit vehicle, travel time on board the vehicle, potentially transfer time and additional in-vehicle time, and walking time from a transit stop or station to the destination.

Because it is not possible to provide a one-seat trip between every possible combination of origin and destination, except in the smallest communities, transfers are often a necessary part of a transit trip. Each transfer adds to a passenger's total trip time, although the transfer time can be minimal when headways are short or when timed transfers are used. Introducing a transfer into what was previously a one-seat service may have a net positive benefit for passengers, if the new feeder-and-trunk service allows for higher frequencies or other passenger benefits compared to the previous service (*50*).

Transfers increase the possibility that a missed connection will occur, which would lengthen a passenger's trip by the amount of one headway on the connecting line. Transfers can also increase the complexity of a transit trip for first-time passengers.

Safety and Security

Passengers' perceptions of safety must be considered in addition to actual conditions.

Riders' perceptions of the safety and security of transit, as well as actual conditions, enter into the mode choice decision. *Safety* involves the potential for being injured while using transit (e.g., crashes, slips and falls). *Security* involves the potential for becoming the victim of a crime while using transit. It also covers irritants, such as encountering unruly passengers or having to listen to someone else's music, that may not be an actual threat but nevertheless makes passengers uneasy that the system's code of conduct is not being enforced.

Security at transit stops can be improved by placing stops in well-lit areas and by having well-marked emergency phones or help points available. Passengers may also feel more comfortable when other passengers are around (i.e., when one is not the only passenger on the car of a train or the only one waiting at a stop). Transit systems use a variety of methods to enhance security on board transit vehicles, including having

uniformed and plainclothes police officers ride transit, establishing community volunteer programs, providing two-way radios and silent alarms for emergency communication, and using surveillance cameras.

Several studies of real-time information have found that passengers feel safer as a result of having the information, particularly after dark (*58, 59*). Studies in Great Britain have also found reductions in anxiety and stress as a result of having real-time information (*23*).

Cost

Free parking at a worksite is a disincentive to transit use.

Potential passengers weigh the cost and value of using transit against the out-of-pocket costs and value of using other modes. Out-of-pocket transit costs consist of the cost of the fare for each trip or the cost of a monthly pass (and possibly the cost of parking at a station), while out-of-pocket automobile costs include road and bridge tolls and parking charges. Other automobile costs, such as fuel, maintenance, insurance, taxes, and the cost of buying an automobile generally do not occur for individual trips and thus usually do not enter into a person's consideration for a particular trip. Thus, if a person does not pay a toll to drive someplace and free parking is provided at the destination, transit will be at a disadvantage because there will be no immediate out-of-pocket cost for driving, while there will be for transit. Some transportation demand management (TDM) techniques seek to overcome this obstacle by encouraging employers who provide free parking (in effect, subsidizing the true cost of providing parking) to also provide subsidized transit passes or other means of encouraging transit use as an alternative to the private automobile.

Appearance and Comfort

Having clean, attractive transit stops, stations, and vehicles improves transit's image, even among non-riders. For example, the presence of shelters can help non-users become aware of the existence of transit service in the areas that they normally travel past in their automobiles. On the other hand, a dirty or vandalized shelter or vehicle can raise questions in the minds of non-users about the comfort and quality of transit service, and about other aspects of the service, such as maintenance, that may not be as obvious. Some transit systems have established standards for transit facility appearance and cleanliness and have also established inspection programs (*5*).

Passengers are also interested in personal comfort while using transit, including

- Appropriate *climate control* for local conditions, such as heating in the winter and air conditioning in the summer;
- *Seat comfort,* including seat size, amount of padding, and leg room; and
- *Ride comfort,* including the severity of acceleration and braking, vehicle sway, odors, and vehicle noise. Ride comfort is particularly important for older passengers and persons with disabilities.

Amenities: frills or necessities?

Many elements of transit infrastructure help make transit comfortable for passengers and make transit more competitive with the automobile. This infrastructure is often referred to as *amenities*; however, some have argued that the term "amenities" implies something extra and not necessarily required. Passengers sweltering on a non–air conditioned bus on a hot day would likely not agree that air conditioning is a frill, instead of a necessity.

The types of amenities provided are generally related to the number of boarding passengers at a stop. Examples of transit amenities include the following (*60*):

- *Benches,* to allow passengers to sit while waiting for a transit vehicle.
- *Shelters,* to provide protection from wind, rain, and snow in northern climates and from the sun in southern climates. In cold climates, pushbutton-operated overhead heaters are sometimes provided at major transit centers or stations.
- *Lighting,* to improve passenger security.
- *Informational signing,* to identify the routes using the stop, their destinations (both intermediate and ultimate), and/or scheduled or actual arrival times.
- *Trash receptacles,* to reduce the amount of litter at the transit stop. Because of security concerns, some transit agencies are choosing to remove them, though.
- *Telephones,* to provide the ability to make emergency calls. Telephones should be programmed to allow outgoing calls only to discourage loitering.
- *Vending facilities,* ranging from newspaper racks at commuter bus stops to manned newsstands, flower stands, food carts, transit ticket and pass sales, and similar facilities at rail stations and bus transfer centers.
- *Air conditioning* on transit vehicles, to provide a comfortable ride on hot and humid days, as well as *heating* in stations and on vehicles in colder climates.

TCRP Report 19 (*60*) *provides guidelines for designing, locating, and installing transit amenities.*

Customer Relations

Transit agency staff are the public face of the agency and driver friendliness or helpfulness frequently appears in surveys as an important customer satisfaction factor. Helpful staff can help offset some the effects of poor service quality, while staff with poor attitudes can damage the impression of the transit agency with both passengers and the public at large (*11*). British research indicates that a good interaction with a driver upon boarding a bus provides the same positive value of time effect as having seating available at the bus stop (*11*).

4. QUALITY OF SERVICE, RIDERSHIP, AND SERVICE COSTS

Improving the quality of service can result in ridership growth, but it may also entail added costs. Transit agencies need to consider both issues as they plan service and allocate resources. In some cases, measures to improve aspects of quality of service—in particular, speed and reliability—can result in operating cost savings or opportunities to further improve service quality (e.g., frequency) that result in additional ridership growth. This section discusses the impact of quality of service changes on ridership and operating and capital costs.

QUALITY OF SERVICE AND RIDERSHIP

Improvements in quality of service can result in increases in ridership, which in many cases, can result in an improvement in a transit agency's financial performance. Of course, if ridership increases sufficiently, additional service must be added and additional costs will likely be incurred. The opposite result is often true in ADA paratransit service, where most trips are made with only one passenger: increased ridership results in increased transit agency costs, without the economies of scale that apply to fixed-route service (*5*).

The impacts of quality of service on ridership are usually estimated using one of two methods. *Discrete choice models* estimate the probability that a traveler will use a particular mode choice (e.g., transit) from a variety of mode choice options available. Given a known number of travelers in an area, the number of people using each mode can thus be estimated. *Elasticity* relates the observed percentage change in ridership to the percentage change in some other factor (e.g., fares, headways, etc.).

A presentation of detailed procedures for estimating ridership is beyond the scope of this manual, and readers are referred to textbooks on discrete choice models for further information. However, some general guidelines on the impacts of quality of service changes on ridership are presented below, based primarily on information from the *TCRP Report 95: Traveler Response to Transportation System Changes* series (*61*). This reference also presents formulas for applying elasticities; all of the elasticities presented below are midpoint arc elasticities.

Response to Service Frequency Changes

Ridership is more responsive to changes in service frequencies when the existing service is infrequent (30-min headways or longer), in middle- and upper-income areas, and when the distances traveled are short enough that walking is an option. Ridership is less responsive when service was already relatively frequent, in lower-income areas, and when most trips are long. All other factors being equal, climate (which affects passenger comfort while waiting for service), the condition of the local economy, the overall transit agency image, and the way the new service is marketed will also affect the amount of the response (*50*).

Observed elasticities generally range from 0.0 (no change in ridership) to +1.0 (i.e., a 1% increase in frequency results in a 1% increase in ridership), with an average elasticity in the range of +0.3 to +0.5. More recent observations have grouped around either +0.3 (mainly central city urban systems) or +1.0 (suburban systems with positive images undergoing planned, comprehensive service increases). Limited research

suggests that improvements in hours of service can be as important as improvements in service frequency (*50*).

Commuter rail elasticities related to service frequency are generally higher than those for buses, in part because commuter rail frequencies tend to be relatively low. Observed *headway* elasticities range from –0.7 to –0.9 for headways greater than 50 minutes (i.e., a 1% increase in headway results in a 0.7 to 0.9% *decrease* in ridership), and from –0.4 to –0.6 at shorter headways. In contrast, light rail and heavy rail elasticities related to service frequency are typically less than those for buses because these rail modes already operate at relatively high frequencies (*50*).

Response to Reliability Changes

Reports of passenger responses to decreases in reliability are mostly anecdotal, indicating that ridership is lost when service is perceived to be unreliable. Part of this response can be attributed to additional wait time incurred when transit vehicles leave early or are late (or never arrive at all), and part can be attributed to passenger uncertainty, anxiety, and annoyance. However, a British study (*62*) found that transit lateness and reliability have little effect on demand. A U.S. study (*63*) found that it is difficult to screen out the many other factors that influence ridership, giving the example of a bus route where added running time improved the route's on-time performance from 65% to better than 85%, yet the route lost ridership.

London Transport has estimated that elasticities due to unplanned service losses (e.g., scheduled vehicle miles not operated) are 33% larger than elasticities related to planned service cuts (*64*). An analysis of automatic vehicle location (AVL) and automated passenger counter (APC) data in Portland, Oregon found that a 10% reduction in headway delay variation (the average absolute value of the difference between the actual and scheduled headway) on radial bus routes during the a.m. peak hour led to an increase of 0.17 passengers per trip per timepoint (*65*).

As discussed more in Chapter 5, Quality of Service Methods, reliability can be expressed in terms of excess wait time (the difference between the actual and scheduled departure time when a transit vehicle is late), which can be included as part of overall travel time or perceived travel time. Changes in reliability that reduce excess wait time thus decrease travel time and can be included in an analysis of ridership response to travel time changes (*8*).

Response to Travel Time Changes

TCRP Report 118: Bus Rapid Transit Practitioner's Guide (*66*) suggests a range of elasticities of -0.3 to -0.5 related to travel time, with -0.4 typical.

Response to Service Coverage Changes

Average elasticities of service expansions of existing systems (measured in terms of bus miles or bus hours) range from +0.6 to +1.0, with the higher values occurring in areas where the existing service level is below average, such as in small cities and suburbs, and during off-peak hours. (Note that existing ridership is often low in these situations, and that the same number of new passengers will result in a greater percentage increase in ridership when starting from a lower ridership level than from a higher ridership level.) Packages of improvements, combining better routes and

schedules, with new buses and/or reduced fares have been found to do particularly well in attracting new ridership (*17*).

Studies of service expansions since the 1960s—whether by extending existing routes, or by adding reverse-commute or suburb-to-suburb routes—indicate a success rate (i.e., the service was retained after the experimental period) at or slightly higher than 50 percent. New bus routes take 1 to 3 years to reach their full patronage potential, while entirely new bus systems may take even longer. New residential and multi-purpose feeders to line-haul bus and commuter rail services tend to attract 100 to 600 daily trips after 2 to 3 years, while single-employer shuttles are in the range of 25 to 600 daily trips (*17*).

Response to Fare Changes

Peak-period riders, persons traveling to and from work, and captive riders are significantly less responsive to fare changes than others. Passengers in larger cities are less sensitive to fare increases than are passengers in smaller cities. Perhaps similarly, ridership is less sensitive in areas where transit is in a competitive price and service position relative to the automobile. Elasticities do not appear to be different for large fare changes compared with small changes, nor for fare increases versus fare decreases (*67*).

The average elasticity of bus fare changes is –0.40 (i.e., a 1% fare increase results in a 0.4% decrease in ridership). The elasticity of rapid transit fare changes is about half as great, averaging –0.17 to –0.18. Off-peak ridership sensitivity is generally twice as sensitive as peak ridership, as new or infrequent riders are attracted to transit as a result of fare decreases. Peak-period riders, with the exception of senior citizens, tend not to shift travel to off-peak periods in response to off-peak fare reductions. The average senior citizen fare elasticity is –0.21 (*67*).

With the exception of downtown free-ride zones, eliminating fares systemwide results in no greater increase in ridership than would be predicted from a 100% fare reduction. Downtown free-ride zones and free shuttles are attractive for lunchtime trips and often attract trips previously made by walking (*67*).

Response to Packages of Improvements

Studies of corridor ridership before and after the implementation of BRT service have found up to a 25% increase in ridership in the corridor beyond what would be expected simply from frequency and travel time improvements. It is hypothesized that other elements of BRT—exclusive running ways, branding, enhanced stops and stations, etc.—contribute to a "premium service" image that is attractive to passengers. *TCRP Report 118* provides a method for estimating the amount of additional ridership increase for a given package of BRT elements (*66*).

An evaluation of a package of "streamlining" improvements to selected frequent-service routes in Portland, including additional service hours, transit signal priority, curb extensions, and upgraded stops, along with real-time information at nine stops, found that ridership on the streamlined routes increased by 18.2%, compared to an increase in service hours of 16.3%. This represents an elasticity of 1.11, compared to the service hour elasticity of 0.3 observed on non-streamlined routes at the same time, suggesting that the package of improvements produced a greater ridership impact than could be accounted for by service hour changes alone (*68*).

QUALITY OF SERVICE AND SERVICE COSTS

Costs Associated with Frequency Changes

Operating costs are very sensitive to changes in frequency. All other things being equal (in particular, travel times or speeds), doubling the frequency on a line will result in the operating costs doubling. If the frequency is added during peak periods, additional vehicles will be needed to provide the service (assuming no reductions to service elsewhere) and additional infrastructure (e.g., new or larger maintenance facility) may eventually also be needed, both of which entail capital costs.

Driverless rail systems are also subject to increased operating costs with increased frequency. However, because the labor cost of a driver is not incurred with these systems (only power and maintenance costs), the operating cost increment to add frequency is less.

Some rail lines are designed economically, with signal and power systems designed to accommodate near- and mid-term planned headways. Increasing frequency beyond the design level on these lines will incur capital costs to upgrade these systems.

Costs Associated with Service Hour Changes

Increasing the hours of service increases operating costs, as transit vehicles are in service longer, with the corresponding costs to power them and (usually) to drive them. All other things being equal, a 20% increase in the hours operated over the course of the week will typically increase operating costs by 20%, whether the added hours come from extending hours of service by 2 hours a day on weekdays, or by providing 10 hours of new service on Saturdays. Depending on the terms of the contract with the drivers or the contracted service provider, it may cost more to add service at night or on weekends, compared to adding service during the day on weekdays.

There are typically no direct capital costs involved with increasing service hours during off-peak periods, as sufficient vehicles typically are available to provide the new service. Vehicles would receive extra use, which could require them to be replaced sooner and undergo scheduled maintenance more frequently.

Costs Associated with Service Coverage Changes

Operating costs associated with providing service to an area that has not received service before typically increase in proportion to the number of vehicle hours required to operate the route(s) serving the area. Similar to changes in frequency, additional transit vehicles may be needed to provide the additional service, and the capacity of maintenance facilities to accommodate the additional vehicles will need to be evaluated. Other capital costs include costs to install bus stop signage, shelters, landing pads, etc.

Costs Associated with Reducing Crowding

Vehicle crowding issues that are the result of too much demand (as opposed to crowding as a result of reliability issues) can be addressed in a number of ways. Adjusting the headway of individual trips to balance out demand can be done without increasing operating costs. If more capacity is needed, then three potential options exist:

1. Adding frequency to reduce the average load per trip. This entails all of the costs described above for frequency.

2. Using a larger vehicle while maintaining existing frequency. For example, substituting an articulated bus for a standard bus. This approach adds capital costs for the new vehicles. If the vehicles have not been used in the system before, then there will also be costs associated with training mechanics to work on the vehicles and potential costs to modify maintenance facilities to accommodate the vehicles and to stock a larger selection of spare parts. There will be a minor increase in operating costs, as larger vehicles are typically less fuel-efficient.
3. Using longer trains, for rail systems that have sufficient platform length to accommodate longer trains. Additional rail cars are required to provide the extra capacity and potentially extra storage space will be needed in yards. There will be an increase in operating costs to maintain the additional vehicles, along with a minor increase in costs to power them. Electrically powered rail systems may require an electrical system upgrade to provide sufficient power to operate the extra cars, which can entail substantial capital costs.

Costs Associated with Reliability Changes

The costs to address reliability issues depend on the cause(s) of reliability problems and the techniques selected to address them. Adding running time to the schedule may increase the line's cycle time to the point that an extra vehicle needs to be added to maintain the desired headway. Infrastructure improvements, such as bus lanes or traffic signal priority, have associated capital costs (and sometimes operating costs as well). *TCRP Synthesis 83* (*69*) describes the costs associated with a variety of transit preferential treatments.

Costs Associated with Travel Time Changes

As with reliability, the costs to provide travel time improvements depend on the method(s) selected to provide travel time savings: stop consolidation, fare collection changes, or infrastructure improvements. If sufficient time can be saved that a transit vehicle can be removed from service while keeping the existing headway, operating cost savings will result (or, alternatively, an opportunity will exist to improve service on another route at no added cost).

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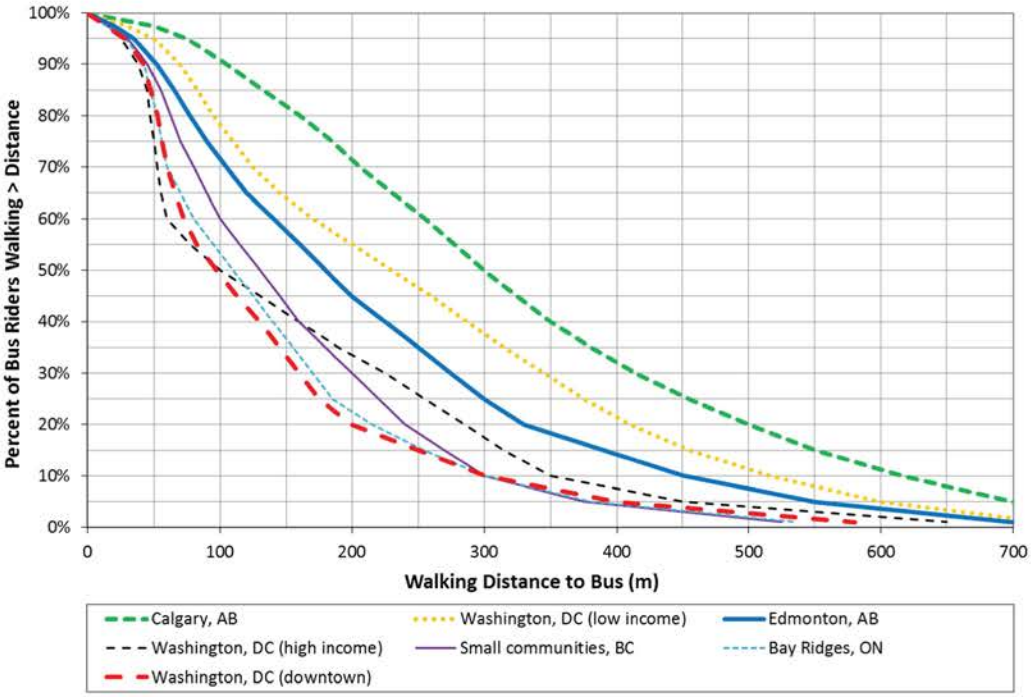
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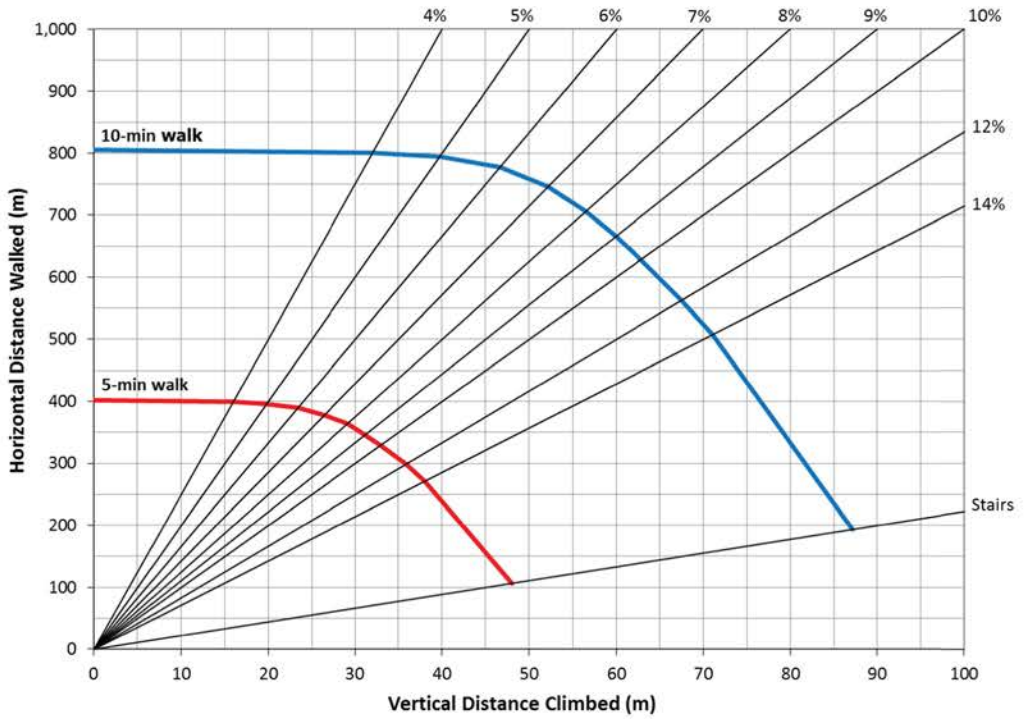
APPENDIX A: EXHIBITS IN METRIC UNITS

Exhibit 4-12m
Walking Distance to Bus Stops



Sources: Atkinson (*31*), Lam and Morrall (*32*), Peterson (*33*), and Shortreed and Maynes (*34*).

Exhibit 4-13m
Effect of Grade on Distance Walked



Source: Municipal Planning Association (*35*).

CHAPTER 5
QUALITY OF SERVICE METHODS

1. User's Guide
2. Mode and Service Concepts
3. Operations Concepts
4. Quality of Service Concepts
5. **Quality of Service Methods**
6. Bus Transit Capacity
7. Demand-Responsive Transit
8. Rail Transit Capacity
9. Ferry Transit Capacity
10. Station Capacity
11. Glossary and Symbols
12. Index

CONTENTS

1. INTRODUCTION 5-1
How to Use This Chapter 5-1
Other Resources 5-2

2. FIXED-ROUTE QUALITY OF SERVICE 5-3
Overview 5-3
Measures of Availability 5-3
Measures of Comfort and Convenience 5-22
Multimodal Level of Service 5-39

3. DEMAND-RESPONSIVE QUALITY OF SERVICE 5-47
Overview 5-47
Availability Measures 5-47
Comfort and Convenience Measures 5-56

4. APPLICATIONS 5-71
Comprehensive Planning 5-71
Long-Range Transportation Planning 5-71
Statewide Transportation Planning 5-75
Comprehensive Operational Analysis 5-75
Transit Development Plans 5-76
Service Planning 5-77
Corridor Planning 5-77
Demand-Responsive Transit Operations 5-78

5. CALCULATION EXAMPLES 5-79
Calculation Example 1: Service Coverage Analysis (Planning Level) 5-79
Calculation Example 2: Service Coverage Analysis (Detailed) 5-85
Calculation Example 3: Reliability 5-89
Calculation Example 4: Multimodal Transit LOS 5-93

6. REFERENCES 5-101

LIST OF EXHIBITS

Exhibit 5-1 Quality of Service Framework: Fixed-Route Transit 5-3
Exhibit 5-2 Fixed-Route Frequency QOS 5-4
Exhibit 5-2 (cont'd.) Fixed-Route Frequency QOS 5-5
Exhibit 5-3 Fixed-Route Hours of Service QOS 5-7
Exhibit 5-4 Fixed-Route Service Coverage QOS 5-10
Exhibit 5-5 Example of Air- and Walk-Distance Service Coverage Area Differences 5-12
Exhibit 5-6 Street Pattern Types 5-13
Exhibit 5-7 Street Connectivity Factors 5-13
Exhibit 5-8 Relationship Between Network Connectivity Index and Street Pattern Type 5-14
Exhibit 5-9 Grade Factor 5-14
Exhibit 5-10 Pedestrian Crossing Factor 5-15
Exhibit 5-11 Average Pedestrian Street Crossing Delay: Signalized Crossings 5-16
Exhibit 5-12 Average Pedestrian Crossing Delay (s): Unsignalized Crossings with No Yielding to Pedestrians 5-17
Exhibit 5-13 Service Coverage Area Compared to Transit-Supportive Area and Transit District Boundary 5-18
Exhibit 5-14 Service Coverage Calculation Results: Table Form 5-19
Exhibit 5-15 Service Coverage Calculation Results: Map Form 5-19
Exhibit 5-16 Fixed-Route Passenger Load QOS (Vehicles Designed for Mostly Seated Passengers) 5-23
Exhibit 5-17 Fixed-Route Passenger Load QOS (Vehicles Designed for Mostly Standing Passengers) 5-24
Exhibit 5-18 Body Ellipse 5-25
Exhibit 5-19 Body Ellipses: Clothed 95th-percentile U.S. Males in the Early 1970s and Mid-2000s 5-26
Exhibit 5-20 U.S. Male Passenger Space Requirements 5-27
Exhibit 5-21 Fixed-Route On-Time Performance QOS 5-30
Exhibit 5-22 Fixed-Route Headway Adherence QOS 5-31
Exhibit 5-23 Components of Long-headway Waiting Time 5-33
Exhibit 5-24 Fixed-Route Transit–Auto Travel Time Ratio QOS 5-35
Exhibit 5-25 Examples of Transit Service Attributes 5-38
Exhibit 5-26 Transit LOS Input Data 5-40
Exhibit 5-27 Variables for Pedestrian Environment Score 5-45
Exhibit 5-28 Thresholds for Transit LOS Values 5-46

Exhibit 5-29 Quality of Service Framework: Demand Responsive Transit 5-47
Exhibit 5-30 DRT Response Time QOS 5-48
Exhibit 5-30 (cont'd.) DRT Response Time QOS 5-49
Exhibit 5-30 (cont'd.) DRT Response Time QOS 5-50
Exhibit 5-31 DRT Days of Service QOS 5-52
Exhibit 5-31 (cont'd.) DRT Days of Service QOS 5-53
Exhibit 5-32 DRT Hours of Service QOS 5-54
Exhibit 5-33 Example DRT Service Coverage Graphic 5-56
Exhibit 5-34 DRT On-time Performance QOS With a 30-min On-time Window 5-58
Exhibit 5-34 (cont'd.) DRT On-time Performance QOS With a 30-min On-time Window 5-59
Exhibit 5-35 DRT Trips Turned Down QOS 5-62
Exhibit 5-35 (cont'd.) DRT Trips Turned Down QOS 5-63
Exhibit 5-36 DRT Travel Time QOS 5-64
Exhibit 5-36 (cont'd.) DRT Travel Time QOS 5-65
Exhibit 5-37 Example DRT Travel Time Calculation Process 5-67
Exhibit 5-38 DRT No-Show QOS 5-69
Exhibit 5-38 (cont'd.) DRT No-Show QOS 5-70
Exhibit 5-39 Example Activity Center QOS Map 5-72
Exhibit 5-40 Seattle Priority Bus Network Map 5-73
Exhibit 5-41 Example Service Coverage Map 5-74
Exhibit 5-42 QOS-related Measures Applicable to Peer Reviews 5-77
Exhibit 5-43 List of Calculation Examples 5-79
Exhibit 5-44 Calculation Example 1: Riverbank City Map 5-80
Exhibit 5-45 Calculation Example 1: TAZ Locations 5-80
Exhibit 5-46 Calculation Example 1: Population and Employment Data 5-81
Exhibit 5-47 Calculation Example 1: Service Coverage Area 5-82
Exhibit 5-48 Household and Job Densities 5-82
Exhibit 5-49 Calculation Example 1: Transit-Supportive TAZs 5-83
Exhibit 5-50 Calculation Example 1: Transit-Supportive Areas Served (Existing Conditions) 5-84
Exhibit 5-51 Calculation Example 2: Study Area Map 5-85
Exhibit 5-52 Calculation Example 2: Street Data 5-86
Exhibit 5-53 Calculation Example 2: Excess Pedestrian Delay Calculations 5-87
Exhibit 5-54 Calculation Example 2: Service Coverage Reductions by Stop 5-88
Exhibit 5-55 Calculation Example 2: Reduced Service Coverage Area 5-88
Exhibit 5-56 Calculation Example 3: Bus Departure Time Data 5-90

Exhibit 5-57 Calculation Example 3: Schedule Deviation Calculations 5-91
Exhibit 5-58 Calculation Example 3: Headway Deviation Calculations 5-92
Exhibit 5-59 Calculation Example 3: Budgeted Wait Time and Excess Wait Time Calculation 5-92
Exhibit 5-60 Calculation Example 4: Street Cross-Section by Alternative 5-94
Exhibit 5-61 Calculation Example 4: Transit Data by Scenario 5-95
Exhibit 5-62 Calculation Example 4: Pedestrian Environment Data by Scenario 5-95
Exhibit 5-63 Calculation Example 4: Transit Wait–Ride Score Calculation Results 5-98
Exhibit 5-64 Calculation Example 4: Pedestrian Environment Score Calculation Results 5-99
Exhibit 5-65 Calculation Example 4: Transit LOS Results 5-100

1. INTRODUCTION

Chapter 4 introduced the concept that quality of service (QOS) reflects the passenger's perception of the service offered and delivered by the transit agency. It also introduced the concept that transit performance can be evaluated from a variety of (sometimes contrasting) points of view. Evaluating QOS is an important activity for transit agencies to undertake, as it measures things that make transit service attractive to existing and potential passengers, as well as things that can help build community support for transit service. At the same time, the ideal QOS from a passenger's point-of-view may not be the best use of limited agency resources. Therefore, transit agencies need to balance the QOS they provide with the resources they have available, using their policies, objectives, and standards as guides to achieving that balance.

Chapter 5 of the *Transit Capacity and Quality of Service Manual* (TCQSM) presents methods and measures for assessing the quality of service of both fixed-route transit and demand responsive transit provided for the general public:

Organization of Chapter 5.

- Section 2 presents QOS measures for fixed-route transit.
- Section 3 presents QOS measures for demand responsive transit.
- Section 4 presents potential applications of QOS measures to a variety of transit and planning agency activities.
- Section 5 provides calculation examples.

HOW TO USE THIS CHAPTER

Service measures have associated QOS tables that interpret measure results from the passenger and transit operator points of view.

This chapter provides service measures and other performance measures for evaluating QOS. *Service measures* are the measures that appear in the QOS frameworks introduced in Chapter 4, Quality of Service Concepts, and repeated in this chapter. QOS tables describing what passengers and transit operators experience at a given QOS level are provided for each service measure. These tables can be used to help interpret the results of a QOS analysis, to provide guidance in setting QOS-based service standards, and to help identify what would be required to take QOS to the next level.

A variety of other QOS-related performance measures are also presented in this chapter. No QOS tables are provided for these measures, but they are included because they measure other important aspects of QOS not covered, or only partially covered, by the service measures.

Select QOS measures to evaluate based on the goals and objectives associated with a given analysis.

In many cases, a particular analysis will require evaluating only a subset of the QOS measures presented in this chapter. This chapter's applications section suggests which measures may be most appropriate for different types of analyses, based on typical analysis objectives. However, an overarching consideration should always be the goals and objectives associated with the analysis—for example, transit or planning agency objectives, or specific project objectives. The measures selected for a given analysis should be ones that can measure how well QOS-related objectives are being achieved.

As discussed in Chapter 1, User's Guide, this edition of the TCQSM has a reduced focus on the use of level of service (LOS) letters to evaluate QOS. No A-F letter grades are associated with the service measures contained in the fixed-route and demand responsive QOS frameworks. However, for those users who wish to evaluate LOS, a

"multimodal transit LOS" measure is provided that incorporates most of the elements of the fixed-route QOS framework, but produces a single LOS letter as a result, rather than the six that were produced in previous editions of the TCQSM. The LOS letter produced by this measure can be directly compared to LOS letters produced for companion measures for the bicycle, pedestrian, and automobile modes, as the letters indicate similar levels of traveler satisfaction across modes. The 2010 *Highway Capacity Manual* (*1*) provides methods for evaluating multimodal LOS for the other modes. The multimodal measures are particularly useful for evaluating the QOS perceived by users of all modes using a street and for evaluating the effects of potential projects on those users.

A "multimodal transit LOS" measure is provided for users desiring an A-F LOS result.

OTHER RESOURCES

Other TCQSM material related to quality of service includes:

- The "What's New" section of Chapter 1, User's Guide, which describes the changes made in this chapter from the 2nd Edition;
- Chapter 4, Quality of Service Concepts, which introduces the QOS framework and describes how changes in QOS can affect ridership, operating costs, and capital costs;
- Chapter 10, Station Capacity, which uses specialized LOS measures for evaluating and designing the pedestrian circulation elements of transit stops and stations; and
- The manual's CD-ROM, which includes a spreadsheet for evaluating the transit multimodal LOS measure, and links to electronic versions of all of the TCRP reports referenced in this chapter.

The CD-ROM accompanying the manual includes a spreadsheet for evaluating the transit multimodal LOS measure.

2. FIXED-ROUTE QUALITY OF SERVICE

OVERVIEW

This section presents QOS measures for fixed-route transit services, along with methods for calculating and interpreting these measures. The measures have been grouped into two areas: (*a*) availability and (*b*) comfort and convenience. The core QOS measures are listed in Exhibit 5-1, along with the exhibit(s) where the service levels for each measure are presented. Chapter 4, Quality of Service Concepts, introduced these categories and the reasons behind the choice of measures presented there. Therefore, this section focuses on describing how to evaluate these measures.

Exhibit 5-1
Quality of Service Framework: Fixed-Route Transit

Availability	Comfort and Convenience
Frequency (Exhibit 5-2)	Passenger Load (Exhibit 5-16 and Exhibit 5-17)
Service Span (Exhibit 5-3)	Reliability (Exhibit 5-21 and Exhibit 5-22)
Access (Exhibit 5-4)	Travel Time (Exhibit 5-24)

MEASURES OF AVAILABILITY

The core availability QOS measures address how often, how long, and where transit service is available.

Access to information about the service, access to fare media, and availability of capacity are also aspects of transit availability.

The core fixed-route availability measures presented in this section describe *how often* service is provided (frequency), *how long* service is provided (hours of service), and *where* service is provided (access). Looked at in combination, these measures describe both the temporal and spatial aspects of transit availability.

Simply having service available where and when a potential passenger wishes to use is not sufficient, however. Passengers need to know where to go and how to use the service (information provision), need to have or be able to obtain the correct fare media, and need to have capacity available (e.g., at a park-and-ride lot, on board the vehicle) at the time they want to travel.

Service Frequency

Service frequency determines how often potential transit users have access to service.

From the user's perspective, *service frequency* determines how often a potential user has access to transit service. Other travel modes—driving, bicycling, and walking—are always available for immediate use by users who have the necessary equipment (e.g., a car, a bicycle), although safety, security, cost, and comfort concerns (e.g., drunk drivers, poor or missing infrastructure, crime, pricing, poor weather) may limit the times and locations where one chooses to use one of those modes. In contrast, transit service can only be used at discrete times. If transit service is only offered hourly, there is a very limited window of time during the hour when a transit trip can be started immediately. More-frequent service provides more opportunities for immediate travel, and allows transit service to more closely resemble competing modes in terms of departure time convenience.

Frequency is a key driver of operating costs.

From the transit operator's perspective, frequency is a key driver of operating costs, as discussed in Chapter 4, Quality of Service Concepts. All other things being equal (in particular, average travel speeds), doubling the frequency doubles operating costs (driverless transit systems being the exception) and increases capital costs to the degree that additional vehicles are used and infrastructure improvements are needed to allow the increased frequency. Also as discussed in Chapter 4, frequency is a key driver

of ridership, with more frequent routes being more attractive to potential passengers, all other things being equal.

Service standards based on frequency are typically developed at the route level, and are linked to the route's intended function, ridership, or both. From a passenger point of view, the quality of service provided can also relate both to the total service provided at a location (across all routes) and to specific destinations (which may be served by more than one route). Exhibit 5-2 describes the quality of service provided at different route headways, and the corresponding perspectives of the transit operator.

Exhibit 5-2
Fixed-Route Frequency QOS

Average Headway	Passenger Perspective	Operator Perspective
≤5 min	• Very frequent service, no need for passengers to consult schedules • Bus bunching more likely, which can result in longer-than-planned waits for a bus and more variable passenger loads	• Feasible for bus or rail service in very high-density (high-ridership) corridors, and where routes converge to serve a major activity center • Exclusive right-of-way highly desirable to reduce external impacts on transit operations and to keep operating speeds high (minimizing operating costs) • In mixed traffic, bus and streetcar headways approach traffic signal cycle lengths: bunching can easily occur • Adding more frequency to add capacity may not be feasible or effective due to (*a*) minimum train spacing requirements or (*b*) unused capacity due to bus bunching • Using larger or longer vehicles, or replacing seats with standing area, may be options for adding capacity short of upgrading transit modes
>5–10 min	• Frequent service, no need for passengers to consult schedules • Bus bunching possible, which can result in longer-than-planned waits for a bus and more variable loads	• Feasible on high-density corridors with bus or rail service, and where routes converge to serve a major activity center • Short headways needed for circulator routes to be able to compete with walking and bicycling (*2*) • Exclusive right-of-way desirable to reduce external impacts on transit operations and to keep operating speeds high (minimizing operating costs) • Traffic congestion, dwell time variability, and differences in bus operator driving styles may result in bus bunching • Increasing frequency to add capacity usually feasible (budget permitting) when exclusive right-of-way provided in congested areas

Exhibit 5-2 (cont'd.)
Fixed-Route
Frequency QOS

Average Headway	Passenger Perspective	Operator Perspective
11–15 min	• Relatively frequent service, but passengers will usually check scheduled arrival times to minimize their waiting time at the stop or station • Maximum desirable wait time for the next service if a bus or train is missed	• Often branded as "frequent service" in conjunction with long service hours, including weekends • Feasible in higher-density corridors (e.g., 15 dwelling units/net acre for bus service [*3*]), routes with strong anchors on both ends, and park-and-ride–based peak-period commuter bus service • Typically the longest feasible off-peak headway that would justify light rail or BRT service
16–30 min	• Passengers will check scheduled arrival times to minimize their waiting time • Passengers must adapt their travel to the transit schedule, often resulting in less-than-optimal arrival or departure times for them	• Typically provided as 20- or 30-min headways (e.g., 3 or 2 buses per hour) • Other headways can also be seen when traffic congestion increases bus running time, but budget not available to add service • Feasible in moderate-density corridors (e.g., 7 dwelling units/net acre for bus service [*3*]) • Typical commuter rail headway; longest commuter bus headway
31–59 min	• Non-clockface headways require passengers to check scheduled arrival times • Passengers must adapt their travel to the transit schedule, usually resulting in less-than-optimal arrival and/or departure times for them • Provides more bus departures per day than hourly service over the same service span	• Typically provided as 40- or 45-min headways • Other headways can also be seen when traffic congestion increases bus running time, but budget not available to add service • Feasible in low-to-moderate density corridors (e.g., 5–6 dwelling units/net acre [*3*])
60 min	• Provides a minimal service level to meet basic travel needs • Passengers must adapt their travel to the transit schedule, usually resulting in less-than-optimal arrival and departure times for them	• Typical maximum headway for fixed-route bus service • Potentially feasible at densities as low as 4 dwelling units/net acre, depending on ability to subsidize service (*3*) • May be provided to meet a service coverage standard
>60 min	• Undesirable for urban transit service due to typical long waits for return trips and when a bus is missed	• May wish to consider some form of demand-responsive transit to provide service that better meets passengers' travel needs

Existing service frequency can be readily determined from a transit agency's timetable data. Estimating future service frequency (for example, to determine longer-term service needs) typically involves estimating future ridership demand for analysis hours of interest, dividing hourly demand by the transit agency's loading standard for the service to determine the number of required hourly trips, adjusting demand for any

ridership changes induced by changes (up or down) in future frequency, and comparing the results to the agency's *policy headway*, which may specify minimum service levels.

At a system level (e.g., for use in peer comparisons), an average system peak-period headway can be determined from NTD data. First, divide *directional route miles* by the average system speed (*revenue miles* per *revenue hour*) to give the average round-trip (cycle) time for all vehicles on all routes. Divide this result by the *number of vehicles operated in peak service* to give an average peak headway in hours, and multiply by 60 to give a result in minutes. Even on single-line transit systems (e.g., a small commuter rail operation), the average system peak-period headway may not represent actual headways experienced by passengers (for example, due to differences in headways between the two directions of the route). Nevertheless, this measure is a good general indicator of relative differences in peak headways among transit systems (*4*).

Hours of Service

Hours of service represents the number of hours during the day when transit service is provided along a route, is available at a specific location, or is available between two locations. It plays as important a role as frequency and service coverage in determining the availability of transit service to potential users: if transit service is not provided at the time of day a potential passenger needs to take a trip, it does not matter where or how often transit service is provided the rest of the day. The longer the hours of service that are provided, the greater the variety of trip purposes that can be served. Longer hours of service than needed to serve a particular market (e.g., office workers) gives those customers travel flexibility, particularly for their return trip (e.g., to work late, to run errands after work).

Hours of service helps determine the potential markets that transit can serve.

From the transit operator's perspective, hours of service affects operating costs, as transit vehicles are in service longer, with the corresponding costs to power them and (usually) to drive them. All other things being equal, a 20% increase in the hours operated over the course of the week will typically increase operating costs by 20%, whether the added hours come from extending hours of service by 2 hours a day on weekdays, or by providing 10 hours of new service on Saturdays. Another consideration for rail operators is that their ability to provide long (particularly all-night) hours of service may be constrained by their need to perform track maintenance at some point during the day or week.

Longer hours of service result in increased operating costs, all other things being equal.

Service standards based on hours of service are typically developed at the system level (for smaller transit systems, where all routes connect to each other) and at the route level for larger transit systems. Route-level standards are typically linked to the markets served by the route, ridership, or both. Ridership-based standards may allow for lower ridership on the last trip of the day, to provide insurance against stranding riders who would normally take the next-to-last trip of the day.

Exhibit 5-3 describes the quality of service provided at different ranges of hours of service, and the corresponding perspectives of the transit operator.

Exhibit 5-3
Fixed-Route Hours of Service QOS

Hours of Service	Passenger Perspective	Operator Perspective
>18 h	• A full range of trip purposes can be served • Allows bus travel to replace potentially riskier travel by other modes late at night (e.g., crime, drunk driving, poor visibility)	• Often branded as "night" or "owl" service • May require added driver pay for late-night work • May require increased security measures on transit vehicles and in transit facilities • May only be offered certain days (e.g., Friday and Saturday nights) • May be operated on a different set of routes than operate the rest of the day (e.g., emphasizing coverage over travel time)
15–18 h	• Provides service late into the evening and/or earlier in the morning, allowing a broad range of trip purposes to be served (e.g., night classes, retail and industrial employee work trips, social and entertainment trips, early morning flights/train trips)	• May require more than two full-time drivers per vehicle or overtime pay • To enhance nighttime passenger security off the bus, some bus operators allow flag stops where safe, to minimize passenger walking distance to their destination • Evening service may be operated on a different set of routes than operate the rest of the day (e.g., emphasizing coverage over travel time)
12–14 h	• Provides a long enough service span to serve work trips based around traditional office hours, with some arrival and departure time flexibility	• Can be covered by two full-time drivers per vehicle
7–11 h	• Allows trips to be made during the middle of the day • At the upper end of the range, still not enough service for someone working traditional office hours who needs flexibility to run errands after work	• Provides sufficient work for full-time drivers, but may require a midday gap in service for a driver lunch break in a system with few routes • Two part-time drivers per bus could also provide service on a route without a lunch-break service gap • Not uncommon weekday service hours for small city service; good weekend small city service
4–6 h	• With peak-period service (e.g., commuter bus), allows some choice of a.m. and p.m. departure times • With hourly service, allows opportunities to make trips during a defined period of time, with less wasted time waiting for the return trip	• Typical service hours for commuter bus and commuter rail service that operates peak periods only • Provides sufficient work for part-time drivers • Minimum service hours for hourly service (e.g., small city weekend service)
<4 h	• Basic lifeline service that allows a round trip in one day or a half day • Passengers' days must be planned around the transit schedule, with little or no flexibility	• Might be provided on rural routes with only a few daily departures (e.g., morning, midday, afternoon) • Buses and drivers may need to alternate between routes for resources to be used effectively

Hours of service can be calculated as follows:

- **Service at least hourly.** Subtract the departure time of the first trip of the day from the departure time of the last trip of the day, add 1 h, and round down any fractional hours. For example, service every 30 min between 5:30 a.m. and 8:00 p.m. results in 15 hours of service (20:00 – 05:30 = 14:30, add 1, and round down the fraction).
- **Hourly-or-worse service.** Count the number of departures. For example, departures at 5:30 a.m., 6:30 a.m., 7:30 a.m., 10:00 a.m., 1:00 p.m., 3:30 p.m., 4:30 p.m., and 5:30 p.m. equals 8 hours of service.

Hours of service can be measured at a given location, or for a particular origin–destination pair. It may be more appropriate to measure hours of service this way than by route, as multiple routes may serve the same pairs of locations during different times of the day. For example, an express bus may operate peak hours only between a park-and-ride lot and the CBD. During off-peak hours, the same trip might still be possible using local bus routes, perhaps involving a transfer. From a passenger's perspective, the trip could be made by transit using either route, resulting in longer hours of service than if each route were considered separately. (Other QOS measures can be used to describe the differences in service between the express and local routes for the same trip.)

Existing hours of service can be readily determined from a transit agency's timetable data. Estimates of future hours of service for planning purposes would typically be developed as part of a series of alternatives to be analyzed, or would be determined by agency policy.

At a system level (e.g., for use in peer comparisons), the NTD's *service span* measure can be used to provide a coarse comparison of the hours of service operated, preferably by comparing individual modes to each other. Service span is defined as the time between the first and last services of the day anywhere in the system, so it does not necessarily reflect "average" or "typical" hours of service on individual routes (*4*).

Access

Access to transit considers the spatial elements of transit availability:

- Is transit service provided near one's desired origins and destinations?
- Can one get to and from the necessary transit stops or stations?

The first question considers city- or region-wide mobility and connectivity. The second question considers more localized issues of street, sidewalk, and bicycle facility existence and connectivity; topography; parking capacity; Americans with Disabilities Act (ADA) requirements, and safety and security. Both the large-scale (coverage) and small-scale (local access) aspects of access are discussed in this section.

Access to transit can occur in a number of ways. As previously discussed in Chapter 4, Quality of Service Concepts, the main transit access modes are (*5*):

- *Walking*—the dominant access mode to local bus service and to transit stations in higher-density locations and at university campuses;
- *Bicycling*—can serve more than 5% of arriving passengers, under the right circumstances;

- *Auto drop-off*—can account for 10–15% of ridership at suburban transit stations; and
- *Auto park-and-ride*—the dominant access mode at transit stations in suburban locations.

All of these access modes are discussed within this section. However, walking access receives the most attention, due to its dominance in local bus access and at the destination end of a trip, and as an important access mode to many types of transit stations. The market areas of park-and-ride lots were discussed in Chapter 4; this section presents measures of the quality of auto access at the stop or station level.

Walking Access

Service coverage is the area located within walking distance of transit service. As with the other availability measures, it does not provide a complete picture of transit availability by itself, but when combined with frequency and hours of service, it helps identify the number of opportunities people have to access transit from different locations. Service coverage can be measured in a number of ways:

- **Route density.** Measures such as *route miles per square mile* are relatively easy to calculate from NTD data, but do not address how well transit service is distributed across a given area, nor how well the most potentially productive portions of the area are served.
- **Geographic or population coverage.** A common way of expressing a service coverage goal is in terms of *percentage of the system area served,* or *percentage of the population served.* However, depending on how a system's political boundaries have been drawn, there can be big differences in geographic coverage between city-focused systems and countywide systems (which may include large areas of unserved rural land). In addition, land use patterns—something a transit agency typically has no control over—may dictate how readily an area's population can be served by transit.
- **Potential fixed-route transit market coverage.** As discussed in Chapter 3, Operations Concepts, fixed-route service requires certain levels of population and employment density to be viable. Of course, density is not the only factor that drives the viability of transit service in an area—demographic factors such as car ownership also play a role. However, density is an important starting point, as it determines how many potential customers exist within a given area. Measuring the *transit-supportive area served* allows one to measure systemwide access, while focusing on the portions of the region best suited to support fixed-route service, and is therefore the recommended measure.

"Transit-supportive area served" is the recommended measure of systemwide access.

Transit-supportive areas are capable of supporting at least hourly weekday bus service.

Exhibit 5-4 describes the quality of service provided at different levels of service coverage, along with the corresponding policy decisions the transit operator has made explicitly or implicitly, and the implications for route productivity. The processes for determining transit-supportive areas and the areas served by fixed-route transit are described following this exhibit.

Exhibit 5-4
Fixed-Route Service Coverage QOS

Service Level	Passenger Perspective	Operator Perspective
>90% of service area population served	• Transit serves nearly all destinations within a community • On-board travel time may be long, as routes wind and loop through neighborhoods to meet a service coverage standard	• Transit operator has made a policy decision to emphasize coverage over cost-efficiency • Portions of routes covering low-density areas likely to be unproductive
>90% of transit-supportive area served	• Transit serves nearly all higher-density areas within the community • Destinations located in lower-density areas may not be accessible	• May be inefficient to serve isolated portions of the transit-supportive area due to poor street connectivity or geographic barriers • Likely inefficient to serve small pockets of higher density surrounded by large areas of low density
75–90% of transit-supportive area served	• Most destinations within higher-density areas are served, but not all	• Balances coverage and cost-efficiency objectives
50–74% of transit-supportive area served	• A majority of destinations within higher-density areas are served • Walking and bicycling access to transit likely to be longer, as service is provided farther away from many origins and/or destinations	• Potential opportunity to add service, as many areas that could support service have no service
<50% of transit-supportive area served	• Service is typically provided only in the community's highest-density corridors • What service is provided is likely to be relatively direct, resulting in relatively short travel times	• Transit operator has made a policy decision to emphasize cost-efficiency over coverage

Defining the Service Coverage Area

The following method for determining a transit system's service coverage area can be implemented at various levels of complexity, ranging from a planning-level activity that only considers air distances from stops and stations to more detailed analyses that also incorporate considerations of street network patterns, sidewalk existence, street-crossing difficulty, terrain, and age of the population. A decision on the level of complexity to use in an analysis should consider:

- **Available tools.** The use of GIS software is highly recommended. Given sufficient time, a basic planning-level analysis can be performed manually; details of the process are provided in the TCQSM 2nd Edition (*1*). Incorporating consideration of street network patterns into the analysis is simplified by GIS software that can trace paths along the street network.
- **Available data.** The more detailed levels of analysis require more detailed data (e.g., sidewalk presence, traffic volumes, grades) than may be available locally.
- **Available time and budget.** Shorter timeframes and smaller budgets suggest a less detailed level of analysis, particularly when multiple alternatives are being evaluated.

- **Questions being asked.** Some types of studies may benefit from a more detailed analysis. Incorporating more details allows the effects on access of more types of infrastructure projects to be evaluated. Conversely, simple questions may only require a basic level of analysis.

As discussed in Chapter 4, Quality of Service Concepts, depending on the study and the specific characteristics of the location studied, between 50 and 95% of transit passengers walk no farther than 0.25 mi (400 m) to a local bus stop, with an average value from these studies of about 75%. Passengers are willing to walk at least twice as far to rapid-transit service (rail or BRT). At an average walking speed of 3 mi/h (5 km/h), a 0.25-mi walk distance is equivalent to a 5-min walk.

For a planning analysis, the service coverage area of a local bus stop is defined as the air distance within 0.25 mi (400 m) and the service coverage area of a rapid transit (rail or BRT) station is defined as the air distance within 0.5 mi (800 m). Because actual walking distances from the edges of these circles will be longer than the air distance, these circles can be assumed to encompass a large majority of the people who will walk to the stop or station.

Service coverage areas extending across barriers that block pedestrian access should be removed.

The buffering feature of GIS software can be used to draw these circles around stops and stations. Service coverage areas that extend across barriers (e.g., freeways, railroads, water bodies) where no pedestrian access exists should be identified and removed. When accurate bus stop location data are not available, the service area of a bus route can be approximated by drawing a 0.25 mi (400 m) buffer around the route. This approximation is most accurate when the average stop spacing is six stops per mile (four stops per kilometer) or more frequent.

If a more-detailed analysis is desired, each stop's service coverage area can be reduced in proportion to the additional time required to climb hills, cross busy streets, wind one's way out of a subdivision, and so on. Each stop ends up with an individual service radius that, in most cases, is smaller than the 0.25 to 0.5 mi (400 to 800 m) base distance, and therefore serves a smaller number of people and jobs. This can be expressed mathematically as shown in Equation 5-1:

Equation 5-1

$$r_s = r_0 f_{sc} f_g f_{pop} f_{px}$$

where

r_s = transit stop service radius (mi, m);

r_0 = ideal transit stop service radius (mi, m),

= 0.25 mi (400 m) for bus stops, and 0.5 mi (800 m) for busway and rail stations;

f_{sc} = street connectivity factor;

f_g = grade factor;

f_{pop} = population factor; and

f_{px} = pedestrian crossing factor.

Because of the greater number of factors incorporated in a more detailed analysis, this method is better suited for analyzing small areas that range from the vicinity of an individual stop to a neighborhood. However, it can be applied to larger areas, up to an entire system, if data are available or if the analyst develops default values (e.g., default hourly traffic volumes by street class and location) for missing data. The selected methodology should be applied consistently throughout the study area.

Because a planning-level analysis will produce different results than a more detailed one, only one method should be applied to a given analysis.

Refinement for actual walking distances. Exhibit 5-5 illustrates that there can be a significant difference in service coverage areas defined by air distances from transit stops, compared to the coverage areas when actual walking distances are used, particularly when there is poor street connectivity. A map like Exhibit 5-5 can be used to highlight the need for good pedestrian connections to provide the maximum possible access to the transit service that is being offered.



(a) Air distance–based coverage area (b) Walk distance–based coverage area

Source: Kittelson & Associates, Inc. and URS, Inc. (*7*).

Exhibit 5-5
Example of Air- and Walk-Distance Service Coverage Area Differences

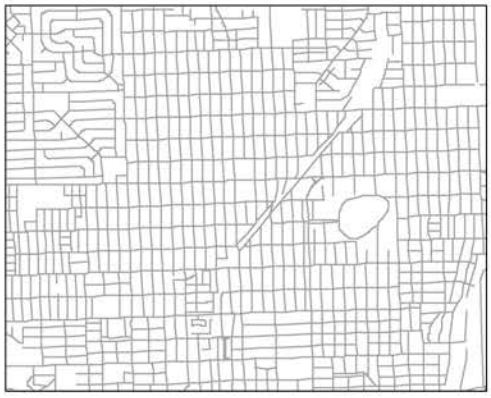
GIS software with path-tracing functionality can be used to create such a map. When GIS software is used, f_{sc} = 1.0, as the buffers created by the software already account for street connectivity. If sidewalk data are available, this method could conceivably be further refined by tracing paths only where sidewalks exist.

If path-tracing functionality is not available, the air distance buffer can be reduced instead in proportion to the amount of out-of-direction travel a pedestrian is forced to make to get to a transit stop from the surrounding land uses. Three types of street patterns are defined (*8*):

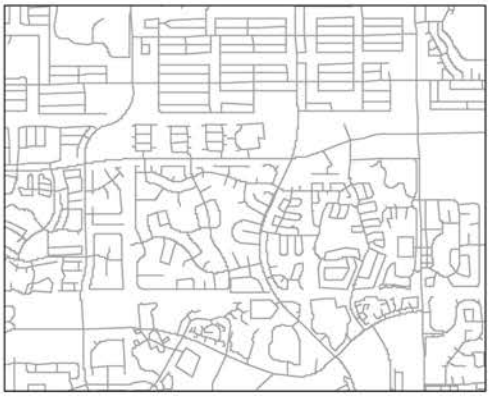
- *Type 1,* a traditional grid system;
- *Type 2,* a hybrid layout that incorporates elements of both Type 1 and Type 3 street patterns; and
- *Type 3,* a cul-de-sac based street network with limited connectivity.

Exhibit 5-6 illustrates the three types of street patterns. These sketches may be used to estimate the area type surrounding the bus stops under study.

Exhibit 5-6
Street Pattern Types



(a) Type 1—Grid



(b) Type 2—Hybrid



(c) Type 3—Cul-de-Sac

As can be seen from the above sketches, a grid street pattern provides the most direct pedestrian access to transit stops. However, walking distances to and from a transit stop can still be about 42% longer than the corresponding air distance. Stated another way, only about 64% of the area within 0.25-mi (400-m) air distance of a transit stop in a grid street pattern lies within 0.25-mi walking distance of the stop. The amount of coverage provided by the other street patterns is even lower: 54% of the area within a 0.25-mi radius of a transit stop in an average hybrid street pattern lies within 0.25-mi walking distance, and only 28% of the area in an average cul-de-sac street pattern lies within 0.25-mi walking distance.

Starting with the grid street pattern as the best case (i.e., no reduction in coverage is made for a grid pattern), Exhibit 5-7 provides suggested street connectivity factors for the other street patterns. The factor is based on the ratio of each street pattern's area covered to the area covered in a grid network.

Exhibit 5-7
Street Connectivity Factors

Street Pattern Type	Street Connectivity Factor, f_{sc}
Type 1—Grid	1.00
Type 2—Hybrid	0.85
Type 3—Cul-de-Sac	0.45

Using a network connectivity index to determine the street pattern type.

As an alternative to using the sketches, a measure of the network connectivity may be used instead to determine the area type. The *network connectivity index* is the number of links (i.e., street segments between intersections) divided by the number of nodes (i.e., intersections) in a roadway system (*8*). It is assumed for this application that all of the roadways provide for safe pedestrian travel. The index value ranges from about 1.7 for a well-connected grid pattern to approximately 1.2 for a cul-de-sac–based suburban pattern. Exhibit 5-8 shows the relationship between the network connectivity index and the street pattern type.

Exhibit 5-8
Relationship Between Network Connectivity Index and Street Pattern Type

Network Connectivity Index	Street Pattern Type
>1.55	Type 1—Grid
1.30-1.55	Type 2—Hybrid
<1.30	Type 3—Cul-de-sac

Refinement for terrain. As was shown in Chapter 4, Quality of Service Concepts (Exhibit 4-13, page 4-19), the horizontal distance that pedestrians travel in a given period of time decreases as the vertical distance climbed increases, particularly when the grade exceeds 5%. The area located within a given walking time of a transit stop decreases in proportion to the square of the reduced horizontal distanced traveled. Exhibit 5-9 gives reduction factors for the effect of average grades on a given stop's service coverage area.

Exhibit 5-9
Grade Factor

Average Grade	Grade Factor, f_g
0-5%	1.00
6-8%	0.95
9-11%	0.80
12-15%	0.65

This factor assumes that pedestrians will have to walk uphill either coming or going. If the transit route network provides service on parallel streets, such that a person could walk downhill to one route on an outbound trip and downhill from another route back to one's origin on the return trip, use a grade factor of 1.00.

Refinement for population characteristics. Average pedestrian walking speed depends on the proportion of elderly pedestrians (65 years or older) in the walking population (*9*). The average walking speed of a younger adult is 4.0 ft/s (1.2 m/s), but when elderly pedestrians constitute 20% or more of the pedestrian population, a 3.3 ft/s (1.0 m/s) average speed should be used. For transit stops where 20% or more of the boarding volume consists of elderly pedestrians, a population factor, f_{pop}, of 0.85 should be used to account for the reduced distance traveled during a 5-min walk.

Refinement for street crossing difficulty. Wide, busy streets pose a barrier to pedestrian access to transit stops. Pedestrians start to become impatient once pedestrian crossing delay exceeds 30 s (*1*). Therefore, it can be assumed that any street crossing delay in excess of 30 s results in added travel time to reach a transit stop. Put another way, if a person has a fixed maximum time budget to spend in accessing transit, street crossing delay reduces the amount of budget available for actual walking. As a result, street crossing delay results in shorter maximum walking distances and a reduction in the size of a stop's service coverage area (*7*).

The pedestrian crossing factor reduces transit availability in proportion to the number of people who walk, for example, 4 min or less to a transit stop, compared to those who walk 5 min or less. Using the Edmonton, Alberta curve (representing the approximate mid-point of the reported results) from Exhibit 4-12, Walking Distance to Bus Stops, in Chapter 4 (page 4-18), about 85% of bus passengers walk no more than 0.25 mi (400 m) to access transit, while about 75% of bus passengers walk no more than 1,000 ft (300 m) to access transit. If excess crossing delays amounted to the time required to walk 320 ft (100 m), then the stop's service area would be effectively reduced by a factor of 75% divided by 85%, or 0.88 (*7*). Taking the square root of this result, in this case 0.94, provides the walking distance reduction that results in that reduced service area.

A best-fit curve was applied to the Edmonton data to develop the following equation for a distance-based pedestrian crossing factor (*7*):

Equation 5-2

$$f_{px} = \sqrt{(-0.0005d_{ec}^2 - 0.1157d_{ec} + 100)/100}$$

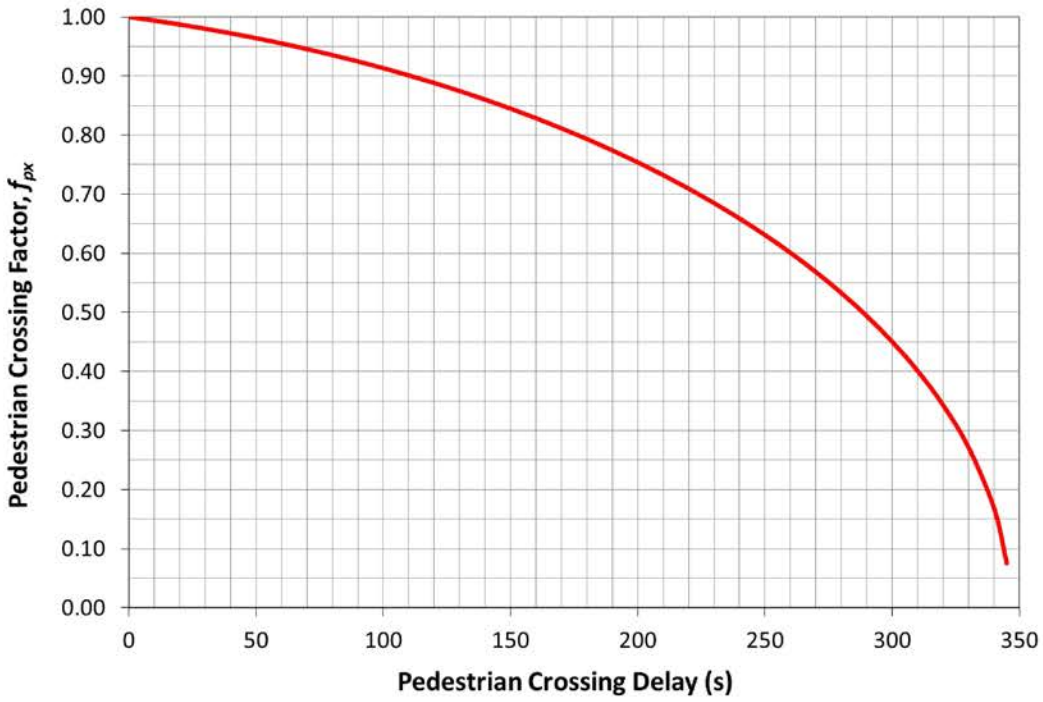
where

f_{px} = pedestrian crossing factor, and

d_{ec} = pedestrian crossing delay exceeding 30 s (s).

Exhibit 5-10 depicts this curve. The factor is 1.00 whenever pedestrian crossing delay on the street with transit service is less than or equal to 30 s. When d_{ec} exceeds 345 s, f_{px} should be automatically set to 0.0.

Exhibit 5-10
Pedestrian Crossing Factor



At signalized pedestrian crossings, average crossing delay is based on the cycle length and the amount of time available for pedestrians to begin crossing the street, as shown in the following equation (*1*):

$$d_p = \frac{(C - g_{\text{Walk}})^2}{2C}$$

Equation 5-3

where:

d_p = average pedestrian delay (s),

C = traffic signal cycle length (s), and

g_{Walk} = effective green time for pedestrians (WALK time + 4 s of flashing DON'T WALK) (s).

Exhibit 5-11 shows typical delays incurred by pedestrians when crossing streets at signalized locations, for various street widths and median types. Only the portion of the delay exceeding 30 s should be used in calculating the pedestrian crossing factor.

Exhibit 5-11
Average Pedestrian Street Crossing Delay: Signalized Crossings

	Transit Street Crossing Distance							
Lanes	**1**	**2U**	**2D**	**3**	**4U**	**4D**	**5**	**6D**
ft	**15**	**24**	**28**	**36**	**48**	**54**	**60**	**78**
m	**4.6**	**7.3**	**8.5**	**11.0**	**14.6**	**16.5**	**18.3**	**23.8**
Assumed cycle length (s)	60	60	60	90	90	120	140	180
Assumed WALK time (s)	7	7	7	7	7	7	7	9
Delay (s)	20	20	20	35	35	50	59	78
Delay exceeding 30 s (s)	0	0	0	5	5	20	29	48

Source: Calculated from Equation 5-3, using the assumed cycle length, lane widths, and WALK times shown. WALK time assumed to be the greater of 7 s or 5% of the cycle length.

Note: U=undivided, D=divided (with raised median or other pedestrian refuge).

At unsignalized pedestrian crossings where pedestrians do not have the legal right-of-way (or where motorists do not grant pedestrians their legal right-of-way), average crossing delay is based on the crossing distance, average pedestrian walking speed, and traffic volumes (vehicle flow rates). To the extent that motorists yield to pedestrians, delay can be reduced. *Highway Capacity Manual* (HCM, *1*) methods can be used to calculate pedestrian delay at unsignalized locations, including locations where automobiles yield to pedestrians. These delay estimates are based on pedestrians waiting as long as necessary for a safe gap in traffic; however, as noted previously, pedestrians start exhibiting risk-taking behavior (e.g., forcing their way into the crossing, accepting shorter gaps) after about 30 s of delay (*1*).

Exhibit 5-12 shows typical values of delay at unsignalized intersections calculated from the HCM, based on various combinations of lane widths, median types, and traffic volumes. This exhibit assumes no yielding to pedestrians and single-stage crossings (i.e., pedestrians must cross the entire street width at one time); therefore, these delay values are conservative. Only the portion of the delay exceeding 30 s should be used in calculating the pedestrian crossing factor. Where pedestrians are routinely granted the right-of-way, they experience a minimal amount of delay (well below the 30-s threshold) waiting to make sure that traffic will stop for them before they start to cross the street.

Exhibit 5-12
Average Pedestrian Crossing Delay (s): Unsignalized Crossings with No Yielding to Pedestrians

		Crossing Distance					
		1 lane	2	3	4	5	6
Volume (veh/h)	Flow Rate (veh/s)	15 ft 4.6 m	24 7.3	36 11.0	48 14.6	60 18.3	72 22.0
200	0.056	1	3	6	8	13	19
300	0.083	2	4	10	15	24	36
400	0.111	3	6	15	24	40	63
500	0.139	3	9	21	36	63	105
600	0.167	4	12	30	52	97	172
700	0.194	6	15	41	75	147	279
800	0.222	7	20	55	107	223	*
900	0.250	9	25	75	151	*	*
1,000	0.278	11	31	100	214	*	*
1,100	0.306	N/A	39	133	302	*	*
1,200	0.333	N/A	48	178	*	*	*
1,300	0.361	N/A	60	237	*	*	*
1,400	0.389	N/A	74	317	*	*	*
1,500	0.417	N/A	91	*	*	*	*
1,600	0.444	N/A	112	*	*	*	*
1,700	0.472	N/A	137	*	*	*	*
1,800	0.500	N/A	169	*	*	*	*
1,900	0.528	N/A	208	*	*	*	*
2,000	0.556	N/A	256	*	*	*	*

Source: Calculated using the HCM 2010 (*1*), assuming no yielding to pedestrians, single-stage crossings, pedestrian walking speed of 4.0 ft/s (1.2 m/s), and pedestrian start-up and end clearance time of 3 s. To the extent that automobiles yield to pedestrians, actual delays will be less.

Notes: *Delay exceeds 345 s—set f_{px} = 0.0.
N/A: not applicable—unlikely to achieve volumes shown with one lane.

Defining Transit-Supportive Areas

"Jobs" refers to jobs at worksites.

Research described in Chapter 3, Operations Concepts, suggests that a household density of 4.5 units per *net acre* (11 units per net hectare) is a typical minimum residential density for hourly daytime transit service to be feasible (i.e., generate enough ridership to be productive at a 33% farebox recovery level) (*3*). A residential density of 4.5 units per net acre is approximately equivalent to 3 units per *gross acre* (7.5 units per gross hectare). Research also suggests that an employment density of approximately 4 jobs per gross acre (10 jobs per gross hectare) produces the same level of ridership as a household density of 3 units per gross acre (*10*). The equivalent combination of residential and employment density has not been well researched; however, most mixed-use developments provide densities well in excess of either the minimum residential or minimum employment densities.

These minimum density values define *transit-supportive areas*: areas that are capable of supporting hourly fixed-route transit service. For policy reasons, or simply to provide a route connecting two higher-density areas, an agency may choose to—and likely will—cover a larger area than that defined by its transit-supportive areas. To the extent that an agency's average or policy farebox recovery differs from 33%, an agency could choose to adjust the densities defining a transit-supportive area up or down as appropriate.

Net acres and gross acres compared.

When calculating these densities, it is important to distinguish between net and gross acres. Net acres are often referenced in zoning codes and consider only the area developed for housing or employment. Gross acres are total land areas, which may include streets, parks, water features, and other land not used directly for residential or employment-related development. Gross acres are also easier to work with in GIS software. This method uses residential and employment densities calculated using gross acres to determine transit-supportive areas.

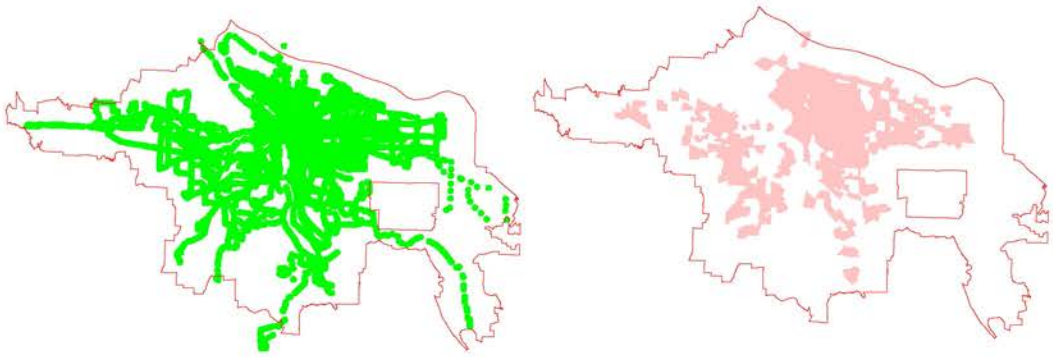
Example Calculation Steps: Planning-Level Analysis

This example is based on 2002 data for TriMet, the transit provider for Portland and many of its suburbs in Oregon. An example of performing a more detailed analysis, along with specific calculation examples, is provided in Section 5.

Step 1: Assemble data. The following data are obtained:

- Transit stop and station locations from the regional government's GIS database. At the time this analysis was performed, the transit modes operated by TriMet consisted of bus and light rail.
- Transportation analysis zone (TAZ) data (households, jobs, and TAZ boundaries) from the regional transportation planning model. Alternatively, census blocks or similar relatively small areas could also have been used.

Step 2: Determine the service coverage area. All of the bus stops are buffered using a 0.25-mi (400-m) radius and all of the light rail stations are buffered using a 0.5-mi (800-m) radius. Inaccessible areas formed by barriers are removed. The resulting service coverage area is shown in Exhibit 5-13(a) and compared to the TriMet district boundary.



(a) Service coverage area (b) Transit-supportive area

Exhibit 5-13
Service Coverage Area Compared to Transit-Supportive Area and Transit District Boundary

Step 3: Determine the transit-supportive area. For each TAZ, the number of households is divided by the TAZ area to obtain a household density in households per acre. Each TAZ's job density is calculated similarly. All TAZs with a household density of 3.0 or more households per acre, a job density of 4.0 or more jobs per acre, or both, are then identified. These TAZs are shown as shaded areas in Exhibit 5-13(b).

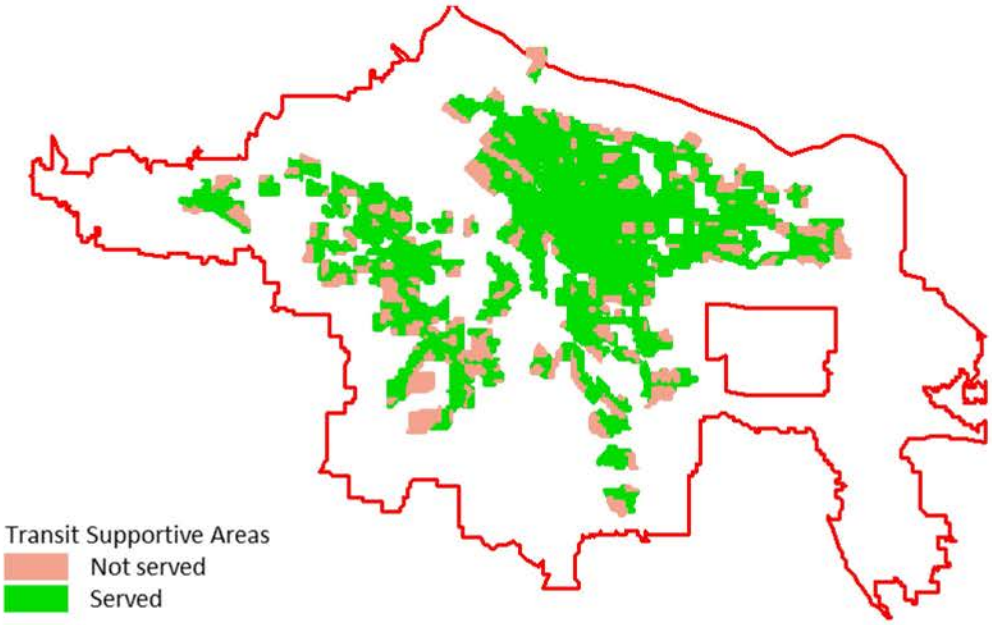
Step 4: Compare service coverage to transit-supportive areas. GIS software is used to intersect the service coverage with the TAZ layer. This process divides TAZs that are only partially served by transit into two sections: (*a*) a section completely served by transit and (*b*) a section completely unserved by transit. Households and jobs can be

allocated between the two sections based on the relative areas of the two sections. Next, the GIS software's area-calculation function is used to determine the areas of each section. The areas of all of the transit-supportive areas served by transit are summed and divided by the total area of all transit-supportive areas (both served and not served by transit). The result is the performance measure of interest: *percent transit-supportive area served.* Exhibit 5-14 and Exhibit 5-15 present the results in the form of a table and a map, respectively.

Exhibit 5-14
Service Coverage Calculation Results: Table Form

Analysis Area	Area (mi^2)	Households	Jobs	% Area Served
TriMet district	563.8	458,076	786,713	
Service coverage area	243.1	345,260	664,684	
Transit-supportive area	132.9	273,341	639,375	
Transit-supportive area served	114.4	244,587	588,072	86.1%

Exhibit 5-15
Service Coverage Calculation Results: Map Form



Comparing the transit-supportive area served result of 86.1% to Exhibit 5-4, it can be seen that from the passenger perspective, most (but not all) destinations in higher-density areas are served. From the operator perspective, this coverage represents a balance between coverage and efficiency objectives.

Measuring Service Coverage at a Stop Level

The general process described above for calculating service coverage at a system level can also be used to calculate coverage at an individual stop level. Since the decision has already been made to provide transit service to the area, the objective of this level of analysis is identify how much of the area within theoretical walking distance of the stop can actually access the stop. The more detailed analysis procedure described above can be used, in combination with path-tracing GIS software, to identify the effects of sidewalk gaps and difficult street crossings on stop access.

ADA Accessible Routes

A pedestrian network that is usable by persons with disabilities improves the mobility options of that segment of the population. It can also make fixed-route transit service accessible by persons who would otherwise have to rely on potentially less convenient and more costly (for both the passenger and the provider) demand responsive service.

Although the ADA does not require that jurisdictions provide sidewalks, it does require that where sidewalks are provided, they need to be accessible to persons with disabilities. A lack of sidewalks on access routes to transit stops makes access to transit inconvenient and potentially unsafe (if the only practical route is to walk in the street) for all potential passengers, not just those with disabilities.

At the time of writing, the Access Board's guidelines for accessible public rights-of-way had not been finalized. However, the primary elements of an accessible route have been well established for some time. These include (*11*):

- Providing sufficient clear width on access routes for wheelchairs, with passing opportunities provided at intervals;
- Firm, stable, slip-resistant surfaces;
- Limits on the grade, cross-slope, and surface discontinuities of an accessible route;
- Need for suitable transitions between sidewalks and streets (e.g., detectable warnings, curb ramps or blended transitions); and
- Accessible pedestrian signals.

The Access Board's website (http://www.access-board.gov/prowac/) should be consulted for the most recent guidance and regulations relating to accessible routes within public rights-of-way. ADA requirements for transit facilities (e.g., bus stops, rapid transit station elements) are discussed in TCQSM Chapter 10, Station Capacity.

Bicycle Access

The use of a bicycle extends the effective service coverage area of a stop or station. Since typical persons can bike about five times faster than they can walk, the effective coverage area of a stop or station also greatly increases: up to 1.25 mi (2 km) for a local bus stop and 2.5 mi (4 km) for a rapid transit station for 5- and 10-min bicycle rides, respectively. Because these distances are much greater than the typical transit route spacing—even in suburban areas—it is not particularly meaningful to try to map bicycle coverage at a system level. Even when the shortest route to a transit stop may have inadequate bicycle facilities, other choices may be available within a 5- or 10-min ride along better bicycle facilities. At a system level, focusing on improving bicycle facilities and connectivity generally may be a better approach, recognizing that improved bicycle access to transit will be one of the benefits of that effort.

At a station level, a more detailed evaluation of bicycling conditions on access routes to the station can be used to prioritize locations for bicycle infrastructure improvements that could help improve bicycle mode share to the station. To the extent that bicycling attracts passengers from park-and-ride as an access mode, the demand for parking at the station can be reduced. The *bicycle level of service* measures in the HCM 2010 (*1*) can

be used to identify areas with poor bicycling conditions, due to a lack of bicycle infrastructure, high traffic volumes, high traffic speeds, and other factors.

The availability of onboard bicycle storage and bicycle parking capacity can also be used as indications of potential constraints to bicycle access. The number of *bicycle pass-ups* can be surveyed (i.e., the number of times persons waiting to board a transit vehicle with a bicycle are unable to do so due to a lack of available bicycle rack or interior storage space). Alternatively, the *number of trips when all onboard bicycle rack or onboard storage spaces are in use* can be surveyed. As it is usually difficult to increase the number of bicycles that can be transported on board a vehicle, this measurement could be used to suggest locations where bicycle parking improvements might be needed, or—if a number of routes are affected—the need for a bikesharing program at major destinations, to reduce the need for persons to take their bicycles with them. As a lack of secure bicycle parking can be a reason for persons to want to take their bicycles with them on transit, tracking the availability and usage (e.g., *percent secure bicycle parking utilized*) of secure bicycle parking is another way of measuring bicycle access.

Automobile Access

As was discussed in Chapter 4, Quality of Service Concepts, the area served by larger park-and-ride lots varies considerably by the type of lot, land uses within its market area, congestion on nearby roadways, and other factors specific to the metropolitan region where the lot is located. However, many of the studies are consistent in finding that approximately one-half of a park-and-ride lot's users start their trip within 2 to 3 mi (3 to 5 km) of the lot. This inner market area is a relatively compact area that can be used to assess a lot's service coverage. The outer market area will provide a similar number of users, but they will be scattered over an area four or more times as large as the inner service area, with the result that park-and-ride users within the lot's outer market area form a much smaller portion of the general population.

For the purposes of assessing service coverage at a planning level, a 2.5-mi (4-km) radius around larger (100 spaces or more) park-and-ride lots may be used. For smaller lots (e.g., a 25-space shared church lot with only local transit service), a smaller coverage area is probably appropriate. The park-and-ride coverage area should be added to the walking coverage area determined through either the planning or detailed methodologies described earlier. Because park-and-ride lots usually serve the home end of a trip, and often are designed to serve passengers who do not live in higher-density areas, *percent persons served* is recommended as the park-and-ride lot performance measure, with the service area consisting of the transit agency's service area (e.g., a defined county, district, or metropolitan area). When this measure is used, it is recommended that it be reported in combination with the walking coverage service measure.

Being able to find a place at park-and-ride lot is an important component of automobile access. For this reason, many larger transit agencies track the *percent parking spaces utilized* at their park-and-ride lots as a means of identifying where insufficient parking capacity may be constraining transit ridership.

MEASURES OF COMFORT AND CONVENIENCE

If transit is an option for a given trip, comfort and convenience considerations determine the likelihood of a passenger using it.

As discussed previously, transit service availability is a minimum requirement for transit being a travel option for a given trip. However, transit's comfort and convenience aspects also contribute to passenger satisfaction with the service and their likelihood of using it. The core measures of fixed-route comfort and convenience are *passenger load* (reflecting crowding), *reliability* (reflecting schedule adherence), and *transit-auto travel time* (reflecting the time competitiveness of transit service with respect to the auto mode).

There are other comfort and convenience factors that contribute to passenger satisfaction, but they are more difficult to measure or forecast; these include safety, security, and employee interactions with customers.

Passenger Load

From the passenger perspective, the passenger load on a transit vehicle affects the comfort of the on-board vehicle portion of a transit trip—both in terms of being able to find a seat and in overall crowding levels within the vehicle. From a transit operator's perspective, a poor quality of service may indicate the need to increase service frequency or vehicle size to reduce crowding and increase passenger comfort.

Transit vehicles can be designed for the majority of passengers to be seated (e.g., typical transit buses) or for the majority of passengers to be standing (e.g., subway cars). The choice depends on capacity needs (seated passengers use more space than standing passengers), the length of time passengers are expected to stand (standing is more tolerable for short trips than for long), and regulatory and liability constraints. The type of vehicle used in service thus helps to set passenger expectations for whether or not they will have to stand during their trip. The performance measures used to measure passenger load QOS also reflect these expectations.

For transit vehicles designed for mostly seated passengers—that is, where seats are provided for half or more of the vehicle's design load—passenger load can be defined by *load factor* (passengers per seat). These vehicles include nearly all buses (except for special-purpose buses designed to serve short trips, such as Denver's 16th Street MallRide), all ferries, all commuter rail, and potentially other rail vehicles with narrow aisles and many seats. For transit vehicles designed for mostly standing passengers, *average standing passenger space,* expressed in square feet (meters) per passenger, can be used to describe the level of crowding on board the vehicle.

Passenger load standards typically specify a design load for a transit vehicle, the sum of the seated and standing passengers that is a desirable maximum. Different standards are sometimes established for peak and off-peak periods, reflecting both the need to balance transit agency costs (e.g., increased frequency, longer trains) with passenger comfort during peak periods and differing passenger characteristics at different times of the day. Standards can be expressed as an absolute not to be exceeded, or as an average during a peak 15-, 30-, or 60-min period. Using an average passenger load in a standard provides more flexibility and greater design capacity than using an absolute load, as less capacity has to be held in reserve (and possibly not used) as an allowance for surges in passenger demand. Finally, standards can be expressed as a condition that occurs at any point in the route, or for a specified period of time (e.g., "no passenger should stand for more than X minutes").

Exhibit 5-16 describes the quality of service provided at different load factors for vehicles designed for mostly seated passengers, along with the potential implications for transit agencies regarding route productivity and operating issues.

Exhibit 5-16
Fixed-Route Passenger Load QOS (Vehicles Designed for Mostly Seated Passengers)

Service Level	Passenger Perspective	Operator Perspective
Up to 50% seated load	• No passenger need sit next to another • Perceived travel time = actual travel time	• Unproductive service if condition occurs at the maximum load point in the peak direction • Condition may occur at the outer end of a route with only one anchor, or in the off-peak direction
Up to 80% seated load	• Passengers have some freedom in where they sit • Perceived travel time = actual travel time	• Marginally productive service if condition occurs at the maximum load point in the peak direction
Up to 100% seated load	• All passengers can sit • Perceived travel time up to 1.1 x actual travel time	• Productive service • Often used as a service standard for commuter bus and commuter rail services, where passengers may be on the vehicle for long periods
Up to 125% seated load	• Up to 20% of passengers must stand • Standees may need to shift position within the vehicle at each stop as other passengers board or alight • Perceived travel time up to 1.25 x actual travel time for seated passengers and up to 2.1 x actual travel time for standees	• Very productive service • Often used as a service standard for off-peak bus service • Time to serve boarding and alighting passengers goes up when standees are present, resulting in longer dwell times and potentially slower travel speeds than at lower loading levels
Up to 150% seated load	• Up to ⅓ of passengers must stand • Difficult for alighting passengers to get to doors • Boarding passengers must get others to move • Perceived travel time up to 1.4 x actual travel time for seated passengers and up to 2.25 x actual travel time for standees	• Very productive service • Maximum design load for peak-of-the-peak conditions • High potential for boarding and alighting delays, resulting in longer dwell times and slower travel speeds than at lower loading levels • Increases chances for bunching on high-frequency routes
Greater than 150% seated load	• Crush loading conditions • Passengers may choose to wait for the next vehicle, or drivers may choose to pass up stops—both conditions create delays for passengers waiting to board • Perceived travel times continue to go up	• Likely to generate complaints about overcrowding and pass-ups • Longer dwell times and slower travel speeds compared to lower loading levels • Increases chances for bunching on high-frequency routes

Source: Perceived travel times based on Balcombe (*12*).

Notes: Vehicles designed for mostly seated passengers will have 50% or more of the design load seated. These include nearly all buses, ferries, commuter rail, and potentially other rail vehicles with narrow aisles and a large number of transverse seats.

The best QOS from a passenger point of view (e.g., low crowding, good choice of seats) is often undesirable from an operator point of view, as it can represent unproductive service. However, the condition can also occur in the off-peak direction of a route or early along a route without a strong anchor at its outer end. In contrast, the worst QOS from a passenger point of view (crush loading) is also undesirable from an operator point of view, as dwell times are longer at stops, which can lead to longer travel times and poorer schedule reliability, both of which can result in higher operating costs. This condition also indicates that there is no additional capacity available to accommodate ridership growth and that potential passengers are not being served.

Exhibit 5-17 describes the quality of service provided at different levels of crowding for vehicles designed for mostly standing passengers, along with potential implications for transit agencies regarding transit operations.

Exhibit 5-17
Fixed-Route Passenger Load QOS (Vehicles Designed for Mostly Standing Passengers)

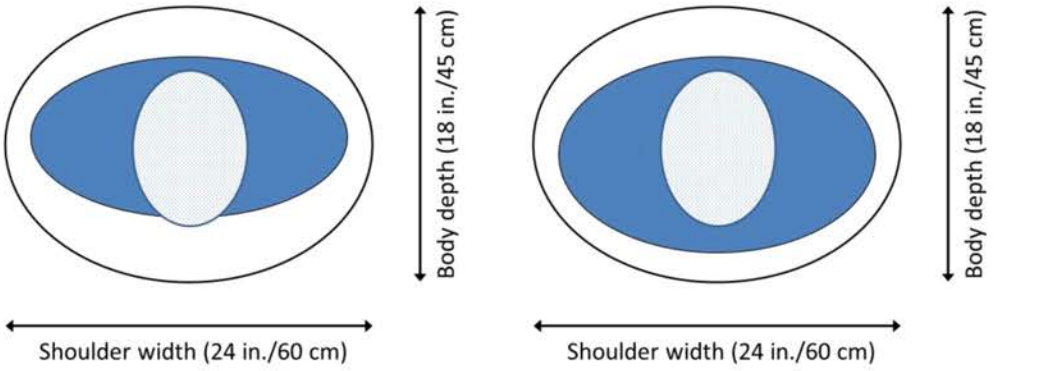
Standing Passenger Space	Passenger Perspective	Operator Perspective
>10.8 ft^2/p >1.00 m^2/p	• Passengers are able to spread out • Many/all passengers are able to sit, when vehicles provide a relatively high number of seats (e.g., light rail, heavy rail)	• Unproductive service if condition occurs in the maximum load section in the peak direction • Condition may occur at the outer end of a route, or in the off-peak direction
5.4–10.8 ft^2/p 0.5–1.0 m^2/p	• Comfortable standing load that retains space between passengers	• May be used as a peak-hour design standard for new rail systems trying to provide a higher quality of service (*13*) • Easy circulation within vehicle (*13*)
4.3–5.3 ft^2/p 0.40–0.49 m^2/p	• Standing load without body contact • Standees have similar amount of personal space as seated passengers	• Reasonably easy circulation within vehicle (*13*)
3.2–4.2 ft^2/p 0.30–0.39 m^2/p	• Occasional body contact • Standees have less space than seated passengers	• Provides a balance between passenger comfort and capacity • Moving to and from doorways requires some effort, which may increase dwell time (*13*)
2.2–3.1 ft^2/p 0.20–0.29 m^2/p	• Approaching uncomfortable conditions for North Americans (*13*) • Frequent body contact and inconvenience with packages and briefcases (*13*)	• Maximum schedule load for design • Moving to and from doorways extremely difficult, increasing dwell time (*13*) • Passengers waiting to board may try to shift to a door in a less-crowded section of the vehicle, increasing dwell time
<2.2 ft^2/p <0.20 m^2/p	• Crush loading conditions	• Moving to and from doorways extremely difficult, increasing dwell time (*13*) • Passengers waiting to board may try to shift to a door in a less-crowded section of the vehicle, increasing dwell time • Passengers waiting to board may choose to wait for the next vehicle, increasing platform crowding

Notes: Vehicles designed for mostly standing passengers will have more than 50% of the design load standing. These include most light rail, heavy rail, and AGT vehicles.

Body Ellipse

Passenger space values toward the lower end of the range for maximum schedule load conditions—2.2 ft²/p (0.2 m²/p)—have appeared in the literature since the early 1970s, when the concept of a body ellipse was introduced to pedestrian facility analysis (*14*). The body ellipse (Exhibit 5-18[a]) represents the area occupied by a heavily clothed man with a high-percentile shoulder breadth (measured from the outside of the deltoid muscles) and a high-percentile body depth, including allowances for body sway, a small amount of personal space, and the ability to carry a small object. It measured 18 by 24 in. (45 by 60 cm), representing an occupied space of approximately 2.35 ft² (0.22 m²) (*14*).

Exhibit 5-18
Body Ellipse



(a) Original body ellipse (b) Body ellipse with 50th-percentile 1970s U.S. male

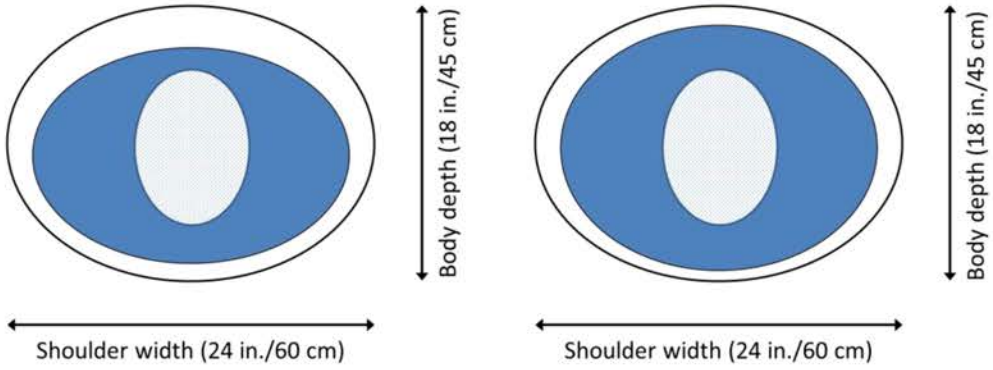
Sources: (a) Fruin (*14*), (b) research for the TCQSM 3rd Edition.

The perimeter of the body ellipse was designed to accommodate maximum clothed dimensions of 22.5 in. (57 cm) broad and 14.5 in. (37 cm) deep (*14*), reflective of 95th-percentile U.S. male values in the early 1970s (*15*). The dimensions of the person superimposed within the body ellipse can be determined by scaling from the original figure. Although not stated specifically, these dimensions—shoulder breadth of 20.5 in. (52 cm) and body depth of 10.5 in. (27 cm) —were likely intended to reflect an average person. However, while the shoulder breadth is that of a 50th-percentile clothed U.S. male from the 1970s, the body depth is reflective of only a 5th-percentile clothed male (*15*). The visualization, therefore, may give an incorrect impression of the amount of extra space provided within the ellipse. Exhibit 5-18(b) illustrates the space taken up within the ellipse by a 50th-percentile clothed male from the early 1970s, based on a 50th-percentile body depth of 10.8 in. (27.5 cm) and a 2-in. (5 cm) allowance for heavy outer clothing (*15*). About half of the additional body depth shown in Exhibit 5-18(b) is the result of the assumption of heavy clothing being worn.

The American population has become larger since the time the body ellipse was invented. Measurements of a cross-section of the U.S. population conducted periodically by the National Health and Nutrition Examination Survey (NHANES, *16–19*) show that the 95th-percentile male's weight has increased from 225 lb (102 kg) in 1971–74 to 270 lb (123 kg) in 2003–06, and that his waist circumference in 2003–06 was 50.3 in. (128 cm). Unfortunately for this purpose, NHANES has never collected body depth data. However, a body depth representative of a mid-2000s 95th-percentile U.S. male can be

estimated by extrapolating relationships between weight and body depth from other anthropometric data (*15*).

Exhibit 5-19 compares how much of the body ellipse would be occupied by a 95th-percentile clothed U.S. male in the early 1970s and the mid-2000s. Although the mid-2000s male continues to be contained within the ellipse, the area available for body sway, personal space, and carrying small objects has been reduced, as his body depth is 2 in. (5 cm) greater than in the early 1970s. Therefore, to provide the same amount of personal space for a mid-2000s design male that a mid-1970s design male would have had, the body depth component of the body ellipse should be expanded by 2 in. (5 cm), resulting in a 20 by 24 in. (50 by 60 cm) ellipse that occupies approximately 2.6 ft² (0.24 m²)—close to the midpoint of the range of maximum design load values in Exhibit 5-17.



(a) Early 1970s (b) Mid-2000s

Exhibit 5-19
Body Ellipses: Clothed 95th-percentile U.S. Males in the Early 1970s and Mid-2000s

Space Occupied by Worn and Carried Objects

Passengers with larger objects (e.g., daypacks, computer bags, bicycles) will occupy more space than the body ellipse. For example, a person wearing a daypack takes up at least 60% more space than a passenger without one. A weighted average of the space required for different types of passengers can be used to develop an average passenger space for design purposes, using values from Exhibit 5-20. For example, if 15% of passengers wear daypacks on average, 3% have mid-size strollers, and the body ellipse is assumed to be 2.6 ft² (0.24 m²), then a weighted average space that could be used for design would be (0.15 × 4.2) + (0.03 × 9.9) + (0.82 × 2.6) = 3.1 ft² (0.29 m²).

Exhibit 5-20
U.S. Male Passenger Space Requirements

Situation	Projected Area (ft^2)	Projected Area (m^2)
Standing	2.2–2.6	0.20–0.24
... with briefcase, computer bag	3.4–4.1	0.32–0.38
... with daypack	3.8–4.2	0.35–0.39
... with suitcases	4.4–6.3	0.41–0.59
... with stroller	7.3–12.5	0.95–1.15
... with bicycle (horizontal)	11.8–16.6	1.10–1.54
Holding on to stanchion	3.5–4.0	0.33–0.37
Tight double seat	3.8 per person	0.35 per person
Comfortable seating	5.9 per person	0.55 per person
Personal transporter	3.8–5.5	0.35–0.51
Wheelchair/scooter space (ADA)	10.0 (30 in. x 48 in.)	0.93 (0.76 m x 1.22 m)

Sources: Derived from Batelle Institute (*20*), *TCRP Synthesis 88* (*21*), Landis et al. (*22*), and additional research for the TCQSM 3rd Edition.

Calculating Standing Passenger Area

Standing passenger area is one of two values used in calculating average standing passenger space, which is used to evaluate quality of service for transit vehicles designed to have most passengers standing. This value may be available as part of the specifications for a given transit vehicle. However, if it is not known, it can be estimated as follows (*6, 13*):

1. *Calculate the gross interior floor area.* Multiply the interior vehicle width by the interior vehicle length. For standard buses, subtract 6 in. (0.15 m) from the external width to estimate the interior width (reduction for wall thickness), and subtract 8.5 ft (2.6 m) from the external bus length to estimate the internal length (engine compartment, operator, and front door areas). For heavy and light rail cars, subtract 8 in. (0.67 ft, 0.2 m) from the external width (wall thickness) and 6 ft., 7 in. (6.58 ft, 2.0 m) from the external length (driver cab at one end).
2. *Calculate the area occupied by seats and other objects:*
   - Transverse seating: 5.4 ft^2 (0.5 m^2) per seat.
   - Longitudinal seating: 4.3 ft^2 (0.4 m^2) per seat, which includes a buffer area in the aisle for seated passenger foot room.
   - Wheelchair position: 10.0 ft^2 (0.95 m^2) per position (use when the wheelchair position is not created by fold-up seats).
   - Rear door: 8.6 ft^2 (0.8 m^2) per door channel.
   - Interior aisle stairs: 4.3 ft^2 (0.4 m^2)
   - Low-floor bus wheel well: 10.0 ft^2 (0.95 m^2) each
3. *Calculate the standing passenger area.* Subtract the area calculated in step 2 from the gross interior floor area calculated in step 1.

For example, some of Chicago's older heavy rail cars have external measurements of 48 ft long by 8 ft wide and contain 42 transverse seats. Their internal area is estimated as (48 – 6.58 ft) by (8 – 0.67 ft), or 303.7 ft^2. The seats take up (5.4 × 42 = 226.8 ft^2), leaving 76.9 ft^2 for standees. Assuming a standing passenger area of 2.6 ft^2/p under maximum schedule load conditions, there is room for 30 standees. Newer cars have the

same dimensions, but 38 longitudinal seats, which take up (4.3 × 38 = 163.4 ft²), leaving 140.3 ft². This space accommodates 54 standees at the maximum schedule load.

Reliability

Several different measures of reliability are used by transit operators. The most common of these are

- On-time performance,
- Headway adherence (the consistency or "evenness" of the interval between transit vehicles),
- Excess wait time (the average departure time after the scheduled time),
- Missed trips (i.e., scheduled trips not made),
- Percent of scheduled time in operation (for automated systems), and
- Distance traveled between mechanical breakdowns.

The first three measures in the list incorporate the effects of all potential sources of delay and unreliability. In addition, all three can be derived from measured bus departure times, a task that is simplified using archived AVL data. For example, *on-time performance* is the percent of schedule deviations (actual departure minus scheduled departure) that fall within a defined range (e.g., 1 min early to 5 min late), *headway adherence* is the coefficient of variation of headways (the standard deviation of headways divided by the mean headway), and *excess platform wait time* is the average of the non-negative schedule deviations (i.e., on-time or late departures).

Reliability aspects under the control of the transit operator.

The last three measures in the list reflect aspects of reliability that are under the control of the transit operator: driver and vehicle availability, mechanical and electronic reliability (i.e., choice of vehicle, technology, vendor, etc.), fleet age, and maintenance quality. Passengers experience the effects of these kinds of unreliability as long delays that occur rarely. In contrast, the first three measures reflect the effects of both rare delays and the more common occurrence of a transit vehicle running a few minutes ahead or behind schedule.

On-time Performance

On-time performance is the most widely used reliability measure in the North American transit industry (*23, 24*). It can be applied to any transit service that operates according to a published timetable, although from the passenger perspective it is best applied to services operating at longer headways (e.g., longer than 10 min). At shorter headways, a transit vehicle can be off-schedule, but a passenger may not notice it because another vehicle arrives at or near the scheduled time. From an operator perspective, on-time performance can be important to measure for all scheduled services, as a late vehicle may be out of position for its next assignment, which may be on a different route.

Locations for measuring on-time performance.

On-time performance should be measured at locations that make the most sense for a given analysis. For example, measuring on-time performance at the next-to-last timepoint may be more relevant to the passenger perspective than measuring it at the route terminal, if most passengers disembark prior to the end of the route. On the other hand, if the route terminal is a timed-transfer center, on-time performance arriving at that location would be of great interest to passengers. The arrival time of transit

vehicles at the route terminal relative to the schedule is also of interest to operators, as it impacts the schedule recovery time and the route cycle time. Some agencies measure on-time performance at several timepoints along a route; multiple measurement locations may be necessary to diagnose the causes of unreliability. Using archived AVL data makes it possible to measure on-time performance and other reliability metrics at many points of interest without the need for manual, potentially expensive data collection (*25*).

Industry definitions of "on time."

One negative aspect of on-time performance as a performance measure is that the measured result is highly dependent on how "on time" is defined. A survey of U.S. agencies in the mid-1990s found that 42% allowed buses to be more than 5 min late and still be considered "on time," and 24% allowed some early buses to be considered on-time (*23*). A Canadian survey in 2000 found less-lenient definitions: of the 17 agencies that defined an on-time standard, 11 defined "on time" as being no more than 3 or 4 min late, and the remainder defined it as being no more than 5 min late. Only 2 of the 17 surveyed Canadian agencies allowed some early buses to be considered on time (*24*). A more consistent definition of "on time" across the industry would allow transit agencies to compare their performance with each other (*4*). Calculating on-time performance on the basis of archived headway deviation data allows any "on-time" definition to be used, allowing on-time performance to be compared on the basis of any desired definition. A minimum of 20 observations (manual or AVL) are needed to achieve a 5% resolution in performance and many more observations are needed to achieve a particular level of statistical significance.

Treatment of early departures.

One key issue related to defining "on-time" is how early departures are treated. From the perspective of a passenger arriving at a stop close to the time a transit vehicle is scheduled to depart, an early departure is not on-time in terms of when the passenger can board a transit vehicle; rather, it is equivalent to a vehicle being late by the amount of one headway. On the other hand, an early arrival toward the end of the route, when no passengers are boarding, would not be seen as a problem by passengers on the bus and would in fact likely be viewed positively.

A review of U.S. transit agencies that publically report their on-time performance found that many use an "on-time" definition of 1 min early to 5 min late. Although any early departure, even one minute, can be seen as undesirable from an arriving passenger's standpoint, most transit agencies that use such a standard make a note in their timetables that vehicles may depart up to 1 min early, thereby giving passengers notice of their policy. Slightly early departures can also help maintain schedule reliability farther down a route and reduce holding delay at timepoints for passengers already on the bus. Therefore, in the interest of working toward a common industry "on-time" definition that reflects both passenger and operator perspectives, this edition of the TCQSM defines "on-time" as a departure from a timepoint as 1 min early to 5 min late or an arrival at the route terminal up to 5 min late.

TCQSM definition of "on-time."

Exhibit 5-21 presents the passenger and operator perspectives of different ranges of on-time performance.

Exhibit 5-21
Fixed-Route On-Time Performance QOS

On-time Performance	Passenger Perspective	Operator Perspective (System Level)
95–100%	• Passenger making one round trip per weekday with no transfers experiences one not-on-time vehicle every 2 weeks	• Achievable by transit services operating below capacity on a grade-separated guideway not shared with non-transit vehicles, with few infrastructure or vehicle problems
90–94%	• Passenger making one round trip per weekday with no transfers experiences one not-on-time vehicle every week	• Achievable by transit services operating on a grade-separated guideway not shared with non-transit vehicles
80–89%	• Passenger making one round trip per weekday with no transfers experiences up to two not-on-time vehicles every week	• Typical range for commuter rail that shares track with freight rail • Typical range for light rail with some street running • Achievable by bus services in small- to mid-sized cities
70–79%	• Passenger making one round trip per weekday with no transfers experiences up to three not-on-time vehicles every week • Passenger making one round trip per weekday with a transfer experiences a not-on-time vehicle every day	• Typical range for light rail with a majority of street running • Achievable by bus services in large cities
<70%	• Service likely to be perceived as highly unreliable	• May be best possible result for mixed-traffic operations in congested CBDs

Notes: Depending on local conditions, any given route can operate considerably better or worse than the typical ranges given here. "On-time" defined as a departure 1 min early to 5 min late or an arrival at the route terminus more than 5 min late.

Headway Adherence

When transit vehicles operate at headways of 10 min or less, particularly on surface streets, vehicle bunching can occur, where two or more vehicles on the same route arrive together or in close succession, followed by a long gap between vehicles. From a passenger perspective, the lead vehicle is usually overcrowded, having picked up its own passengers and passengers arriving early for the next service, and passengers arriving during the gap in service experience a longer waiting time than expected. From the operator point of view, the less-utilized trailing vehicles represent wasted capacity, and more time is needed at the end of the route for schedule recovery, which increases the route's cycle time and thus potentially increases operating costs.

The bunching effect can be measured in terms of *headway adherence*—the regularity of transit vehicle arrivals with respect to the scheduled headway. It is calculated as the coefficient of variation of headways c_{vh}: the standard deviation of headways (representing the range of actual headways), divided by the average (mean) headway. Because c_{vh} is a statistical measure, it may be more difficult to explain to stakeholders. Nevertheless, it is the best available measure for describing the bunching effect.

As shown in Exhibit 5-22, the coefficient of variation of headways can be related to the probability P that a given transit vehicle's headway h_i will be off-headway by more than one-half the scheduled headway h. This probability is measured by twice the area

to the right of Z on one tail of a normal distribution curve, where Z in this case is 0.5 divided by c_{vh}. For an illustration of these relationships, see Exhibit 6-56 (page 6-65).

Exhibit 5-22
Fixed-Route Headway Adherence QOS

c_{vh}	P (abs[h_i-h] > 0.5 h)	Passenger and Operator Perspective
0.00-0.21	≤2%	Service provided like clockwork
0.22-0.30	≤10%	Vehicles slightly off headway
0.31-0.39	≤20%	Vehicles often off headway
0.40-0.52	≤33%	Irregular headways, with some bunching
0.53-0.74	≤50%	Frequent bunching
≥0.75	>50%	Most vehicles bunched

Note: Applies to average scheduled headways of 10 min or less.

The following examples illustrate how to measure headway adherence:

1. A bus route is scheduled to operate at fixed 10-min headways. During one peak hour, the actual measured headways between buses are 12, 8, 14, 6, 7, and 13 min. The population standard deviation of these values is 3.4 min, and the resulting coefficient of variation is 0.34: vehicles are often off headway, if this day's results are typical (in practice, a larger set of observations should be used to measure bus route reliability).
2. A bus route is scheduled at 5- to 11-min headways during the peak period. The following table shows the scheduled headway between buses, the actual headway (based on AVL data), and the corresponding headway deviation.

Scheduled Headway (s)	600	600	600	600	660	600	420	540	540	420	420	420	360	300
Actual Headway (s)	786	906	700	302	616	198	304	918	538	120	308	876	168	134

The mean headway is 506 s, with a standard deviation of 265 s. The coefficient of variation is 0.52, indicating that some bunching occurs, approaching a frequent occurrence.

Excess Wait Time

A variety of performance measures can be defined based on relationships between when passengers arrive at a transit stop, when the transit vehicle is scheduled to depart, and when it actually departs. As discussed in Chapter 4, Quality of Service Concepts, when departures on a route are scheduled at short headways (approximately 10 min or less), passengers arrive at random. If transit vehicles depart perfectly reliably and sufficient capacity is available that no pass-ups occur, the average passenger wait time is half the average headway. When departures are not perfectly reliable, the average waiting time is longer than half the average headway and is related to the spread in the headway distribution (*25*):

Equation 5-4

$$t_w = 0.5 h_o (1 + c_{vh}^2)$$

where

t_w = average wait time (min),
h_o = average observed headway (min), and
c_{vh} = coefficient of variation of headways.

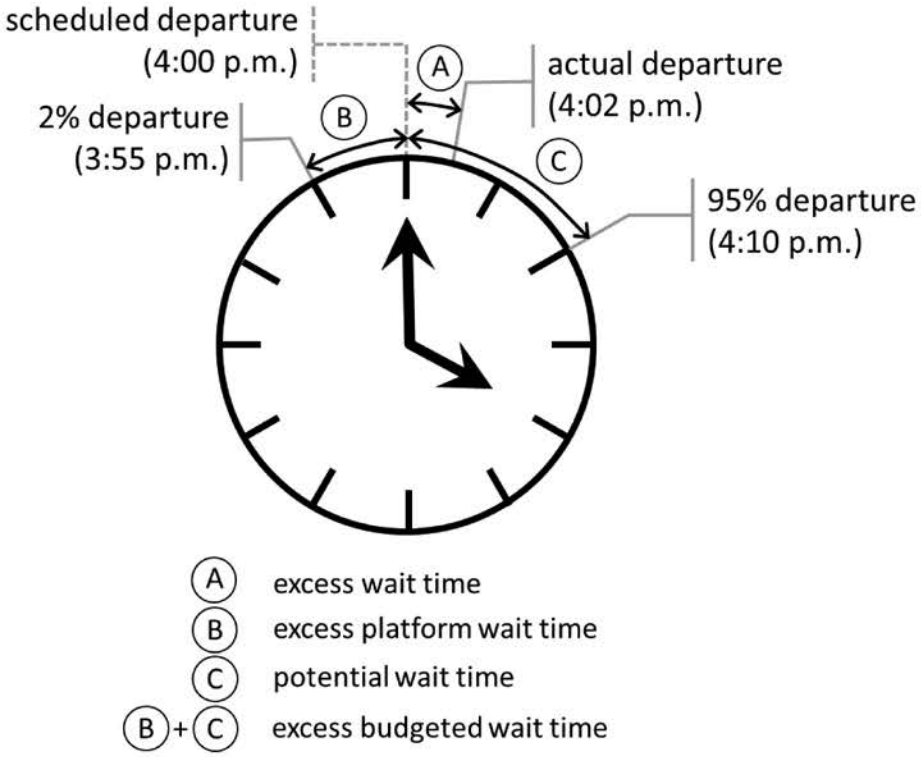
When transit service is scheduled at long headways (approximately 15 min or more), passengers time their arrival based on their knowledge of the schedule and the service's reliability. With perfectly reliable service, passengers would pick the last departure that would get them to their destination before their desired arrival time and would arrive at the stop or station shortly before the scheduled departure time. When service is unreliable, passengers will adjust their arrival time at the stop to be relatively certain that they will arrive at their destination before their desired time. *TCRP Report 113* (*25*) assumes that passengers will plan their arrival based on the 2% departure time (to avoid having to wait one headway if the vehicle departs early) and will plan their trip based on the 95% departure time (so that they will arrive late at their destination no more than 5% of the time, assuming they have chosen a particular trip based on knowledge of the range of possible arrival times at their destination).

Performance measures that can be defined based on these passenger arrival times and vehicle departure times include (*25*):

- *Excess wait time,* the actual departure time minus the scheduled departure time, representing extra wait time that passengers experience at the stop, compared to what was promised in the schedule. As discussed in Chapter 4, Quality of Service Concepts, passengers perceive waiting time as being more onerous than in-vehicle time. Early departures can be treated as a departure one headway late, as that is what late-arriving passengers experience.
- *Excess platform waiting time,* the scheduled departure time minus the 2nd percentile departure time, representing the extra time that passengers must plan to arrive early (and likely wait) to avoid being left behind by an early-departing bus. (This measure can be negative if vehicles always leave late.)
- *Potential waiting time,* the 95th percentile departure time minus the scheduled departure time, representing the time that passengers must budget to avoid being late at their destination more than 5% of the time. Most of the time, passengers experience this time as arriving at their destination earlier than necessary, time that they may not be able to use productively.
- *Budgeted waiting time,* the sum of excess platform waiting time and potential waiting time, the amount of time that passengers must incorporate into their trip planning to accommodate unreliable service. On a given day, some of this time will be spent waiting at the departure stop because the transit vehicle did not arrive as early as it might and some of this time will be manifested as an earlier-than-planned arrival at the destination.

Exhibit 5-23 illustrates the calculation of these measures. As discussed in Chapter 4, Quality of Service Concepts, there are two other components to a passenger's trip planning that are not related to transit service reliability. The first is *synchronization time,* extra time that passengers budget to arrive at the stop or station by their targeted time, while the second is *schedule incovenience time,* which arises because long-headway service often results in extra time between when one would prefer to travel (e.g., immediately at the end of one's work day) and when one actually can travel (i.e., when the transit service is provided) (*25*).

Exhibit 5-23
Components of Long-headway Waiting Time



Source: Derived from *TCRP Report 113* (*25*).

As transit unreliability increases, the performance measures shown in Exhibit 5-23 increase in magnitude. Excess wait time represents the passenger inconvenience on a given trip, while budgeted waiting time represents the inconvenience based on passenger knowledge of the service's reliability. With knowledge of passengers' values of time, these measures can also be converted into perceived travel times, for use in evaluating a passenger's overall trip. An example application is the use of perceived excess wait time as part of the transit LOS measure described in a subsequent section.

Excess wait time and its related measures can be measured manually, but the use of archived AVL data is recommended. A minimum of 250 data points are recommended for determining the 2nd percentile departure time used to calculate excess platform wait time (*25*).

Travel Time

An important factor in a potential transit user's decision to use transit on a regular basis is how much longer the trip will take in comparison with the automobile. Time spent travelling from point A to point B is time not necessarily available for other uses, so all other things being equal, a person will prefer a faster trip for time-sensitive trips. As discussed in Chapter 4, Quality of Service Concepts, the quality of the travel experience also impacts the decision: for example, persons perceive the time spent in crowded conditions to be more onerous than time spent in uncrowded conditions. Similarly, being able to use travel time productively—to read, relax, catch up on extra work, etc.—without having to deal with the hassles of rush-hour driving, can help offset any time advantage the automobile may have.

At the route level, *travel time*, *average speed,* and *travel time rate* are useful metrics for transit agencies for assessing and forecasting performance:

- Travel time directly impacts the number of transit vehicles needed to operate on a route at a given headway and the impact of location-specific transit preferential treatments and operational strategies will typically be expressed as a travel time saved per location.
- Average speed (distance divided by time) lends itself to comparisons with peer routes or peer transit agencies; ridership elasticity factors (such as those given in Chapter 4) exist for average speed, allowing the impact of speed improvements on ridership to be estimated.
- Travel time rate (time divided by distance) is forecast by the TCQSM's bus speed procedures and the impact of corridor-based transit preferential treatments is typically expressed in terms of its effect on travel time rate.

While all of the above measures are useful for many types of analysis, none directly reflect the passenger point of view.

The quality of service measure is the *transit–auto travel time ratio,* the in-vehicle transit travel time divided by the in-vehicle single-occupant auto travel time for a given trip. This measure can be applied to the evaluation of route segments (reflecting passengers' experiences in those segments), to a route as a whole (e.g., for operational evaluations), or for origin–destination trips (in which case, transfer time is also included in the transit travel time). The use of a ratio normalizes results, allowing segments, routes, and trips of different lengths to be compared. The measure is sensitive to both route or trip speed and directness (i.e., relatively fast, but circuitous trips and relatively direct, but slow trips both produce poor QOS). Exhibit 5-24 shows the passenger and operator perspectives associated with different service levels.

The travel times used to calculate the transit–auto travel time ratio can be obtained from a variety of sources, including:

- Field data, from auto travel time runs and transit AVL data;
- Estimates of auto and transit speeds from the *Highway Capacity Manual* (*1*) or simulation;
- Online mapping tools that can provide estimates of auto and transit travel times, including the effects of recurring traffic congestion; or
- Regional travel models, for origin–destination trips.

Whichever source is selected, it should be used as the basis for both transit and auto travel times. When travel times are estimated, rather than measured directly, a sample of estimates should be compared against existing conditions to verify the reasonableness of the estimates and, if necessary, develop correction factors for them. For example, one transit–auto travel time analysis using a major metropolitan area's regional model found that the model underestimated transit travel times by an average of 24% and overestimated auto travel times by 45% (*26*). Because each service level in Exhibit 5-24 encompasses a relatively wide range of transit–auto travel time ratios, it is not necessary that travel time estimates be exactly accurate—particularly for route and origin–destination analyses—but it is nevertheless desirable that any estimation errors for each mode be of comparable magnitudes and directions (i.e., both underestimated or both overestimated).

Exhibit 5-24
Fixed-Route Transit–Auto Travel Time Ratio QOS

Transit–Auto Travel Time Ratio	Passenger Perspective	Operator Perspective
≤1	• Faster trip by transit than by auto	• Feasible when transit operates in a separate right-of-way and the roadway network is congested
>1–1.25	• Comparable in-vehicle travel times by transit and auto • For a 40-min commute, transit takes up to 10 min longer	• Feasible with express service • Feasible with limited-stop service in an exclusive lane or right-of-way
>1.25–1.5	• Tolerable for choice riders • For a 40-min commute, transit takes up to 20 min longer	
>1.5–1.75	• Round trip up to 1 h longer by transit for a 40-min one-way trip	
>1.75–2	• A trip takes up to twice as long by transit than by auto	• May be best possible result for mixed traffic operations in congested downtown areas
>2	• Tedious for all riders	• May be best possible result for small city service that emphasizes coverage over direct connections

Other Comfort and Convenience Measures

Although the comfort and convenience factors presented above are both important to passengers and relatively straightforward to quantify and forecast, there are also other factors that have been shown to be important to passengers, but which are more difficult to quantify and very difficult to forecast. These include:

- Passenger safety and security;
- Customer service, particularly driver friendliness; and
- Quality of the passenger environment.

Safety and Security

Safety (relating to being injured in an accident) and security (related to becoming the victim of a crime) are both highly important to transit passengers and employees. Although it is hard to forecast future performance in any but the most general terms, it is possible to track individual aspects of safety and security that can provide indications of potential problems. *TCRP Report 88* (*27*) suggests the following customer-focused measures:

- *Accident rate*—the number of vehicle accidents per specified distance (e.g., 100,000 mi) or time (e.g., year). Accidents are typically categorized as preventable or non-preventable.
- *Passenger safety*—passenger injuries or fatalities per specified number of boardings or time period.
- *Percent positive drug and alcohol tests*—an example of a leading indicator, as an increase in the measured value indicates a greater likelihood of safety problems in the future.

- *Number of traffic tickets issued to operators, percent of buses exceeding the speed limit*—these measures identify potential safety problems with bus operators. The former measure can be categorized by type of infraction, while the latter measure allows problems to potentially be identified and addressed before a driver is ticketed.
- *Number of station overruns*—on manually operated rail systems, this measure can indicate a lack of operator attentiveness or driving skill; on automated systems, it can indicate that the system design parameters are not being met.
- *Number of fires*—fires are a serious safety issues, particularly underground.
- *Number of crimes (crime rate)*—measures number of reported crimes on transit property; these can be categorized by type and severity. The measure does not address unreported incidents, nor does it address the perception of crime. Surrogate measures, such as fare evasion rate, incidents of graffiti or other vandalism, and number of security-related complaints can address to some degree the perception of crime.
- *Ratio of police officers to transit vehicles*—a measure of the visibility of police officers (crime deterrent, passenger reassurance); however, it may be difficult to track how often officers are deployed on vehicles.
- *Number or percent of vehicles (or stops or stations) with specified safety devices*—these can include security cameras, intercom systems, emergency alarms, lighting, and vehicle tracking capabilities. The presence of security cameras in vehicles and stations has been shown to improve passengers' sense of security.

Customer Service

Public transit is a customer service industry, and maintaining high levels of customer satisfaction helps retain customers who have or obtain other travel choices. It also helps attract new customers through good word-of-mouth from satisfied existing customers. Therefore, regularly quantifying customer service performance is essential for transit agencies to continue to improve on their strengths and to identify and address areas of weakness before they become serious customer service issues.

Transit agencies use a number of techniques for measuring customer service, ranging in level of effort from direct measurements of agency services (e.g., telephone hold time), to tracking customer compliments and complaints, to conducting customer satisfaction surveys.

Direct Measurement

TCRP Report 88 (*27*) identifies the following service-related performance measures that can be readily tracked:

- *Percent of missed phone calls*—percent of total calls to a telephone line (e.g., reservation service, information center) in which the customer hangs up prior to speaking with an agent.
- *Percent of calls held excessively long*—percent of total calls to a telephone line where the customer hold time exceeds a defined standard.
- *Customer service response time*—the time between first being contacted by a customer (e.g., by phone, letter, or e-mail) and when a substantive response is

provided (i.e., simply acknowledging receipt of the contact—while important in letting the customer know it was received—does not provide the information or assistance being sought). Service standards can be set for different forms of contact or different types of questions and assistance, with performance compared to the standards.

Compliment and Complaint Tracking

Giving customers tools to provide feedback to the transit agency is a relatively inexpensive way to track customer service performance over time. Because customer satisfaction surveys can be expensive to conduct, compliment and complaint tracking can be used to provide continuous input about customer service between major surveying efforts. Although the information is based only on those customers who take the time to provide feedback, it is still useful for identifying patterns of problems and for recognizing exceptional service.

A variety of means are recommended for providing feedback (e.g., web-based forms, customer service e-mail address, customer service hotline, postage-paid card), along with regularly highlighting the existence of these feedback tools to customers. It is also recommended that customers receive feedback promptly, so they feel that they are being listened to and are feel encouraged to continue providing feedback. Complaints and compliments can be categorized by topic (e.g., driver courtesy, late bus, graffiti) and complaint and compliment rates can be measured per boarding (e.g., per 100,000 passenger boardings) or per month (*27*).

Customer Satisfaction Surveys

Customer surveys help transit operators identify the quality of service factors of greatest importance to their customers. They can also be used to help prioritize future quality of service improvement initiatives, measure the degree of success of past initiatives, and track changes in service quality over time. Surveys can identify not only areas of existing passenger satisfaction or dissatisfaction, but the degree to which particular factors influence customer satisfaction. Thus, these surveys can help identify the quality of service factors of greatest importance to the riders of a particular transit system. Exhibit 5-25 shows examples of service attributes that could be rated as part of a customer satisfaction survey, with each attribute rated on a 1 to 5 or 1 to 10 scale, for instance.

See TCRP Report 47 *for detailed information on customer satisfaction surveys.*

Appendix A of *TCRP Report 88* (*27*) provides a brief overview of customer satisfaction surveying, while *TCRP Report 47* (*28*) provides detailed guidance on performing customer satisfaction surveys.

Exhibit 5-25
Examples of Transit Service Attributes

Absence of graffiti	Frequency of service on Saturdays/Sundays
Absence of offensive odors	Frequent service so that wait times are short
Accessibility to persons with disabilities	Friendly, courteous, quick service from personnel
Availability of handrails or grab bars	Having station/stop near one's destination
Availability of monthly discount passes	Having station/stop near one's home
Availability of schedule information	Hours of service during weekdays
Availability of schedules/maps at stops	Number of transfer points outside downtown
Availability of seats on train/bus	Physical condition of stations/stops
Availability of shelter and benches at stops	Physical condition of vehicles and infrastructure
Cleanliness of interior, seats, windows	Posted minutes to next train/bus at stations/stops
Cleanliness of stations/stops	Quietness of the vehicles and system
Cleanliness of train/bus exterior	Reliable trains/buses that come on schedule
Clear and timely announcements of stops	Route/direction information visible on trains/buses
Comfort of seats on train/bus	Safe and competent drivers/conductors
Connecting bus service to main bus stops	Safety from crime at stations/stops
Cost effectiveness, affordability, and value	Safety from crime on trains/buses
Cost of making transfers	Short wait time for transfers
Display of customer service number	Signs/information in Spanish as well as English
Ease of opening doors when getting on/off	Smoothness of ride and stops
Ease of paying fare, purchasing tokens	Station/stop names visible from train/bus
Explanations and announcements of delays	Temperature on train/bus—not hot/cold
Fairness/consistency of fare structure	The train/bus traveling at a safe speed
Freedom from nuisance behaviors of riders	Trains/buses that are not overcrowded
Frequency of delays from breakdowns/emergencies	Transit personnel who know system

Source: *TCRP Report 47* (*28*).

Passenger Environment Surveys

Passenger environment surveys use a "secret shopper" technique, in which trained checkers travel through the transit system, rating a variety of trip attributes in order to provide a quantitative evaluation of factors that passengers would think of qualitatively (*27*). For example, one rail system has rated the interior cleanliness of train cars on a 0 (lowest) to 7 (highest) scale. Points are deducted for each incidence of small litter (smaller than a 3-by-5-inch or 75-by-125-mm card), large litter, food, broken glass, spills, and biohazards, with different point values applying to each category (*29*).

Factors that could be evaluated for transit vehicles include (*27*):

- *Cleanliness and appearance*—amount of litter; exterior dirt conditions; floor and seat cleanliness; graffiti; and window condition;
- *Customer information*—readable and correct vehicle signage; presence of priority seating stickers (bus); correct and legible maps; correct and adequate bus stop signage; and audible, understandable, and accurate public address announcements;
- *Equipment*—climate control conditions; operative kneeling feature, wheelchair lift, windows, and rear door (bus); or door panel condition and lighting (rail); and
- *Operators*—proper uniforming; proper display of badges and proper use of kneeling feature (bus).

Factors that could be evaluated for transit stations include (*27*):

- *Cleanliness and appearance*—amount of litter; station floor and seat cleanliness; and graffiti;
- *Customer information*—readable and correct signage; correct and legible maps; and audible, understandable, and accurate public address announcements;

- *Equipment*—functional speakers in stations; escalators/elevators in operation; public telephones in working order; station control areas that have a working booth microphone; trash receptacles usable in stations; functional token/MetroCard vending machines; and functional turnstiles; and
- *Station agents*—proper uniforming and proper display of badges.

Additional information on preparing and conducting passenger environment surveys can be found in *TCRP Report 88* (*27*).

MULTIMODAL LEVEL OF SERVICE

Overview

The TCQSM's CD-ROM provides an Excel spreadsheet for implementing this method.

Multimodal LOS was developed by an NCHRP project (*28*) as part of a family of measures for estimating automobile, pedestrian, bicycle, and transit LOS. These measures were subsequently incorporated into the *Highway Capacity Manual 2010* (*1*). They can be used to compare the relative quality of service provided to the users of each mode using a street, and to estimate the impact of reallocating street right-of-way on each mode's quality of service. Because the transit LOS component incorporates many of the factors included in the fixed-route QOS framework, it is also useful for analyses where a range of transit QOS factors are desired to be evaluated, but only a single transit LOS letter is desired as an output.

This method can be used to evaluate transit service that operates at grade within a roadway right-of-way (typically bus, light rail, and streetcar), including off-street surface roadways. The method was not designed to evaluate transit operating in grade-separated rights-of-way above or below a roadway. The A-F LOS letter produced by this method for transit service on the street can be directly compared to the LOS letters produced for the automobile, pedestrian, and bicycle modes operating on the street (e.g., LOS B for transit and LOS B for bicycle indicates a similar level of traveler satisfaction with each mode). Individual modal LOS values should not be combined into an overall LOS for the roadway.

Transit LOS incorporates factors that bear on all aspects of a transit trip up to the point a passenger boards a transit vehicle at a stop along an urban street:

- *Walking to the stop satisfaction*—measured by the quality of the pedestrian environment along the street;
- *Waiting for transit service satisfaction*—measured by service frequency, schedule reliability, and the kinds of amenities provided at the transit stop; and
- *On-board satisfaction*—measured by the level of crowding on the transit vehicle as it departs the stop and the speed of the service.

To allow comparisons with other travel modes on a street, a common unit of a street segment is used. A street segment is defined as the length of street between intersections where traffic on the street may have to stop due to traffic control (i.e., signalized intersections, roundabouts, intersections where the street is STOP or YIELD controlled), plus the intersection at the downstream end of the segment. Each direction of travel on the street is analyzed separately.

This section presents only the method for calculating transit LOS. To calculate the LOS of other modes on an urban street, consult Chapter 17 (Urban Street Segments) of the *Highway Capacity Manual 2010* (*1*).

Input Data

Exhibit 5-26 summarizes the input data required to calculate transit LOS and potential sources for them. The data are divided into transit operations data, transit amenity data, and pedestrian environment data. Details about each item are provided after the exhibit.

Exhibit 5-26
Transit LOS Input Data

Item	Potential Sources
TRANSIT OPERATIONS DATA	
Frequency (veh/h)	Timetables
Average excess wait time (min)	Archived AVL data, field data
Average passenger load factor (p/seat)	Archived APC data, field data, transit agency vehicle data
Average transit travel speed (mi/h)	Timetables, TCQSM methods, HCM methods, field data
Average passenger trip length (mi)	Default, NTD, field data for NTD, archived APC/smart card data
TRANSIT AMENITY DATA	
Percent stops in segment with a shelter	Field data, transit agency infrastructure database
Percent stops in segment with a bench	Field data, transit agency infrastructure database
PEDESTRIAN ENVIRONMENT DATA	
Sidewalk width (ft)	Field data, aerial photography, infrastructure database
Buffer width from sidewalk to street (ft)	Field data, aerial photography
Presence of continuous barrier	Field data, aerial photography
Outside lane, shoulder, and bicycle lane widths (ft)	Field data, aerial photography, infrastructure database
Number of through travel lanes in analysis direction (lanes)	Field data, aerial photography, infrastructure database
Motorized vehicle flow rate (veh/h)	Traffic counts
Motorized vehicle running speed (mi/h)	Field data, HCM methods, simulation

Frequency

Transit frequency is the number of transit vehicles scheduled to stop in or near the segment during one hour. For the purposes of determining frequency, transit service can be considered "local" or "nonlocal." Local service makes regular stops along the street (typically every 0.25 mi [400 m] or less), but does not necessarily stop within a given segment when segment lengths are short or when transit stops alternate between the near and far sides of the boundary intersections that define a segment. Nonlocal service operates at longer stop spacing than local routes (e.g., limited-stop, bus rapid transit, and express routes). Local service is always included in determining frequency. Nonlocal service is only included when it stops within the segment. When a bus stop is not located in the segment, use average values for the closest stops in either direction, as long as they are located within 0.25 mi of one end of the segment or the other.

Average Excess Wait Time

Average excess wait time is calculated as described in the Reliability section above.

Average Passenger Load Factor

Load factor is calculated as described in the Passenger Load section above, and is used for both bus and rail vehicles, regardless of relative standing and seated capacities. When field observations are used to determine passenger loading, it is sufficient to define just a few categories that can be readily observed from outside the vehicle (e.g., numerous empty seats, nearly full seated load, some standees, many standees, packed vehicle) and to develop a default load factor for each category. This variable has no impact on LOS below an 80% seated load and has more of an impact on LOS when standees are present than when they are not.

Average Transit Speed

Average transit speed reflects speed within the segment. If transit LOS is being compared to other modal LOS, average transit speed should be calculated using the method given in the *Highway Capacity Manual* (*1*) to allow consistent comparisons of LOS results between modes, as motorized vehicle speed is an input to other modes' LOS calculations. If only transit LOS is being evaluated and future conditions are part of the analysis, then either TCQSM or HCM speed estimation methods, or simulation, can be used to estimate average transit speed; however, the selected method should be used for all analyzed conditions. If only transit LOS under existing conditions is being evaluated, then timetable data or field measurements can also be considered. When different routes with different speeds are included in the segment's frequency value, an average speed weighted by frequency should be used.

Average Passenger Trip Length

Average passenger trip length is used by the method to convert schedule reliability and values of time for amenities into a perceived travel time rate. The value can be defaulted using an average U.S. value of 3.7 mi (6.0 km) (*28*) or a transit agency default value derived from the NTD by dividing total passenger miles by total unlinked trips. A route-specific value can also be determined from archived APC or smart card data or from NTD count sheets for the route by dividing total passenger miles by the total number of boarding passengers.

Passenger Amenity Data

Information about the presence of benches and shelters is required for each stop in an analysis segment. Shelters with benches are counted as both shelters and benches. The percentage of stops in each segment with each type of amenity should be determined. The existence of passenger amenities is used by the method in determining average perceived waiting time at a stop.

Pedestrian Environment Data

Pedestrian environment data is used by the method to adjust the transit LOS result based on the quality of the pedestrian environment in the segment. Most of the required data elements can be readily determined from a field visit or detailed aerial photography. However, motorized traffic flow rates (peak 15-min flows expressed in terms of vehicles per hour) and running speeds (average segment speed, including delay at the downstream intersection) may require data collection or analysis using other tools (e.g., the HCM [*1*]).

A continuous barrier is defined as a solid object (e.g., Jersey barrier) at least 3 ft (0.9 m high) or a row of repetitive vertical objects (e.g., trees or bollards) at least 3 ft high with an average spacing of 20 ft (6 m) or less.

Calculation Steps

Step 1: Determine the Transit Wait–Ride Score

The transit wait–ride score is a performance measure that compares the attractiveness of the transit service being evaluated to a baseline transit service that operates once an hour at an average travel speed of 10 or 15 mi/h (16 or 25 km/h), depending on the location of the analysis segment. The value of the transit wait–ride score reflects the relative ridership that the service would attract compared to the baseline service. Thus, a value of 2.0 for the transit wait–ride score indicates that the service being evaluated would be expected to attract twice as much ridership as the baseline service, due to its higher quality of service. It is not necessary to actually estimate ridership for the route; the proportional change in ridership that would occur is the value of interest.

If no transit service is provided within the segment in the direction of travel being analyzed, then the transit wait–ride score is set to 0.0. Otherwise, the transit wait–ride score is calculated using Equation 5-5. A larger score corresponds to better performance.

$$s_{w-r} = f_h f_{tt} \quad \text{Equation 5-5}$$

where

s_{w-r} = transit wait–ride score,

f_h = headway factor, and

f_{tt} = perceived travel time factor.

The process for calculating the two component factors of the transit wait–ride score, the headway factor, and the perceived travel time factor, is described below.

Headway Factor

The headway factor represents the ratio of the estimated ridership at the transit headway being evaluated to the estimated ridership at a base headway of 60 min. The ridership estimates are developed from an assumed set of ridership elasticities for changes in headway (*31*). The headway factor is computed by Equation 5-6 (*1*).

$$f_h = 4.00e^{-1.434/(f+0.001)} \quad \text{Equation 5-6}$$

where

f_h = headway factor, and

f = transit frequency for the segment (veh/h).

Perceived Travel Time Factor

The perceived travel time factor represents the ratio of the estimated ridership at the perceived transit speed being evaluated to the estimated ridership at a base speed.

The base speed is 10 mi/h (16 km/h) for the central business districts of metropolitan areas with populations of 5 million or more and 15 mi/h (25 km/h) otherwise.

The perceived speed of transit service is affected by the actual speed of the service, the degree of crowding on board the transit vehicle, the reliability (lateness) of the service, and the amenities provided at the transit stop. Each of these elements is converted into a travel time rate expressed in minutes per mile, and are subsequently combined to produce an overall perceived travel time rate. The ridership estimated for a given travel time rate is developed from an assumed elasticity for changes in travel time rate (*32*). The perceived travel time factor is determined from Equation 5-7:

Equation 5-7

$$f_{tt} = \frac{(E-1)T_{btt} - (E+1)T_{ptt}}{(E-1)T_{ptt} - (E+1)T_{btt}}$$

with

Equation 5-8

$$T_{ptt} = \left(f_{pl}\frac{60}{S}\right) + (2T_{ex}) - T_{at}$$

Equation 5-9

$$f_{pl} = \begin{cases} 1.00 & L_f \le 0.80 \\ 1 + \dfrac{4(L_f - 0.80)}{4.2} & 0.80 < L_f \le 1.00 \\ 1 + \dfrac{4(L_f - 0.80) + (L_f - 1.00)(6.5 + [5(L_f - 1.00)])}{4.2L_f} & L_f > 1.00 \end{cases}$$

Equation 5-10

$$T_{at} = \frac{1.3p_{sh} + 0.2p_{be}}{l_{pt}}$$

where

f_{tt} = perceived travel time factor;

E = ridership elasticity with respect to changes in the travel time rate (default - 0.40);

T_{btt} = base travel time rate = 6.0 for the CBD of a metropolitan area with 5 million persons or more, otherwise = 4.0 (min/mi);

T_{ptt} = perceived travel time rate (min/mi);

T_{ex} = excess wait time rate due to late arrivals (min/mi) = t_{ex} / l_{pt};

t_{ex} = excess wait time due to late arrivals (min);

l_{pt} = average passenger trip length (mi);

T_{at} = perceived amenity time rate (min/mi);

f_{pl} = passenger load weighting factor;

S = average travel speed of transit vehicles along the segment (mi/h);

L_f = average passenger load factor (p/seat);

p_{sh} = proportion of stops on segment with shelters (decimal); and

p_{be} = proportion of stops on segment with benches (decimal).

Equation 5-8 shows that the perceived travel time rate has three components:

- A perceived travel speed, based on the actual travel speed, but adjusted to reflect on-board crowding;
- Added perceived travel time due to excess wait time; and
- Subtracted perceived travel time due to the provision of amenities at the transit stop.

The perceived travel time weighting factor for crowding ranges from 1.00 when the load factor is 0.8 p/seat or less to 2.32 at a load factor of 1.6 p/seat (*12*). The weighting factor for excess wait time is 2, reflecting that waiting time is perceived as being more onerous than in-vehicle time. Shelters are assumed to provide a perceived travel time benefit of 1.3 min, while benches provide a perceived travel time benefit of 0.2 min (*12*). Because excess wait time and the amenity travel time benefit are both expressed in units of time, these are converted to travel time rates by dividing them by the average passenger trip length.

Step 2: Determine the Pedestrian Environment Score

The pedestrian environment score reflects the quality of the pedestrian environment in the vicinity of the transit stop. A poor pedestrian environment produces a worse transit LOS for a given transit service condition, while a good pedestrian environment produces a better transit LOS. The score is sensitive to the existence and quality of pedestrian facilities, their perceived separation from motorized vehicle traffic, and the volume and speed of motorized vehicle traffic.

The pedestrian environment score is calculated using Equation 5-11:

$$I_p = 6.0468 + f_w + f_v + f_s \quad \textbf{Equation 5-11}$$

with

$$f_w = -1.2276 \ln\left(W_v + 0.5W_1 + 50p_{pk} + W_{buf}f_b + W_{aA}f_{sw}\right) \quad \textbf{Equation 5-12}$$

$$f_v = 0.0091\frac{v_m}{4} \quad \textbf{Equation 5-13}$$

$$f_s = 4\left(\frac{S_R}{100}\right)^2 \quad \textbf{Equation 5-14}$$

where

I_p = pedestrian environment score;

f_w = cross-section adjustment factor;

f_v = motorized vehicle volume adjustment factor;

f_S = motorized vehicle speed adjustment factor;

$\ln(x)$ = natural log of x;

W_v = effective total width of outside through lane, bicycle lane, and shoulder (parking lane) as a function of traffic volume (see Exhibit 5-27) (ft);

W_1 = effective width of combined bicycle lane and shoulder (see Exhibit 5-27) (ft);

p_{pk} = proportion of on-street parking occupied (decimal);

W_{buf} = buffer width between roadway and available sidewalk (= 0.0 if sidewalk does not exist) (ft);

f_b = buffer area coefficient = 5.37 for any continuous barrier at least 3 ft (0.9 m) high that is located between the sidewalk and the outside edge of roadway; otherwise use 1.0;

W_A = available sidewalk width = 0.0 if sidewalk does not exist (ft);

W_{aA} = adjusted available sidewalk width = min(W_A, 10) (ft);

f_{sw} = sidewalk width coefficient = 6.0 – 0.3 W_{aA};

v_m = outside lane motorized vehicle demand flow rate at mid-segment (i.e., lane closest to the subject sidewalk) (veh/h); and

S_R = average motorized vehicle running speed in the segment, including delay at the downstream intersection (mi/h).

Exhibit 5-27
Variables for Pedestrian Environment Score

Condition	Variable When Condition Is Satisfied	Variable When Condition Is Not Satisfied
p_{pk} = 0.0	$W_t = W_{ol} + W_{bl} + W_{os}^*$	$W_t = W_{ol} + W_{bl}$
v_m > 160 veh/h or street is divided	$W_v = W_t$	$W_v = W_t (2 - 0.005\ v_m)$
p_{pk} < 0.25 or parking is striped	$W_1 = W_{bl} + W_{os}^*$	$W_1 = 10$

Notes: W_t = total width of the outside through lane, bicycle lane, and paved shoulder or parking lane (ft);
W_{ol} = width of the outside through lane (ft);
W_{os}^* = adjusted width of paved outside shoulder or parking lane; if curb is present $W_{os}^* = W_{os} - 1.5 \geq 0.0$, otherwise $W_{os}^* = W_{os}$ (ft);
W_{os} = width of paved outside shoulder or parking lane (ft); and
W_{bl} = width of the bicycle lane (= 0.0 if bicycle lane not provided) (ft).

The conditions listed in Exhibit 5-27 are evaluated in order. If a condition is satisfied, then the equation in the second column of the row is used to calculate a variable, otherwise, the equation in the third column of the row is used.

If a continuous sidewalk does not exist for the entire length of the segment, the segment will need to be divided into subsegments and a pedestrian environment score calculated for each subsegment. A weighted pedestrian environment score should be calculated based on the length of each subsegment.

Step 3: Determine the Transit LOS Score

The transit LOS score is computed as follows:

Equation 5-15

$$I_t = 6.0 - 1.50 s_{w-r} + 0.15 I_p$$

where I_t is the transit LOS score, $\mathbf{s_{w-r}}$ is the transit wait–ride score, and I_p is the pedestrian environment score.

Step 4: Determine Transit LOS

Transit LOS is determined by comparing the transit LOS score with the thresholds in Exhibit 5-28.

Exhibit 5-28
Thresholds for Transit LOS Values

LOS	LOS Score
A	≤2.00
B	>2.00–2.75
C	>2.75–3.50
D	>3.50–4.25
E	>4.25–5.00
F	>5.00

3. DEMAND-RESPONSIVE QUALITY OF SERVICE

OVERVIEW

This QOS framework is not intended to apply to evaluating ADA paratransit service.

This section describes a QOS evaluation framework for demand-responsive transportation (DRT). The framework can be used for both general public and limited eligibility DRT services, but it is not intended for evaluation of ADA paratransit service. Federal regulations governing ADA paratransit stipulate specific service criteria that establish required levels of service for those riders that are ADA-eligible. This section's QOS evaluation framework is also not intended to evaluate the range of flexible services, beyond DRT, that are discussed in Chapter 2, Mode and Service Concepts. Some of these QOS measures could be useful for assessing the various flexible services beyond DRT, with revision or adaption to the service levels provided, but the wide range of these services precludes the use of one standard QOS evaluation framework.

Consistent with the evaluation framework for fixed-route transit presented in the previous section, the service measures for DRT are provided in two categories: (*a*) availability and (*b*) comfort and convenience. The core demand responsive QOS measures are listed in Exhibit 5-29, along with the exhibit(s) where the service levels for each measure are presented.

Exhibit 5-29
Quality of Service Framework: Demand Responsive Transit

Availability	Comfort and Convenience
Response time (Exhibit 5-30)	Reliability (Exhibit 5-35)
Service span (Exhibit 5-31 and Exhibit 5-32)	Travel time (Exhibit 5-36)
Service coverage (no separate exhibit provided)	No-shows (Exhibit 5-38)

AVAILABILITY MEASURES

Response Time

Response time is an important availability measure for passengers, defining how far in advance they must schedule a DRT trip. Response time is measured as the minimum amount of time a rider needs to schedule and access a trip or the minimum advance reservation time. This measure is most appropriate when the trips are scheduled each time a rider wants to travel. When service is provided on a standing-order or subscription basis —that is, riders are picked up on pre-scheduled days at pre-scheduled times and do not need to call in advance for each trip —the service is essentially guaranteed, and riders do not have to consider response time for each trip. This is a high level of service for riders, and is included as one of the seven service levels shown in Exhibit 5-30. These levels range from "guaranteed" service for a passenger with a standing-order reservation—requiring only an initial call to schedule service—to service that requires a passenger to schedule a trip more than one week in advance.

The first service level, *guaranteed/standing-order service,* is included in the framework as it represents a high level of service for those riders with regular trips. The next level is *same-day* DRT, allowing passengers to make spontaneous trips, though requiring the transit agency's DRT control room staff to handle the faster pace and increased pressure of real-time scheduling. Same-day service requires the transit agency to ensure effective procedures for scheduling and dispatching trips on a real-

time basis. Technology such as GPS/AVL and mobile data computers (MDCs) can be particularly effective to support same-day service.

Same-day service on a space-available basis is the third service level, provided by some DRT systems to take advantage of same-day cancellations and other same-day service adjustments that open up capacity. The additional capacity is made available to riders for trips on a short-notice basis. While there may be limited capacity for trips on a space-available basis on the day of travel, offering this capacity for additional trips can be convenient for riders and increase productivity for the transit agency.

The fourth level is *will-call* or "*call when ready"* service. DRT systems may provide this level of service only for certain trips, typically return trips from medical appointments that often run late. If a return trip from a medical appointment is scheduled in advance and the appointment runs late, the passenger is a no-show because she is not ready to leave, and the DRT control center then has to schedule a second return trip by inserting a trip into the schedule. A will-call or "call when ready" trip can be an effective way to address such situations.

At subsequent service levels, the response time increases for riders, so that more advance planning is required for trips. At the last level, when trips require more than one week in advance to schedule, DRT service is definitely not an option for spontaneous trips. From the transit agency perspective, the requirement for a longer advance reservation allows more time to create vehicle schedules and plan driver shifts; however, a longer advance reservation time period usually means a higher rate of cancelled trips and often more late cancels and no-shows as well. When passengers book DRT trips days in advance, there are more opportunities for the passenger to change their trip plans and even to forget a booked trip, resulting in a no-show.

Response Time	Passenger Perspective	Transit Agency Perspective
Guaranteed (Standing-order or subscription service)	• Provides riders with recurring trips the opportunity to make one call to request service and then rely on that service to arrive on the requested days and time • Eliminates the need for riders with standing-order service to call before each repetitive trip • Restricts flexibility for riders who make one-time and random trips if the transit agency uses most of its capacity to serve standing-order trips (in which case the service becomes "captive" to repeat passengers)	• Effectively serves recurring trips for work, school, medical services, and human service programs • Eliminates the need for DRT control center staff to respond to repeated requests for passenger trips needed at the same time on the same days • Helps to develop driver schedules, with standing-order trips providing a "skeleton" onto which one-time trips are placed • Requires periodic evaluation of standing-order trip schedules to maintain schedule efficiency and to ensure sufficient capacity for random trips • Requires policies/procedures to ensure riders cancel unneeded trips; riders may be less diligent in canceling standing-order trips

Exhibit 5-30
DRT Response Time QOS

Note that the first service level – guaranteed – is available only to riders who have standing-order service. Riders without standing-order service are provided with different QOS depending on the capacity of the DRT service and the agency's policy on response time.

Exhibit 5-30 (cont'd.)
DRT Response Time QOS

Response Time	Passenger Perspective	Transit Agency Perspective
Same-day service	• Allows passengers to make DRT trips relatively spontaneously • Requires very little advance planning, with the ability to take a trip within as little as 2 to 3 hours of a trip request	• Requires the DRT control center staff to handle the faster pace and increased pressure of real-time scheduling • May also be scheduled/dispatched by drivers, using cell phones or other technology (e.g., GPS/AVL), on a real-time basis • May work more effectively when scheduling and dispatching are facilitated with technology, particularly GPS/AVL and MDCs • May experience fewer late cancels/ no-shows compared to DRT requiring more advance notice
Same-day service on space available basis	• Provides riders the opportunity to book a same-day trip if space is available • May be adequate service for trips that are last-minute and not time sensitive • Requires riders to be flexible as to time of travel and open to a trip turn-down if space not available	• Allows DRT provider to use capacity that otherwise might go unused due to same-day cancellations or other day-of-service adjustments • Requires the DRT control center staff to continually monitor service and watch for "slack" time in drivers' schedules when an additional trip could be inserted
Will-call or Call When Ready	• Provides option for passenger to call for return trip when ready; eligibility may be restricted to specific trip purposes (e.g,. a medical appointment) • Eliminates passenger anxiety about missing the return trip • Requires a potentially longer time for the DRT vehicle to arrive after calling for a return trip	• Requires the DRT control center staff and drivers to adapt procedures to insert trips into a driver's schedule on short notice • Reduces the number of passenger no-shows for scheduled return trips

Exhibit 5-30 (cont'd.)
DRT Response Time QOS

Response Time	Passenger Perspective	Transit Agency Perspective
Next-day/ 24-hour advance reservation	• Requires some advance planning • Inconvenient if transit agency requires reservation literally "24-hours-in-advance" rather than by the end of the previous day	• Requires the transit agency to adopt policies and procedures for deadlines to request next-day service (e.g. by the end of the previous business day or literally 24 hours in advance) • Must address how and when passengers request next-day service if service is not provided 7 days/week • If no weekend service, this could mean allowing requests for Monday service to be made on Fridays, more than 24 hours in advance • Alternatively, requests could be allowed via electronic or telephone message over the weekend, but the transit agency must provide staff and establish procedures to schedule Monday trips
Two-day/48-hour advance reservation and up to one week	• Requires more advance planning than next-day service • For important time-sensitive trips, passengers may want the option to schedule more than one week in advance	• Increases risk for higher rates of cancellations, late cancels, and no-shows • A longer advance period may be needed for passengers to request important time-sensitive trips
More than one week in advance	• Requires advance planning for all DRT trips • For important time-sensitive trips, passengers may like the option to schedule trips more than one week in advance	• Results in higher rates of cancellations and likely higher rates of late cancel and no-shows as well • Consider whether response time policy balances riders' ability/ options for scheduling trip requests, while keeping cancellations/late cancels/no-shows to a minimum

Most DRT systems offer a mix of standing-order service and independently scheduled demand response trips. The response times for demand trips vary by transit agency policy and operational practice. DRT systems should monitor quality of service by examining actual response times to ensure operational practice is consistent with stated policy. To calculate response time, the DRT provider should look at the minimum amount of time that a passenger needs to schedule a trip in relation to the response time policy. For example, if the policy of the DRT system is that service is provided on a next-day or 24-hours-in-advance basis, a rider should be able to reserve a DRT trip the day before the service is desired. Some riders may schedule their trips more than a day in advance if the transit agency's policy permits this, but if the DRT provider's policy states that service is provided on a next-day basis, then riders should routinely be able to reserve trips on a next-day basis.

Data on response time can be obtained from DRT control center staff that book trips (e.g., call-takers, reservationists, dispatchers). Another approach is to survey riders to obtain their input and experience with response time.

Using an average for this measure is not appropriate if riders are able to reserve trips farther in advance than the stated minimum response time policy. For example, a user might call one week in advance to book a trip even though this is not necessary. An average would capture such response times for trips scheduled farther in advance than is necessary and would thus not be representative of actual operations.

Many DRT providers have a maximum response time, in addition to a minimum. This is stated in DRT rider guides as, for example, "riders may schedule trips between one to seven days in advance of the desired travel date." A number of DRT systems use 14 days as the maximum, a time period that originated with the original ADA regulations, which stipulated that ADA paratransit systems allow trip reservations to be made 14 days in advance. Amendments to the ADA in 1996 removed that requirement, among other changes.

A maximum advance reservation window means that riders cannot schedule trips farther ahead than the stated policy. Without a maximum, riders may schedule trips *far* in advance and then find their travel plans change, so they cancel their scheduled trips or forget the reservation and no-show the trip. Both excessive cancellations and no-shows negatively impact DRT performance. Research on DRT performance found excessive cancellations can be mitigated by shortening the advance reservation window, so riders will be more sure of their travel plans when they book trips and less likely to cancel or even to forget about their previously reserved trips (*33*).

Service Span

Service span measures the days per week and hours per day that DRT service is available in a particular area. To properly assess DRT service span, one must look at the two components of service span: *days* of service and *hours per day* of service. Assessment of service span may be particularly important for the DRT mode since, in many small urban communities and rural counties, service is not provided on a full weekly basis. Service may not be available on weekend days, and, if funding is limited, service may not be available on all weekdays.

Days of Service

Days of service is the first component for measuring DRT service span, with five service levels as shown in Exhibit 5-31. At the first level, DRT service is available seven days per week. This is a high level of service for passengers, though seven-day service will require more resources for the transit agency to support. Significantly, for those riders who are transit dependent, service availability on Saturdays and Sundays as well as weekdays allows for trips that are more often social and recreational. Such trips have been referred to as "life-fulfilling" when compared to trips to the grocery store, medical appointments, bank, etc., that are "life-sustaining" trips.

At the second service level, DRT is available six days per week, still a relatively high level of service. At the next level, five days per week of service, DRT is available on weekdays, Monday through Friday. Daily weekday service is considered basic transit service for a community, and the minimum level of service for riders who have other transportation options.

Service availability decreases at the last two levels: service *less than five days per week* and *less than weekly*. At these levels, DRT serves only transit-dependent individuals and trip purposes that are often life sustaining. *Less than weekly* service

might be the best service that a rural transit agency can provide, rationing resources so that DRT service rotates among scattered small communities within a large service area, providing a "lifeline" service for those who have no other transportation options.

Exhibit 5-31
DRT Days of Service QOS

Days of Service	Passenger Perspective	Transit Agency Perspective
7 days/week	• Allows DRT trips every day of the week including the weekend • Increases access to employment and education any day of the week • Permits trips on weekend days that are more likely "life-fulfilling" (e.g., trips for social, recreational, religious purposes)	• Provides transit service every day of the week • Ensures community residents have access to trips for "life-fulfilling" purposes (as opposed to life-sustaining purposes) • Requires more operating funds to provide weekend service in addition to weekday service • Requires a larger driver work force to cover 7-day service span • Increases vehicle maintenance needs and impacts maintenance scheduling • May need to consider strategies to reduce payroll hours, e.g., by increasing part-time work assignments or providing weekend service on an on-call basis (only for trips reserved in advance) or through a taxi-voucher program or volunteer drivers • May increase risk of greater driver absenteeism on weekend days • May reduce productivity (passenger trips per hour) during lower demand periods on weekend days
6 days/week	• Allows DRT trips every day of the traditional work week and at least one weekend day • Increases access to employment and education opportunities beyond the traditional work week to include at least one weekend day • Increases access to medical services available six days per week (e.g., dialysis treatment) • Allows for trips on a weekend day that are more likely "life-fulfilling"	• Increases transit service to the community beyond weekdays by adding DRT on either Saturday or Sunday, depending on agency goals/objectives and community preferences • Requires more operating funds to provide service one weekend day in addition to weekday service • Requires a larger driver work force to cover 6-day service span • Increases vehicle maintenance needs and impacts maintenance scheduling • May increase risk of greater driver absenteeism on the one weekend day • May reduce productivity during lower demand periods on the weekend day

Exhibit 5-31 (cont'd.)
DRT Days of Service QOS

Days of Service	Passenger Perspective	Transit Agency Perspective
5 days/week	• Allows DRT trips every day of the traditional work week • Permits trips by DRT for full-time, weekday employment and education if combined with appropriate hours per day • Provides access to medical services five days per week	• Provides basic weekday transit service for a community • Requires operating funds for service five days per week • Provides the minimum service that may attract choice riders, depending on hours per day of service
Less than 5 days/week	• Provides weekly access by DRT to essential shopping, personal business, medical appointments, and social or government services • Allows trips for part-time employment and education if combined with appropriate hours per day. • Requires pre-planning transit trips for the specific weekdays when service is available • Limits access to some medical services (e.g., dialysis, some medical clinics)	• Provides transit services for transit-dependent riders such as seniors and people with disabilities • Provides options for choice of days in consideration of trip needs for transit-dependent population in the community, e.g., if community has intercity bus service, transit service might be provided on the days allowing transfer connections • Requires less operating funds for service operated fewer than five days per week
Less than weekly	• Allows for "lifeline" trips such as grocery shopping, banking, one-time medical appointments, etc. if planned in advance • Limits the opportunity to use DRT for purposes other than lifeline trips	• Serves only transit-dependent riders • Minimizes the cost of providing transit services and may be the only transit service affordable in a large rural service area with scattered small communities • Requires public information/rider guide material to be clear and specific in explaining the limited service

Hours of Service

The second component of DRT availability is hours of service, as depicted in Exhibit 5-32. At the highest service level, DRT is available 16 or more hours per day, which allows for trips until the mid-evening hours. The second level, with service available 12 to 15.9 hours per day, is good DRT service for most communities and allows DRT to become an integral community service (assuming service is available at least five days per week).

DRT service hours decrease over the next three levels, with more limited hours each service day for trip-making. The last level, service available less than five hours per day, can be seen in rural areas, where, along with limited days of service per week, the transit agency must stretch limited DRT resources over a large geographic area, offering lifeline service to transit-dependent residents in small, isolated communities.

Exhibit 5-32
DRT Hours of Service QOS

Hours of Service	Passenger Perspective	Transit Agency Perspective
≥16.0 h/day	• Allows use of DRT for all trip purposes during daytime hours and until mid-evening • Provides DRT for full-time employment or education, including hours extending until mid-evening	• Provides robust DRT service hours for a community • Requires a commitment of operating funds to sustain this high level of service availability • May increase need to consider strategies to reduce payroll hours, e.g., by increasing part-time work assignments or by providing evening service an on-call basis (only for trips reserved in advance) or through a taxi-voucher program or volunteer drivers
12.0–15.9 h/day	• Allows for DRT use during typical business hours including early evening hours • Permits DRT service for many full-time workers and for full-time and part-time students • Enables DRT trips for medical appointments and health services including some extended hours	• Provides good DRT service hours for most communities. • Allows for transit service to become an integral community service, if matched with service at least 5 days/week.
9.0–11.9 h/day	• Allows DRT trips during daytime business hours • Permits DRT trips for some users with full-time jobs, depending on trip length/travel time from home to work location • Allows transit use for most medical appointments and health services	• Provides basic transit service for a community, if funding does not allow at least 12 hours of service/day
5.0–8.9 h/day	• Allows opportunity for DRT trips for essential shopping, personal business, medical appointments, human or government services, and some part-time jobs and educational programs • Requires pre-planning transit trips to ensure both "going" and return trips are scheduled within service hours	• Provides limited transit service for a community, acceptable if this is the most service a transit agency can provide with available funding
<5.0 h/day	• Limits the opportunity to use transit for any purpose other than lifeline trips such as grocery shopping, banking, or medical appointments • Requires pre-planning transit trips to ensure both "going" and return trips are scheduled within limited hours	• Serves only transit-dependent riders • Minimizes the cost of providing transit services and may be the only transit service affordable in a large rural service area with scattered small communities

Service Coverage

In addition to DRT response time and service span, DRT availability can be measured by the geographic area where passengers can travel: *service coverage* or the service area. This measure is applied differently for DRT than for fixed-route service. For fixed route, service coverage measures the area within walking distance of the transit routes. When combined with the hours and frequency of fixed-route service, service coverage helps to identify the specific areas where people have to access transit routes.

For DRT, service is typically provided throughout the jurisdiction of the transit agency that is funding and providing the transportation service. For example, a city dial-a-ride program will serve all locations within the city limits, for both passenger pick-ups and drop-offs. In some cases, DRT systems may also serve a limited number of specific destinations outside the jurisdictional limits that are important trip destinations for the jurisdiction's residents, for example, a community college located several miles outside the city limits. But typically service coverage for DRT is not like fixed route, where only riders located within specific areas of the jurisdiction are served. All residents (i.e., a general public DRT) or all those defined as eligible (i.e., limited eligibility DRT) can call the DRT system to request a DRT trip from any origin to any destination within the jurisdiction. This means the level of service as measured by service coverage is the same for all DRT riders in the jurisdiction.

There are exceptions to the typical DRT service coverage. The first is ADA paratransit. The ADA regulations, among other service requirements, require transit agencies that operate fixed-route transit to also provide ADA paratransit service within the same service area as the fixed routes, which generally includes a ¾-mile corridor on either side of the routes. Riders who are determined eligible for ADA paratransit can travel between any origin and destination within that defined area. If the transit agency limits ADA paratransit service to the required service area, the rest of the jurisdiction is not available to ADA riders when traveling by ADA paratransit.

Another exception to typical DRT service coverage occurs with some large rural DRT systems. When the DRT provider, often a rural county transit system, must spread limited DRT resources across a large geographic area that includes a number of communities of varying sizes, DRT service may not be available equally throughout the county limits. The largest community in the county may have DRT service throughout the week, and the smaller communities may have service only on specific days each week or possibly on certain days each month; the DRT resources rotate among the smaller communities so that each has at least some DRT availability. And there may be some parts of the rural county that do not have any DRT service coverage, for example very small population clusters, or national forests or other large federal or state lands without residential uses.

In such cases where the service coverage and service span vary within a jurisdiction or larger service area, it may be useful to display the different levels of DRT availability on a map. The graphic would illustrate DRT service coverage as well as the service span, identifying the different levels of service within the large service area. An example is shown in Exhibit 5-33.

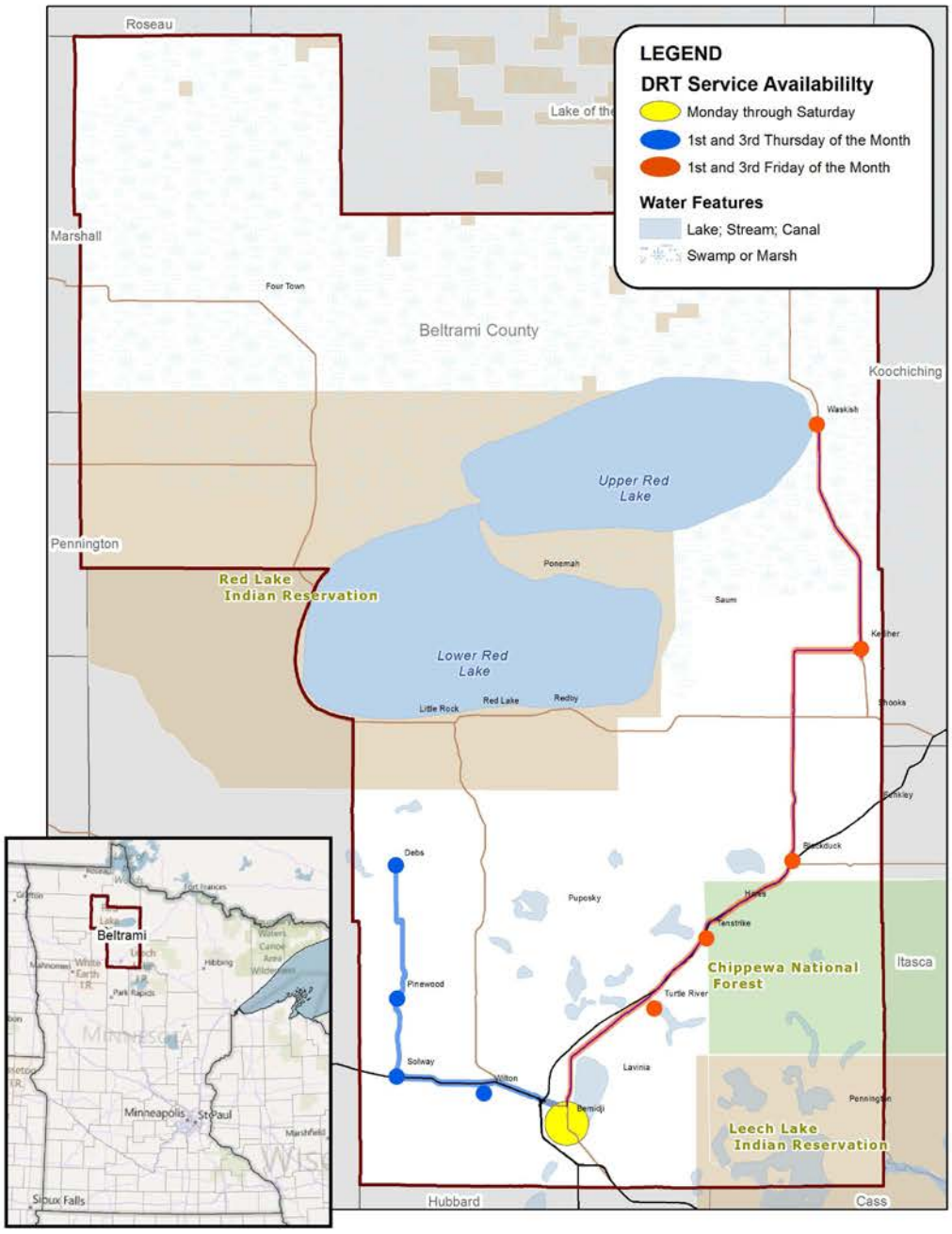


Exhibit 5-33
Example DRT Service Coverage Graphic

COMFORT AND CONVENIENCE MEASURES

Reliability

Reliability of DRT is a critical measure of service level from the passengers' perspective. Passengers want to know: "Will I be able to reserve a trip when I call, or will all the rides be taken?" And once the trip is booked, passengers may ask on the day of service, "Will the vehicle arrive on time?" "Will the driver get me to my appointment on time or will my trip be too long?"

Because of the nature of DRT where riders schedule individual DRT trips, there is more variability than there is for fixed-route service. For fixed-route service, the rider simply walks to the bus stop along the published route a few minutes before the scheduled time when the vehicle will pass by. The rider boards the bus and gets off at the appropriate stop at the scheduled time.

For DRT service, there are several steps to a trip, each with reliability issues. The passenger must first call or contact the DRT office to request the particular trip. Depending on available capacity, the passenger may or may not be able to reserve the desired trip. If there is capacity, the trip may or may not be available at the exact desired time. If the exact time is not available and if the rider has some flexibility, an alternate time may be available. Once the trip is booked, the rider must wait for the vehicle to arrive on the day of service at the scheduled time. This time is typically a *window* of time, so the rider must be ready and waiting during this time frame. The vehicle may arrive on time, or it may be late. And on isolated occasions, unfortunately, the vehicle may never arrive. Once on board the vehicle, the passenger travels to the scheduled destination, with a travel time that varies depending on other passengers who may be sharing the ride and their trip characteristics. If everything goes as scheduled, the rider arrives at his or her destination on time.

Given the different steps involved with a DRT trip, DRT reliability is assessed with two measures: on-time performance and trips turned down.

On-Time Performance

On-time performance measures the degree to which DRT vehicles arrive at the scheduled times. The measure is calculated at the pick-up end of the trip and, for time sensitive trip (e.g., work, school, medical appointments, etc.), at the drop-off end as well.

Many transit agencies, particularly those in urban areas, give passengers a "window of time" within which the DRT vehicle is scheduled to arrive. For example, the agency may have a 30-min on-time window policy, which is common in urban areas. If a passenger books a 10:00 a.m. pick-up, the trip reservationist or dispatcher will tell the passenger the DRT vehicle will arrive between 9:45 and 10:15 a.m., or, depending on specifics of the scheduling process, a variation of 30 min tied to 10:00 a.m. (e.g., 9:50-10:20, 10:00-10:30). If the DRT vehicle arrives any time within that 30-min timeframe, it is on time.

On-time performance is usually measured to ensure that DRT vehicles do not arrive late. However, being *early* can be a problem, too. If the DRT vehicle arrives at the pick-up location before the on-time window begins, passengers may not be ready to leave, and an early arrival at the destination in the morning may mean the passenger is dropped off before the destination building is even open. Generally, transit agencies require that DRT drivers who arrive early for the pick-up wait until the on-time window begins before starting the official "wait time" for the passenger, typically 5 min, but sometimes 3 or up to 10 min depending on the DRT system.

Calculating on-time performance is done on a percentage basis for all trips during the defined time period or for a sample of days over the time period. All trips should be assessed at the pick-up end to determine if the DRT vehicle arrived within the on-time window. Time-sensitive trips should be assessed also at the destination end to see if the vehicle arrived at or before the required time. Trips that are missed by the DRT provider—that is, the vehicle never arrives—should be included within the count of late

trips. Some transit agencies record missed trips as a subset of late or very late trips, and some classify trips that are very late as missed. From the passenger's perspective, DRT reliability is poor if the vehicle is very late or never arrives.

The length of the on-time window is determined by each DRT system. While a 30-min window is common, some transit agencies use 20 min or even 15 min. Other transit agencies may use a window longer than 30 min. DRT providers in rural areas may have a 60-min window, if a window is used at all. Those transit agencies that use a longer on-time window to measure timeliness should achieve a higher percentage of trips on time.

The quality of service levels for DRT on-time performance, shown in Exhibit 5-34, assume a 30-min on-time window, since this is typical. If a different window is used, the LOS thresholds may need adjustment. For example, if a DRT system establishes a 15-min on-time window, it may be appropriate to have 85% and higher as the first service level, with subsequent adjustments to the remaining service levels. If a 60-min window is used, the first service level might be 100%, again with adjustments to the remaining service levels. Importantly, since the on-time window acts as a constraint for scheduling, the length of the window must be considered when evaluating service quality for riders and DRT performance.

Exhibit 5-34
DRT On-time Performance QOS With a 30-min On-time Window

On-Time Percentage	Passenger Perspective	Transit Agency Perspective
≥95.0%	• Provides high level of on-time service • Passengers can rely on DRT to get to destinations/appointments on time • For a frequent rider taking two trips (or one round trip) each weekday per month, 95% on-time performance means no more than 2 late trips out of the monthly total of 40 DRT trips	• Requires constant attention to timely service, with well-trained, effective schedulers/dispatchers, well-trained drivers, timely pull-outs for the DRT vehicles, and riders who are ready to board at the start of the on-time window, especially in a large urban environment • Reduces productivity (passenger trips per revenue hour): maintaining higher on-time performance may require reducing the number of shared rides per trip • May increase cost per passenger trip; lower productivity will result in a higher cost per passenger trip
90.0–94.9%	• Provides good on-time service, assuming late trips are not "very late" (e.g. no more than 10 to 15 min past the on-time window) • Means passengers can rely on DRT to get to destinations/appointments on-time for most scheduled trips, but there will be exceptions on an infrequent basis • For a frequent rider taking two trips each weekday per month, 90% on-time means 4 late trips per month	• Requires well-trained schedulers/dispatchers, well-trained drivers, and timely pull-outs each day of the DRT vehicles to achieve consistent 90% on-time performance or better • Scheduling/dispatch staff should be able to balance 90% on-time performance with reasonable productivity

Exhibit 5-34 (cont'd.) DRT On-time Performance QOS With a 30-min On-time Window

On-Time Percentage	Passenger Perspective	Transit Agency Perspective
80.0–89.9%	• Means passengers can usually rely on DRT to be on time for most scheduled trips, but there will be exceptions • For a frequent rider taking two trips each weekday per month, 80% on time means 8 late trips per month • Riders with time-sensitive trips (e.g., work, school) will consider DRT unreliable if late pick-ups result in late drop-offs	• Suggests need for more training for scheduling/dispatch staff and drivers or revised policies/procedures to improve on-time performance • Percent on-time performance may fall to low 80% range (or lower) during bad weather and transition periods (new service or new service area, change in service provider, new policies/procedures, fleet maintenance problems, and other major changes). Risks an increase in passenger complaints from riders with time-sensitive trips
70.0–79.9%	• Provides only somewhat reliable on-time service • Means passengers can rely on DRT to get to destinations/appointments on-time for the majority of scheduled trips; however, a significant number of trips may be late • For a frequent rider, 70% on-time means 12 late trips for every 40 trips on DRT service, almost one-third of scheduled trips	• Indicates on-time performance is not a priority for DRT service • More attention is needed for scheduling/providing on-time trips • Scheduling/dispatch staff and drivers may need more training and experience • Decreases passenger satisfaction with DRT service and risks loss of DRT rider markets that require dependable service
<70.0%	• Provides unreliable service • A rider will experience late service for one-third or more of scheduled trips	• Demonstrates limited attention to on-time performance • Transit agency should ensure operating staff (management, scheduling/dispatch staff, drivers) focus greater attention on timely service delivery and provide resources to support additional training and tools such as AVL • Limits DRT rider markets to individuals who have no or limited other options for transportation

At the highest quality of service, 95% or more of DRT trips are on time. This is reliable and high-quality service for DRT passengers. It may also be difficult to sustain in a large urban environment, with the variability of DRT operations on a day-to-day basis including the unpredictability of dwell times for individual DRT passengers and the vagaries of traffic. For a frequent rider who takes two one-way trips (one round trip) each weekday for a month, the rider should experience no more than two late trips per month.

While high levels of on-time performance provide riders a high quality of service, they also impact productivity, a key performance statistic for DRT systems. Maintaining a high on-time performance will lower the number of passenger trips provided per hour

of service (productivity) which at the same time increases the operating cost per passenger trip (*34*).

The second service level, 90.0 to 94.9% on-time performance, is still relatively high-quality DRT service. While the percentage does not indicate how late the late trips are, if they are not unreasonably late (e.g., no more than 10–15 min), passengers will likely continue to view the DRT service as reliable. The perceptions of "late," "very late," and what constitutes "unreasonably late" vary among individuals, thus each passenger's perspective on DRT service quality for on-time performance will also vary. Lateness may also be defined by the transit agency, with a performance goal for on-time trips and perhaps penalties if the DRT provider does not achieve that goal. These definitions also vary and may differ from passengers' definitions. What is important is that transit providers focus on providing timely DRT service as it is a key measure of service reliability for the riders.

DRT timeliness decreases with each successive service level. At the fifth and last level, less than 70% of the trips are on time, as defined by the transit agency. A passenger would experience more than 12 late trips for every 40 one-way trips, roughly a third or more of that passenger's trips. DRT riders would not consider this reliable service. At this quality of service, the DRT system is likely serving only transit-dependent riders who have limited or no other options for transportation.

The importance of on-time service for DRT is often reflected in standards that transit agencies set for this measure. Particularly for contracted service, transit agencies may define an on time performance standard, for example that 90% of DRT trips should be on time, and include the standard in contract specifications. Incentive payments may reward the contractor for exceeding the standard, and penalties (liquidated damages) may be assessed if performance falls below the defined standard. Setting a standard for on-time performance must consider the length of the window within which trips are considered on-time. For the typical 30-min window, an on-time performance standard might be set from 90% to 95%, for example, or as a range from 92–95%. If the on-time window is shorter, the standard should be lower. With the on-time window acting as a scheduling constraint, and with the realities of day-to-day operations (e.g., traffic, driver schedules that vary day to day, unpredictability of wait and dwell times for riders), a short window makes it more difficult to ensure a high standard for on-time performance.

Trips Turned Down

DRT passengers will consider the service reliable if they can request and schedule trips when they wish to travel. DRT providers, however, may sometimes turn down riders' trip requests because there is not enough capacity at the riders' requested time. Capacity refers to the space available on the DRT vehicles and to the time available on the vehicles' schedules, considering the number of passenger trips already booked.

If capacity is not available at the passenger's requested time, DRT control center staff (e.g., call-takers, reservationists) may negotiate with the rider to identify a different time for the trip. If the rider can adjust his or her trip time, then the rider can schedule the DRT trip. A trip that is negotiated for a different time is not considered a turn-down because the rider is provided a trip. However, if the rider cannot adjust the trip time, the rider will not be able to travel by DRT for that trip. Unlike fixed-route service where the bus travels along a pre-determined path at pre-determined times and

picks up passengers until no more standees can fit on the vehicle, a DRT system responds to passengers' individualized trip requests, traveling between different origin and destination locations with schedules that vary day to day. If the DRT capacity is already booked and a rider's requested trip cannot be reasonably inserted into the existing schedule, then the rider's trip is turned down.

Generally, DRT transit services operate with all passengers seated (i.e., the number of passengers scheduled does not exceed the number of seats and wheelchair positions available). Some transit agencies may expand vehicle capacity by accepting standees.

Some DRT providers try to avoid trip turn-downs by over-accepting trip requests which they may or may not be able to schedule and provide on the day of desired travel. If there are cancellations before or on the day of desired travel, those trips may be provided. As another approach, some transit agencies with advance reservation DRT service allow same-day requests on a space-available basis, which they serve with capacity that becomes available on the day of service from same-day trip cancellations.

Most DRT providers turn down trips on an occasional basis, during periods of unusual demand, when they are unexpectedly short on drivers, or because of some other atypical event. However, trip turn-downs that become more frequent signal insufficient capacity at the times when riders wish to travel. The transit agency should monitor and document turn-downs to determine the times of the day and days of the week when they occur. When DRT riders experience frequent trip turn-downs, they may stop requesting trips.

Frequent trip turn-downs suggest the transit agency should review DRT service deployment and try to better match trip capacity with trip demand. Perhaps adjustments of driver schedules or a mix of full-time and part-time driver shifts would provide capacity when it is needed, with part-time shifts scheduled for the higher demand time periods. The transit agency should assess other operational policies and procedures that may affect existing capacity. For example, DRT riders could be encouraged to use service during lower demand time periods with a fare incentive.

If the DRT provider still turns down trips with frequency after adjustments to ensure efficient service deployment and after possible revisions to policies and procedures to maximize capacity, then additional capacity may be needed. This could be additional revenue service hours, or possibly additional vehicles. Other options to add capacity include an arrangement with a local taxi company for supplemental service during high demand time periods, with the transit agency purchasing only those taxi trips that it needs to serve trips that otherwise would be turned down.

The range of quality of service for trips turned down are shown in Exhibit 5-35. At the highest quality of service, a rider would experience essentially no trip turn-downs for each 40 one-way trips requested (equivalent to a round trip each weekday for a month). This is very reliable service. At each subsequent service level, riders will experience trip turn-downs. At the fourth level, with more than 5% and up to 10% of trip requests turned down, riders may stop relying on the DRT service for important trips. At the lowest service level, with more than 10% of trips turned down, a rider will experience trip turn-downs on four trips for every 40 trip requests. At this point, riders will surely question the reliability of the DRT service and may stop riding DRT if another option for transportation is available.

Exhibit 5-35
DRT Trips Turned Down QOS

Percentage Trips Turned Down	Passenger Perspective	Transit Agency Perspective
0–1%	• Riders can rely on DRT for trip needs • For a frequent rider taking two trips each weekday per month (40 one-way trips per month), 0–1% trips turned down means essentially no trips will be refused during an average month	• Provides enough DRT capacity to serve all trip requests • With enough capacity during all times of the day, there may be some excess capacity during low demand periods; transit agency might assess driver scheduling and use of full-time/part-time shifts to ensure driver shifts correspond to ridership patterns
>1–3%	• Riders will find DRT service usually available when needed, thus generally reliable • For a frequent rider taking two trips each weekday per month, 1–3% trips turned down means one trip out of an average 40 DRT requests per month may be refused	• Occasional trips turned down can be expected during periods of higher demand • Suggest alternate trip times to riders if they request trips when capacity is not available, rather than turning down the trip
>3–5%	• Depending on the nature/trip purpose of the trips turned down, riders may consider DRT reasonably reliable • For a frequent rider taking two trips each weekday per month, 3–5% trips turned down means no more than 2 trips out of an average 40 DRT requests per month will be refused	• Requires monitoring trips turned down to determine if they occur on particular days or during specific time periods • Indicates the need to assess operational policies/procedures/practices to ensure service is deployed efficiently, e.g., excess no-shows will use capacity without providing trips for passengers • Increases the need to negotiate alternate trip times for passengers when capacity is not available, rather than turning down the trip • User information/rider's guide should indicate time periods of less demand so riders with a choice of trip times can plan trips accordingly
>5–10%	• Riders may need other options for needed trips when DRT is not available • For a frequent rider taking two trips each weekday per month, 5–10% trips turned down means 2 to 4 trips out of an average 40 DRT requests per month will be refused	• Risks riders with other transportation options may stop using DRT service, particularly for important trips • Calls for an analysis of the number of trips turned down by time of day to analyze patterns and possibly adjust driver scheduling and use of full-time/part-time shifts to ensure driver shifts correspond to ridership patterns • Requires more attention to operational policies/procedures/practices to ensure service is deployed efficiently and capacity is maximized with current resources • Risks an increase in passenger complaints about service availability

Exhibit 5-35 (cont'd.)
DRT Trips Turned Down QOS

Percentage Trips Turned Down	Passenger Perspective	Transit Agency Perspective
>10%	• Riders cannot rely on DRT for all trip needs • A rider will experience more than 4 trip turndowns for every 40 one-way trips requested.	• DRT may be serving riders who have no or limited other options for transportation • Assuming DRT operations are efficient and meeting as much trip demand as possible with current resources, consider adding capacity (revenue vehicle hours and possibly additional vehicles) to serve trips that are turned down for lack of capacity • Consider other options to increase capacity, including arrangements for overflow or supplemental service, e.g., from a local taxi company

Travel Time

Travel time is an important service quality measure for DRT passengers. DRT travel time measures the elapsed time that the passenger is on board the vehicle, from the time the passenger boards the vehicle at the trip pick-up location to arrival at the destination. Travel time does not include the time that the passenger spends waiting for the DRT vehicle to arrive or the time for that passenger to board and alight the vehicle (dwell times); however, travel time does include the time for other passengers who may be sharing the ride to board and alight and this will increase the travel time for riders already on board.

Passengers may compare travel time on a DRT vehicle to that of a comparable automobile trip. Or they may compare the DRT trip with a comparable trip on fixed-route if they use both modes of transit service. Still others may compare DRT travel time with some pre-set length of time, for example, 30 min, or perhaps the personal expectation of the "usual" travel time for the DRT trip.

Whatever their measure of travel time might be, a passenger *should* expect that travel times on DRT will be somewhat longer than the same trips by private vehicle, since DRT is a shared-ride service; passengers with similar trip patterns are scheduled and grouped together on the same vehicle by the DRT scheduling function. Shared-riding is a key premise of DRT, and helps to ensure that the DRT service is reasonably productive, as measured by passenger trips carried per revenue hour, and reasonably cost effective, as measured by operating cost per passenger trip.

However, the DRT passenger also expects that deviations for pick-ups and drop-offs of other passengers sharing the ride should not make the trip "too long." Defining "too long" will depend on the type of trip being taken and the size and travel characteristics of the service area. A trip in a very rural area might be one to two hours or even longer due to distance, and a regional trip in a metropolitan area might be 60 to 90 min because of both trip length in miles and traffic congestion. However, for a short trip—within a rural community or within a city—a trip of 60 to 90 min is likely "too long," even with shared rides.

For the quality of service framework for DRT, travel time is measured as the percent difference between a DRT trip with no-shared riding, which is direct and "exclusive" for

the passenger from the trip origin to the trip destination, and the same DRT trip with ride-sharing. Measuring DRT travel time against an exclusive, direct trip emphasizes DRT's important attribute of shared-ride yet also recognizes the DRT passenger's desire for a shorter rather than a longer trip.

If passengers' DRT travel times are short, similar to direct, exclusive travel, then the DRT scheduling function has not achieved much ride-sharing. On the other hand, if many passengers' travel times are long, the DRT scheduling function may be grouping too many trips or the wrong trips, and passengers may be overly inconvenienced with long on-board times to reach their destinations. A key objective of the DRT scheduling function is to balance shared rides with reasonable travel times. The determination of reasonable travel times will depend on the size and travel characteristics (roadway network, location of major destinations, traffic congestion, etc.) of the transit service area.

The passenger and transit agency perspectives associated with the different ranges of quality of service for DRT travel time are shown in Exhibit 5-36.

Exhibit 5-36
DRT Travel Time QOS

Travel Time	Passenger Perspective	Transit Agency Perspective
Exclusive-ride, direct trip with no ride-sharing (no more than 25% longer than a comparable trip by private taxi or automobile)	• Provides direct service requiring no more than 25% extra time for a DRT trip compared to a trip by taxi or a private vehicle • Requires no delays for other riders to board/alight since no other riders are scheduled on the same trip • Increases a direct, 30-min trip no more than 25%, or 8 min	• Scheduled direct, exclusive-ride DRT trips may happen from time to time but should not be the standard • Indicates the DRT scheduling function may not be grouping passenger trips with similar patterns • Decreases productivity (passenger trips/ revenue hour) • Increases operating cost per passenger trip
>25% to 50% longer than exclusive-ride trip	• Provides good quality service • Requires passengers to share the trip with another rider or two • Increases a direct, 30-min trip no more than 50%, or 15 min	• Indicates DRT scheduling function is successfully grouping passenger trips with similar patterns and also balancing travel times for riders • Allows DRT dispatchers to insert new passenger trips onto driver/vehicle schedules in real-time (e.g., will-calls, go-backs for missed riders) as travel times are reasonable
>50% to 75% longer than exclusive-ride trip	• Provides satisfactory to good service • Requires passengers to share the trip with other riders • Increases a direct, 30-min trip no more than 75%, or 23 min • Should be expected for many DRT trips	• Indicates DRT scheduling function is successfully grouping passenger trips with similar patterns and also balancing travel times for riders • Improves productivity with greater ride sharing • Decreases operating cost per passenger trip with higher productivity

Exhibit 5-36 (cont'd.)
DRT Travel Time QOS

Travel Time	Passenger Perspective	Transit Agency Perspective
>75% to 100% longer than exclusive-ride trip	• Provides adequate to satisfactory service • Requires passengers to share the trip with other riders • Increases a direct, 30-min trip by no more than 100%, or twice the time of the direct trip • Riders may find service adequate if their usual DRT trips have similar travel times or if the longer travel time occurs only occasionally or results from an unusual event (e.g., major traffic incident)	• Indicates DRT scheduling function is grouping passenger trips with similar patterns • Indicates DRT scheduling function may sometimes be grouping more than an optimal number of passenger trips, resulting in some travel times that are "too long" • Requires schedulers to particularly review expected travel time for the first passenger picked up on a trip with consecutive pick-ups/drop-offs • Operating staff should review other factors that may be increasing travel times for certain passenger trips (e.g., for the first passenger on a group trip, excess dwell time for additional passengers will increase travel time for the first passenger) • Improves productivity with greater ride-sharing • Decreases operating cost per passenger trip with higher productivity
More than 100% longer than exclusive-ride trip	• Increases a direct, 30-min trip by more than 100%, or more than twice the time of the direct trip • Riders will probably find DRT trips are too long if these travel times are common • An infrequent trip that is more than 100% longer than a direct, exclusive-ride trip may be excused especially if it results from an unusual event (e.g., major traffic incident) but problematic if it occurs on a regular basis	• Indicates DRT scheduling function is grouping too many riders on the same vehicle for ride-sharing • Increases productivity but at the expense of satisfactory or better travel times for the passengers • Increases risk of passenger complaints

From the passenger's perspective, short DRT travel times are preferred; many DRT riders would be happy to be the only passenger on the vehicle from the trip origin to the destination. A direct, or nearly direct, transit trip is the highest quality of service level for DRT travel time; however, exclusive transit service, similar to a private taxi trip, is counter to the transit agency's objective for shared-ride DRT service.

The successive service levels for DRT travel times show increasing amounts of time on the vehicle, as measured in percent increase over the travel time for a direct trip. As shown in Exhibit 5-36, the second level, up to 50% longer than a direct transit trip, is good quality service for riders: a trip that is 30 min for an exclusive ride would take up to 45 min by shared-ride DRT. The third level, up to 75% longer than a direct transit trip, is satisfactory to good service for riders: a trip that is 30 min with an exclusive ride would take up to 53 min by shared-ride DRT.

At the fourth level, DRT trips are becoming longer and riders who have other options may look to those options if their DRT trips are consistently 75 to 100% longer than a direct trip. At the fifth and lowest service level, DRT trips are more than twice as long as a direct trip. Most passengers would consider such trips too long and a poor quality of service. It is important to note, however, that DRT systems will invariably have unusual days when riders have trips that are "too long," resulting from bad weather, problems with an individual passenger, major traffic incidents, or other atypical events.

While exceedingly long DRT travel times will not be popular with riders, transit agencies should also be concerned with very long travel times, which indicate the scheduling function has grouped too many or the wrong trips together. By comparing the travel time for a passenger on a DRT shared-ride trip to the travel time for a similar, direct transit trip, the transit agency can take into consideration the size and travel characteristics of the service area as well as the type of DRT service and specific trips that are being provided.

A transit agency can calculate DRT travel time using a sample of completed trips for different passengers. The source of actual data can be the automated records using mobile data computers (MDCs), if available, or the written records from driver manifests.

The data required for each passenger trip is the origin location for the selected passenger pick-up, the passenger's destination location, the time to the nearest minute for the selected passenger pick-up, the time to the nearest minute for the arrival at the passenger's destination, and the number of additional passenger stops for the selected passenger's entire trip. The travel time is the actual time elapsed from the selected passenger's pick-up to the arrival at the destination by DRT shared-ride service.

To assess travel time for each selected DRT passenger trip, the transit agency will need to determine the time required to make the same trip by a direct, exclusive trip similar to a personal auto or taxicab. One convenient way to make this calculation is to enter the trip origin and destination in one of the several available Internet mapping programs for travelers. Most Internet mapping programs will provide the distance and time elapsed for travel by auto between any two points. If the service area is included in the online transit maps, the information will likely include the distance and travel time by auto, fixed-route transit, bicycle, and walking, allowing a more robust evaluation of DRT travel time compared to other available transportation modes.

The sample of travel times for completed DRT shared-ride trips can be entered into a spreadsheet for comparison to travel time by a direct, exclusive ride (or by another mode of travel using Google transit maps). The sample should be representative, including a variety of passengers, trip purposes, times of the day and days of the week, and a geographic distribution for the service area. Days when extraordinary circumstances beyond the control of the transit agency delayed all transit service, such as extreme weather conditions, can be excluded. The number of passenger trips should be determined by the transit agency to ensure the representative sample, but the more passenger trips included, the more accurate the assessment. A random selection of 100 passenger trips from a month's record of a completed DRT trips is a good sample size. A higher number of sample passenger trips may be recommended if the service area is large and diverse (for example, if the service area is both rural and urban) or if

passenger trips and trip purposes are varied (for example, if passengers use DRT transit for commute trips, for medical trips, and also for social and recreational purposes).

Calculate the percent travel time for each DRT passenger trip as compared to the travel time for a direct, exclusive trip and then average the percent travel time for all DRT passenger trips to calculate the system average.

An example of this process is shown in Exhibit 5-37.

Exhibit 5-37
Example DRT Travel Time Calculation Process

Passenger Trip	Origin Address	Destination Address	Day	Pickup Time	Passenger Stops	Drop Off Time	DRT Travel Time	Direct Travel Time	DRT Longer Than Direct
Random #1	5701 Westcreek Dr	1001 SE 2nd Ave	10/2	11:08	4	13:07	1:59	0:59	102%
Random #2	124 Main St	1205 Santa Fe Dr	10/6	16:29	2	17:20	0:51	0:41	24%
Random #3	2221 W Highway 199	3000 Alemeda St	10/12	6:07	3	6:51	0:44	0:30	47%
Random #4	907 Eureka St Ste 102	4819 River Oaks Blvd	10/20	19:15	1	20:17	1:02	0:58	7%
Random #5	217 S 6Th St	111 Sycamore	10/27	7:03	2	7:38	0:35	0:28	25%
								Average DRT Travel Time LOS	**41%**

No-Shows

A DRT no-show, when a passenger fails to show up for a scheduled trip, has a negative impact on other passengers' quality of service on a shared-ride trip, and negatively impacts DRT performance for the transit agency. When a scheduled rider no-shows a trip, passengers on board the DRT vehicle spend extra time traveling to the pick-up location and waiting for that rider who does not appear. If the missing rider had cancelled the trip with adequate notice, the dispatcher could have re-routed the vehicle, and the passengers on board would have a less circuitous and time-consuming trip. Late cancels can produce similar negative impacts for on-board passengers when dispatchers cannot effectively re-route the vehicle before the driver travels to the pick-up location of the late-cancelling rider.

For the transit agency, a no-show is essentially a wasted trip. Time and resources are deployed for a scheduled passenger trip that does not occur. Excessive no-shows will reduce productivity. DRT research using simulated service has found that higher rates of no-shows and late cancellations adversely impact productivity, with an approximate 4–5% decrease in productivity for every 10% increase in the no-show/late cancellation rate (*35*).

Some transit agencies have quantified the cost of no-shows. At least two research reports have documented the reported costs of agencies' no-show trips, with costs ranging from an annual cost due to no-shows/ late cancels of $1 million for a large urban transit agency (*33*) to a per trip cost of $32.50 for each no-show trip (*36*).

The nature of DRT service, responding to individual rider requests for trips, is such that providers will invariably experience no-shows on occasion. What is important is establishing policies and procedures to minimize no-shows and informing riders about the importance of cancelling a DRT trip as soon as the rider knows the trip is not needed. A DRT provider should establish and enforce a no-show policy so that riders who habitually no-show face consequences. Such consequences might include, for example, a suspension of DRT service for a defined time period, required fare payment for the no-show trip, or additional requirements to call the dispatcher one hour in advance to confirm each scheduled DRT trip.

It is also important to realize that the provision of on-time and reliable DRT service can help reduce no-shows. If DRT service is often tardy and unreliable, a rider may be

less like to follow rules for cancelling trips and may not wait the full on-time window for the vehicle to arrive for a scheduled trip. The rider may just assume the trip is late, find another transportation option or forego the trip, and no-show the DRT vehicle, inconveniencing other passengers on board and affecting productivity.

While the definition of a DRT no-show is clear, measurement of no-shows and comparisons across DRT systems can be complicated by the fact that transit agencies may include late cancellations in their no-show calculation and definitions of late cancels vary. Some DRT systems define a late cancellation as one where the rider cancels within one hour of the scheduled pick-up time. Others define late cancels as a trip cancelled two hours or less before the scheduled pick-up time. And some DRT systems have a broader definition, with late cancels defined, for example, as those made after 5:00 p.m. the day before the scheduled trip. Those transit systems with a broader definition of late cancels will have more cancellations, and if late cancels are included in the calculation of the no-show rate, the DRT provider will have a higher no-show rate than other providers with a more narrow definition of late cancels.

The no-show rate is calculated as the sum of passenger no-shows divided by the total number of scheduled trips.

Exhibit 5-38 shows three service levels for no-shows. At the first level, no-shows are less than 2% of scheduled DRT trips. This is considered a low rate, and DRT passengers will be inconvenienced infrequently by other passengers' no-shows. While a transit agency may have a low no-show rate, the agency should ensure it has no-show policy with enforcement procedures in place. The transit agency should also ensure that passengers understand the policy and importance of cancelling unneeded trips.

At the next level, with a no-show rate of 2 to 5%, passengers will occasionally experience a trip where another passenger scheduled on the same vehicle is a no-show. A frequent DRT rider who takes 40 one-way trips in a month may be inconvenienced one or two times during an average month by another passenger's no-show. For DRT providers, an increasing rate of no-shows will harm productivity. DRT systems should focus attention on no-shows, ensuring enforcement of their no-show policy and continually educating riders about the policy and sanctions for those who frequently no-show. The agency should make it easy for riders to cancel trips, such as providing a dedicated phone line to record cancellations. Passengers who find busy signals or hold times to cancel a trip will be less inclined to cancel trips they don't need. Control room staff should stay current on cancellations and, as needed, update drivers' schedules so cancelled trips are removed. Riders with excessive no-shows should be identified and sanctioned with appropriate penalties, in keeping with the policy. Typically transit agencies report that it is a small percent of riders who frequently no-show.

When no-shows exceed 5%, which is the lowest service level, riders will experience increasing numbers of no-show passengers while riding DRT, which unnecessarily inconveniences their trips. The transit agency should focus greater attention, as no-shows are impacting productivity, service quality for their passengers, and even on-time performance. When drivers have to wait at scheduled pick-up locations for the full waiting time, or longer, when a dispatcher tries to locate a rider who is not at the scheduled location at the scheduled time, subsequent trips on the driver's schedule are affected. A DRT provider should consider analyzing no-shows to determine any patterns or if specific types of passengers seem to be frequent no-shows (e.g., subscription riders) and take appropriate action. In addition to suspension of DRT service, another

option which has been used by transit agencies to combat no-shows includes additional scheduling requirements for regular riders who frequently no-show such as requiring those passengers to call-in one hour in advance of a scheduled trip to confirm the trip.

Exhibit 5-38
DRT No-Show QOS

Percent No-Shows	Passenger Perspective	Transit Agency Perspective
< 2%	• Experiences few if any instances of no-shows by other riders scheduled on the same vehicle • A frequent rider with 40 one-way trips in a month may be inconvenienced by another passenger who no-shows during an average month	• Experiences a small percentage of scheduled trips as no-shows with limited impact on operations and performance • Requires a formal and enforced no-show/cancellation policy to ensure no-show rate remains low • Reflects passengers who are well informed and adhere to the no-show/ cancel policy or results from an operating environment where no-shows are not an issue
2 – 5%	• May experience occasional trips where another passenger scheduled on the same vehicle is a no-show • A frequent rider with 40 one-way trips in a month may be inconvenienced 1 or 2 times during an average month due to another passenger who no-shows	• Experiences a percentage of no-shows, which may have a negative impact on operations and lower productivity • Requires an effort to mitigate, especially if the trend reflects an increasing number of no-shows • If not already in place, adopt a formal no-show/cancellation policy with appropriate penalties for riders with excessive no-shows • Ensure the riders guide and other passenger information includes the no-show policy, the importance of cancelling unneeded trips, and how to cancel trips • Provide an easy-to-use and well-advertised method for riders to cancel trips (e.g., a dedicated phone line that records messages) • Consider follow-up with riders with frequent no-shows, ensuring their understanding of the policy and consequences of their no-shows on other riders and the DRT service

Exhibit 5-38 (cont'd.)
DRT No-Show QOS

Percent No-Shows	Passenger Perspective	Transit Agency Perspective
> 5%	• Will experience occasional to frequent trips where another passenger scheduled on the same vehicle is a no-show • Delays service and may negatively impact on-time performance • A frequent rider with 40 one-way trips per month will be inconvenienced by 2 or more passengers who no-show during an average month, with increasing numbers of no-shows as the frequency of trips increases	• Experiences excessive no-shows, which have a negative impact on productivity, quality of service for passengers, and potentially on-time performance • Ensure no-show/cancellation policy is understood by all passengers and the rules are enforced • Ensure control center staff stay current on all cancelled trips so driver schedules can be updated, are accurate, and do not include cancelled passenger trips • Analyze factors behind no-shows and take action as appropriate (e.g., are passengers and drivers missing each other at large trip generators such as a mall or medical complex? Are clients of human service agencies no-showing because the agency is booking trips on their behalf without full knowledge of their clients' trip needs, etc.)

4. APPLICATIONS

Material in this section is adapted from the *Transit Quality of Service Applications Guide* prepared for the Florida DOT (*37*). The graphics in this section are intended to illustrate general ways of presenting QOS information; individual details within the graphics not relevant to illustrating the concept may be too small to be legible.

COMPREHENSIVE PLANNING

Multimodal comprehensive plans will provide goals, policies, and objectives for the transit service provided, or desired to be provided, within a community. The transit goals may be aspirational (if the city or county is not the service provider) or may set the groundwork for service standards (when it is the service provider). QOS measures that are potentially relevant to comprehensive planning relate to the availability of transit service. Potential objectives might include the following:

- Service frequency: Minimum service frequency for trunk vs. local transit routes.
- Service span: Minimum span of service for trunk vs. local transit routes.
- Service coverage: Percent of transit-supportive population within walking distance of transit service with a minimum hourly headway.

Comprehensive plans also describe a community's desired future land use patterns. The typical land use densities required to support different levels of transit service presented in Chapter 4 can be used to compare land use alternatives with regard to the level of transit service that could be supported. Service coverage maps could be used to illustrate the impact of different street connectivity or sidewalk provision policies on access to transit service, along with determining the number of route miles required to achieve a particular service coverage goal.

LONG-RANGE TRANSPORTATION PLANNING

Long-range transportation plans (LRTPs) focus on citywide or regional travel needs over the longer term (e.g., 20 years). If the jurisdiction preparing the plan is not the provider of transit service, transit may be addressed in terms of actions the jurisdiction can take to support transit; otherwise, the transit element may be more specific and contain many of the elements of a transit development plan (discussed later).

LRTPs typically identify goals and objectives that describe how the community would like its transportation system to function, along with the role of each travel mode. A series of alternatives comparing different priorities, means of accomplishing goals, and future funding levels are typically created and compared to the established goals and objectives. The alternative that best meets the goals is used as the basis for developing a prioritized list of transportation projects that address the community's long-range transportation needs to the extent funding permits.

Since its introduction, one of the most common applications of the TCQSM has been to LRTP development. However, in many cases, the TCQSM has been used in the limited role of providing a report card on existing conditions. This remainder of this subsection demonstrates how the TCQSM can be used to develop and evaluate alternatives as part of a future conditions analysis. Many of the real-world examples show LOS letters based

on the first two editions of the TCQSM. Although these are no longer used, except for multimodal analysis, the basic concepts are still quite applicable, when one substitutes actual performance measure values for LOS letters and compares which values meet or do not meet an established goal or standard.

Activity Center Analysis

An activity center analysis measures the quality of service between key locations within the study area. Rather than try to assess the quality of every potential trip a person might take, this type of analysis evaluates a representative cross-section of trips. Potential applications include:

- Evaluating existing conditions, identifying pairs of locations with travel demands that may be underserved by transit;
- Demonstrating the benefit of transit investments being evaluated for a particular future alternative; and
- Comparing the service provided to the minimum level of service set by policy for routes connecting different land use types.

Travel time is well suited for evaluating as part of activity center analysis, as it is sensitive to changes made to the transportation system and to changes in demand. If the LRTP's planning model can estimate transit ridership, passenger loads can also be evaluated, along with the need to increase frequency to accommodate the additional demand. Frequency and hours of service can also be evaluated in terms of testing different policy levels of service and their impacts on ridership and roadway LOS.

Exhibit 5-39 shows an activity center map from a long-range transportation plan showing peak-period, peak-direction frequency QOS from Manassas, Virginia to other activity centers in Northern Virginia and Washington, D.C.

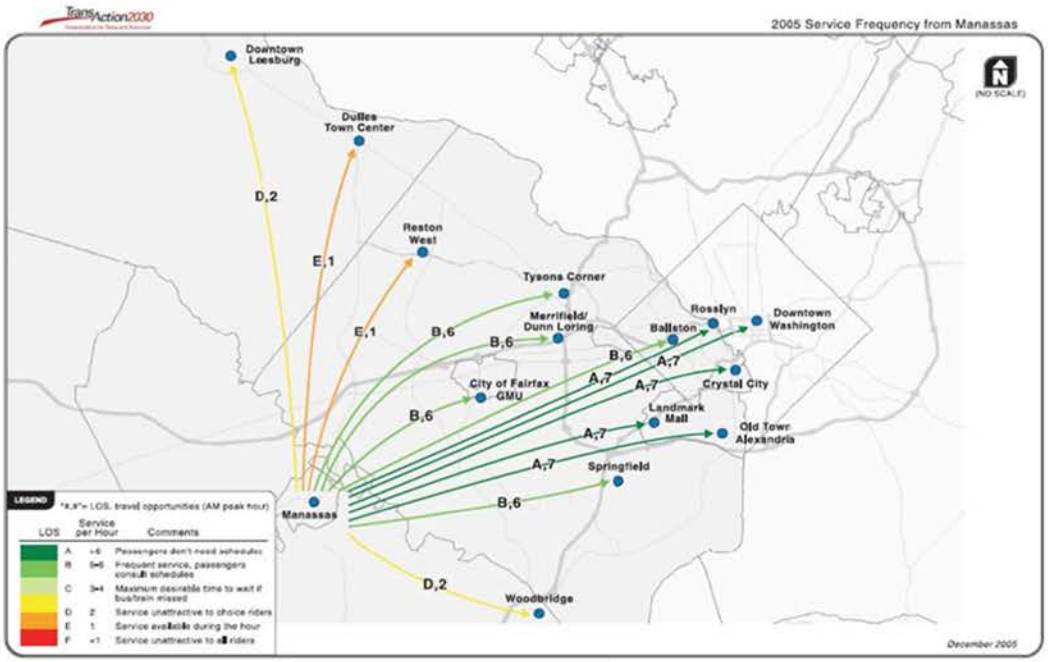


Exhibit 5-39
Example Activity Center QOS Map

Source: Northern Virginia Transportation Commission (*38*).

Activity center QOS results can also be shown in the form of a table, comparing the travel demand for a particular origin–destination pair to the quality of service provided. This format allows frequency and hours of service, for example, to be compared to the actual travel demand, allowing areas with potentially too much or too little service to be flagged for further evaluation. Similarly, comfort and convenience measures can be evaluated for trip pairs with high demands to identify markets where service improvements, roadway projects to improve transit travel times, or a combination of these may pay off with improved ridership.

Corridor Analysis

Some jurisdictions identify transit streets or corridors as part of their roadway functional classification system. These streets typically are slated to have frequent all-day service (e.g., service every 15 min or better during midday hours). Given the concentration of bus service on these streets, it is important that buses operate reliably and quickly for the service to achieve its full ridership potential and minimize its operating costs (slower, less-reliable routes require more buses to operate for a given headway and route length). The reliability and travel time QOS measures can be used to identify corridors where bus-focused roadway improvements may make bus service more competitive with the automobile, or avoid the need to add buses to maintain headways, allowing those buses to be allocated elsewhere in the area. Passenger load QOS in a corridor can also be used to identify the need to add service in the future, if buses would routinely be overcrowded. Exhibit 5-40 illustrates a "priority bus network" for Seattle, consisting of routes with 15-min service or better at least 18 hours a day. The city plans to invest in bus speed and reliability improvements in these corridors.

Exhibit 5-40
Seattle Priority Bus Network Map



Source: City of Seattle Department of Transportation (*39*).

Service Coverage Analysis

Areawide Analysis

The TCQSM's access measures are useful for identifying potentially unserved transit markets. Exhibit 5-41 shows an example of this kind of analysis for an LRTP. In the map, areas shown in red or green (in the electronic version of this document) are transit-supportive (green are served by transit, red are not), while the light shading indicates additional transit-served areas. Transit-supportive areas not served represent potentially unserved transit markets that can be investigated further.



Exhibit 5-41
Example Service Coverage Map

Source: Northern Virginia Transportation Commission (*38*).

Service coverage maps can also be combined with hours of service maps, to show at a glance where transit is planned to be provided in the future, and at what quality of service. When supplemented with demographic information, this kind of analysis can also be used to identify potentially underserved neighborhoods—that is, areas that currently receive some transit service, but are capable of supporting additional service.

Corridor Analysis

The detailed service coverage method provides means for evaluating access to individual stops along a corridor. The method is sensitive to street connectivity, sidewalk presence, and street-crossing difficulty, among other factors, making it useful for comparing the effect of different policies or projects on transit access within the corridor.

STATEWIDE TRANSPORTATION PLANNING

At a statewide level, QOS measures derived from NTD data can be used to track trends in fixed-route transit provision across the state, for the state as a whole, or for groups representing different population ranges. These measures include average system peak-period headway (described in the section on fixed-route frequency), system service span, and average system speed. These measures can be readily derived from NTD data and require no special data collection.

COMPREHENSIVE OPERATIONAL ANALYSIS

Comprehensive operational analyses (COAs) provide a detailed, route-by-route evaluation of existing service, as well as an evaluation of systemwide operations. They are often conducted in conjunction with, or immediately prior to, a Transit Development Plan update. Transit QOS measures can be incorporated into a COA process in several ways: to describe the results in terms of passenger experiences and potential transit agency issues (using the QOS tables in this chapter), to compare the results to established standards, and to compare changes in results from the previous analysis. When archived APC and AVL data are not available to a transit agency, comprehensive operational analyses provide rare opportunities to evaluate in detail the comfort and convenience aspects of the service being provided.

Key measures for fixed-route transit include:

- *Passenger loads.* Are the agency's loading standards (or typical maximum design loads, if no standards have been set) being exceeded and, if so, where and for how long? Relatively good peak-direction QOS may indicate an underperforming route or a route with sufficient capacity to absorb anticipated future growth.
- *Reliability.* Routes with poor on-time performance can be flagged for further evaluation to determine the cause(s). Poor QOS at the start of the route may indicate insufficient schedule recovery time or the need for better driver supervision. A drop in QOS between two timepoints may indicate a need to review the schedule or a need to identify sources of delay in that section of the route that could be treated with transit preferential treatments.
- *Travel time/speed.* Routes with slow travel speeds relative to others in the system can be investigated for possible stop consolidation or transit preferential treatment. Routes with longer layover times than needed for driver breaks and schedule recovery can also be investigated for speed improvements that would allow the route to be served with fewer buses.

Similarly, for agencies operating demand responsive transit service for the general public, the full set of DRT comfort and convenience measures can be evaluated to identify potential opportunities for improving trip scheduling and agency policies. The DRT QOS tables and accompanying commentary in this chapter describe the implications of different service levels for on-time performance, trips turned down, travel time, and no-shows.

QOS measures can be used to help evaluate whether transit service is being provided equitably to lower-income and minority areas, as part of an environmental justice analysis. Frequency, hours of service, coverage, passenger load, and reliability QOS are all applicable to this type of evaluation. The service levels given in this chapter's QOS tables can be used to compare relative quality of service between areas.

TRANSIT DEVELOPMENT PLANS

Transit development plans (TDPs) are six-year plans that set out a transit agency's near-term service strategy. Transit QOS measures can be used in developing these plans and in communicating intended outcomes to decision makers and the general public.

Mapping

Several QOS measures lend themselves to mapping on a route-by-route or street-by-street basis: frequency, hours of service, loading, and reliability. Maps can depict the extent of potential service issues (e.g., the extent of crowded service) as well as illustrate planned service outcomes (e.g., the extent of frequent transit service at the end of the planning period). The QOS categories help in grouping routes on the basis of similar service quality, which helps the viewer better comprehend the information being presented.

Prioritizing Improvements

The passenger load QOS measure can be used by itself, or in combination with other information (e.g., the length of time a certain loading level occurs) to help prioritize service improvements. The reliability and transit–auto travel time QOS measures can be used the same way.

Existing and Future Service Comparisons

Frequency, hours of service, passenger load, service coverage, and travel time lend themselves to being forecasted (either through policy decisions or by identifying needs based on future passenger demand) and thus can be used to compare future conditions under the proposed plan (or alternatives being considered) to existing conditions. This type of comparison allows readers to compare their knowledge of current conditions to the conditions being forecast for the future, to better understand the implications for future service.

Service Equity Comparisons

Transit agencies with service areas that span multiple jurisdictions and that receive tax or direct funding support from those jurisdictions may face questions about whether the communities are receiving an equitable amount of service in return. The availability QOS measures can help answer these questions.

Environmental Justice Comparisons

As with comprehensive operations analyses (discussed above), QOS measures can be used for environmental justice comparisons as part of a TDP process.

Peer Reviews

The development of a TDP often involves comparing existing service with that provided by peer agencies, to identify areas where a transit agency is potentially underperforming and can learn from its peers. A peer comparison often involves using NTD data, because of its standardization and the ease of obtaining peer data. However, with few exceptions, the NTD does not collect measures directly related to QOS. In may be possible, though, to contact peers directly to obtain additional QOS-related

information for use in a peer comparison. Exhibit 5-42 shows potential peer comparison topics related to quality of service and potential QOS measures that could be applied to them. *TCRP Report 141* (*4*) provides detailed guidance on performing peer comparisons.

Exhibit 5-42
QOS-related Measures Applicable to Peer Reviews

Topic Area	Performance Measures	Comments
Perceived service quality	Average system speed	Derivable from NTD data
	On-time performance	Requires consistent "on-time" definition
	Excess wait time	Derivable from archived AVL data
	Passenger loading	Derivable from archived APC/AVL data
	Overall satisfaction	From customer satisfaction surveys
	Complaints per 1,000 boardings Compliments per 1,000 boardings	How aggressively a transit agency solicits passenger feedback will affect the results
Safety and security	Casualty and liability cost per vehicle mile (km)	Derivable from NTD data
	Collisions per 1,000 miles (km) Collisions per 1,000 boardings Incidents per 1,000 boarding	Reported to the NTD, but not publicly released
Delivered service quality	System service span	Derivable from NTD data
	Average system peak headway	Derivable from NTD data
	Revenue miles (km) per urban area sq. mile (km)	Derivable from NTD data
	Revenue miles (km) or hours per capita	Derivable from NTD data

Source: Adapted from *TCRP Report 141* (*4*).

SERVICE PLANNING

Service Monitoring

One function of service planning is to monitor existing service and to make adjustments as needed when service falls outside established service standards. Two areas that transit agencies commonly monitor are passenger loads and service reliability. The QOS tables in this chapter can be used when developing service standards to identify realistic expectations for the loading and reliability levels that can be achieved in different conditions. Once the standards have been set, routes not meeting the standards can be flagged for attention.

Service Development

As communities or regions grow, so may the need for service. The service coverage QOS table can be used to help identify new developments that will have sufficient density at build-out to support particular levels of transit service. The transit–auto travel time QOS table can be used to help identify and prioritize origin–destination patterns that may require quicker transit connections. The on-time performance QOS table can be used to identify the kinds of actions (e.g., localized transit preferential treatments, corridor or guideway improvements) that may be needed to improve transit reliability once "typical" levels have been attained.

CORRIDOR PLANNING

Corridor master plans, preliminary design or project development studies, and premium transit studies address improvements over an extended section of roadway. Transit infrastructure and service improvements may be the focus of the study, or the

study may address means of best accommodating transit service as part of a comprehensive set of multimodal improvements in the corridor.

Scoping Transit Improvements

When planned future transit service will be frequent, consideration should be given to operational and transit preferential treatments that will provide the desired level of speed and reliability for transit service in the corridor. These treatments can include corridor-level improvements, such as a transitway for buses or light rail in the roadway median or bus lanes along the roadway; intersection and spot improvements such as transit signal priority, queue jumps, curb extensions, stop consolidation, and parking restrictions; or a combination of these. At the same time, frequent transit service can potentially create operational and quality of service concerns for users of other modes within the corridor, and these also need to be considered.

Access to Transit Stops

Accessing transit service in a corridor can be made more difficult when the corridor is being widened—whether to provide transitways or bus lanes, or to expand roadway capacity. Wider roadways increase pedestrian crossing delay and can create safety concerns, particularly at unsignalized locations. In addition, transit facilities within the street median can create barriers to pedestrian and bicycle connectivity across the corridor. *TCRP Report 112/NCHRP Report 562* (*40*) provides guidance on potential pedestrian crossing treatments at unsignalized crossing locations, while *TCRP Report 137* (*41*) provides guidance on improving pedestrian and motorist safety along light rail alignments. Assessing service coverage QOS on an individual stop or station basis can also be useful for identifying needed improvements to pedestrian facilities that provide access to the corridor, as well as potential improvements for facilitating pedestrian crossings of the corridor.

Passenger Loading and Ridership

In corridor planning, a transit passenger loading QOS standard can be applied in identifying a required service frequency to serve estimated passenger demand. This is useful in identifying total corridor person throughput, and in estimating transit's mode share of trips along a corridor.

DEMAND-RESPONSIVE TRANSIT OPERATIONS

As discussed in Section 3, the QOS measures for DRT are applicable to general public and limited eligibility DRT service. Potential applications of these measures—discussed in more detail in Section 3—include:

- Comparing DRT performance to stated policies,
- Identifying potential problems with excessive cancellations and no-shows that may suggest the need to change or enforce scheduling and cancellation policies,
- Balancing the QOS provided with operating cost considerations,
- Identifying the potential need for additional staff training, and
- Identifying the potential need for providing additional capacity.

5. CALCULATION EXAMPLES

Exhibit 5-43
List of Calculation Examples

Example	Description
1	Service coverage analysis (planning level)
2	Service coverage analysis (detailed)
3	Reliability
4	Multimodal transit LOS

CALCULATION EXAMPLE 1: SERVICE COVERAGE ANALYSIS (PLANNING LEVEL)

The Situation

Riverbank, population 23,000, is an outer suburb of Anytown. The city is currently updating its long-range transportation plan and expects to grow significantly in the future. As part of this process, Riverbank wishes to evaluate its existing transit QOS with respect to availability and to compare it to the future QOS under a "no-build" (i.e., no change in present service) scenario. This effort will serve as a starting point in the planning process for identifying long-range transit needs. Although Riverbank does not provide transit service itself, it hopes through this effort to better coordinate its planning with that of the regional transit agency that serves this region of 1.5 million people. This example focuses on the service coverage analysis.

The Questions

What is the existing service coverage QOS, and how will it change in 20 years, given planned population and employment growth, if there are no changes to the current route structure?

The Facts

Exhibit 5-44 provides a map of the city, showing the location of bus routes and stops. Major barriers to travel within the city include two freeways and a river. The city's GIS database includes the local street network, bus routes, and bus stop locations, among other information, but not sidewalk information. All bus routes provide local service only (i.e., no BRT or express routes serve the city).

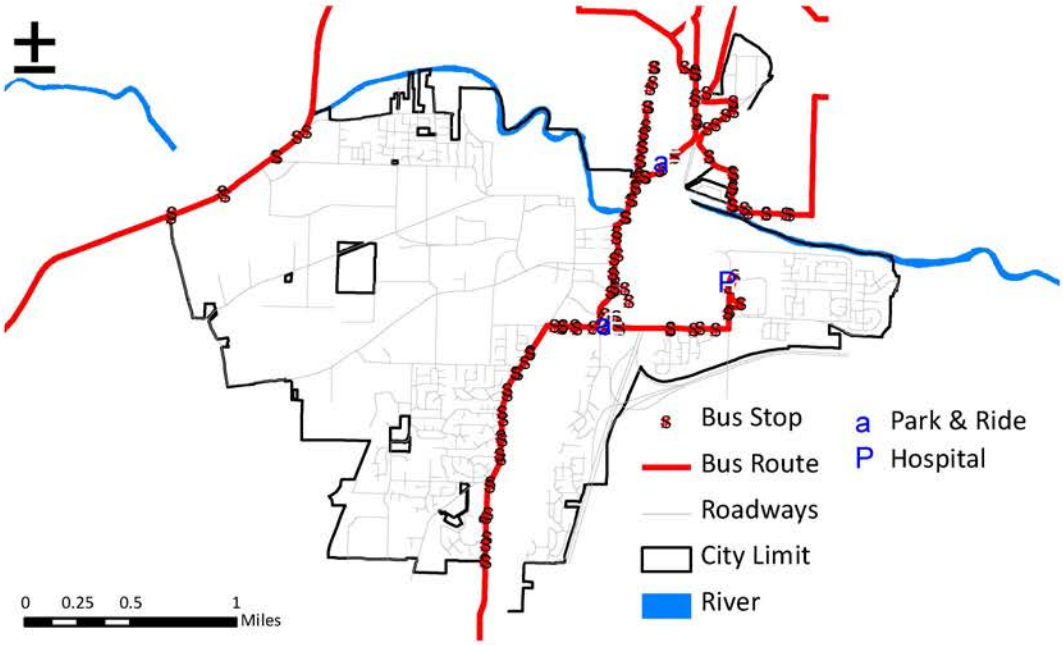


Exhibit 5-44
Calculation Example
1: Riverbank City Map

Exhibit 5-45 shows the locations of the transportation analysis zones (TAZs) covering Riverbank, which were obtained from the regional transportation planning model. Exhibit 5-46 provides year 2015 and year 2035 household and employment data for each TAZ, along with the TAZ areas.

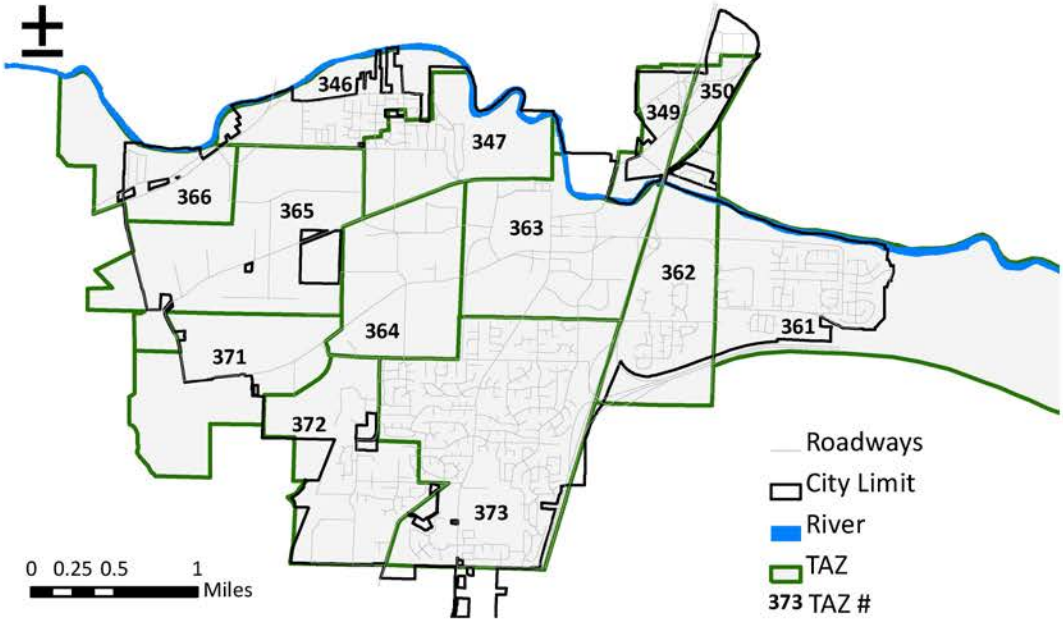


Exhibit 5-45
Calculation Example
1: TAZ Locations

Exhibit 5-46
Calculation Example 1: Population and Employment Data

TAZ	Area (acres)	Year 2015 HH	Year 2015 Jobs	Year 2035 HH	Year 2035 Jobs
346	331.9	506	58	990	676
347	362.3	334	365	1,199	1,204
349	143.9	88	1,346	216	1,524
350	90.8	9	1,203	27	1,415
361	1,203.6	938	472	1,593	844
362	462.8	1,391	1,151	1,864	1,595
363	549.0	854	5,112	2,291	7,572
364	432.0	181	3,022	181	4,373
365	747.3	19	1,518	19	5,361
366	334.4	154	205	516	905
371	500.1	9	375	17	1,344
372	505.0	180	885	826	1,569
373	1,008.3	2,582	580	2,991	891

Note: HH = households.

Computational Steps

Outline of Solution

Determining service coverage QOS requires three basic steps: (*a*) determining the service coverage area provided by the city's bus routes, (*b*) determining which portions of the city have transit-supportive population and employment densities, and (*c*) determining what proportion of the transit-supportive areas are served by transit. Given the citywide scope of the analysis, the planning-level procedure will be used to evaluate service coverage QOS

Step 1: Determine the Service Coverage Area

Riverbank only has local bus service. Therefore, a 0.25-mi (400-m) buffer is created around each bus stop using GIS software, representing the area served by each bus stop. These buffers should be clipped in areas where service coverage would not extend across a barrier. In the case of Riverbank, the river and the two freeways form barriers to travel and portions of bus routes' service coverage areas that extend across these barriers are removed manually.

The results are shown in Exhibit 5-47. For clarity, areas served by transit that are outside the city limits are not shown. The shaded areas represent Riverbank's service coverage area.

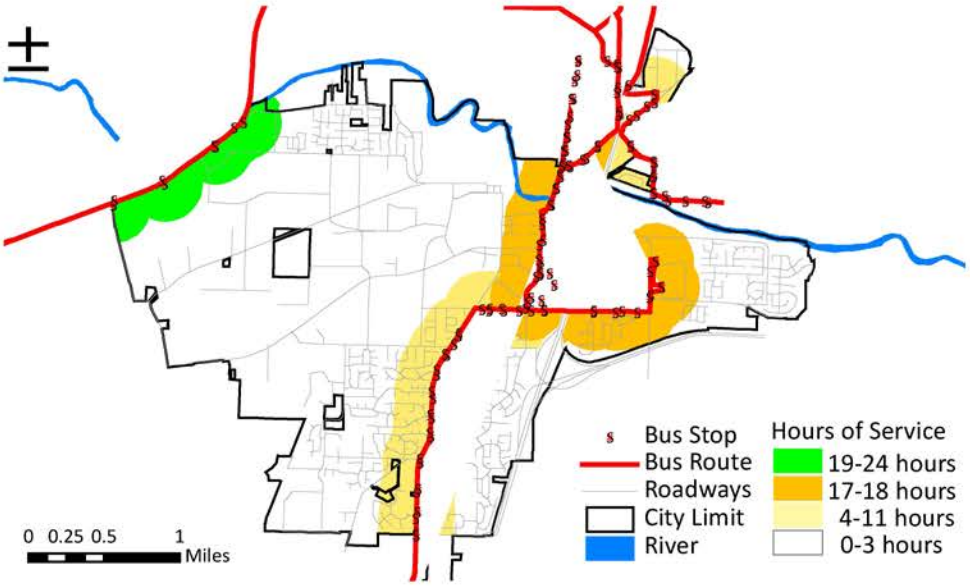


Exhibit 5-47
Calculation Example 1: Service Coverage Area

Step 2: Determine the Transit-Supportive Area

Each TAZ is evaluated to determine whether it meets the criteria for being "transit-supportive" (i.e., a household density of 3 households or more per acre or a job density of 4 jobs or more per acre). Household density is calculated by dividing the TAZ's households (given in Exhibit 5-46) by its area in acres. Job density is calculated similarly. For example, the year 2015 household density of TAZ 362 is 1,391 households, divided by 482.8 acres, or 2.88 households per acre. This is slightly below the criterion for TAZ 362 to be a TSA. Results for all TAZs are given in Exhibit 5-48.

	Year 2015			Year 2035		
TAZ	HH Density	Job Density	TSA?	HH Density	Job Density	TSA?
346	1.52	0.17		2.98	2.04	
347	0.92	3.31		1.01	3.32	
349	0.61	9.35	✓	1.50	10.59	✓
350	0.10	13.25	✓	0.30	15.58	✓
361	0.78	0.39		1.32	0.70	
362	2.88	2.38		3.86	3.30	✓
363	1.56	9.31	✓	4.17	13.79	✓
364	0.42	7.00	✓	0.42	10.12	✓
365	0.03	2.03		0.03	7.17	✓
366	2.17	0.61		1.54	2.71	
371	0.02	0.75		0.03	2.69	
372	0.36	1.75		1.64	3.11	
373	2.56	0.58		2.97	0.88	

Notes: HH = households, TSA = transit-supportive area.
Densities in households/acre and jobs/acre.

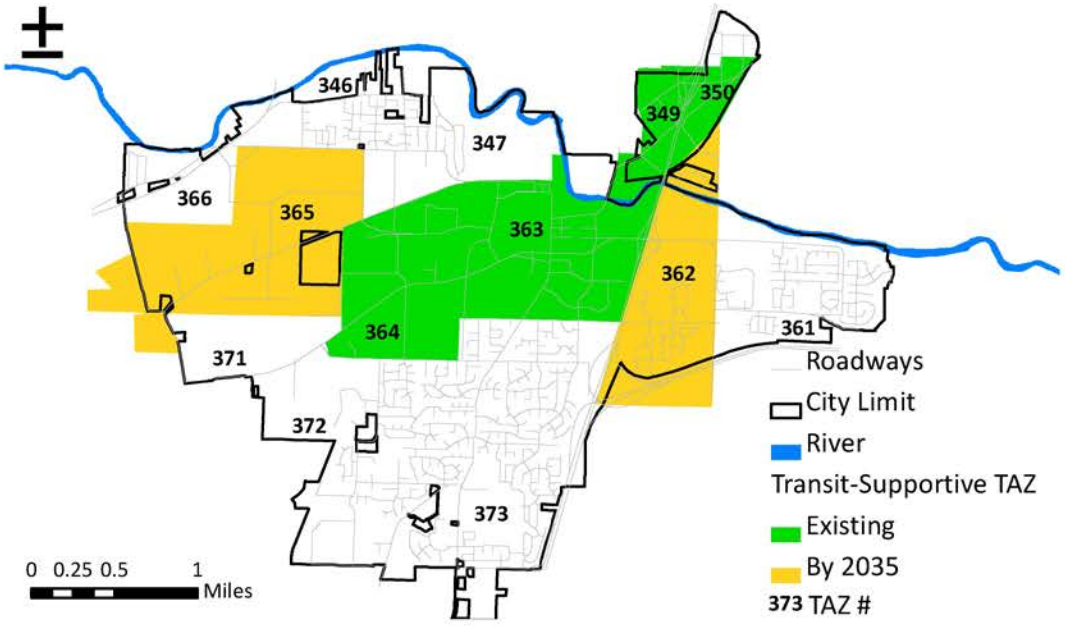
Exhibit 5-48
Household and Job Densities

A more detailed analysis could look at where particular land use types are located within a TAZ.

Note that a local transportation plan might wish to go into more detail to identify potential TSAs. For example, TAZs could be subdivided to remove undeveloped areas. This would have the effect of increasing the density in the developed areas. Also, TAZs could be subdivided based on zoning or comprehensive plan designations, so that households were only assigned to areas zoned for residential development, for example. A further refinement would be to assign more households to areas designated for multi-family housing. Any of these steps would provide greater understanding of the sections of the city that could support hourly transit service, and it is likely that TAZs 346 and 373 would turn out to be transit supportive in the future if these steps were taken.

Exhibit 5-49 shows the locations of the transit-supportive TAZs.

Exhibit 5-49
Calculation Example 1: Transit-Supportive TAZs



Step 3: Determine Transit-Supportive Areas Served

GIS software is used to intersect the transit service area with the TAZs. The result is that the TAZs are subdivided into smaller sub-TAZs, each of which is either entirely inside or outside the service coverage area. Exhibit 5-50 shows the results of this process for Riverbank, for existing conditions. Of the four transit-supportive TAZs, all of TAZs 349 and 350 are served, about one-half of TAZ 363 is served, and almost none of TAZ 364 is served.

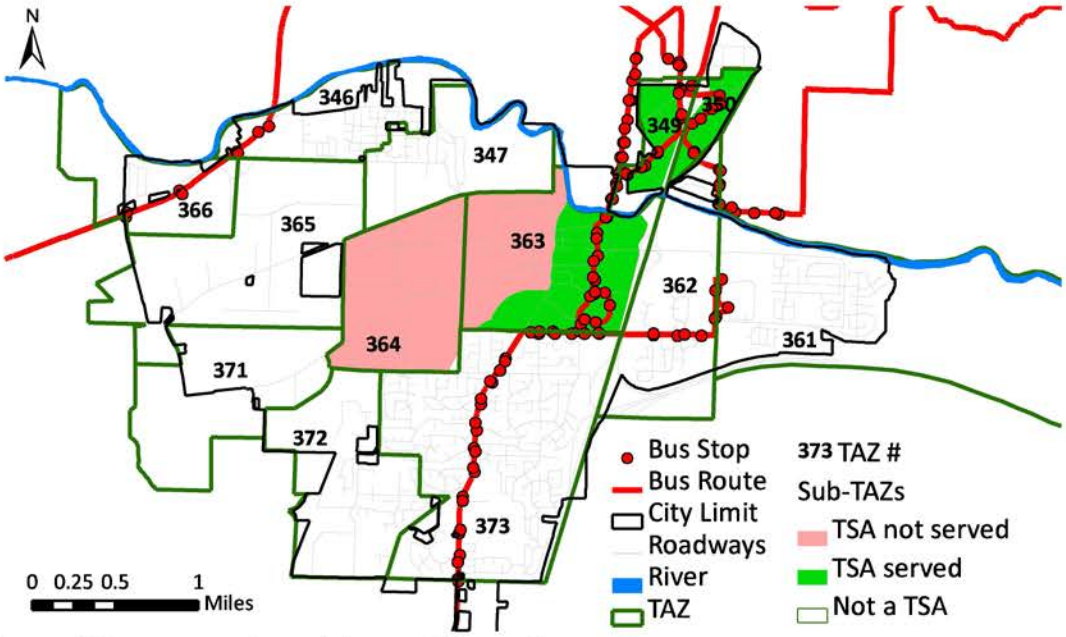


Exhibit 5-50
Calculation Example 1: Transit-Supportive Areas Served (Existing Conditions)

Note: TAZ = transportation analysis zone, TSA = transit-supportive area.

Step 4: Determine Service Coverage QOS

As the final step, GIS software is used to calculate the area (in acres) of the portions of the transit-supportive areas that are served. The result is 540.1 acres. The total area of the transit-supportive TAZs, from Exhibit 5-46, is 1,215.7 acres. Therefore, the percent transit-supportive area served is 44%. Comparing this result to Exhibit 5-4, this result is an indication that the transit agency providing service to Riverbank is likely emphasizing cost efficiency over coverage. Those passengers who are served by transit likely have relatively direct trips, at least for the portion of the trip within Riverbank.

The Results

The service provided to Riverbank is not unusual for a low-density suburb: as most of the residential areas cannot support hourly transit service, park-and-ride lots serve the commuter market out of Riverbank. However, the service coverage analysis indicates that a large area with sufficient employees to support transit service is not receiving service, and that this area will be even larger in 20 years.

Comments

The employment areas appear to be the most promising areas for future transit service. Relatively low-density employment areas can be difficult to serve productively with all-day service. Therefore, peak-period fixed-route service provided by the transit agency or employee shuttle service provided by individual employers or an employer association might be considered. Alternatively, the possibility for a cross-town route linking Riverbank to the next suburb to the west, passing through the employment area, could be considered. If demand between the cities was strong enough to support the route, the employment area could also be served along the way at minimal extra cost to the agency and minimal inconvenience to passengers traveling between the cities. *TCRP Report 116* (*42*) provides guidance on implementing suburban transit service.

CALCULATION EXAMPLE 2: SERVICE COVERAGE ANALYSIS (DETAILED)

The Situation

The Cowford Transit Authority has developed a good working relationship with the City of Cowford, and the city routinely gives extra priority to public works projects, such as sidewalk and pedestrian crossing improvements, that provide transit benefits. The two agencies are currently evaluating Route 29, which runs parallel to an elevated freeway, to determine what kinds of improvements might provide better access to transit.

The Questions

What is Route 29's service coverage area, compared with the ideal, and what can be done to improve it?

The Facts

Exhibit 5-51 shows a map of the study area. Exhibit 5-52 lists the traffic volumes and geometric characteristics (street width and median type) for the streets used by the route. There are two traffic signals in the area: one at the intersection of Spring Park Road and Spring Glen Road, which has a 90-s cycle length, and one at the intersection of Barnes Road and University Boulevard, which has a 180-s cycle length. All of the streets are undivided, although Barnes Road South has a two-way left-turn lane, so that pedestrians have to cross the equivalent of three lanes. The area is flat, and the senior population forms less than 20% of the total area population.

Exhibit 5-51
Calculation Example 2: Study Area Map

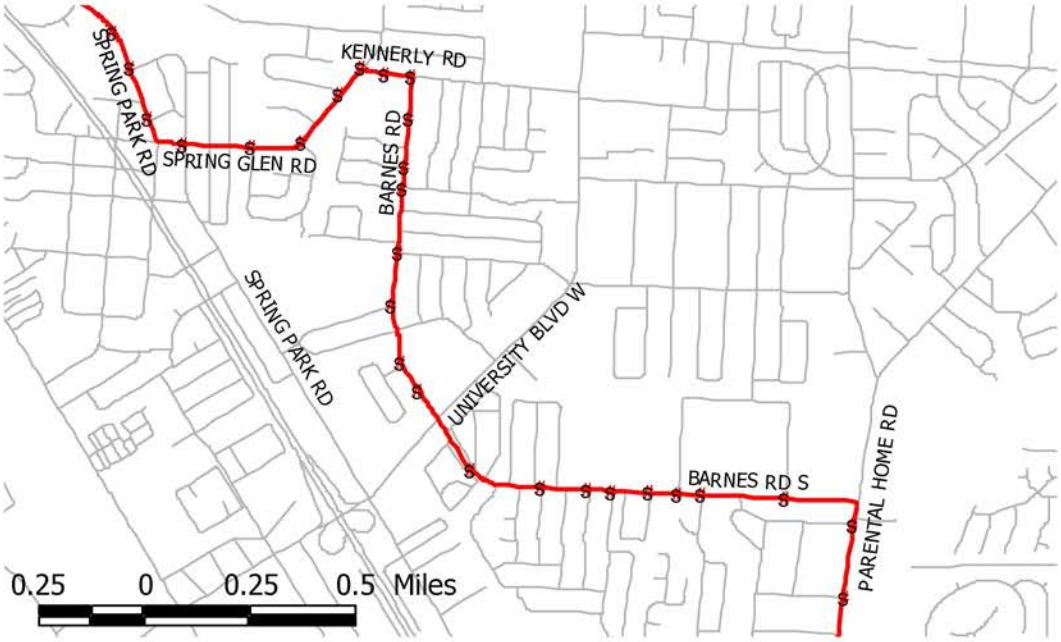


Exhibit 5-52
Calculation Example 2: Street Data

Street Name	Peak Hour Traffic Volume (veh/h)	Street Width (lanes)
Spring Park Road	350	2
Spring Glen Road	1,150	2
Kennerly Road	500	2
Barnes Road	550	2
Barnes Road South	1,000	3
Parental Home Road	1,300	2

Computational Steps

Outline of Solution

The detailed service coverage method will be used to identify the effective area served by each bus stop, accounting for the street pattern, the difficulty pedestrians have crossing streets, and any other applicable factors. The relative contribution of each factor to the reduction in coverage area will be determined. Finally, the size of the reduced service coverage area will be compared with the size of the ideal service coverage area.

Step 1: Determine the Service Coverage Adjustment Factors

The TCQSM uses an air distance of 0.25 mi as the base radius served by a local bus stop. Equation 5-1 will be used to determine the reduction in this radius due to the following four factors: street connectivity factor, terrain, population characteristics, and pedestrian crossing difficulty.

Street Connectivity

Comparing the map of the study area with the street pattern types depicted in Exhibit 5-6, it appears that the street pattern most closely resembles the Type 2 (hybrid) pattern. The street network does not form a grid; yet, there is some connectivity provided and relatively few dead-end streets and culs-de-sac. From Exhibit 5-7, the street connectivity factor for a Type 2 pattern is 0.85.

Terrain

The area is flat, so the grade factor is 1.00.

Population Characteristics

Less than 20% of the area's population is elderly; therefore, the population factor is 1.00.

Pedestrian Crossing Difficulty

To determine the pedestrian crossing factor, first determine how much delay pedestrians encounter while crossing streets. For example, Barnes Road South has a traffic volume of 1,000 vehicles per hour and a three-lane width. From Exhibit 5-12, the average pedestrian delay is 100 s. Subtracting 30 s from this result gives the amount of excess pedestrian delay at this location—70 s. The results for all unsignalized crossings are listed in Exhibit 5-53.

Exhibit 5-53
Calculation Example 2: Excess Pedestrian Delay Calculations

Street Name	Average Pedestrian Delay (s/ped)	Excess Pedestrian Delay (s/ped)
Spring Park Road	5	0
Spring Glen Road	44	14
Kennerly Road	9	0
Barnes Road	10	0
Barnes Road South	100	70
Parental Home Road	60	30

For the two signalized intersections, Equation 5-3 should be used. In the absence of other information, the typical minimum WALK time of 7 s given in the MUTCD (*43*) will be used to generate a worst-case delay. Four seconds of flashing DON'T WALK time will be added to the WALK time, giving an effective green time of 11 s. At the Spring Park/Spring Glen intersection, the traffic signal cycle length is 90 s. Applying this information to Equation 5-3 gives the following average pedestrian delay, in seconds:

$$d_p = \frac{(C - g_{\text{Walk}})^2}{2C} = \frac{(90 - 11)^2}{(2)(90)} = 35 \text{ s}$$

The excess delay is the average pedestrian delay minus 30 s, or 5 s. Performing the same calculation for the Barnes/University intersection produces an average pedestrian crossing delay of 80 s and an excess delay of 50 s.

Next, Equation 5-2 is applied to determine the pedestrian crossing factor. Using Barnes Road South as an example, with 70 s of excess delay, the pedestrian factor is:

$$f_{px} = \sqrt{(-0.0005 d_{ec}^2 - 0.1157 d_{ec} + 100)/100}$$

$$f_{px} = \sqrt{(-0.0005(70)^2 - 0.1157(70) + 100)/100}$$

$$f_{px} = 0.95$$

Although this factor may seem small, it should be kept in mind that the area served is reduced in proportion to the square of the radius. The square of 0.95 is 0.90; thus the area served by stops along Barnes Road South is reduced by 10% from the ideal.

The other pedestrian crossing factors are as follows:

- Spring Park Road: 1.00
- Spring Glen Road (signalized intersection): 1.00
- Spring Glen Road (unsignalized intersections): 0.99
- Kennerly Road: 1.00
- Barnes Road (signalized intersection): 0.96
- Barnes Road (unsignalized intersections): 1.00
- Parental Home Road: 0.98

Step 2: Calculate Each Stop's Service Radius

Each stop's service radius is calculated by multiplying 0.25 mi by the four adjustment factors determined in Step 1. The results are shown in Exhibit 5-54.

Street Name	Combined Factors	Adjusted Radius (mi)
Spring Park Road	0.85	0.213
Spring Glen Road (signalized)	0.85	0.213
Spring Glen Road (unsignalized)	0.84	0.210
Kennerly Road	0.85	0.213
Barnes Road (signalized)	0.82	0.205
Barnes Road (unsignalized)	0.85	0.213
Barnes Road South	0.81	0.203
Parental Home Road	0.83	0.208

Exhibit 5-54
Calculation Example 2: Service Coverage Reductions by Stop

Step 3: Determine Service Coverage Area

GIS software is used to create an air buffer around each stop based on the adjusted radius. In this case, no adjustment is made to the radius due to the freeway, as access is possible at street crossings under the elevated freeway. The resulting service coverage area can be compared with the ideal area developed using a 0.25-mi radius, as shown in Exhibit 5-55. The inner shaded area shows the adjusted service coverage area, while the outer shaded area shows the ideal area. Although visually the two areas do not seem that much different, in reality, the reduced area is 18% smaller than the ideal area. This difference is approximately equal to one service level if the area is transit supportive.

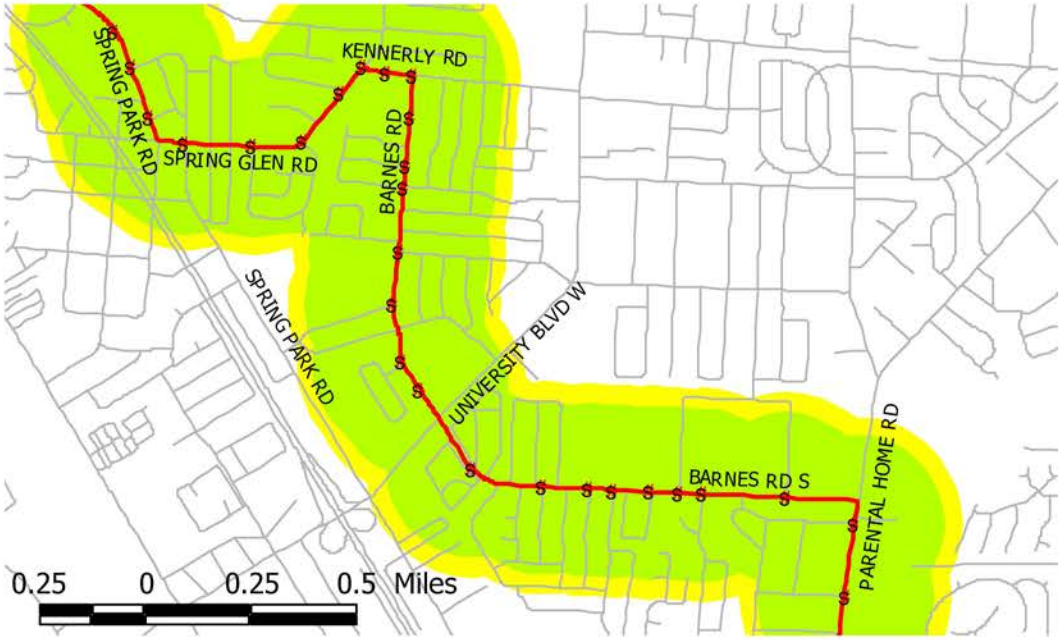


Exhibit 5-55
Calculation Example 2: Reduced Service Coverage Area

The Results

The adjusted service coverage area is 18% smaller than the ideal service coverage area. Because the reduction in area is proportional to the number of people willing to walk a given distance to transit on average, this result indicates that this section of the route serves 18% fewer people than it could. This result is due to less-than-ideal street network patterns and street crossing delays.

The biggest impact on service coverage is due to the street pattern. Because this area is already developed, there is not much that can be done in the short term to

improve pedestrian connectivity. In the longer term, zoning provisions to require more pedestrian connectivity as land redevelops could be considered. However, lessons learned in this area could be applied to other less-developed areas of Cowford that have yet to be developed and could be developed with better pedestrian connections.

In terms of pedestrian crossing difficulty, Barnes Road South and Parental Home Road are the most difficult to cross, with average delays of 60 to 100 s. Extra priority to pedestrian crossing improvements could be considered here, both to improve access to transit and to improve the overall pedestrian environment.

CALCULATION EXAMPLE 3: RELIABILITY

The Situation

As part of a comprehensive operations analysis, a transit agency is conducting an evaluation of the reliability of its highest frequency (and highest ridership) routes. This calculation example focuses on one of these routes, Route 14.

The Questions

How reliably does the route operate at different times of the day? What are the implications from the passenger's and transit agency's points of view?

The Facts

- The a.m. peak is defined for this route as departures prior to 9:00 a.m., midday is defined as departures from 9:00 a.m. to 3:30 p.m., and the p.m. peak is defined as departures after 3:30 p.m.
- The agency has set a standard of 90% on-time performance, measured on a daily basis, with "on-time" being defined as a departure between 1 min early and 5 min late.
- The transit agency's buses are equipped with AVL units, and the agency has an established program for archiving and analyzing data from the AVL system. For ease of presentation in this example, Exhibit 5-56 shows scheduled and actual departure times for only one day and one timepoint in one direction along the route. An actual analysis would desirably use data from multiple weekdays (e.g., a month, if available) to capture the effects of day-to-day variations in passenger demand and traffic delays. In addition, diagnosing the causes of unreliability usually requires analyzing multiple locations along the route.

Calculation Steps

Outline of Solution

Four of the reliability measures presented in this chapter will be evaluated. On-time performance will be used to compare operations to the transit agency's standards. Headway adherence will be used to evaluate potential bus bunching issues during the periods with the highest-frequency service. Budgeted wait time and excess wait time will be used to express reliability in terms of its impacts on passengers.

Exhibit 5-56
Calculation Example 3: Bus Departure Time Data

A.M. Peak		Midday		P.M. Peak	
Scheduled	Actual	Scheduled	Actual	Scheduled	Actual
5:06 a.m.	5:06 a.m.	9:06 a.m.	9:06 a.m.	3:52 p.m.	3:52 p.m.
5:37 a.m.	5:38 a.m.	9:22 a.m.	9:21 a.m.	4:02 p.m.	4:05 p.m.
5:52 a.m.	5:52 a.m.	9:38 a.m.	9:38 a.m.	4:12 p.m.	4:13 p.m.
6:06 a.m.	6:07 a.m.	9:54 a.m.	9:56 a.m.	4:22 p.m.	4:29 p.m.
6:20 a.m.	6:20 a.m.	10:09 a.m.	10:09 a.m.	4:32 p.m.	4:32 p.m.
6:32 a.m.	6:34 a.m.	10:24 a.m.	10:25 a.m.	4:42 p.m.	4:47 p.m.
6:47 a.m.	6:48 a.m.	10:39 a.m.	10:39 a.m.	4:52 p.m.	4:48 p.m.
7:01 a.m.	7:04 a.m.	10:57 a.m.	10:59 a.m.	5:02 p.m.	5:02 p.m.
7:16 a.m.	7:22 a.m.	11:12 a.m.	11:11 a.m.	5:13 p.m.	5:15 p.m.
7:32 a.m.	7:38 a.m.	11:25 a.m.	11:25 a.m.	5:26 p.m.	5:30 p.m.
7:47 a.m.	7:51 a.m.	11:40 a.m.	11:40 a.m.	5:41 p.m.	5:46 p.m.
8:02 a.m.	8:06 a.m.	11:54 a.m.	11:52 a.m.	5:57 p.m.	6:01 p.m.
8:17 a.m.	8:20 a.m.	12:09 p.m.	12:09 p.m.	6:15 p.m.	6:17 p.m.
8:33 a.m.	8:35 a.m.	12:24 p.m.	12:24 p.m.	6:33 p.m.	6:36 p.m.
8:50 a.m.	8:50 a.m.	12:39 p.m.	12:40 p.m.	6:49 p.m.	6:50 p.m.
		12:54 p.m.	12:53 p.m.	7:06 p.m.	7:08 p.m.
		1:10 p.m.	1:11 p.m.	7:21 p.m.	7:23 p.m.
		1:26 p.m.	1:25 p.m.	7:36 p.m.	7:36 p.m.
		1:42 p.m.	1:40 p.m.		
		1:57 p.m.	1:58 p.m.		
		2:12 p.m.	2:12 p.m.		
		2:27 p.m.	2:25 p.m.		
		2:39 p.m.	2:41 p.m.		
		2:49 p.m.	2:52 p.m.		
		3:01 p.m.	3:02 p.m.		
		3:15 p.m.	3:15 p.m.		
		3:30 p.m.	3:31 p.m.		

The data given in Exhibit 5-56 can be used to calculate all four measures, either by comparing actual to scheduled departure times (schedule deviations) or actual to schedule headways (headway deviations).

Step 1: Calculate On-time Performance

For each departure, determine the schedule deviation (actual departure time minus the scheduled departure time). This information will also be used later in calculating excess wait time. For example, the scheduled 6:47 a.m. departure actually left at 6:48 a.m., a schedule deviation of +1 min. Similarly, the scheduled 7:32 a.m. departure had a schedule deviation of +6 min and the 1:42 p.m. departure had a schedule deviation of -2 min. Comparing these schedule deviations to the TCQSM's (and, in this case, agency's) "on-time" window of -1 to +5 min, the 6:47 a.m. departure is considered on-time, while the other two departures are considered late.

Exhibit 5-57
Calculation Example 3: Schedule Deviation Calculations

A.M. Peak		Midday		P.M. Peak	
Scheduled Departure	Schedule Deviation (min)	Scheduled Departure	Schedule Deviation (min)	Scheduled Departure	Schedule Deviation (min)
5:06 a.m.	+0	9:06 a.m.	+0	3:52 p.m.	+0
5:37 a.m.	+1	9:22 a.m.	-1	4:02 p.m.	+3
5:52 a.m.	+0	9:38 a.m.	+0	4:12 p.m.	+1
6:06 a.m.	+1	9:54 a.m.	+2	4:22 p.m.	+7
6:20 a.m.	+0	10:09 a.m.	+0	4:32 p.m.	+0
6:32 a.m.	+2	10:24 a.m.	+1	4:42 p.m.	+5
6:47 a.m.	+1	10:39 a.m.	+0	4:52 p.m.	-4
7:01 a.m.	+3	10:57 a.m.	+2	5:02 p.m.	+0
7:16 a.m.	+6	11:12 a.m.	-1	5:13 p.m.	+2
7:32 a.m.	+6	11:25 a.m.	+0	5:26 p.m.	+4
7:47 a.m.	+4	11:40 a.m.	+0	5:41 p.m.	+5
8:02 a.m.	+4	11:54 a.m.	-2	5:57 p.m.	+4
8:17 a.m.	+3	12:09 p.m.	+0	6:15 p.m.	+2
8:33 a.m.	+2	12:24 p.m.	+0	6:33 p.m.	+3
8:50 a.m.	+0	12:39 p.m.	+1	6:49 p.m.	+1
		12:54 p.m.	-1	7:06 p.m.	+2
		1:10 p.m.	+1	7:21 p.m.	+2
		1:26 p.m.	-1	7:36 p.m.	+0
		1:42 p.m.	-2		
		1:57 p.m.	+1		
		2:12 p.m.	+0		
		2:27 p.m.	-2		
		2:39 p.m.	+2		
		2:49 p.m.	+3		
		3:01 p.m.	+1		
		3:15 p.m.	+0		
		3:30 p.m.	+1		

Note: Shaded cells indicate departures not on-time (more than 1 min early or 5 min late).

Looking at the a.m. peak, 13 of 15 departures (87%) were on time. During the midday period, 89% were on time, and during the p.m. peak, 89% were on time. Over the entire day, 88% of departures were on time.

Step 2: Calculate Headway Adherence

Headway adherence can be evaluated for the departures where the scheduled headway is 10 min or less (in this case, from 4:02 p.m. to 5:02 p.m.). The headway deviation (actual headway minus the scheduled headway) is measured for each departure. For example, the actual headway between the scheduled 3:52 p.m. and 4:02 p.m. departures was 13 min, compared to the scheduled headway of 10 min, a headway deviation of +3 min. Exhibit 5-58 shows the headway deviations for all of the departures with scheduled headways of 10 min or less.

Scheduled Departure	Headway Deviation (min)
4:02 p.m.	+3
4:12 p.m.	-2
4:22 p.m.	+6
4:32 p.m.	-7
4:42 p.m.	+5
4:52 p.m.	-9
5:02 p.m.	+4

Exhibit 5-58
Calculation Example 3: Headway Deviation Calculations

Normally, headway deviation would be calculated based on a larger dataset compiled over a number of days, but for illustrative purposes, the calculation process is shown based on one day only. The average scheduled headway is 10 min. The sample standard deviation of the headway deviations in Exhibit 5-58 is 6.1 min. (The sample standard deviation is used here because this dataset represents only one day's worth of data, while we are trying to estimate the value of headway adherence over a longer period of time. If the dataset included all of the trips for the study time period—for example, when all buses are AVL-equipped and their data are included in the dataset—then the population standard deviation would be used.) Headway adherence is calculated as the coefficient of variation of headway deviations (the standard deviation divided by the mean scheduled headway), or 0.61.

Step 3: Calculate Budgeted Wait Time and Excess Wait Time

Budgeted wait time is the difference between the 2nd and 95th percentile departure times. The procedure for calculating budgeted wait time recommends collecting at least 250 departure time observations to calculate these values. Because this example provides only 60 observations (and even fewer for each time period of interest), the minimum and maximum values in the data set will serve as surrogates for the 2nd and 95th percentile values, respectively. Exhibit 5-59 shows the resulting calculations.

Excess wait time is based on the average bus departure time minus the scheduled departure time. If there are no early departures, average excess wait time is simply the average of the schedule deviations. Since the transit agency allows buses to depart up to 1 min early, any departure that meets the agency policy will be included in the average. Earlier departures will be treated as being one headway late, and the scheduled headway will be substituted for those schedule deviations. Exhibit 5-59 also shows the results of this calculation.

Performance Measure	A.M. Peak	Midday	P.M. Peak
Minimum schedule deviation (min)[a]	+0	-2	-4
Maximum schedule deviation (min)[a]	+6	+3	+7
Budgeted wait time (min)	6	5	11
Average excess wait time (min)	2.2	2.0	2.8

Note: [a] Due to insufficient data points, minimum and maximum schedule deviations are used as surrogates for the 2nd and 95th percentile schedule deviations, respectively.

Exhibit 5-59
Calculation Example 3: Budgeted Wait Time and Excess Wait Time Calculation

The Results

Comparing the on-time performance results to Exhibit 5-21, the route's performance would be considered good, if this particular day's results are typical. Nevertheless, they are slightly below the transit agency's standard of 90%. One obvious

solution to improve on-time performance would be better control of early departures, as four of the seven not-on-time departures left more than 1 min early. In addition, during the a.m. peak, the two not-on-time departures occurred as part of an hour of late departures. During this hour, adding running time to the schedule could be considered (depending on its impacts on passenger load and the route's vehicle and driver needs). The causes and locations of the extra running time could also be investigated further and transit preferential treatments or operating changes considered to help speed up buses at those locations.

Comparing the headway adherence result of 0.61 to Exhibit 5-22, one can conclude that buses bunch frequently during the peak of the afternoon peak period. A typical passenger will experience a bus arrival that is off-headway more than half a headway (i.e., more than 5 min off-headway) between one-third and one-half of the time. This is an undesirable result that will lead to overcrowding problems on a number of peak-hour buses, along with other potential operating problems. This result should be a flag for the transit agency to investigate the causes of bus bunching more closely, followed by identifying potential solutions for the issue. Note that although the on-time performance results for the p.m. peak period did not indicate particular problems, the headway adherence results did flag a problem during a portion of the peak period.

The budgeted wait time results show that reliability is best during the midday and a.m. peak periods, when passengers should plan at being at the bus stop for up to 5–6 min. Passengers need to budget about twice as much time, 11 min, during the weekday p.m. peak period. The excess wait time results show that the average bus departure occurs approximately 2–3 min late, depending on the time of day. (The midday results would be significantly better had the three too-early departures not occurred.) If APC data were available, this excess wait time could be weighted by the number of passengers boarding at this stop on each trip to give a weighted average excess wait time that reflects what the average passenger experienced.

CALCULATION EXAMPLE 4: MULTIMODAL TRANSIT LOS

The Situation

An arterial street runs through an older commercial district of a city a couple of miles from the city center. As part of a planning effort to revitalize the district and improve transportation options in the area, various ways of allocating the available right-of-way among the travel modes are being investigated. Multimodal LOS, including transit LOS, is one of the performance measures being used to evaluate the alternatives.

As illustrated in Exhibit 5-60, the arterial street's current configuration is a four-lane street with on-street parking and 8-ft sidewalks on both sides. Buildings built up to the edge of the sidewalk preclude any street widening. Three alternatives are being evaluated initially:

- Alternative 1 would replace the on-street parking with bicycle lanes and wider sidewalks.
- Alternative 2 would reduce the roadway to one travel lane in each direction, keep the on-street parking, and add a buffered bicycle lane (cycle track) to the right of the parking. A landscaped median would be provided between intersections, along with left-turn lanes at intersections. At intersections, on-

street parking would be removed and the bicycle lane merged into a right-turn lane.

- Alternative 3 would create part-time (peak hour, peak direction) bus lanes, and would widen the sidewalks and plant street trees between intersections. A right-turn lane would be developed on the near sides of intersections. Left turns would be prohibited at intersections. Bus stops would be relocated to the far sides of intersections. Due to the low volume of bus traffic, bicycles would be allowed to use the bus lanes during peak periods. The bus lane would be used for parking and bicycles during off-peak periods.

This example only evaluates the multimodal transit LOS associated with each option, for the purpose of illustrating the calculations involved. A real-world evaluation would need to consider many other factors (e.g., cost, safety, business impacts) associated with each alternative. Other alternatives are also conceivable.

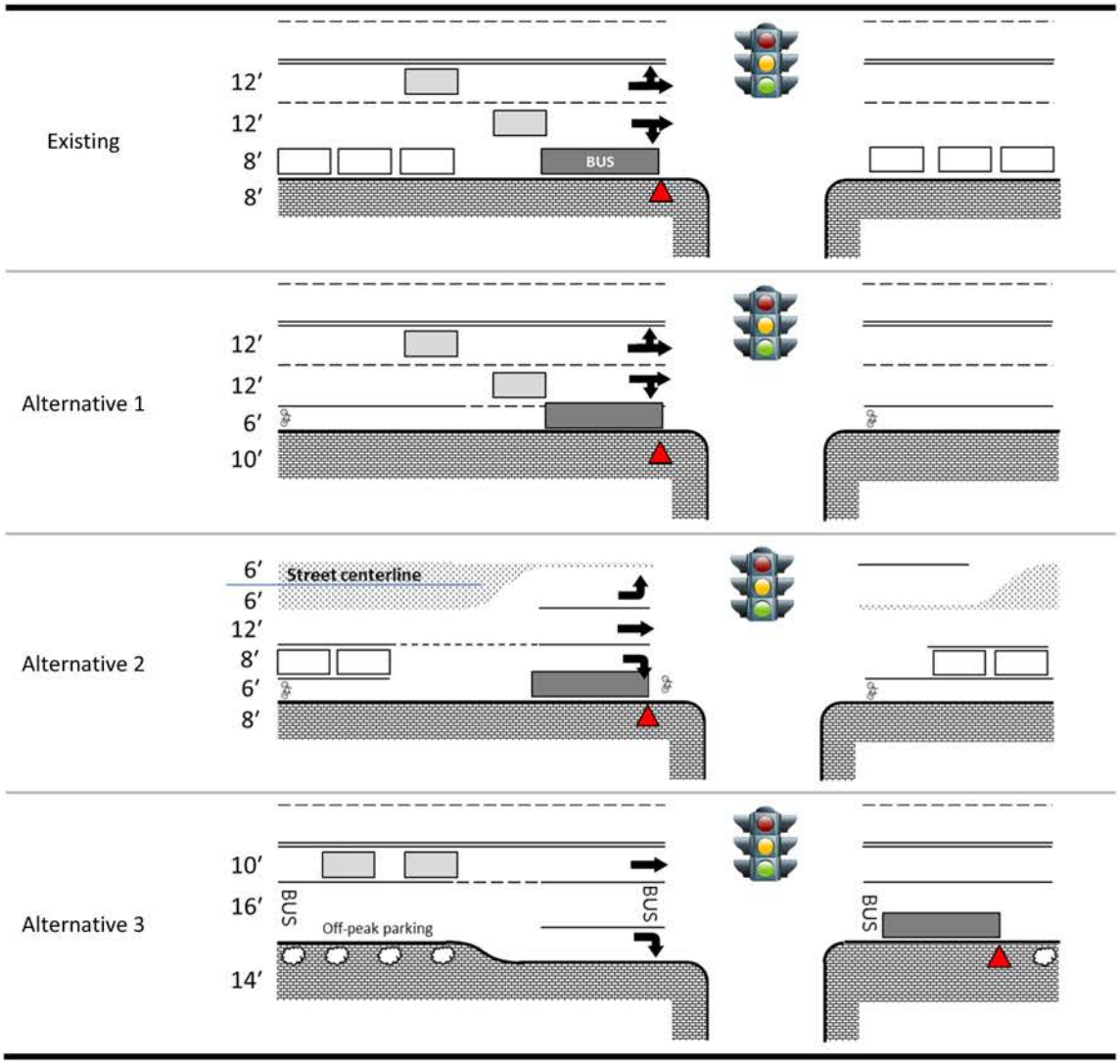


Exhibit 5-60
Calculation Example 4: Street Cross-Section by Alternative

The Question

What is each alternative's transit LOS during the weekday a.m. peak hour?

The Facts

- Only one bus route serves the street, with service provided every 15 min during the weekday a.m. peak period. Bus stops are located 750 ft apart on average on this portion of the route.
- Exhibit 5-61 provides the transit data for each alternative for the weekday a.m. peak hour. Existing condition data was measured in the field (frequency and amenities) or was calculated from archived AVL and APC data (all others). Future conditions were determined using HCM methods (bus speeds) and assumptions based on the performance of other bus lanes existing within the city (excess wait time).
- Potential changes in demand for each mode are being evaluated by a separate performance measure and analysis. For the purposes of calculating multimodal LOS, it has been decided to focus on the impact of the QOS changes resulting from different allocations of street right-of-way. Therefore, it has been assumed that the demand for each mode is constant under each scenario.

Exhibit 5-61
Calculation Example 4: Transit Data by Scenario

Condition	Frequency (bus/h)	Bus Speed (mi/h)	Load Factor (p/seat)	Excess Wait Time (min)	Shelter?	Bench?
Existing	4	6.9	1.1	2.8	No	No
Alternative 1	4	6.9	1.1	2.8	No	No
Alternative 2	4	7.4	1.1	2.8	No	No
Alternative 3	4	9.0	1.1	1.0	Yes	Yes

- Exhibit 5-62 provides the data required for determining the pedestrian environment factor. Sidewalk-related data were measured in the field for existing conditions and are based on the cross-section concepts developed for each future alternative. Traffic counts were conducted to determine existing conditions; this analysis assumes no change in demand for the future alternatives, but demand may redistribute between lanes depending on the future alternative lane configuration. Average motorized vehicle running speeds in the outside lane, including traffic signal delay, were estimated using HCM methods for both existing and future conditions.
- On-street parking is typically fully utilized. The parking utilization percentage is a length-weighted average of 100% utilization where parking is allowed and 0% where it is prohibited (e.g., at bus stops).

Exhibit 5-62
Calculation Example 4: Pedestrian Environment Data by Scenario

					Outside Lane	
Condition	Sidewalk Width (ft)	Sidewalk Buffer (ft)	% Segment with Utilized Parking	Number of Lanes by Direction	Flow Rate (veh/h)	Motor Vehicle Speed (mi/h)
Existing	8	0	80%	2	400	15
Alternative 1	10	0	80%	2	400	15
Alternative 2	8	0	0%	1	800	17
Alt. 3 (typical)	10	4	100%	2	4	9
Alt. 3 (near side)	8	0	0%	2	80	17

Calculation Steps

Outline of Solution

The full calculation process will be shown for existing conditions. The results of the calculations will be shown for the alternatives. There are four main values to calculate: the transit wait–ride score, the pedestrian environment score, the transit LOS score, and the transit LOS letter.

Step 1: Determine the Transit Wait–Ride Score

The transit wait–ride score has two components: a headway factor and a perceived travel time factor.

Headway Factor

Calculating the headway factor requires knowing the frequency of bus service. Since the bus route on this street stops more frequently than every 0.25 mi (1,320 ft), it is considered local service and its frequency of 4 buses per hour is counted, even in cases where no bus stops are physically located within a segment. The headway factor is calculated from Equation 5-6:

$$f_h = 4.00e^{-1.434/(f+0.001)}$$

$$f_h = 4.00e^{-1.434/(4+0.001)}$$

$$f_h = 2.80$$

This result indicates that the route is estimated to produce 2.8 times the ridership that would occur if the route operated hourly.

Perceived Travel Time Factor

The perceived travel time factor includes components relating to passenger loads, speed, reliability, and stop amenities. These will be addressed one at a time.

The passenger load factor is determined using Equation 5-9. Because the average load factor in this segment (1.1 p/seat) is greater than 1.0, the last of the three choices given in Equation 5-9 will be used:

$$f_{pl} = \begin{cases} 1.00 & L_f \le 0.80 \\ 1 + \dfrac{4(L_f - 0.80)}{4.2} & 0.80 < L_f \le 1.00 \\ 1 + \dfrac{4(L_f - 0.80) + (L_f - 1.00)(6.5 + [5(L_f - 1.00)]}{4.2L_f} & L_f > 1.00 \end{cases}$$

$$f_{pl} = 1 + \frac{4(1.10 - 0.80) + (1.10 - 1.00)(6.5 + [5(1.10 - 1.00)]}{4.2(1.10)}$$

$$f_{pl} = 1.41$$

The perceived amenity time rate is given by Equation 5-10. There are no amenities at the stop under existing conditions, but there are in Alternative 3. In the absence of other information, the average passenger trip length will be assumed to be the national average, 3.7 mi:

$$T_{at} = \frac{1.3p_{sh} + 0.2p_{be}}{l_{pt}}$$

$$T_{at} = \frac{1.3(0) + 0.2(0)}{3.7}$$

$$T_{at} = 0 \text{ min/mi}$$

The excess wait time rate for late arrivals T_{ex} is the excess wait time t_{ex} divided by the average passenger trip length l_{pt}, as indicated in the list of variables following Equation 5-10. Therefore, T_{ex} is (2.8 min)/(3.7 mi) or 0.76 min/mi.

The perceived travel time rate is the actual travel time rate multiplied by the passenger load factor, plus the excess wait time rate multiplied by a perception factor of 2, minus the perceived amenity time rate, as given in Equation 5-8:

$$T_{ptt} = \left(f_{pl}\frac{60}{S}\right) + (2T_{ex}) - T_{at}$$

$$T_{ptt} = \left(1.41\frac{60}{6.9}\right) + (2)(0.76) - 0$$

$$T_{ptt} = 13.8 \text{ min/mi}$$

Although the bus route itself operates at an average travel time rate of 8.7 min/mi (6.9 mi/h) in this segment, the perceived time is considerably greater, due to the standing conditions on board, the relatively unreliable service, and the lack of amenities at the bus stop.

Next, the perceived travel time factor is calculated from Equation 5-7. In the absence of other information, the default travel time rate elasticity of -0.4 will be used. Because this segment is not located within the central business district of a metropolitan area of 5 million or more, the base travel time rate used will be 4 min/mi.

$$f_{tt} = \frac{(E-1)T_{btt} - (E+1)T_{ptt}}{(E-1)T_{ptt} - (E+1)T_{btt}}$$

$$f_{tt} = \frac{(-0.4-1)(4) - (-0.4+1)(13.8)}{(-0.4-1)(13.8) - (-0.4+1)(4)}$$

$$f_{tt} = 0.64$$

This result indicates that if the perceived speed of 6.9 mi/h was averaged over the entire route, the route would be estimated to produce 64% that of the ridership produced by a route operating at a perceived speed of 15 mi/h.

The transit wait–ride score can now be calculated using Equation 5-5:

$$s_{w-r} = f_h f_{tt}$$

$$s_{w-r} = (2.80)(0.64)$$

$$s_{w-r} = 1.79$$

Exhibit 5-63 summarizes the transit wait–ride score calculation results for all alternatives.

Condition	f_h	f_{pl}	T_{at}	T_{ptt}	f_{tt}	$s_{w\text{-}r}$
Existing	2.80	1.41	0.0	13.79	0.64	1.79
Alternative 1	2.80	1.41	0.0	13.79	0.64	1.79
Alternative 2	2.80	1.41	0.0	12.96	0.65	1.82
Alternative 3	2.80	1.41	0.4	9.54	0.72	2.01

Exhibit 5-63
Calculation Example 4: Transit Wait–Ride Score Calculation Results

There are no differences in transit conditions between Alternative 1 and existing conditions, so their transit wait–ride scores are identical. Alternative 2 produces a small improvement in the score due to the slightly improved speed, while Alternative 3 produces a larger improvement due to improved speed and reliability, and the provision of a shelter and bench at this segment's bus stop.

Step 2: Determine the Pedestrian Environment Score

The pedestrian environment score includes a constant value and factors relating to traffic volumes, traffic speeds, and the roadway cross-section.

Motorized Vehicle Volume Adjustment Factor

This factor is calculated using Equation 5-13. Its input is the motorized vehicle demand flow rate at mid-segment (400 veh/h for existing conditions).

$$f_v = 0.0091\frac{v_m}{4}$$

$$f_v = 0.0091\frac{400}{4}$$

$$f_v = 0.91$$

Motorized Vehicle Speed Adjustment Factor

This factor is calculated using Equation 5-14 and the average outside-lane motor vehicle running speed for the segment (15 mi/h for existing conditions).

$$f_s = 4\left(\frac{S_R}{100}\right)^2$$

$$f_s = 4\left(\frac{15}{100}\right)^2$$

$$f_s = 0.09$$

Cross-Section Adjustment Factor

This factor includes a number of components that reflect pedestrians' perceived separation from traffic. First, the variables given in Exhibit 5-27 will be calculated, which are used to determine the amount of buffering provided by the outside lane, bicycle lane, and parking lane or shoulder. This exhibit lists three conditions which are evaluated in turn. Whether or not a given condition is satisfied then determines how each variable is calculated:

- First, the percentage of utilized parking in the segment *is not* zero under existing conditions; therefore, the total width W_t is calculated as the sum of the widths of the outside lane (12 ft) and the bicycle lane (0 ft), or 12 ft.

- Second, the segment's demand flow rate *is* greater than 160 veh/h under existing conditions; therefore the effective total width $W_v = W_t$ or 12 ft.
- Third, the percentage of utilized parking in the segment *is not* less than 0.25 under existing conditions; therefore the effective combined width of the bicycle lane and shoulder (parking lane) W_1 = 10 ft.

Next, the factor relating to the buffering effect of barriers or street trees is considered. There are no barriers under existing conditions, therefore the buffer area coefficient f_b = 1.0, according to the list of variables following Exhibit 5-15. The sidewalk is curb-tight, therefore the buffer width W_{buf} is 0 ft.

The adjusted available minimum sidewalk width W_{aA} is the lesser of the actual sidewalk width (8 ft) or 10 ft, so it is 8 ft. The sidewalk width coefficient f_{sw} is calculated as 6.0 – 0.3 W_{aA}, from the list of variables following Exhibit 5-15, or 2.4.

With these intermediate calculations out of the way, the cross-section adjustment factor can now be determined from Equation 5-12:

$$f_w = -1.2276 \ln\left(W_v + 0.5W_1 + 50p_{pk} + W_{buf}f_b + W_{aA}f_{sw}\right)$$

$$f_w = -1.2276 \ln(12 + 0.5(10) + 50(0.8) + (0)(1.0) + (8)(2.4))$$

$$f_w = -5.47$$

and the pedestrian environment score can now be calculated from Equation 5-11:

$$I_p = 6.0468 + f_w + f_v + f_s$$

$$I_p = 6.0468 - 5.47 + 0.91 + 0.09$$

$$I_p = 1.58$$

In the multimodal LOS methodology, a pedestrian environment score of 1.58 corresponds to a pedestrian LOS A for the portion of the segment between signalized intersections (it uses the same LOS scale as shown for transit in Exhibit 5-28). Exhibit 5-64 provides the results for all of the alternatives. Because two different pedestrian cross-sections exist under Alternative 3, two subsegments must be defined and a weighted average score calculated based on the relative lengths of each subsegment.

Exhibit 5-64
Calculation Example 4: Pedestrian Environment Score Calculation Results

Condition	f_s	f_v	W_t	W_v	W_1	f_w	I_p
Existing	0.09	0.91	12	12	10	-5.47	1.58
Alternative 1	0.09	0.91	18	18	6	-4.83	2.22
Alternative 2	0.12	1.82	18	18	10	-5.41	2.58
Alt. 3 (typical)	0.03	0.01	16	16	10	-5.26	1.16
Alt. 3 (near side)	0.03	0.12	10	10	10	-4.64	

As can be seen, pedestrian conditions degrade in Alternatives 1 and 2, but improve in Alternative 3. Alternatives 1 and 2 provide pedestrian LOS B, while Alternative 3 is at pedestrian LOS A. Removing the on-street parking removes a perceived barrier between pedestrians and motorized traffic, which has a noticeable impact on the pedestrian environment score. In addition, all of the motorized vehicle traffic is concentrated in the outside lane in Alternative 2, instead of being distributed across two lanes, which also contributes to pedestrian discomfort. In Alternative 3, only buses and right-turning traffic use the outside lane, which improves pedestrian comfort.

Step 3: Determine the Transit LOS Score and Step 4: Determine Transit LOS

The transit LOS score is computed from Equation 5-15. For existing conditions, these calculations are as follows:

$$I_t = 6.0 - 1.50s_{w-r} + 0.15I_p$$

$$I_t = 6.0 - 1.50(1.79) + 0.15(1.58)$$

$$I_t = 3.56$$

Comparing this result to Exhibit 5-28, the transit LOS is D for existing conditions. Exhibit 5-65 shows the results for all scenarios.

Exhibit 5-65
Calculation Example 4: Transit LOS Results

Condition	Transit LOS Score I_t	LOS
Existing	3.56	D
Alternative 1	3.65	D
Alternative 2	3.66	D
Alternative 3	3.16	C

Alternative 3 performs the best from a transit LOS perspective, with the bus lane providing improved speed and reliability. Alternatives 1 and 2 perform worse than under existing conditions, due to the reduction in the pedestrian environment quality, but still produce the same LOS result. Alternative 2's improved bus speeds, in particular, are offset by the poorer pedestrian environment.

The Results

Alternative 3 performed the best for transit in this segment, although there was not a huge variation in the transit LOS score results (two-thirds the width of an LOS range separates the best-performing from the worst-performing scenario). This indicates that the relatively small speed improvements did not result in large differences in perceived travel time and QOS. The transit agency could also consider operational improvements (e.g., stop consolidation) or physical improvements (e.g., transit signal priority or queue jumps) to speed up buses further. Improving transit frequency on this street, if warranted by ridership, would do the most to improve the transit LOS score.

From a pedestrian standpoint, Alternative 3 performed the best. Similar calculations could be performed using HCM techniques for the automobile and bicycle modes to identify which scenario performed the best for those modes. Individual segment scores could then be combined to produce an overall facility score by mode.

Note that these LOS results are just one set of performance measures among many that should be used to evaluate alternatives. For example, although Alternative 3 performed the best from the transit and pedestrian QOS perspectives, the mixing of buses and bicycles in a lane might pose safety issues that would need to be considered, and traffic pattern changes with the loss of the left-turn opportunities on the street would also need to be considered.

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CHAPTER 6
BUS TRANSIT CAPACITY

1. User's Guide
2. Mode and Service Concepts
3. Operations Concepts
4. Quality of Service Concepts
5. Quality of Service Methods
6. **Bus Transit Capacity**
7. Demand-Responsive Transit
8. Rail Transit Capacity
9. Ferry Transit Capacity
10. Station Capacity
11. Glossary and Symbols
12. Index

CONTENTS

1. INTRODUCTION 6-1
How to Use This Chapter 6-2
Other Resources 6-2

2. FUNDAMENTALS 6-3
Sources of Bus Delay 6-3
Factors Determining Bus Capacity 6-15
Planning-Level Capacity Values 6-20

3. PREFERENTIAL TREATMENTS 6-24
Overview 6-24
Busways and Freeway Managed Lanes 6-26
Urban Street Bus Lanes 6-31
Transit Signal Priority (TSP) 6-40
Site-Specific Priority Treatments 6-46
Summary 6-51

4. OPERATIONAL TOOLS 6-53
Overview 6-53
Bus Stop Placement 6-53
Bus Stopping Patterns 6-55
Route Design 6-57
Yield-to-Bus Laws 6-58
Summary 6-59

5. BUS CAPACITY METHODOLOGY 6-60
Introduction 6-60
Step 1: Define the Facility 6-61
Step 2: Gather Input Data 6-61
Step 3: Set a Design Bus Stop Failure Rate 6-63
Step 4: Determine Dwell Time 6-66
Step 5: Determine Loading Area Capacity 6-70
Step 6: Determine Bus Stop Capacity 6-77
Step 7: Determine Facility Bus Capacity 6-80
Step 8: Determine Facility Person Capacity 6-84

6. BUS SPEED METHODOLOGY 6-86
Step 1: Define the Facility 6-87
Step 2: Gather Input Data 6-87
Step 3: Determine Section Maximum Capacity 6-87
Step 4: Determine Base Bus Running Time Rate 6-87
Step 5: Adjust for Skip-Stop Operation 6-91
Step 6: Adjust for Bus Congestion 6-92
Step 7: Determine Average Section Speed 6-93
Step 8: Determine Average Facility Speed 6-94

7. BUS RELIABILITY 6-95
Factors Influencing Bus Reliability 6-95
Scheduling and Holding Strategies 6-96
Relationships of Service Characteristics to Reliability 6-96
Applications of AVL Data 6-97
Forecasting Reliability 6-97

8. APPLICATIONS 6-98
Alternative Mode, Facility, and Service Comparisons 6-98
Fare Collection Technology Changes 6-98
Assessing the Impact of Transit Preferential Treatments 6-99
Diagnosing and Treating Capacity Issues 6-100
Sizing BRT Facilities for a Given Demand 6-100

9. CALCULATION EXAMPLE 6-102
The Situation 6-102
The Question 6-102
Bus Capacity 6-103
Bus Speed 6-110
Options Assessment 6-112
Comments 6-119

10. REFERENCES 6-120

APPENDIX A: EXHIBITS IN METRIC UNITS 6-125

APPENDIX B: DWELL TIME DATA COLLECTION 6-126
Introduction 6-126
Passenger Service Times 6-126
Dwell Times 6-127

APPENDIX C: BUS BUNCHING AND PERSON CAPACITY 6-129
Reference 6-130

LIST OF EXHIBITS

Exhibit 6-1 Sources of Bus Delay Associated with Bus Stops 6-3
Exhibit 6-2 Bus Acceleration Characteristics 6-4
Exhibit 6-3 Bus Stop Failure Illustrated 6-5
Exhibit 6-4 Individual Passenger Service Times (Level Boarding) 6-7
Exhibit 6-5 On-Line and Off-Line Loading Areas 6-9
Exhibit 6-6 Illustrative Relationship of Stop Spacing and Speed (Urban Street, Mixed Traffic) 6-10
Exhibit 6-7 Estimated Average Bus Speeds on Grade-Separated Busways (mi/h) 6-11
Exhibit 6-8 On-Street Bus Stop Locations 6-12
Exhibit 6-9 On-Street Bus Stop Location Comparison 6-13
Exhibit 6-10 Illustrative Effect of Bus Volume on Urban Street Bus Speeds 6-14
Exhibit 6-11 Bus Loading Areas, Stops, and Facilities 6-15
Exhibit 6-12 Loading Area Design Types 6-16
Exhibit 6-13 Loading Area Utilization Example 6-17
Exhibit 6-14 Relative Contributions of Dwell Time, g/C Ratio, and Number of Loading Areas to Bus Stop Maximum Capacity 6-18
Exhibit 6-15 Characteristics of Common Bus Transit Vehicles —United States and Canada 6-20
Exhibit 6-16 Planning-Level Bus Lane Service Volumes 6-21
Exhibit 6-17 Maximum Standard Bus Passenger Service Volumes for Planning Purposes 6-21
Exhibit 6-18 Illustrative Urban Street Bus Lane Capacities with One Loading Area 6-22
Exhibit 6-19 Illustrative Mixed-Traffic Bus Capacities 6-23
Exhibit 6-20 At-Grade Busway Station Examples 6-27
Exhibit 6-21 Bus Tunnel Examples 6-27
Exhibit 6-22 Typical Impacts of Busways and Freeway Managed Lanes on Bus Operations 6-28
Exhibit 6-23 Typical Freeway Managed Lane Minimum Operating Thresholds 6-28
Exhibit 6-24 General Planning Guidelines for Busways and Freeway Managed Lanes 6-29
Exhibit 6-25 Houston Freeway Managed Lane Example 6-30
Exhibit 6-26 Freeway Ramp Queue Bypasses 6-30
Exhibit 6-27 Examples of Bus on Shoulder Operation (Minneapolis) 6-31
Exhibit 6-28 Sources of Delay for Buses Operating in Mixed Traffic at Intersections 6-32
Exhibit 6-29 Bus Lane Development via Parking Restrictions 6-32

Exhibit 6-30 Median Busway Center Station Examples 6-33
Exhibit 6-31 Exclusive Bus Lane Examples 6-35
Exhibit 6-32 Contraflow Lane Examples 6-35
Exhibit 6-33 Bi-directional Operation Example (Eugene) 6-36
Exhibit 6-34 General Planning Guidelines for Bus Lanes on Urban Streets 6-38
Exhibit 6-35 Degree of Bus Lane Impacts 6-39
Exhibit 6-36 Observed Travel Time Savings with Urban Street Bus Lanes 6-39
Exhibit 6-37 Observed Reliability Improvements with Urban Street Bus Lanes 6-40
Exhibit 6-38 Types of Bus Signal Priority Systems 6-41
Exhibit 6-39 Bus Signal Priority Concept—Red Truncation and Green Extension 6-42
Exhibit 6-40 Special Bus Left-Turn Phasing Examples 6-42
Exhibit 6-41 Optical TSP System Example 6-43
Exhibit 6-42 Summary of TSP Benefits and Impacts 6-45
Exhibit 6-43 Right-Turn Lane Queue Jump Process 6-46
Exhibit 6-44 Example Queue Jump Applications with Bus Lanes 6-47
Exhibit 6-45 Boarding Island Example 6-49
Exhibit 6-46 Curb Extension Examples 6-50
Exhibit 6-47 Bus Preferential Treatments Comparison 6-52
Exhibit 6-48 Bus Stop Spacing Patterns Illustrated 6-55
Exhibit 6-49 Example Skip-Stop Pattern and Signing 6-56
Exhibit 6-50 Examples of Bus Exemptions from Movement Restrictions 6-58
Exhibit 6-51 Yield-to-Bus Law Notification Examples 6-59
Exhibit 6-52 Bus Operations Tool Comparison 6-59
Exhibit 6-53 Bus Capacity Methodology Flowchart 6-60
Exhibit 6-54 Bus Lane Types 6-63
Exhibit 6-55 Statistical Basis of Failure Rate 6-65
Exhibit 6-56 Values of Z Associated with Given Failure Rates 6-65
Exhibit 6-57 Illustrative Relationships Between Failure Rate, Operating Margin, and Design Loading Area Bus Capacity 6-66
Exhibit 6-58 Percent Passengers Using Busiest Bus Door Channel (No Fare Payment) 6-68
Exhibit 6-59 Average Bus Reentry Delay (Stops Not Near Traffic Signals) 6-73
Exhibit 6-60 Default Through Movement Saturation Flow Rates (veh/h of green) 6-74
Exhibit 6-61 Illustrative Queue Service Delays (s) (100-s Cycle Length) 6-75
Exhibit 6-62 Illustrative Reentry Delay by Case 6-77
Exhibit 6-63 Efficiency of Multiple Linear Loading Areas at Bus Stops 6-78
Exhibit 6-64 Examples of Auto Turning Conflicts with Buses 6-79
Exhibit 6-65 Right-Turn Vehicle Capacities c_{rt} for Planning Applications (veh/h) 6-79

Exhibit 6-66 Bus Stop Location Factor f_l 6-80
Exhibit 6-67 Typical Values of Adjustment Factor f_k for Availability of Adjacent Lanes 6-83
Exhibit 6-68 Values of Adjustment Factor f_k for Type 2 Bus Lanes with Alternate Two-Block Skip-Stops 6-83
Exhibit 6-69 Bus Speed Methodology Flowchart 6-86
Exhibit 6-70 Illustrative Unimpeded Running Time Rates (min/mi): CBD 6-89
Exhibit 6-71 Illustrative Unimpeded Running Time Rates (min/mi): Suburban Arterial 6-89
Exhibit 6-72 Illustrative Unimpeded Running Time Rates (min/mi): Busway 6-90
Exhibit 6-73 Estimated Bus Running Time Losses t_l on Urban Streets (min/mi) 6-90
Exhibit 6-74 Illustrative Skip-Stop Speed Adjustment Factor Values 6-92
Exhibit 6-75 Bus–Bus Interference Factor f_{bb} Values 6-93
Exhibit 6-76 Calculation Example: Summary of Existing Bus Stop Characteristics 6-104
Exhibit 6-77 Calculation Example: Average Boardings and Alightings per Bus by Stop 6-104
Exhibit 6-78 Calculation Example: Average Boardings and Alightings by Door Channel—Existing Conditions 6-105
Exhibit 6-79 Calculation Example: Average Passenger Flow Time by Door Channel (s)—Existing Conditions 6-106
Exhibit 6-80 Calculation Example: Average Dwell Time by Stop (s) —Existing Conditions 6-106
Exhibit 6-81 Calculation Example: Reentry and Clearance Times by Stop (s) —Existing Conditions 6-108
Exhibit 6-82 Calculation Example: Loading Area Capacity by Stop (bus/h) —Existing Conditions 6-108
Exhibit 6-83 Calculation Example: Bus Stop Capacity—Existing Conditions 6-109
Exhibit 6-84 Calculation Example: Average Boardings and Alightings by Door Channel (s)—Pay-on-Exit 6-113
Exhibit 6-85 Calculation Example: Average Passenger Flow Time by Door Channel (s)—Pay-on-Exit 6-114
Exhibit 6-86 Calculation Example: Average Dwell Time by Stop (s) —Pay-on-Exit 6-115
Exhibit 6-87 Calculation Example: Summary of Impacts—Pay-on-Exit 6-115
Exhibit 6-88 Calculation Example: Bus Stop Group Capacities (bus/h) —Skip Stops 6-116
Exhibit 6-89 Calculation Example: Summary of Impacts—Skip Stops 6-117
Exhibit 6-90 Calculation Example: Loading Area Capacity by Stop (bus/h): Design Option 1 6-118
Exhibit 6-91 Calculation Example: Summary of Design Option 1 Impacts 6-118

Exhibit 6-92 Calculation Example: Traffic Blockage Factor f_l by Stop (veh/h) 6-119
Exhibit 6-93 Calculation Example: Summary of Design Option 2 Impacts, No Skip-Stop Operation 6-119
Exhibit 6-7m Estimated Average Bus Speeds on Grade-Separated Busways (km/h) 6-125
Exhibit 6-73m Estimated Base Bus Running Time Losses, t_l (min/km) 6-125
Exhibit 6-B1 Sample Passenger Service Time Data Collection Sheet 6-127
Exhibit 6-B2 Sample Dwell Time Data Collection Sheet 6-128

1. INTRODUCTION

Factors that influence bus capacity also influence bus speeds and reliability—issues of interest to any size transit agency. See Chapter 3 for a discussion of these relationships.

As discussed in Chapter 3, Operations Concepts, bus capacity is not just an interest of high-ridership, major-city bus systems. The factors that ultimately determine the capacity of a service or facility—dwell time, traffic signal timing, and so on—also affect passenger quality of service elements such as travel speed and travel time reliability, as well as a service provider's operations costs. These are issues of concern to any size transit agency.

Bus capacity, speed, and reliability address the movement of both buses and the movement of people within those buses:

- *Capacity* deals with how many people and buses can move past a given location during a given time period under specified operating conditions; without unreasonable delay, hazard, or restriction; and with reasonable certainty.
- *Speed* deals with how quickly people and buses can move from one location to another.
- *Reliability* deals with how well the bus schedule can be maintained.

Bus capacity, speed, and reliability are influenced by the timing, location, and magnitude of passenger travel demands; by external factors such as traffic signal timing and traffic congestion along the roadways used by buses; and by a transit agency's operating budget and service policies, which influence bus frequencies and allowed passenger loads, among other things. Ultimately, bus capacity is constrained by (*a*) the ability of bus stops and facilities to serve buses and their passengers, (*b*) the number and type of buses operated, and (*c*) the distribution of passenger demand.

Organization of Chapter 6.

Chapter 6 of the *Transit Capacity and Quality of Service Manual* (TCQSM) presents methods for calculating fixed-route bus capacity and speed for a variety of facility types, and provides a summary of the current state of knowledge about factors influencing service reliability.

- Section 2 provides bus-specific speed and capacity concepts, building upon the general concepts information presented in Chapter 3, Operations Concepts. It also presents capacity values suitable for planning analyses.
- Section 3 is an overview of transit preferential treatments (infrastructure improvements) that can improve bus capacity, speed, reliability, or a combination of these.
- Section 4 describes operational tools available to transit agencies that can improve bus capacity, speed, and reliability.
- Section 5 presents a computational procedure for estimating bus capacity.
- Section 6 presents a computational procedure for estimating average bus speeds.
- Section 7 describes current knowledge about the factors that affect bus reliability.
- Section 8 presents potential applications of this chapter's methods to a variety of questions that transit agencies may face.

- Section 9 provides a comprehensive example of the calculations involved in performing bus capacity and speed analyses.
- Appendix A provides substitute exhibits in metric units for selected exhibits that use U.S. customary units.
- Appendix B provides a standardized procedure for collecting bus dwell time data in the field.
- Appendix C discusses the effects of bus bunching on bus capacity.

HOW TO USE THIS CHAPTER

The early sections of this chapter, Sections 2–4, provide bus-specific concepts that support the computational methods presented later in the chapter, but which are also intended to be a useful resource for a wide range of transit and transportation professionals. Section 8, describing applications of this chapter's methods, is written with both non-technical and technical audiences in mind.

Sections 5 and 6 provide step-by-step guidance for performing bus capacity and speed evaluations, and Section 9 gives examples of the calculations involved. Although capacity may not be the ultimate output of an analysis, it is a necessary input to this chapter's speed estimation procedures. Buses interfere with each other as the number of buses using a facility approaches the facility's maximum capacity, thereby reducing average bus speeds. Analysts should be familiar with these sections prior to using the spreadsheet that implements these methods, found on the accompanying CD-ROM. Although Section 7 is less mathematical, as insufficient research exists to present a computational method for estimating bus reliability, this section is also intended primarily for analysts.

Appendix B serves as a resource to those who wish to collect bus dwell time data in the field. Appendix C supplements Sections 5 and 7 with information on bus bunching that, while theoretically sound, has not yet been confirmed through field testing.

OTHER RESOURCES

Other TCQSM material related to bus capacity includes:

- The "What's New" section of Chapter 1, User's Guide, which describes the changes made in this chapter from the 2nd Edition.
- Chapter 2, Mode and Service Concepts, which defines and illustrates the various bus submodes and typical service patterns.
- Chapter 3, Operations Concepts, which defines capacity and presents general capacity, speed, and reliability concepts applicable to all transit modes.
- The "Passenger Load" section of Chapter 5, Quality of Service Methods, which serves as a resource for determining the standing capacity of a bus at a design passenger loading level.
- Chapter 10, Stop and Station Capacity, which provides a method for sizing off-street bus facilities.
- The TCQSM's CD-ROM, which includes a bus speed and capacity spreadsheet and links to electronic versions of all of the TCRP reports referenced in this chapter.

2. FUNDAMENTALS

SOURCES OF BUS DELAY

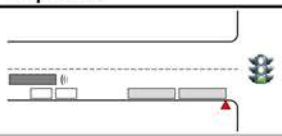
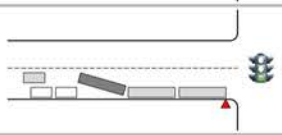
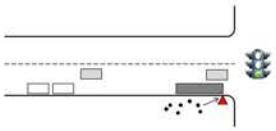
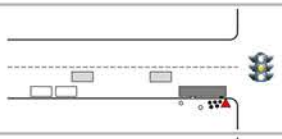
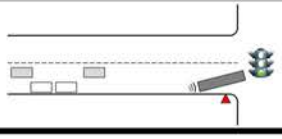
Delay Associated with Bus Stops

Delay affects bus speeds (a quality of service issue) and, ultimately, the cost to operate a bus route.

Without passengers to serve, there would be no point in operating bus service. However, each stop that a bus makes along its route requires time, which affects (*a*) how fast the route operates, which influences (*b*) how many buses are required to operate the route, which in turn ultimately sets (*c*) the cost of operating the route. Therefore, setting bus stop locations requires balancing passenger convenience (which affects ridership) with transit agency operating needs.

Exhibit 6-1 lists the main sources of delay to a bus each time it serves a bus stop, relative to proceeding down the street without stopping. Each of these sources of delay is discussed in more detail following the exhibit.

Exhibit 6-1
Sources of Bus Delay Associated with Bus Stops

Source of Delay	Description	Depiction	Typical Values
Deceleration	Extra time spent slowing to serve a stop, compared to proceeding at the bus' running speed past the stop		4.5 s while slowing from 25 mi/h (40 km/h)
Bus stop failure	Bus arrives at a stop to find all loading areas occupied, forcing the bus to wait until other buses leave the stop		Up to the dwell time and signal delay time of the buses already using the stop
Boarding lost time	Time spent waiting for passengers to walk to the bus door(s) from their waiting position at the stop		Stops with 1 loading area: none Stops with 3 loading areas: 2.5–9 s, depending on loading area position
Passenger service (dwell time)	Time spent opening and closing bus doors, plus time spent for passenger flow onto and off the bus		Minor stop: 10 s Major downtown stop, transit center, park-and-ride: 60 s
Traffic signal delay	Time spent waiting for a green light after passenger flow has been completed		0–70 s, depending on when the bus is ready to depart and the traffic signal cycle length
Reentry delay	Time spent waiting for a gap to pull back into traffic from the bus stop		0–10 s (unsignalized locations), 0 s up to length of green interval (at traffic signals)
Acceleration	Extra time spent speeding up to running speed, compared to proceeding past the stop at the bus's running speed		5.5 s during acceleration to 25 mi/h (40 km/h)

It can be seen from Exhibit 6-1 that dwell time and traffic signal delay are typically the largest contributors to the delay associated with serving a bus stop. However, over the course of a bus route with many stops, even relatively small delays can add up to significant time losses.

Dwell time and traffic signal delay are the largest contributors to bus stop delay.

Deceleration and Acceleration Delay

It takes time for a bus to slow from its running speed to serve a bus stop, and additional time to accelerate back to its running speed after serving the stop. At a comfortable deceleration rate of 4.0 ft/s^2 (1.2 m/s^2) and a typical 40-ft (12-m) diesel bus acceleration rate of 3.3 ft/s^2 (1.0 m/s^2) to 25 mi/h (40 km/h) , a bus takes approximately 10 s longer to travel the same distance, compared to proceeding past the bus stop without stopping. This delay is incurred

At urban street speeds, acceleration and deceleration delay amounts to about 10 s per stop where the bus would not have had to stop anyway due to traffic control.

- Always, at far-side stops at signalized intersections, and at all other bus stops where the bus would not otherwise be required to stop by a traffic control device;
- Sometimes, at near-side stops at signalized intersections and roundabouts, where the bus might have been required to stop anyway due to a traffic control device (traffic signal or YIELD sign); and
- Never, at bus stops located on the near side of a STOP-controlled intersection approach, as the bus would have had to stop anyway for the STOP sign.

The average acceleration characteristics of a bus are dependent on the ultimate speed reached (average acceleration rates are lower when accelerating to higher speeds) and on the bus's propulsion system characteristics. Exhibit 6-2 provides examples of various buses' acceleration characteristics.

Exhibit 6-2
Bus Acceleration Characteristics

Bus Type	Average Time to Reach Speed (s)			Average Acceleration to Speed (ft/s^2)	
	10 mi/h	20 mi/h	50 mi/h	20 mi/h	50 mi/h
40-ft standard diesel	5.0	8.7	33.2	3.4	2.2
45-ft motor coach diesel	4.0	7.4	27.1	4.0	2.7
60-ft articulated diesel	4.0–4.7	9.1	42.3–43.6	3.2	1.7
Double deck diesel	6.2	10.4	43.6	2.8	1.7
60-ft articulated hybrid	3.8	8.6	35.2	3.4	2.1

Source: *TCRP Synthesis 75* (*1*).

Diesel motor coaches have better acceleration characteristics than other types of diesel-powered transit buses, particularly to high speeds, and this is one reason why these buses are frequently used for commuter bus service that typically operates at freeway speeds. Higher-capacity diesel buses have generally comparable acceleration characteristics to standard diesel buses when accelerating to downtown street speeds, but have worse acceleration when accelerating to higher speeds. However, 60-ft (18-m) articulated hybrid electric buses have acceleration performance that equals or exceeds that of typical 40-ft standard diesel buses.

Regardless of size or propulsion system, buses have a lower average acceleration rate to freeway or grade-separated busway speeds than to urban street speeds.

Acceleration and deceleration delay associated with grade-separated busway speeds is at least 25 s per stop.

A loading area is a curbside position where a single bus can load and unload passengers. Bus stops are formed from one or more loading areas.

Bus stop failure is undesirable from both bus and traffic operations standpoints, but is also unavoidable during near-capacity operating conditions.

Bus Stop Failure

A bus stop served by a large number of buses can experience a condition known as *bus stop failure,* where a bus arrives at a stop only to find that all available loading areas are already being used or are blocked by other buses. In this case, the bus must wait in the street for a loading area to open up, which may not occur until all of the buses already at the stop have finished serving their passengers and (at the near side of a signalized intersection) have a green signal enabling them to proceed down the street.

Bus stop failure is undesirable from a bus operations standpoint, as it negatively affects bus reliability and speed. (Although bus stop throughput is maximized when the next set of buses is already waiting to use the stop, this benefit is more than offset by the speed and reliability impacts.) Bus stop failure is also undesirable from a traffic operations standpoint, as the bus(es) sitting in the street waiting to enter the bus stop block other vehicles using the street. This condition is particularly undesirable at far-side stops, as the buses and other vehicles that are blocked may form a queue that blocks the intersection. Exhibit 6-3 illustrates an extreme case of bus stop failure caused by the a lack of a passing lane at a BRT station.

Exhibit 6-3
Bus Stop Failure Illustrated



Boarding lost time occurs at larger bus stops with multiple loading areas, when there is a delay between the doors opening and the first passenger arriving to board the bus.

Boarding Lost Time

When passengers wait at bus stops with multiple loading areas, such as those found at high-volume BRT stations served by multiple routes, they do not know in advance which loading area their bus will stop at when it arrives. Because a bus will use the frontmost loading area that is available when it arrives, passengers will tend to wait in a location that minimizes their potential walking distance. When a bus arrives, there is a typically a delay, or *boarding lost time,* from the time the bus doors open and when the first passengers arrives to board the bus, depending on where the passengers were waiting relative to where the bus stopped, how quickly they could determine where the bus would stop, and how crowded the platform area was.

Passenger waiting patterns were studied at a busway station in Brisbane, Australia with three loading areas. This study found that passengers tended to concentrate within half a loading area length of the front of the second loading area—the point where the door of the second bus would be located. Once this optimal area became too crowded,

passengers first spilled toward the front loading area and, later, toward the rear loading area, but would move into the optimal area when an opportunity presented itself (*2*).

The amount of boarding lost time was found to vary by loading area position and platform crowding level, with median values ranging from 2.4 to 3.5 s and 85th-percentile values ranging from 4.5 to 8.8 s for the stop with three loading areas. Lower platform crowding levels resulted in higher average boarding lost times, as the benefit of faster walking speeds resulting from less crowding was more than offset by a greater percentage of passengers being able to wait in the optimal location, resulting in the first boarding passenger having walked longer on average to a bus arriving at the first or third loading area than under more crowded conditions (*2*).

Each loading area in the Brisbane study was marked with striping for bus drivers and signs for waiting passengers, allowing buses to stop at consistent locations. Electronic next-arrival signs let passengers know when to expect their bus.

Dwell Time

Dwell time is the time a bus spends serving passenger movements, including the time required to open and close the bus doors and boarding lost time. Any extra time the bus spends sitting with the doors open while waiting for a green light after all waiting passengers have been served is part of signal delay time. Door opening and closing time depends on the mechanical properties of a given bus model's doors and whether the bus's kneeling mechanism is used, but typically totals 2 to 5 s (*3, 4*).

The TCQSM defines dwell time as the sum of passenger service time, boarding lost time, and door opening and closing time.

Passenger service time is the largest component of dwell time and is influenced by the following factors:

Many factors influence passenger service time, which is the largest component of dwell time.

- *Passenger demand.* The more people that wish to get on and off the bus, the longer it will take to serve them.
- *Fare payment.* The time required to pay a fare is a major influence on the time required to serve each boarding passenger. Smart card fare payment systems that require passengers to "check out" when leaving the bus will also affect the time to serve alighting passengers.
- *Vehicle configuration.* A bus's floor height relative to the platform level affects service time, as having to ascend or descend steps takes more time than level boarding. If the fare payment system allows passengers to use any door or door channel, then buses with more doors, wider doors, or both, can process passengers faster than buses with fewer or narrower doors.
- *Passenger load.* When standing passengers are present on a bus, it takes more time for boarding passengers to clear the farebox area, making it available for the next passenger to board. Standees can also interfere with the movement of alighting passengers trying to reach a door.
- *Door usage.* Alighting passengers that exit through the front door delay the start of the boarding process. Boarding passengers that block doors used by alighting passengers slow down the alighting process.
- *Platform configuration.* Missing sidewalks or landing pads at bus stops may require the rear bus door(s) to remain closed, concentrating passenger activity at the remaining doors.

Dwell time can vary significantly from one bus to the next serving a stop.

Section 5 provides estimates of the time required for loading wheelchairs and bicycles.

Dwell time can vary significantly from one bus to the next, due to variations in passenger demand between routes serving a given stop, variations in demand from one trip to the next on a given route, and variations in the time required to serve a given number of passengers. Potential sources of the latter type of variation include:

- Passengers with mobility aids, strollers, luggage, etc. that take significantly longer to board and alight than the average passenger;
- Standing loads on some arriving buses that result in longer passenger boarding and alighting times;
- Passengers loading and unloading bicycles from bus-mounted bicycle racks;
- Passenger questions to the bus driver; and
- Fare payment issues (e.g., defective fare media, passengers fishing for change or farecards in their pockets).

Most activities that create extra-long dwell times compared to the average occur randomly and are treated in addition to dwell time.

An operating margin is used to adjust capacity to reflect longer-than-average dwells.

In most cases, these activities occur relatively randomly and are treated in addition to average dwell time. It is nevertheless important to account for them, as unexpectedly long dwell times can result in bus stop failure when the number of buses using a bus stop approaches its capacity. The TCQSM's method for estimating a bus stop's design capacity uses the concept of *operating margin*—extra time allotted in consideration of longer-than-average dwells—to account for these random delays.

Exhibit 6-4 shows average passenger service times associated with level boarding using a variety of fare payment methods. Level boarding is increasingly becoming the standard for bus operations—either through the use of low-floor buses or through raised platforms in the case of some BRT systems—as it provides faster boarding for all passengers, and particularly for passengers with mobility aids. When non-level boarding is required, add 0.5 s/p to the times shown in Exhibit 6-4 for standard stairs (*5*) and 1.0 s/p for the steep stairs typically found on motor coaches.

Exhibit 6-4
Individual Passenger Service Times (Level Boarding)

Situation	Average Passenger Service Time (s/p)	
	Observed Range	Suggested Default
BOARDING		
No fare payment	1.75–2.5	1.75
Visual inspection (paper transfer/flash pass/mobile phone)	1.6–2.6	2.0
Single ticket or token into farebox	2.9–5.1	3.0
Exact change into farebox	3.1–8.4	4.5
Mechanical ticket validator	3.5–4.0	4.0
Magnetic stripe card	3.7–6.5	5.0
Smart card	2.5–3.2	2.75
ALIGHTING		
Front door	1.4–3.6	2.5
Rear door	1.2–2.2	1.75
Rear door with smart card check-out	3.4–4.0	3.5

Sources: Jaiswal (*2*), TCQSM 2nd Edition (*5*), Milkovits (*6*), Diaz and Hinebaugh (*7*), additional research for the TCQSM 2nd and 3rd Editions.

Note: Add 0.5 s/p to boarding times when standees are present. Add 0.5 s/p for non-level boarding (1.0 s/p for motor coaches).

As can be seen from Exhibit 6-4, fare collection activities can sometimes more than double the minimum passenger service time. The placement of the fare collection device(s) and their ease of use has an impact on service times (*6*), as does the complexity of fare payment (e.g., paying with several bills and coins, as opposed to one or two coins) and the susceptibility of fare media to damage (e.g., magnetic-stripe tickets). The information in Exhibit 6-4 can be used to estimate changes in dwell time (and, ultimately, changes in bus travel speeds and route cycle times) associated with changes in fare collection methods and the vehicle–platform interface.

Exhibit 6-4 can be used to evaluate the dwell time and bus speed impacts of changing fare collection methods.

The route cycle time is the time required for a transit vehicle to make one round trip on a route. Along with frequency, it determines how many vehicles are required to operate a route—and the cost.

Traffic Signal Delay

A traffic signal located in the vicinity of a bus stop and its loading areas will serve to meter the number of buses that can enter or exit the stop. For example, at a far-side stop (or a mid-block stop downstream from a traffic signal), buses can only enter the stop during the portion of the hour when the signal is green for the street that the stop is located on. The lower the green time provided to the street, the lower the capacity, and the longer a bus is likely to wait if it has to wait for the traffic signal to turn green again.

Similarly, at a near-side stop, a bus may finish loading passengers but have to wait for the signal to turn green before leaving the stop. As a result, the bus occupies the stop longer than if it would have if it could have left immediately, and capacity is lower as a result. Due to the nature of bus operations, shorter traffic signal cycle lengths offer more opportunities for buses to move through a given signal during the course of an hour. In comparison, at unsignalized locations well away from the influence of upstream traffic signals, buses can enter and exit stops immediately, subject to traffic conditions (accounted for by clearance time, discussed in the next subsection) .

The traffic signal cycle length is the time required to display a complete sequence of traffic signal indications. Shorter cycle lengths are generally better for bus operations, as long as sufficient intersection capacity is maintained.

The effect of traffic signals is accounted for by the *green time ratio* (g/C *ratio*), which is the average amount of effective green time for the traffic movement used by buses, divided by the traffic signal cycle length (the time required to display a complete sequence of traffic signal indications). For example, if traffic moving parallel to a particular bus stop receives a green signal for an average of 54 s, and the total cycle length is 120 s, the g/C ratio at that stop is 54 divided by 120, or 0.45. The g/C ratio at unsignalized locations well away from the influence of traffic signals is 1.00, because bus access to the stop or its loading areas is not metered by a signal.

The combination of traffic signal cycle length and g/C ratio directly affect potential bus delay at a traffic signal. At the traffic signal described above with a 120-s cycle length and a 0.45 g/C ratio, a bus could potentially be delayed up to 66 s if it arrives just as the signal turns red. Shorter cycle lengths reduce the potential delay—for example, the maximum bus delay would be about 34 s with a 75-s cycle and a 0.45 g/C ratio. Longer g/C ratios also reduce potential delay, but to a lesser degree. The purpose of transit signal priority (TSP) treatments (discussed in detail in Section 3) is to minimize these delays, typically by holding the signal green a little bit longer to allow a bus to make it through the intersection, or by returning to green sooner to reduce delay to buses already stopped at an intersection.

Bus operations are not the only consideration in setting traffic signal cycle lengths. Intersection capacity must also be considered, as insufficient capacity creates queues of vehicles that can delay buses trying to approach the intersection. Coordination with other nearby traffic signals is also considered, as is the minimum amount of time needed to serve pedestrian crossing movements. Nevertheless, minimizing the traffic signal cycle length to the extent possible helps reduce bus delay and improve overall bus speeds. In addition, which bus service on a route is frequent (i.e., particularly when headways are twice the traffic signal cycle length or less), long traffic signal cycle lengths can promote the formation of bus bunching, as a bus that misses a green light suddenly ends up a minute or more closer to the bus behind it.

Long traffic signal cycle lengths can promote bus bunching, particularly when headways are twice the traffic signal cycle length or less.

Bus Stop Position

The position of a bus stop relative to the traffic lane affects how easily buses can reenter traffic and continue on their route. The TCQSM defines two bus stop positions: *on-line,* where buses stop in the traffic lane, and *off-line*, where buses pull out of the traffic lane (e.g., into the parking lane or a bus pullout). These are illustrated in Exhibit 6-5.

Exhibit 6-5
On-Line and Off-Line Loading Areas



(a) On-line (Portland)



(b) Off-line (Albuquerque)

With an on-line stop, a bus can resume its route as soon as all passengers have been served and the traffic signal (if present) allows it to proceed. Buses experience no reentry delay with on-line stops. However on-line stops also require vehicles behind the bus to go around the bus (if possible) or to wait until the bus moves to proceed. Some transit agencies (as well as some roadway agencies) require off-line stops when traffic speeds are high (typically above 35 or 40 mi/h [60 or 70 km/h]) for safety reasons. They may also require an off-line stop after several on-line stops on roadways without passing opportunities, to minimize the build-up of vehicles behind the bus and the potential for illegal or unsafe passing maneuvers.

With an off-line stop, and in the absence of yield-to-bus laws, a bus must wait for a gap in traffic before it can reenter the traffic lane and resume its route. At bus stops located at unsignalized locations, this delay typically ranges from 0–10 s, depending on traffic volumes, but can be significantly longer at near-side stops at traffic signals, when the bus has to wait for a long queue of vehicles to clear. As discussed in Section 4, yield-to-bus laws offer the potential to reduce reentry time, depending on motorist compliance with the law. Some transit agencies in jurisdictions without yield-to-bus laws use stickers or signs on the back of the bus to encourage motorists to let the bus back into traffic (*8*). Queue jumps, discussed in Section 3, are another potential tool for addressing reentry delay.

Bus Facility Influences on Delay

In addition to delays associated with individual stops, the roadway facility on which buses operate also contributes delays that affect bus speed, capacity, or both. The most important factors are:

- *Stop spacing*—how often a bus must stop as it travels along a facility;
- *Exposure to general traffic*—the less exclusive the facility, the more buses are exposed to delays caused by other traffic using the facility;
- *Facility design*—in particular, the lack of ability for buses to move around each other or other traffic; and
- *Bus operations*—the number of buses scheduled relative to capacity and how buses and routes are organized.

Stop Spacing

As was seen previously, each stop that a bus makes to serve passengers causes the bus to experience some delay. Even in the absence of traffic and traffic signal effects, a bus incurs a minimum of 15 s of delay with each stop on an urban street just to decelerate, open and close the bus doors, and accelerate back to speed. The more a bus stops, the more these delays add up.

Increasing stop spacing improves overall bus speeds, even though dwell times increase at the remaining stops.

Increasing the spacing between stops reduces the overall delay incurred. Even though dwell times will increase at the remaining stops, the overall time saved will result in an improvement in speed. Exhibit 6-6 shows an illustrative case showing the improvement in average bus speed in mixed traffic as stop spacing goes from 12 stops/mi (approximately every 135 m), with a dwell time of 10 s, to 4 stops/mi (every 400 m), with a proportional increase in the number of passengers served per stop.

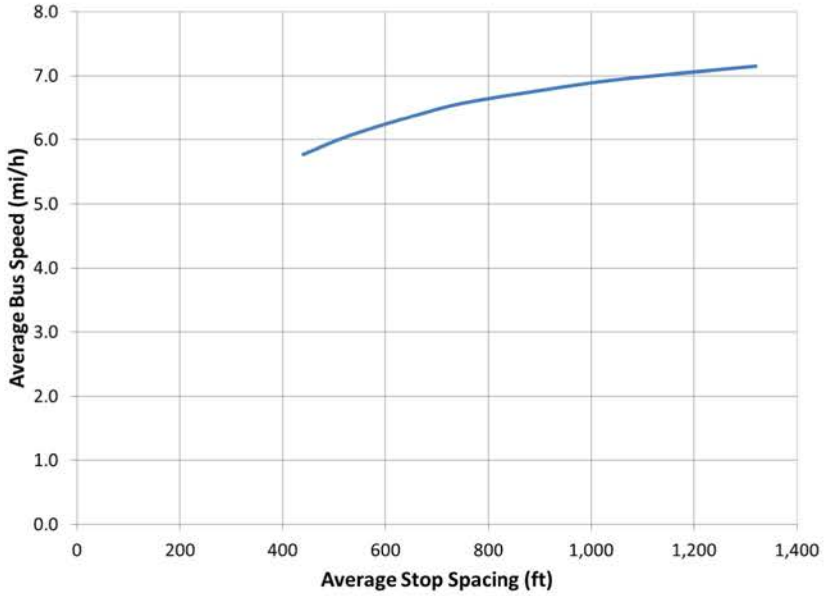


Exhibit 6-6
Illustrative Relationship of Stop Spacing and Speed (Urban Street, Mixed Traffic)

Notes: Calculated using this chapter's bus speed methodology. Assumes a 15-s dwell time at 12 stops/mi, 3.4 ft^2/s acceleration, 4.0 ft^2/s deceleration, 25 mi/h posted speed, mixed traffic operations within the central business district (CBD), and a proportional increase in passenger service time as stop spacing increases. Assumes scheduled bus volumes are less than half the facility's capacity.

The ability to increase stop spacing depends in part on the quality of the pedestrian network in the area—can pedestrians safely and directly walk to the next-closest stop? It may also depend on the characteristics of the passengers using the stop—for example, persons with limited mobility may find it difficult to walk to the next stop. Finally, local residents may object to losing "their" stop. However, in many cases, the extra time spent walking to another stop will be more than made up with time savings during the trip on the bus, when a stop consolidation program is implemented along an entire route.

Exhibit 6-7 presents average travel speeds for buses operating on grade-separated busways for a variety of average dwell times and stop spacings. Because buses accelerate more slowly to busway speeds than to urban street speeds, each stop produces a minimum of 25 s of delay in addition to the time required to serve passengers. The expected pattern of lower speeds with more frequent and longer stops is also seen here.

Exhibit 6-7
Estimated Average Bus Speeds on Grade-Separated Busways (mi/h)

Average Stop Spacing (mi)	Average Dwell Time (s)				
	0	15	30	45	60
50 mi/h RUNNING SPEED					
0.5	31	23	20	17	15
1.0	38	32	28	25	23
1.5	42	36	33	30	28
2.0	43	39	36	34	31
2.5	44	41	38	36	34
55 mi/h RUNNING SPEED					
0.5	32	24	20	17	15
1.0	41	33	29	26	23
1.5	44	38	34	31	29
2.0	47	41	38	35	33
2.5	48	43	41	38	36
60 mi/h RUNNING SPEED					
0.5	33	24	20	17	15
1.0	43	34	30	26	24
1.5	47	40	36	33	30
2.0	50	43	40	37	34
2.5	52	46	43	40	37

Source: Calculated using this chapter's methods.
Note: Assumes average 2.2 ft/s^2 acceleration and 4.0 ft/s^2 deceleration rate (40-ft standard diesel bus).
Use the zero dwell time column for express buses slowing, but not stopping at stations (25 mi/h station speed limit and 325-ft-long speed zone through station assumed). Assumes passing lane available for non-stopping buses and no at-grade pedestrian crossings within the station.
A metric version of this exhibit appears in Appendix A.

Exposure to General Traffic

As was discussed in Chapter 2, Mode and Service Concepts, transit facilities can be classified into four main types of operating environments that describe how much protection transit vehicles have from other vehicles:

- *Grade separated*—Only other transit vehicles use the facility and there are no interactions with other vehicles along the facility. Bus facility examples include grade-separated busways and freeway managed lanes that are reserved for buses only.

- *Exclusive*—Only other transit vehicles use the facility, but interactions with other vehicles occur where the facility is crossed by other roadways. Exclusive bus lanes are an example of this type of facility.
- *Semi-exclusive*—Similar to exclusive facilities, but other vehicles are allowed to use the facility under certain circumstances. Bus facility examples include exclusive bus lanes that allow right-turning traffic to use the lanes at intersections and freeway managed lanes that also allow carpools or vehicles that have paid a toll.
- *Mixed traffic*—Buses operate in the same lanes as other traffic and are exposed to a wide range of potential traffic-related delays.

Facility Design

Two other aspects of facility design influence how much other traffic sharing roadway lanes with buses interferes with bus operations: (*a*) bus stop location and (*b*) bus ability to pass.

Bus Stop Location

As shown in Exhibit 6-8, on-street bus stops can be located in three places relative to an intersection—near side, far side, and mid-block. Under certain circumstances, such as when buses share a stop with streetcars running in the center of the street, or when a median busway exists, a bus stop may be located on a boarding island within the street rather than curbside.

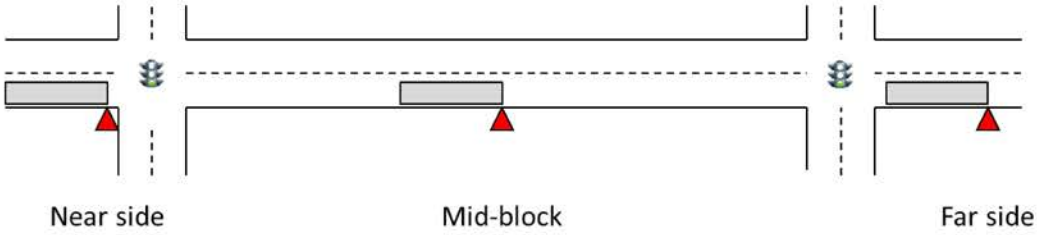


Exhibit 6-8
On-Street Bus Stop Locations

Bus stop location influences bus speeds and capacity, particularly when other vehicles can make right turns from the curb lane (which is typical, except for certain kinds of exclusive bus lanes and at intersections with one-way streets where right turns are prohibited). Far-side stops have the least negative impact on speed and capacity (as long as buses are able to avoid right-turn queues on the approach to the intersection), followed by mid-block stops, and near-side stops.

Far-side stops have the most beneficial effect on bus speeds and capacity, but other factors must also be considered when siting bus stops.

However, speed and capacity are not the only factors which must be considered when selecting a bus stop location. Potential conflicts with other vehicles operating on the facility, transfer opportunities, passenger walking distances, locations of passenger generators, signal timing, driveway locations, physical obstructions, and the potential for implementing transit preferential measures must also be considered.

For example, near-side stops are often preferable when curb parking is allowed, since buses may use the intersection area—where cars would not be parking in any event—to reenter the moving traffic lane. Near-side stops are desirable where buses make a right turn, while far-side stops are desirable where buses make left turns. At intersections with one-way streets, both traffic and transfer opportunities may need to

be considered. If traffic on the one-way street moves from left to right, for example, right-turning traffic volumes might suggest a far-side stop, while providing a convenient transfer to routes on the cross street might suggest a near-side stop.

Mid-block stops are typically only used at major passenger generators or where insufficient space exists at adjacent intersections (*9*). How passengers will cross the street to get to or from a mid-block bus stop must be carefully considered.

Exhibit 6-9 compares the advantages and disadvantages of each kind of bus stop location. Additional guidelines for the spacing, location, and geometric design of bus stops are given in *TCRP Report 19* (*10*). These guidelines must be carefully applied to ensure both good traffic and transit operations.

Exhibit 6-9
On-Street Bus Stop Location Comparison

Location	Advantages	Disadvantages
Far Side	• Minimizes conflicts between right-turning vehicles and buses • Provides additional right-turn capacity by making curb lane available for traffic. • Minimizes sight distance problems on intersection approaches • May encourage pedestrians to cross behind the bus, depending on distance from intersection • Buses can decelerate through the intersection, so less curb space may be needed for the bus stop • Buses can take advantage of gaps in traffic flow created at signalized intersections • Facilitates bus signal priority operation, as buses can pass through intersection before stopping	• Could result in traffic queued into intersection when a bus stops in the travel lane • May obscure sight distance for crossing vehicles • May increase sight distance problems for crossing pedestrians • Can cause a bus to stop far side after stopping for a red light, interfering with both bus operations and all other traffic • May increase the number of rear-end crashes since drivers may not expect buses to stop again after stopping at a red light
Near -Side	• Minimizes interferences when traffic is heavy on the far side of the intersection • Allows passengers to access buses close to crosswalk • Intersection width available for bus to pull away from the curb and accelerate • Eliminates potential for double stopping • Allows passengers to board and alight while bus stopped for red light • Allows driver to look for oncoming traffic, including other buses with potential passengers	• Increases conflicts with right-turning vehicles • May result in stopped buses obscuring curbside traffic control devices and crossing pedestrians • May obscure sight distance for side street vehicles stopped to the right of the bus • Increases sight distance problems for crossing pedestrians • Complicates bus signal priority operation, may reduce effectiveness or require a special queue-jump signal if the stop is located in the parking lane or a right-turn lane • Potentially more difficult to merge back into traffic at traffic signals, due to vehicle queues
Mid-Block	• Minimizes sight distance problems for vehicles and pedestrians • May result in passenger waiting areas experiencing less pedestrian congestion.	• Requires longer no-parking zone • Encourages passengers to cross street mid-block (jaywalking) when no mid-block crossing opportunity provided • Increases walking distance for passengers crossing at intersections if no mid-block crossing opportunity provided

Source: Derived from *TCRP Report 19* (*10*).

Freeway bus stops.

Special bus stops are sometimes located along freeway rights-of-way, usually at interchanges or on parallel frontage roads. These stops are used to reduce bus travel times by eliminating delays associated with exiting and reentering freeways. Freeway stops should be located away from the main travel lanes and adequate acceleration and deceleration lanes should be provided. To be successful, attractive and well-designed pedestrian access to the stop is essential (*9*).

Off-street bus stop design is discussed in Chapter 10.

Off-street bus stops, such as transit centers and intermodal terminals, are often designed based on factors other than capacity, including accommodating driver layovers and separating a large number of routes so passengers can easily find their desired buses. Chapter 10, Station Capacity, describes off-street bus stop design.

Bus Ability to Pass

A bus' ability to pass obstacles in its lane, if a lane is available and traffic permits, is the other facility-related design feature that affects capacity and speed. When a roadway provides two or more lanes in the bus' direction of travel (or, in the case of busways, a passing lane is provided at stations), buses have the potential opportunity to pass other vehicles stopped in their lane, including other buses. This ability decreases as the adjacent lane fills with vehicles, leaving few gaps for buses to use to change lanes.

Bus Operations

Scheduled Volume Relative to Capacity

Bus speeds drop once about half of facility's maximum bus capacity is used.

Once approximately half of a facility's maximum bus capacity is reached, interference between buses using the facility (e.g., an increase in passing activity) causes speeds to drop. The effect becomes more pronounced once approximately 70% of a facility's maximum bus capacity is scheduled. Exhibit 6-10 illustrates the effects of increasing bus lane volumes on bus speeds.

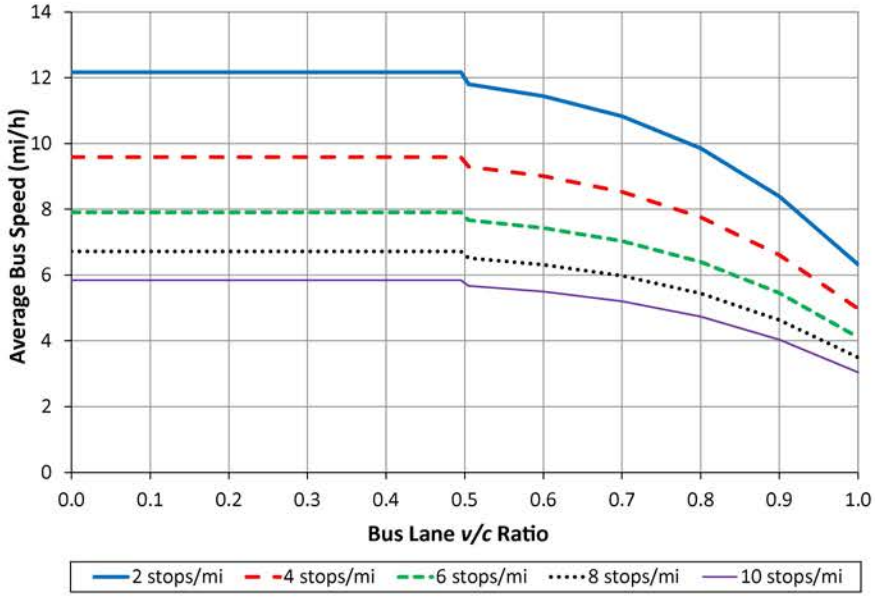


Exhibit 6-10
Illustrative Effect of Bus Volume on Urban Street Bus Speeds

Source: Calculated using this chapter's bus speed methodology.

Notes: Assumes 30-s dwell times, 25 mi/h running speed, CBD bus lane with right-turn delays, and typical signal timing. *v/c* ratio = volume-to-capacity ratio.

Bus Stopping Patterns

How buses are organized when using a facility also affects speed and capacity. *Platooning,* where two or more buses travel the facility as a group, results in bus stops being used more efficiently. *Skip-stop operation,* where bus routes are divided into two or more groups that use separate sets of stops along the facility, allows many more buses to share a facility than if all buses used the same set of stops. Both of these techniques are described in more detail in Section 4 of this chapter.

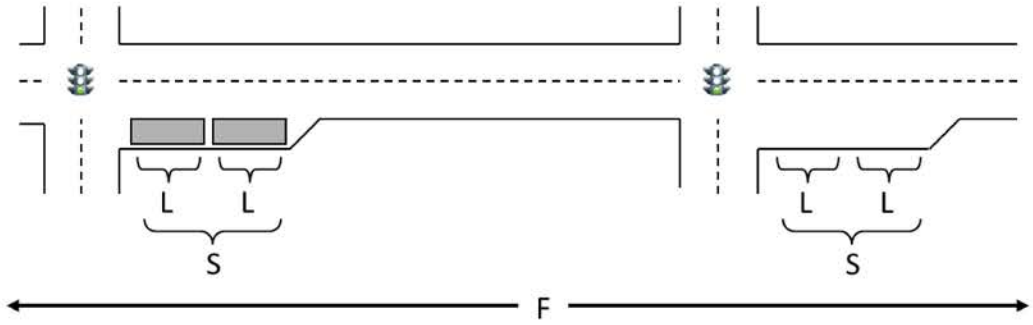
FACTORS DETERMINING BUS CAPACITY

Capacity Calculation Process

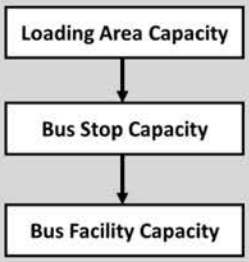
Bus capacity is calculated for three key locations, illustrated in Exhibit 6-11:

1. *Bus loading areas (berths),* curbside spaces where a single bus can stop to load and unload passengers;
2. *Bus stops,* consisting of one or more adjacent loading areas; and
3. *Bus facilities,* continuous sections of roadways used by buses that include at least one stop, but typically many more.

Exhibit 6-11
Bus Loading Areas, Stops, and Facilities



L = loading area, S = bus stop, F = bus facility



The capacity of a single loading area is a key input into determining the capacity of a bus stop. Likewise, the capacity of the critical bus stop is a key determinant of the bus facility capacity.

As is the case throughout the TCQSM, capacity can be determined for both vehicles (in this case, buses) and persons, and it can be determined both as a *maximum capacity,* maximizing throughput without regard for reliability or operational issues, and as a *design capacity,* the number of buses or persons that can be served at a desired quality of service. When not specified otherwise, "capacity" means design capacity.

Loading Area Capacity

The capacity of a loading area can be simply expressed as follows:

Equation 6-1

$$\text{Loading area capacity} = \frac{\text{Seconds in an hour available for bus movement}}{\text{Seconds that a design bus occupies the loading area}}$$

The number of seconds in an hour available for bus movement is 3,600 s/h, multiplied by the percentage of the hour that buses can access the loading area—100% for stops away from traffic signals, or the *g/C* ratio for stops at traffic signals.

The seconds that a design bus occupies the loading area consists of the following:

- Average time spent serving passengers while the traffic signal is green (the average dwell time multiplied by the *g/C* ratio);
- Possible reentry delay waiting for a gap in traffic to exit the stop;
- Average time for a bus to travel its own length, freeing up the curb space for another bus to pull in behind it (dead time not usable by buses); and
- An operating margin that reduces maximum capacity to design capacity, by adding in the number of seconds that a design bus with a longer-than-average dwell time would occupy the stop at the design failure rate.

All of these factors were addressed previously in the subsection on bus delay.

Bus Stop Capacity

The capacity of a bus stop consists of the capacity of a single loading area at the stop, multiplied by the equivalent effectiveness of all the loading areas forming the stop, and by the percentage of time that movement into and out of the stop is allowed by traffic control devices, such as traffic signals.

Loading Area Effectiveness

The more loading areas available at a bus stop, the greater the bus stop's capacity, because more buses can load and unload passengers simultaneously. However, some designs are more efficient than others at adding capacity, depending on whether they allow independent bus movement into and out of the loading area.

There are four typical loading area designs, as shown in Exhibit 6-12: linear, sawtooth, drive-through, and angle. Linear loading areas are typically used for on-street bus stops, as they require the least amount of space. However, they typically operate on a first-in, first-out basis, which can result in one bus blocking other bus' ability to access loading areas or to leave immediately once their passengers have been served. The other three loading area designs are termed *non-linear loading areas,* and their designs allow buses to pull in and out of loading areas independently of each other.

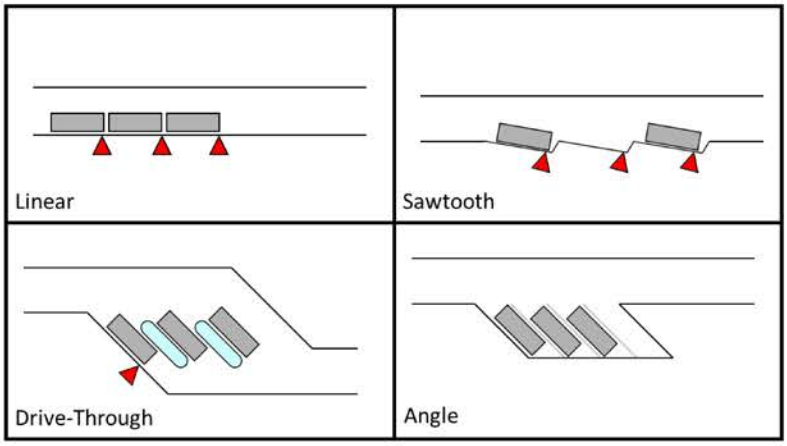


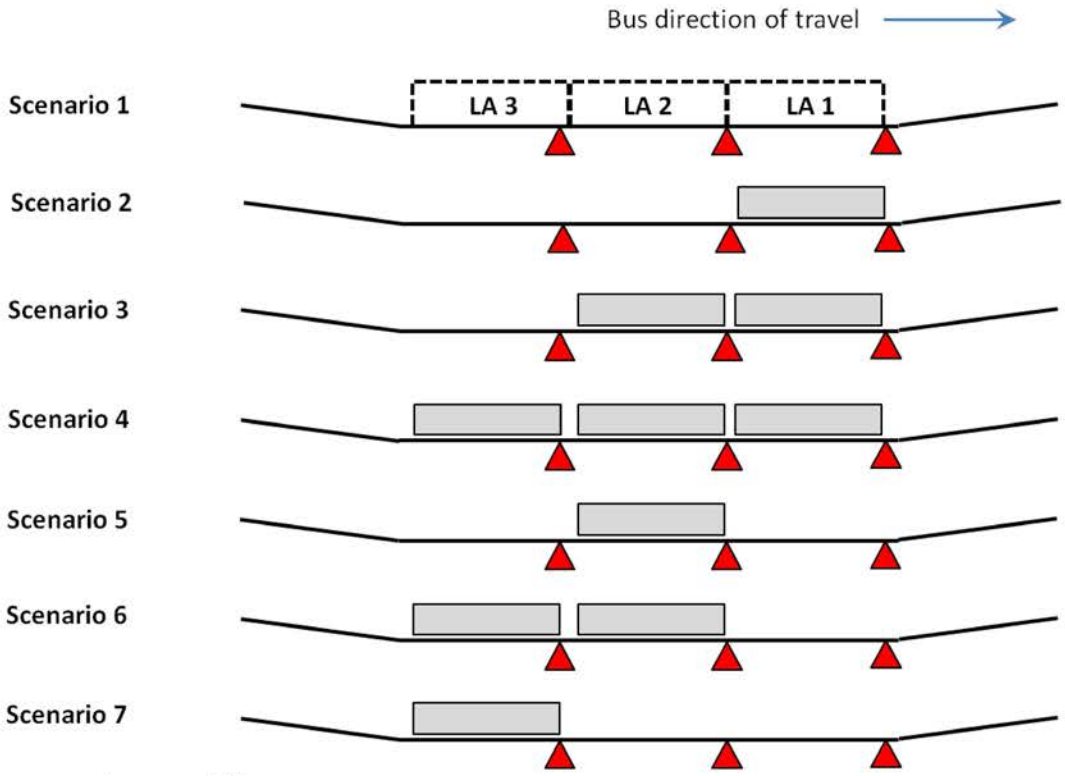
Exhibit 6-12
Loading Area Design Types

Non-linear loading area designs are fully effective: doubling the number of loading areas doubles the stop's capacity.

Non-linear designs are *fully effective*: doubling the number of loading areas doubles the stop's total bus capacity. The full effectiveness results from buses being able to move independently of each other. In addition, buses are typically assigned to a particular loading area when non-linear designs are used, so no boarding lost time occurs when several buses arrive at once. Because of the extra space required, non-linear designs are rarely seen at on-street locations, except at on-street transit centers.

Exhibit 6-13 shows the possible ways that a bus stop consisting of three linear loading areas can be utilized. The loading areas are numbered from1 to 3, with loading area 1 being the front-most loading area.

Exhibit 6-13
Loading Area Utilization Example



Source: Based on Jaiswal (*2*).
Note: LA = loading area.

Doubling the number of linear loading areas at a stop increases capacity by less than a factor of 2, due to bus blocking effects.

In Scenario 1, the bus stop is empty. The first bus to arrive will stop at loading area 1, as in Scenario 2. If a second bus arrives before the first bus departs, it will stop at loading area 2, as shown in Scenario 3. A bus in loading area 2 is blocked from leaving the stop until the bus in loading area 1 leaves. (When scheduled bus volumes are well under the stop capacity, a bus in loading area 2 could leave more room between itself and the bus in loading area 1, allowing it to exit independently. However, it would block access to loading area 3 in the process.)

In Scenario 4, all three loading areas are utilized, but bus #2 is blocked from leaving by bus #1, and bus #3 is blocked by both buses in front of it. If bus #1 is the last to finish serving passengers, all three buses will exit the stop as a platoon.

In Scenario 5, a bus in loading area 1 departed after the bus in loading area 2 arrived. If another bus arrives before bus #2 is ready to leave, it will have to stop in

loading area 3, as bus #2 blocks access to loading area 1, leaving its potential capacity unavailable for the moment (Scenario 6). If yet another bus arrives, bus stop failure will occur, because loading area 3 is occupied and the arriving bus is blocked from using loading area 1 by the other two buses.

Finally, in Scenario 7, a bus occupies loading area 3. The next bus to arrive will experience bus stop failure, as its access to loading areas 1 and 2 is blocked. Two-thirds of the stop's potential capacity is unavailable for the moment.

As this example illustrates, as more loading areas are added to a bus stop, the greater the likelihood that one or more loading areas will be blocked or will block other loading areas. Therefore, the extra capacity provided by another loading area drops with each additional loading area added to the stop. The TCQSM uses the concept of *effective loading areas* to describe the fractional capacity added by another loading area.

Exhibit 6-14 illustrates the diminishing effect of adding additional linear loading areas to a bus stop. It shows maximum on-line bus stop capacity for selected dwell times and g/C ratios, based on a 10-s clearance time and random bus arrivals at the stop. *Increasing the number of linear loading areas has a much smaller effect on changes in capacity than reducing dwell times.* Note that for dwell times greater than 60 s, the differences between a g/C of 0.5 and 1.0 are small.

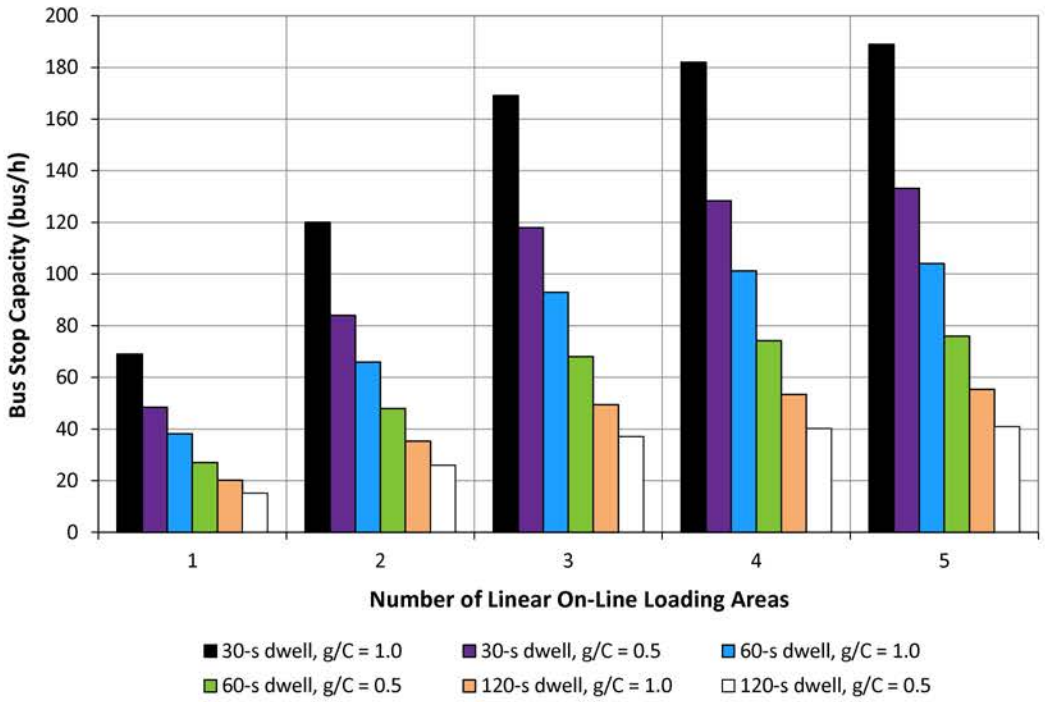


Exhibit 6-14
Relative Contributions of Dwell Time, g/C Ratio, and Number of Loading Areas to Bus Stop Maximum Capacity

Note: Calculated using this chapter's bus capacity methodology. Based on 10-s clearance time, 25% failure rate, 0.6 coefficient of variation of dwell times, and random bus arrivals at on-line stops.

Traffic Congestion Effects

When right turns are allowed from the curb lane, queues of cars waiting to turn right may block bus access to a near-side stop. Queues of cars may also block bus access to a far-side stop, but if another lane is available and traffic permits, buses may be able to change lanes to move around the queue. To the extent that buses are blocked,

however, some of the traffic signal green time that would otherwise be available for bus movement into the bus stop is made unavailable, reducing the overall stop capacity.

Bus Facility Capacity

The capacity of a bus facility is determined by the capacity of the critical stop along the facility. The critical stop will be the bus stop used by all buses that has the lowest capacity. There are two exceptions to this general rule:

A managed lane is a lane that restricts usage to certain vehicle types—for example, buses and carpools or buses and toll-paying vehicles.

1. Grade-separated facilities without stops (e.g., freeway managed lanes) or with passing lanes at stops (e.g., grade-separated busways) act as pipes; their capacity will typically be constrained at a point before or after the facility (for example, by the capacity of the bus terminal that the facility feeds).
2. Skip-stop operation separates bus routes into groups that stop at different sets of stops along a facility. In this case, the sum of the critical bus stop capacity of each group becomes the starting point for determining bus facility capacity, allowing a nearly two- to four-fold increase capacity, depending on the number of stop patterns used.

Person Capacity

Person capacity can be determined as either a *scheduled* person capacity or a *design* person capacity. The former determines how many people *can* be reliably served in an hour under the current schedule; the latter determines how many people *could* be served if the facility was operated at capacity, given a set of design criteria or assumptions (e.g., vehicle mix, design failure rate).

Person capacity is based on the number of vehicles that are or could be operated on the facility and the design passenger capacity of those vehicles. The design passenger capacity is set based on (*a*) quality of service considerations and (*b*) a desire to avoid pass-ups (i.e., allowing some unused space to accommodate surges in demand from one trip or day to the next).

Typical bus vehicle types, dimensions, and passenger capacities are given in Exhibit 6-15. Note that in any transit vehicle, the total passenger capacity can be increased by removing seats and making more standing room available. This lowers the quality of service provided to passengers, when passengers must stand who would not have done so otherwise, but also frees up space that can be put to specialized use (e.g., stroller storage) (*1*).

Exhibit 6-15
Characteristics of Common Bus Transit Vehicles—United States and Canada

Bus Type	Length (ft)	Floor Level	BRT Features	Passenger Doors	Seats	Maximum Standees [a]
Small bus/minibus	18–30	High	None	1	8–30	NA
Standard bus	35	High	None	2	35–40	NA
	35	Low	None	2	30–35	NA
	40	High	None	2	40–45	NA
	40	Low	None	2	37–43	30–34
	40	Low	Styling	2	39–47	32–46
	40	Low	Styling	3	33	49
Double-deck	40	Low	None	2	79–89	10–15
Motor coach	45	High	None	1	53–65	0[b]
Articulated	60	High	None	2–3	65	NA
	60	Low	None	2–3	61–64	53–57
	60	Low	None	3–4	43	57
	60	Low	Styling	2–3	58	NA
	60	Low	Styling	3–5	64	53
	65	Low	Styling	2–3	67	NA
Purpose-built BRT	60	Low	Yes	3/6[c]	37	67
	60	Low	Yes	4	27	90

Sources: *TCRP Synthesis 75* (*1*), TCQSM 2nd Edition (*5*), *TCRP Report 118* (*11*).

Notes: NA = not available from manufacturer.

(a) Crush load conditions. Depending on available standing area and transit agency policy, design bus standee load is typically 25–50% of the seated capacity, unless seats have been removed to add standing room or other uses (e.g., interior luggage or bicycle racks).

(b) Typically used in high-speed environments where it is desirable to have all passengers seated.

(c) Option for three doors on both sides.

PLANNING-LEVEL CAPACITY VALUES

The bus capacity analysis methodology presented in Section 5 provides a highly detailed treatment of bus operations. The level of precision inherent in that analysis may exceed the accuracy of the available data. In contrast, for planning purposes, the only requirement is a concept for a potential improvement and a general understanding of how existing service operates.

Bus Volume and Capacity Relationships

The observed peak-hour bus movements along freeways and city streets, and to or from bus terminals, provide guidelines for estimating the capacity of similar facilities. They also provide a means of checking or verifying more detailed capacity calculations. General planning guidelines are presented in Exhibit 6-16 that match scheduled bus volumes on downtown streets and arterial streets leading to the city center to qualitative descriptions of bus flow along those streets. Where stops are not heavily patronized (e.g., outlying urban streets), bus volumes could be increased by about 25%.

Exhibit 6-16
Planning-Level Bus Lane Service Volumes

These service volumes may be used for planning purposes. More precise values for operations and design purposes should be computed from the capacity relationships and procedures presented later in the chapter.

Description	Service Volume bus/lane/h	Average bus/lane/h
ARTERIAL STREETS		
Free flow	25 or less	15
Stable flow, unconstrained	26 to 45	35
Stable flow, interference	46 to 75	60
Stable flow, some platooning	76 to 105	90
Unstable flow, queuing	106 to 135	120
Forced flow, poor operation	over 135*	150*
DOWNTOWN STREETS		
Free flow	20 or less	15
Stable flow, unconstrained	21 to 40	30
Stable flow, interference	41 to 60	50
Stable flow, some platooning	61 to 80	70
Unstable flow, queuing	81 to 100	90
Forced flow, poor operation	over 100*	110*

Sources: Hoey and Levinson (*12*) and *Transportation Research Circular 212* (*13*).

Notes: *Results in more than one-lane operation. The values for forced flow conditions should not be used for planning or design. They are merely given for comparative purposes.
Bus volumes shown assume all buses make regular stops along the street.

The number of people per hour that can be served by standard buses on exclusive bus lanes at various bus flow rates and passenger load factors are given in Exhibit 6-17. This exhibit provides a generalized planning guide that assumes that key boarding points are sufficiently dispersed to achieve these bus loads. It suggests *maximum* person-flow rates of about 6,450 people per hour per lane on downtown streets and 8,700 people per hour per lane on arterial streets. Corresponding maximum values for *seated* passenger flows are 4,300 and 5,800 people, respectively. Exclusive use of articulated or double-deck buses would increase these values by one-third to one-half.

Exhibit 6-17
Maximum Standard Bus Passenger Service Volumes for Planning Purposes

Buses per Hour	Load Factor (p/seat) 0.00-0.50	0.51-0.75	0.76-1.00	1.01-1.25	1.26-1.50
ARTERIAL STREETS					
25 or less	535	805	1,075	1,340	1,610
26 to 45	965	1,450	1,935	2,415	2,900
46 to 75	1,610	2,415	3,225	4,030	4,835
76 to 105	2,255	3,385	4,515	5,640	6,770
106 to 135	2,900	4,350	5,805	7,255	8,705
DOWNTOWN STREETS					
20 or less	430	645	860	1,075	1,290
21 to 40	860	1,290	1,720	2,150	2,580
41 to 60	1,290	1,935	2,580	3,225	3,870
61 to 80	1,720	2,580	3,440	4,300	5,160
81 to 100	2,150	3,225	4,300	5,375	6,450

Note: Assumes 43 seats per bus and a peak-hour factor of 1.00.

The passenger volumes presented in Exhibit 6-17 indicate the number of people that can be carried, assuming uniform flow during the peak-hour (i.e., a peak-hour factor of 1.00). As uniform flow rarely occurs and indicates underservicing of demand when it does occur, appropriate peak-hour factors should be used to reduce these

values to design levels to reflect passenger flow variations within the 15-min peak period. Peak-hour factors are discussed in Section 5 of this chapter.

Urban Street Bus Lanes

Exhibit 6-18 shows illustrative urban street bus lane capacities for a *Type 2 bus lane* (i.e., a bus lane where buses can use the adjacent lane to move around stopped traffic or buses) for a range of right-turning traffic and pedestrian crosswalk volumes, applying the conditions shown with the graph to this chapter's capacity methodology. Note that the capacities shown in the graph are based on a single loading area at the critical bus stop. When a bus stop provides multiple loading areas, multiply the capacity value obtained from the graph by the appropriate loading area effectiveness factor from Exhibit 6-63, presented later in Section 5. Capacities of zero shown in the graph are mostly theoretical, as a few turning vehicles ("sneakers") will always complete their turn at the end of the green phase, and may also be allowed to turn right on red, which allows buses to move up in the queue and eventually through the intersection. Nevertheless, low capacities are an indicator that poor bus operations will result.

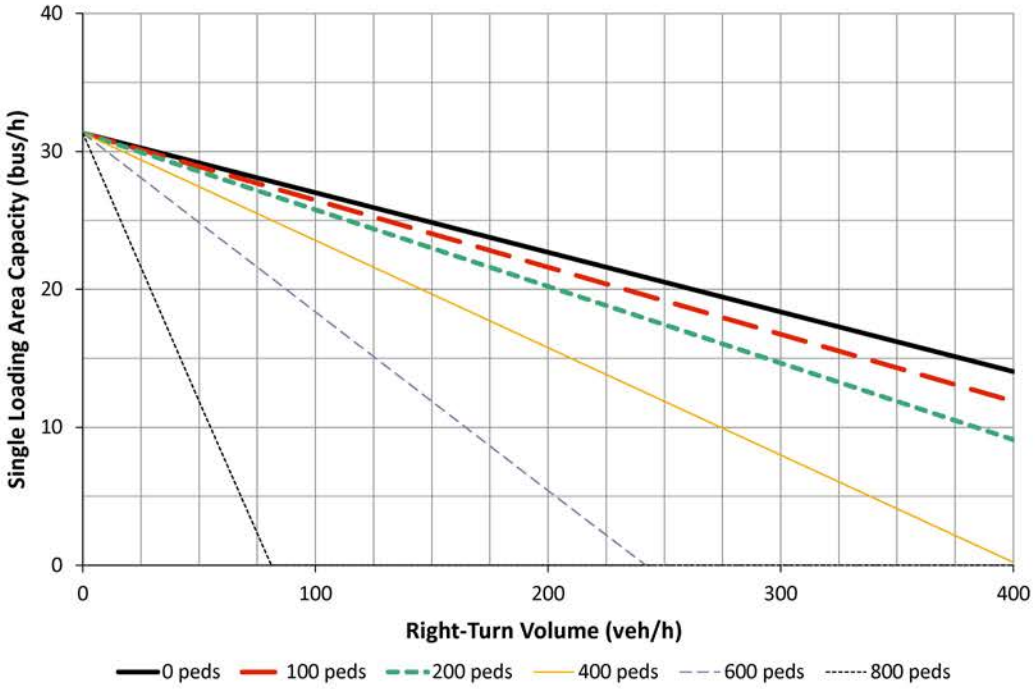


Exhibit 6-18
Illustrative Urban Street Bus Lane Capacities with One Loading Area

Source: Calculated using this chapter's bus capacity methodology.

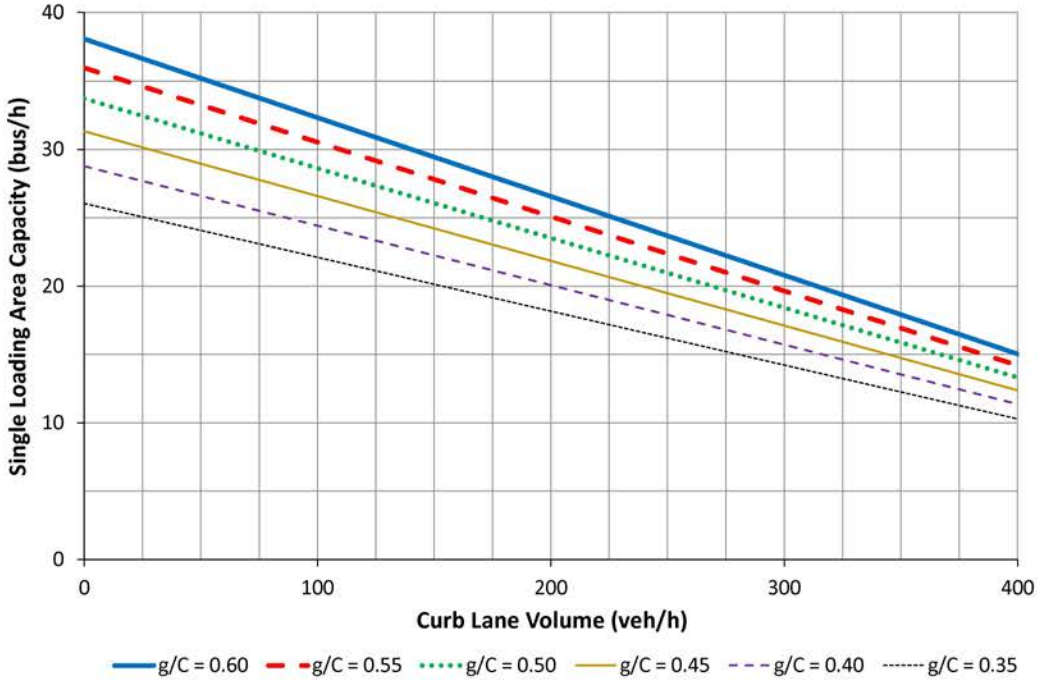
Note: Assumes the following critical bus stop characteristics: Type 2 exclusive bus lane (1 bus lane and at least one general traffic lane in bus' direction of travel), right turns allowed from the bus lane; online, near-side bus stop; 30-s dwell time; 0.6 coefficient of variation of dwell time; g/C = 0.45; and 10% failure rate.

Based on the critical stop having one loading area. Multiply the result from the graph by an appropriate loading area effectiveness value from Exhibit 6-63 for stops with multiple loading areas.

Peds = pedestrians.

Exhibit 6-18 indicates that as either right-turning volumes or pedestrian volumes conflicting with the right turns increase, the number of buses that can be reliably served in an hour by an urban street bus lane drops significantly. The combination of high right-turning volumes and high conflicting pedestrian volumes is especially detrimental to buses, as vehicles turning right from the bus lane must yield to pedestrians, and these vehicles in turn block those buses that not able to move into the adjacent lane. Note also that even when scheduled bus volumes are relatively low, the delaying effect of right-turning traffic will result in lower bus speeds.

Exhibit 6-19
Illustrative Mixed-Traffic Bus Capacities



Source: Calculated using this chapter's bus capacity methodology.

Note: Assumes the following critical bus stop characteristics: Type 2 mixed traffic operation (2+ lanes in bus' direction of travel); online, near-side bus stop; 30-s dwell time; 0.6 coefficient of variation of dwell time; *g/C* = 0.45; and 10% failure rate.

Based on the critical stop having one loading area. Multiply the result from the graph by an appropriate loading area effectiveness value from Exhibit 6-63 for stops with multiple loading areas.

3. PREFERENTIAL TREATMENTS

OVERVIEW

This section presents information related to the implementation of bus preferential treatments. A wide variety of treatments have been developed in urban areas throughout the world to make bus transit more competitive with the private automobile and to provide a higher quality of service for passengers. This section provides an overview of measures developed as of 2012 that have shown promising operations. In addition, the chapter presents suggested warrants and conditions for applications of priority treatments and provides information of treatment impacts on transit operations.

TCRP Synthesis 83 (*14*) conducted a survey of transit agencies and summarized the application of transit preferential treatments in North America as of 2010 and the warrants specific transit agencies use for application. In addition, it provides a decision-making framework and analysis methods for application of some of the priority treatments addressed in sections 3 and 4. TCRP Project A-39, "Improving Transportation Network Efficiency Through Implementation of Transit-Supportive Roadway Strategies," which had just started at the time of writing, is intended in part to document the effects of various preferential treatments in more detail than the results of previous studies presented in this section (*15*).

Bus Preferential Treatment Uses

A significant amount of delay to transit vehicles in urban areas is caused by traffic congestion. This congestion results in longer travel times for passengers and, over time, requires transit agencies to add more buses to routes in order to maintain headways, which results in higher agency operating costs.

Bus preferential treatments seek to offset the delays caused by traffic.

Bus preferential treatments offer the potential to reduce the delays experienced by buses operating in mixed traffic. These measures are aimed at improving schedule adherence and reducing travel times and delays for transit users. The measures may attract new riders, increase transit capacity, and improve the transit quality of service.

Successful priority measures are usually characterized by (*14*):

- An intensively developed downtown area with limited street capacity and high all-day parking costs,
- A long-term reliance on public transportation,
- Highway capacity limitations on the approaches to downtown,
    - Major water barriers that limit road access to the downtown and channel bus flows,
    - Fast non-stop bus runs for considerable distances,
    - Bus priorities on approaches to or across water barriers,
    - Special bus distribution within downtown (often off-street terminals), and
    - Active traffic management, maintenance, operations, and enforcement programs.

Transportation policies that give priority to transit vehicles because of their efficiency benefits may allow transit agencies to implement transit priority measures.

Bus preferential treatments defined.

Bus preferential treatments can be generally defined as a range of techniques designed to speed up transit vehicles and improve overall system efficiency. They include physical improvements, operating changes, and regulatory changes. Bus preferential treatments may reduce travel time variability and improve schedule adherence, depending on the application. When considering implementing these treatments, the total change in person delay (including both passengers in buses and in private vehicles) should be taken into account. Local, regional, or state transportation policies favoring particular travel modes in particular situations may expand or limit the potential for application outlined in this chapter.

Where there has been a strong policy directive to improve the role of public transit in accommodating a community's travel needs, preferential treatments should be implemented with transit agency and traffic engineering agency staff working in a coordinated manner. Measures should be cost effective and should consider both long-term changes to mode split and the potential for attracting new riders. Both of these factors may be difficult to quantify. In most cases, bus preferential treatments will be more acceptable to roadway users and decision makers when improvements to transit operations do not create undue traffic disruptions. However, in a policy environment favoring transit usage over private automobiles, investments in bus preferential treatments rather than expanded roadway capacity may be seen as a means of further improving transit attractiveness and maximizing roadways' person-carrying ability.

In situations where the policy direction is not as clear or the inter-agency working relationships are not as strong, an incremental approach to developing preferential treatments may be more successful. This approach could involve demonstration projects that have a good potential for success and could be used to develop support for broader transportation improvement projects in the future.

Bus preferential treatments can provide a cost effective way of improving transit service based on focused, one-time capital investments as opposed to increased service that requires annual operating funding. They offer the potential for reducing or postponing the need for added service to respond to congestion and can attract new riders to transit, if the treatments provide a noticeable improvement in travel time, service reliability, or both.

Person Delay Considerations

The net change in person delay is an important factor to consider before implementing transit priority measures.

In many cases, providing bus preferential treatments involve trade-offs among the various users of a roadway facility. Providing a bus queue jump at a traffic signal, for example, provides a time-savings benefit for bus passengers, while possibly causing additional delay for motorists, their passengers, bicyclists, and some pedestrians. When considering implementing a preferential measure, one factor to consider should be the net change in person delay to all roadway users as a result of the measure. Of course, other factors such as cost, change in transit quality of service, and local policies encouraging greater transit use should also be considered.

BUSWAYS AND FREEWAY MANAGED LANES

Facilities that provide segregated rights-of-way for buses offer a number of advantages that can improve service quality. Bus travel times, schedule adherence, and vehicle productivity are improved when buses are able to use higher-speed, uncongested facilities. These improvements, in turn, promote efficiency, improve reliability, and increase the potential to gain new riders. However, these facilities often require capital and operating (maintenance) expenditures on the part of the transit agency that are not incurred when buses operate on public roadways.

Industry usage of the terms transitway *and* busway *is not consistent, and the terms are often used interchangeably.*

Busways and freeway managed lanes are the facility types offering segregated rights-of-way. Transit industry use of the terms *busway* and *transitway* is inconsistent, with the two terms often used interchangeably. The term *busway* has been used to describe facilities ranging from bus lanes in the medians of urban streets, to exclusive bus roads with at-grade intersections, to freeway managed lanes used exclusively by buses, to Ottawa-style grade-separated bus facilities with rail-like infrastructure. The TCQSM uses the terms *median busway, at-grade busway, freeway managed lanes,* and *grade-separated busway,* respectively, to describe these facility types.

In North America, busways and freeway managed lanes are found mainly in larger cities, usually with a large downtown employment and heavy peak-hour bus ridership. However, these facilities have found application internationally as a substitute for, or supplement to, rail systems. When facilities are located on exclusive rights-of-way, they may not be easy to walk to. In these cases, most ridership stems from park-and-ride lots located along the facilities, from transfers from other routes, or from buses using the facilities after circulating through a neighborhood.

Operational Overview

At-grade busways, including median busways.

At-grade busways in North America include the 8-mi (13-km) South Dade Busway in Miami; the 15-mi (24- km) Orange Line in Los Angeles; the median busway portion of the Euclid corridor in Cleveland; and portions of the Franklin corridor in Eugene, Oregon. Median busways are used in a number of South American cities, including Belo Horizonte, Curitiba, Porto Alegre, and São Paulo, Brazil; Bogotá, Colombia; and Quito, Ecuador. Median busways are also planned as part of new or enhanced BRT routes in Los Angeles; San Francisco; Montgomery County, Maryland; and Washington, D.C.

Exhibit 6-20 shows examples of at-grade busway stations that utilize level boarding and pre-paid fares. The Cape Town BRT station shown in Exhibit 6-20(a) provides high-level boarding (with platform screens to prevent passengers from entering the busway) and passengers pay their fare on entering the station building. The Eugene BRT station shown in Exhibit 6-20(b) provides level boarding onto a low-flow bus, with fares bought from a machine on the platform and fares randomly inspected on board. Both types of designs allow boarding passengers to utilize all bus doors which, when combined with the level boarding, allows large volumes of passengers to board and alight in a relatively short time, resulting in relatively low dwell times and improved bus speeds.

Exhibit 6-20
At-Grade Busway Station Examples



(a) Cape Town



(b) Eugene

Busways and freeway managed lanes separate buses from other traffic, which reduces the potential for conflicts that result in delays. In some cases, operating speeds may increase significantly with the use of freeway facilities; in others, the savings are less dramatic. After managed lanes were opened along several freeways in Houston, peak-hour bus operating speeds increased from 26 to 51 mi/h (42 to 83 km/h) (*16*).

Effective distribution of buses within downtown areas remains a challenge. Freeway-related treatments generally provide good access to the downtown perimeter, but do not substantially improve service within the downtown core. Furthermore, transit terminals are not always located near major employment locations, and may require secondary distribution. However, other means exist to continue to favor bus movements once buses enter the downtown street network (*17*).

Bus tunnels.

A capital-intensive solution to downtown bus distribution, a 1.3-mi (2.1-km), five-station bus tunnel (Exhibit 6-21a), opened in Seattle in 1991. Bus routes using the tunnel (now combined with light rail transit operations) are operated with a special fleet of dual-mode buses that run on overhead electric power in the tunnel and diesel power on the surface portions of their routes. Both ends of the tunnel connect to freeway ramps; the south end via an at-grade busway. Boston's Silver Line BRT route has a 1.0-mi (1.6-km), three-station tunnel used by dual-powered buses (Exhibit 6-21b), and plans an additional 1.0-mi (1.6-km), two-station extension in the future. Some bus routes in Providence use a former streetcar tunnel that has been converted to bus use, and busways in Brisbane, Australia also have tunnel sections.

Exhibit 6-21
Bus Tunnel Examples



(a) Seattle



(b) Boston

Impacts on Bus Operations

Exhibit 6-22 presents typical impacts of preferential treatments on freeway bus operations.

Exhibit 6-22
Typical Impacts of Busways and Freeway Managed Lanes on Bus Operations

Treatment	Travel Time Improvements	Person Delay Impacts	Additional Considerations
Busways	Up to 10 percent; varies depending on routing and other design details	Minimal to significant, depending on the project	Applications include special detection technologies that distinguish buses from general traffic
HOV lanes	Up to 20 percent; varies on out of direction travel	Significant, dependent on application	
Freeway bus lanes	3–15% of overall travel time, up to 75% of delay	Minimal to significant, highly dependent on the strategy and location	Travel time improvements are a function of the existing delay
Bus lane bypasses	Up to 20%; up to 90% of ramp meter delay	Potentially significant	Potential disruptions to queue storage needs on ramps

Sources: *NCHRP Synthesis 185* (*19*), *TCRP Web-Only Document 12* (*20*), and *TCRP Report 26* (*21*).
Note: HOV = high-occupancy vehicle.

Typical Conditions for Application

Policy and cost considerations usually dictate the lower limit for bus volumes that warrant busway or freeway managed lane treatments. Lower minimum vehicle thresholds can be expected, and are usually accepted, with busways than with freeway facilities; however, the minimum vehicle threshold may be higher in a heavily congested corridor than in one with lower levels of congestion. Non-users in heavily congested areas may be much more vocal about a facility they feel is underutilized than commuters in a corridor where congestion is not at serious levels. Whenever considering providing busway or high-occupancy vehicle (HOV) facilities, the perceptions of commuters and the public, as well as any unique local conditions, should be considered when developing minimum operating thresholds (*18*).

Exhibit 6-23 presents typical minimum freeway managed lane operating thresholds in vehicles per hour per lane (combined bus and HOV volumes), based on U.S. experience. These thresholds balance the number of people using the lane with the cost of constructing the lane.

Exhibit 6-23
Typical Freeway Managed Lane Minimum Operating Thresholds

Facility Type	Minimum Operating Threshold (veh/h/lane)
Separate right-of-way, HOV	800–1,000
Freeway, exclusive two-directional	400–800
Freeway, exclusive reversible	400–800
Freeway, concurrent flow	400–800
Freeway, contraflow HOV	400–800
HOV queue bypass lanes	100–200

Source: *NCHRP Report 414* (*18*).
Note: Volumes include both buses and private vehicles that are HOVs.

Exhibit 6-24 presents planning guidelines for minimum bus or passenger volumes for busways and bus priority treatments associated with freeways. These guidelines balance the number of people using the facility with the cost of constructing the facility and the perceived usage of the facility by non-users.

Exhibit 6-24
General Planning Guidelines for Busways and Freeway Managed Lanes

Treatment	Minimum One-Way Peak Hour Volumes		Related Land Use and Transportation Factors
	Bus	Passenger	
Exclusive busways on special right-of-way	40–60	1,600–2,400	Urban population: 750,000; CBD employment: 50,000; 1.85 million m^2 CBD floor space; congestion in corridor; save buses 1+ min/mi (0.6+ min/km).
Exclusive busways within freeway right-of-way	40–60	1,600–2,400	Freeways in corridor experience peak-hour congestion; save buses 1+ min/mi (0.6+ min/km)
Busways on railroad right-of-way	40–60	1,600–2,400	Potentially not well located in relation to service area. Stations required.
Freeway bus lanes, normal flow	60–90	2,400–3,600	Applicable upstream from lane drop. Bus passenger time savings should exceed other road user delays. Normally achieved by adding a lane. Save buses 1+ min/mi (0.6+ min/km).
Freeway bus lanes, contraflow	40–60	1,600–2,400	Freeways with six or more lanes. Imbalance in traffic volumes permits freeway LOS D in off-peak travel direction. Save buses 1+ min/mi (0.6+ min/km).
Bus lane bypasses at toll plazas	20–30	800–1,200	Adequate queuing area on toll plaza approach, so bus lane access is not blocked.
Exclusive bus access to non-reserved freeway or arterial lane	10–15	400–600	
Bus bypass lane at metered freeway ramp	10–15	400–600	Alternate surface street route available for metered traffic. Express buses leave freeways to make intermediate stops.
Bus stops along freeways	5–10	50–100*	Generally provided at surface street level in conjunction with metered ramp.

Source: Levinson, Adams, and Hoey (*17*).
*Boarding or alighting passengers in the peak hour.

Freeway Managed Lanes

When the term is used in the TCQSM, "managed lane" implies buses may always use the lane and that other vehicle types may be allowed to use the lane.

In its most broad usage, a managed lane is a lane that is restricted to a particular type of vehicle—for example, buses, trucks, vehicles paying tolls to use the lane, or vehicles occupied by a given number of people (usually two or three). These lanes can be immediately adjacent to regular traffic lanes, separated from other traffic by a painted median or removable pylons, or completely separate and protected from other traffic by physical barriers (*23*).

Houston's managed lane system, illustrated in Exhibit 6-25, is the most extensive deployment of managed lanes in North America. The lanes were constructed originally for buses (also used by carpools and vanpools); in 2002, these lanes saved the average commuter 12 to 22 min per trip (*16*). Most of these lanes were converted into high-occupancy toll (HOT) lanes between 2009 and 2012. During peak periods, drivers without passengers are allowed to use the managed lanes by paying a toll. Tolls are based on time of day and the congestion level of the managed lanes. Tolls are paid electronically though an authorized toll tag. Traffic monitoring systems help maintaining traffic speed on the managed lanes to ensure optimal travel times.



Exhibit 6-25
Houston Freeway Managed Lane Example

Freeway Ramp Queue Bypasses

Queue bypasses are a form of priority treatment that allows buses to avoid queues of vehicles (such as those that develop at freeway ramp meters) by providing a short managed lane that avoids the queue. This form of bus priority often involves considerable innovation to find methods of enabling buses to avoid recurring congestion. Exhibit 6-26 depicts a typical queue bypass design on a freeway on-ramp, along with actual applications.

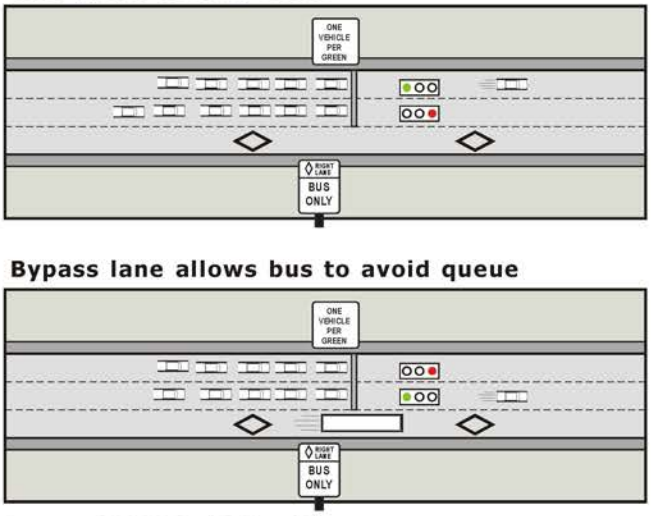






Exhibit 6-26
Freeway Ramp Queue Bypasses

Top right: Los Angeles
Bottom right: The Netherlands

Source: TCQSM 2nd Edition (*5*).

Shoulder Use

In some metropolitan areas—Minneapolis being the best example (Exhibit 6-27)—buses are allowed to use the paved shoulder to bypass congestion in the general traffic lanes on freeways and multilane highways. As a result, bus travel is faster and more reliable than travel in the general traffic lanes. Bus shoulder use is typically considered when (*22*):

- Roadways are congested during peak periods (speeds less than 35 mi/h or 55 km/h);

- Insufficient space or bus volumes exist to add a managed lane;
- Four to six buses or more an hour use the freeway;
- At least 10-ft (3-m) shoulder width is provided—preferably at least 11.5 ft (3.5 m) on long overpasses and 12 ft (3.7 m) or more when higher speed differentials between buses and general traffic are desired; and
- The shoulder is strong enough to support regular bus use.

The use of auxiliary (i.e., exit-only) lanes at freeway off-ramps, shared right-turn lanes at signalized intersections on highways, and ramp metering on freeway on-ramps helps facilitate merging and weaving movements between buses and other vehicles entering and exiting the highway. Buses are typically limited to traveling no more than 10 to 15 mi/h (15 to 25 km/h) faster than adjacent traffic, but even these speed differentials can result in significant time savings over extended distances. *TCRP Report 151: A Guide to Implementing Bus on Shoulder (BOS) Systems* provides case studies of bus use of shoulder lanes and guidance for implementing them (*22*).

Exhibit 6-27
Examples of Bus on Shoulder Operation (Minneapolis)



(a) Freeway



(b) Multilane highway

URBAN STREET BUS LANES

Arterial street bus lanes provide segregated rights-of-way for buses. Because these facilities have *interrupted flow* (e.g., traffic signals), due to intersections with other streets, they provide a lower level of priority to transit than facilities on exclusive rights-of-way. Nevertheless, arterial street bus lanes offer buses significant advantages over mixed-traffic operations. Exhibit 6-28 lists common sources of delays to buses operating in mixed traffic that bus lanes and site-specific preferential treatments help overcome. These delays reduce bus capacity, speed, and reliability, resulting in reduced service quality for passengers and potentially increased operating costs for transit agencies.

Intersection Type	Delay Sources
Signalized	Insufficient traffic signal green time for bus approach Poor signal progression for buses Inadequate vehicle detection at signals
All	Queued vehicles on intersection approach On-street parking maneuvers Inadequate lane width Off-line bus stop reentry delay Right-turning traffic blocking access to stop Left-turning traffic blocking shared lane

Exhibit 6-28
Sources of Delay for Buses Operating in Mixed Traffic at Intersections

Bus lanes can be created by several means:

- Redesignating an existing travel lane as a bus lane,
- Narrowing existing lanes to provide an additional lane,
- Widening the street to add a new lane, and
- Restricting on-street parking (part-time or full-time) to provide a bus lane.

Where there is a relatively high volume of buses operating on a roadway, coupled with significant bus and automobile congestion, exclusive bus lanes can provide more attractive and reliable bus service. Most bus lanes take the form of reserved lanes on city streets, usually in the same direction as the general traffic flow. However, some cities provide bus-only streets, such as 16th Street in Denver, the Nicolet Mall in Minneapolis, the 5th and 6th Avenue transit mall in Portland (where buses now share the roadway with light rail transit), and the Granville Mall in Vancouver.

Exhibit 6-29 shows applications where (*a*) on-street parking was removed and existing lanes narrowed to create a bus lane, and (*b*) parking is restricted during peak periods to provide a bus lane.



(a) Full-time lane (Portland)



(b) Part-time lane (Seattle)

Exhibit 6-29
Bus Lane Development via Parking Restrictions

Median Busway

Description

Median busways are exclusive bus lanes located in the median of an urban street. These facilities require dedicated ROW sufficient for the running way and stations. The median busway interfaces with general traffic at signalized intersections where cross streets are allowed to cross the busway. Left-turn lanes and protected left-turn signal phasing (i.e., left-turn arrows) are provided on the main street to facilitate left- and U-

turns across the busway. Unsignalized minor intersections and local drive ways along the transitway are restricted to right-turn movements in and out.

Station platforms are implemented within the ROW, preferably on the far side of signalized intersections, as this location facilitates the application of transit signal priority and preserves ROW (one station and one general traffic left-turn lane for the opposite direction can be paired on each side of the intersection). Stations are typically located on the right side in the U.S. because doors are located on the right side of the bus. Stations designed with center platforms serving both directions require special buses equipped with doors on both sides, as are used on BRT routes in Cleveland and Eugene (Exhibit 6-30).

Exhibit 6-30
Median Busway Center Station Examples



(a) Cleveland



(b) Eugene

Some form of physical barrier, such as jersey barriers, curbing, or raised pavement markers, is typically used to separate the median busway from general traffic and to prevent pedestrians crossing the transitway. In addition, signage (DO NOT ENTER and PEDESTRIANS AND BICYCLES PROHIBITED) at intersections indicates designated transit use.

Typical Conditions for Application

NCHRP Report 155: Bus Use of Highways—Planning and Design Guidelines (*17*) defines warrants for median bus lanes as 60 to 90 one-way buses per peak hour, with a minimum bus volume of 600 per day, based on providing sufficient usage to make the bus lanes appear used (e.g., 60 buses per hour is equivalent to an average of one bus per minute). However, the North American median busways that had been developed as of 2012 served far fewer buses per hour, having been developed for policy reasons (e.g., to encourage a mode shift to transit) and with a vision of preserving the enhanced bus speed, reliability, and capacity provided by the busway for the long term in the face of increasing traffic congestion.

Median busways require sufficient ROW to accommodate adequately sized station platforms, the bus running way, left-turn lanes at signalized intersections, along with sufficient additional ROW to accommodate other road users (e.g., motorized vehicles, bicyclists, and pedestrians). Providing passing lanes at stations requires additional ROW, but provides operational flexibility to operate a mix of limited-stop and all-stop services along the busway. *TCRP Report 90: Bus Rapid Transit, Volume 2: Implementation Guidelines* (*24*) presents the range of costs for constructing new bus lanes; *TCRP Synthesis 83: Bus and Rail Transit Preferential Treatments in Mixed Traffic* (*14*) estimates their operating and maintenance costs to be modest.

Exclusive Bus Lanes

Exclusive bus lanes are developed along a roadway by widening or dedicating one or more existing general traffic or parking lanes for transit use. They can be peak period only, or all day. These lanes typically allow use by general traffic for turning movements at intersections and driveway. There are four kinds of exclusive bus lanes:

- Concurrent flow,
- Contraflow,
- Bi-directional, and
- Intermittent.

Concurrent-Flow Lanes

A concurrent-flow lane is a lane designated for transit vehicles moving in the same direction as general traffic. In some cases, carpools and vanpools are also allowed to use the lane. The lane can be located:

1. On the right side, adjacent to the curb or shoulder.
    a. If there is on-street parking, this configuration requires the removal of parking, either permanently or during the hours of exclusive bus use.
    b. Right-turn and local access driveway traffic are allowed to use the lane over short distances.
    c. Enforcement (e.g., ticketing and/or towing stopped and parked vehicles), public education, signing , and pavement markings are required to maintain the exclusivity of the bus lane and to preserve the desired bus speed, reliability, and capacity benefits.
2. On an *interior* or *offset* bus lane that operates adjacent to the curb lane.
    a. This configuration leaves the curb lane available for other uses, including parking, loading, and right-turn movements.
    b. An interior transit lane has a significant impact on the travel capacity of the street since one general purpose lane was converted into a transit-only lane. However, parallel streets may be able to absorb diverted automobile traffic.

Concurrent-flow lanes can be developed in a variety of configurations (*14*):

- One permanent lane in each direction of travel;
- One part-time lane operating in the peak direction during its peak period, with another part-time lane serving the opposite direction during its peak period;
- One single lane operating in one direction during one time period, then reversed to operate in the opposite direction during another time period (i.e., a reversible lane); and
- Two permanent or part-time lanes in each direction of travel, providing added capacity and bus stop bypassing capability when bus volumes are high and multiple routes use the facility.

Exhibit 6-31 shows examples of different types of exclusive bus lanes.

Exhibit 6-31
Exclusive Bus Lane Examples



(a) Curbside bus lane with right-turn lane (Copenhagen)



(b) Interior bus lanes (Boston)



(c) Dual bus lanes (New York)

Contraflow Lanes

Contraflow lanes (Exhibit 6-32) are designated exclusive bus lanes that operate in the opposite direction of general traffic. They are developed almost exclusively on one-way streets. Special signage, physical barriers, and/or lane use control signals are used to alert other roadway users of the directional of use of the lane.

Exhibit 6-32
Contraflow Lane Examples



(a) Orlando



(b) Minneapolis

Bi-directional Lanes

Bi-directional transit lanes may be used when there is only enough right-of-way to implement a single dedicated bus lane. Their length is desirably no more than two to three signalized intersections, as they can only serve one direction of bus travel at a time. The longer the bi-directional section, the longer minimum headway between buses traveling in the same direction through the section, when opposite directions of

travel are served alternately. Nevertheless, bi-directional lanes can provide a higher level of reliability compared to congested mixed-traffic operation over the same section.

Bi-directional operation requires advanced signal systems to control bus movement through the section and special signing and pavement markings to alert other roadway users to the bi-directional operation. Stops or stations within a bi-directional section desirably provide lanes for both directions of travel at the station (allowing buses traveling in opposite directions to meet and pass each other); otherwise, separate stations need to be provided for each direction of travel (if buses only have doors on the right side) or buses must have doors on both sides (if one station is to serve both directions from a single bus lane). Exhibit 6-33 illustrates bi-directional operation.



Exhibit 6-33
Bi-directional Operation Example (Eugene)

Intermittent Lane

An intermittent, or moving, bus lane relies on technology and enforcement to provide bus priority. A segment of a general-purpose lane turns into a bus lane before a bus arrives and reverts back to general-purpose operation once a bus has passed. From the bus's point-of-view, the bus receives an exclusive lane continuously as it progresses down a street. Any given section of the lane is restricted to bus-only use only for the short period of time when a bus is present. This approach to bus priority might be useful where bus service is relatively infrequent and traffic-related bus delays are high, but sufficient capacity exists for other vehicles to move out of the bus lane when needed. As bus frequencies increase, a permanent bus-only lane may be considered.

An intermittent lane requires a combination of several technologies:

- Roadway sensors monitor traffic conditions (flow, speed, and queues) in real time;
- An AVL system monitors bus's positions in real time;
- A prediction algorithm estimates a bus's arrival time to the next segment, as well as the time needed for traffic already in the lane to continue forward to empty out of the segment that is about to turn into a bus lane; and
- Variable message signs and flashing lights installed in the pavement along the lane divider communicate to motorists that a bus is approaching and that they must exit the lane.

For this priority treatment approach to be effective, driver education and enforcement are paramount. As of 2012, there were no applications of these bus lanes in North America, although mixed light rail–bus operation along Portland's 5th and 6th Avenue transit mall provides intermittent priority for light rail trains in the left-hand

transit lane, requiring buses not to use the lane when a train approaches. A demonstration project of an intermittent bus lane, using overhead signage and an in-pavement lighting system, was conducted in Lisbon (*25*).

Typical Conditions for Bus Lane Application

Bus lanes have been provided on urban streets by adding lanes, developing contraflow lanes, and converting roadway shoulders for bus use. Factors that influence whether bus lanes may be appropriate include (*21*):

- Congestion,
- Travel time savings,
- Person throughput,
- Vehicle throughput,
- Local agency support,
- Enforceability, and
- Physical roadway characteristics.

Policy and cost considerations generally set the lower limit for bus volumes that warrant priority treatments on urban streets, while bus vehicle capacity sets the upper limit. The procedures presented later in this chapter can be used to determine the design capacity of a bus lane based on specific local conditions. In addition, a variety of studies have developed planning guidelines for minimum and maximum bus volumes for bus lanes, which are summarized below.

A study of bus operations in Manhattan recommended the following desirable maximum a.m. peak-hour bus volumes for arterial street bus lanes (*26*):

- Two lanes exclusively for buses: 180 bus/h;
- One lane exclusively for buses, partial use of adjacent lane: 100 bus/h;
- One lane exclusively for buses, no use of adjacent lane: 70 bus/h; and
- Buses in curb lane in mixed traffic: 60 bus/h.

Exhibit 6-34 presents general planning guidelines for bus preferential treatments on arterial streets. A comparison of person volumes on buses operating in mixed traffic with person volumes in other vehicles operating on the street can also be used to help decide when to dedicate one or more lanes to exclusive bus use.

Exhibit 6-34
General Planning Guidelines for Bus Lanes on Urban Streets

Treatment	Minimum One-Way Peak-Hour Volume		Related Land Use and Transportation Factors
	Bus	Passenger	
Bus streets or malls	80–100	3,200–4,000	Commercially oriented frontage.
CBD curb bus lanes, main street	50–80	2,000–3,200	Commercially oriented frontage.
Curb bus lanes, normal flow	30–40	1,200–1,600	At least 2 lanes available for other traffic in same direction.
Median bus lanes	60–90	2,400–3,600	At least 2 lanes available for other traffic in same direction; ability to separate vehicular turn conflicts from buses.
Contraflow bus lanes, short segments	20–30	800–1,200	Allow buses to proceed on normal route, turn around, or bypass congestion on bridge approach.
Contraflow bus lanes, extended	40–60	1,600–2,400	At least 2 lanes available for other traffic in opposite direction. Signal spacing greater than 500-ft (150-m) intervals.

Sources: Levinson, Adams, and Hoey (*17*) and *NCHRP Report 414* (*18*).

TCRP Report 118: Bus Rapid Transit Practitioner's Guide (*11*) presents additional guidance for the operation of exclusive bus lanes:

1. Concurrent-flow lanes may operate along the outside curb, in the lane adjacent to a parking lane (interior lane), or in a paved median area (without a dedicated median transitway).
2. Concurrent-flow lanes can operate at all times, for extended hours (e.g., from 7 a.m. to 7 p.m.), or just during peak hours.
3. Contraflow lanes should operate at all times.
4. Under conditions of heavy bus volumes, dual concurrent-flow or contraflow lanes may be desirable.
5. Where the bus lanes operate at all times, special colored pavement may be desirable to improve the identity of the BRT operations.
6. Bus lanes should be at least 11 ft wide to accommodate an 8.5-ft bus width.
7. The bus lanes should carry as many people as in the adjacent general traffic lane. Generally, at least 25 buses should use the lanes during the peak hour. (Ideally, there should be at least one bus per signal cycle to give buses a steady presence in the bus lane.) There should be at least two lanes available for general traffic in the same direction, wherever possible. (However, many European bus lane installations leave only one lane for general traffic.)
8. Parking should be prohibited where bus lanes are along the curb, but it may remain where interior bus lanes are provided.
9. There should be suitable provisions for goods delivery and service vehicle access, either during off-hours or off-street.

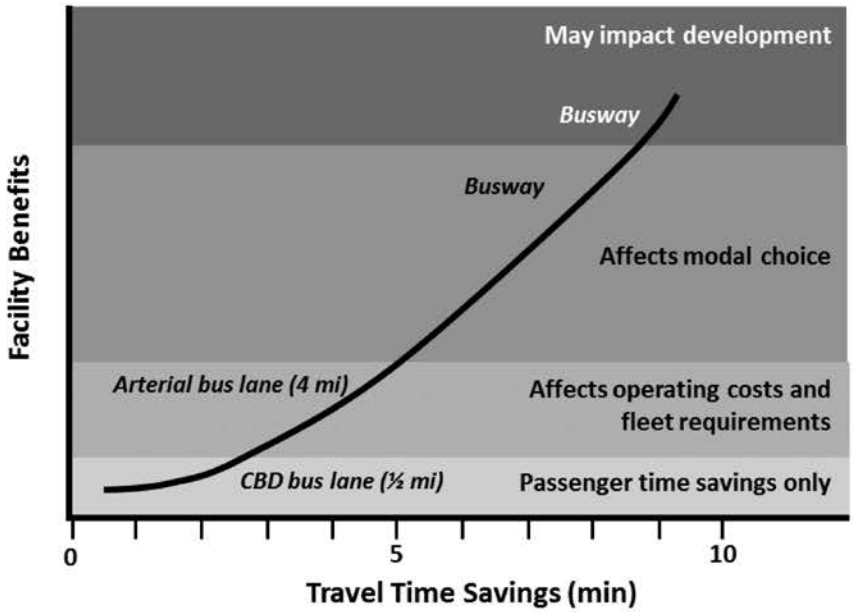
Impacts of Median Busways and Exclusive Bus Lanes on Bus Operations

The primary benefits of median busway and exclusive bus lane operations over mixed-traffic operations are (*a*) reduced conflict with general traffic, resulting in reduced transit travel time, and (*b*) improved transit reliability. In addition, secondary benefits may result depending on the amount of travel time saved, as illustrated in Exhibit 6-35:

- Small amounts of travel time savings primarily benefit passengers.
- As the travel time savings increase, transit fleet requirements and thus operating costs may be reduced.

Travel time savings of more than 5 min (on a typical trip) can affect mode choice and increase ridership. High travel time savings possibly contribute to changes in land development patterns.

Exhibit 6-35
Degree of Bus Lane Impacts



Source: Adapted from *TCRP Report 26* (*21*).

Exhibit 6-36 provides examples of travel time savings documented on urban street bus lanes.

Exhibit 6-36
Observed Travel Time Savings with Urban Street Bus Lanes

City	Street	Travel Time Savings
Los Angeles	Wilshire Boulevard	0.1–0.2 min/mi (a.m.) 0.5–0.8 min/mi (p.m.)
Dallas	Harry Hines Boulevard	1 min/mi
Dallas	Ft. Worth Boulevard	1.5 min/mi
New York	Madison Avenue (dual bus lanes)	43% express bus 34% local bus
San Francisco	1st Street	39% local bus

Sources: *TCRP Report 26* (*21*); *TCRP Report 90, Volume 2* (*24*); and *TCRP Report 118* (*11*).

Exhibit 6-37 shows observed reliability improvements associated with urban street bus lanes. The improved reliability is measured by the percent change in the coefficient of variation of travel time (standard deviation divided by the mean).

Exhibit 6-37
Observed Reliability Improvements with Urban Street Bus Lanes

City	Street	Percent Improvement*
Los Angeles	Wilshire Boulevard	12–27
New York	Madison Avenue (dual bus lanes)	11 (express buses) 31 (local buses)

Sources: *TCRP Report 26* (*21*) and *TCRP Report 118* (*11*).
* Percent change in the coefficient of variation of travel time.

TRANSIT SIGNAL PRIORITY (TSP)

Overview

TSP alters traffic signal timing at intersections to give priority to transit operating in a median busway, in exclusive bus lanes, or in mixed traffic. TSP modifies the normal signal operation to better accommodate transit vehicles while maintaining signal coordination along a route and overall signal cycle length at individual intersections.

Signal priority is different than preemption, which is normally associated with emergency vehicles and railroad crossing operations.

Early attempts to provide signal priority were based on signal *preemption*, where buses were given a nearly immediate green signal, regardless of other conditions, in the same manner that emergency vehicles and railroad trains are able to pre-empt traffic signals. Signal preemption is generally not desirable from a traffic signal control system standpoint and because it raises potential pedestrian crossing safety issues, it has been dismissed by most roadway agencies. Current practice is to provide signal *priority*, where providing preferential treatment for buses is balanced against other system needs.

Reducing the traffic signal cycle length on an arterial or downtown grid system is a passive priority measure.

Signal priority measures include passive, active, and real-time priority. *Passive* strategies attempt to accommodate transit operations through the use of pre-timed modifications to the signal system that occur whether or not a bus is present to take advantage of the modifications. These adjustments are completed manually to determine the best transit benefit while minimizing the impact to other vehicles. Passive priority can range from simple changes in intersection signal timing to systemwide retiming to address bus operations. Passive strategies can utilize transit operations information, such as bus travel times along street segments, to determine signal timing coordination plans.

Conditional strategies can incorporate information on bus schedule status, loading, and recent requests for priority to determine whether or not to grant priority to a given bus.

Active strategies adjust the signal timing after a bus is detected approaching the intersection. Depending on the application and capabilities of the signal control equipment, active priority may be either conditional or unconditional. *Unconditional* strategies provide priority whenever a bus arrives. *Conditional* strategies incorporate information from onboard automatic vehicle location (AVL) equipment (e.g., whether or not the bus is behind schedule, and by how much), and/or automatic passenger counter (APC) equipment (e.g., how many people are on board), along with signal controller data on how recently priority was given to another bus at the intersection, to decide whether or not to provide priority for a given bus (*27*).

Real-time strategies consider both automobile and bus arrivals at a single intersection or a network of intersections. Applications of real-time control have been

limited to date and require specialized equipment that is capable of optimizing signal timings in the field to respond to current traffic conditions and bus locations.

Exhibit 6-38 summarizes common bus signal priority treatments.

Exhibit 6-38
Types of Bus Signal Priority Systems

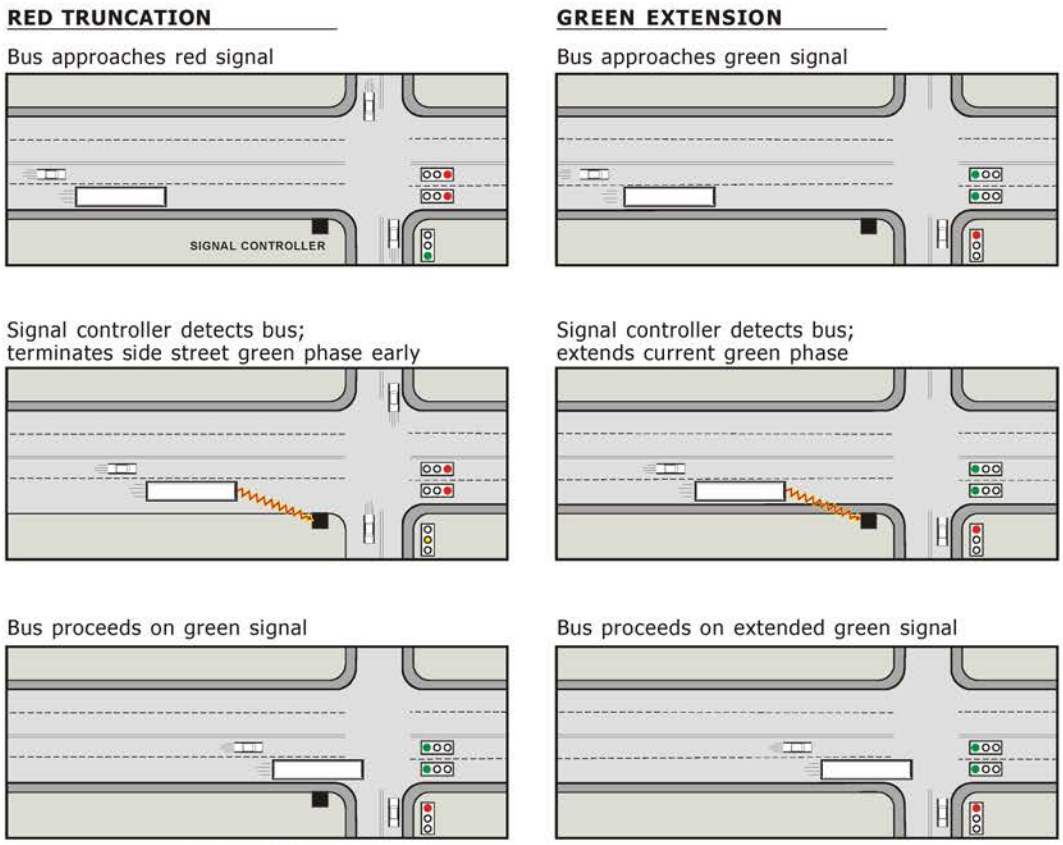
Treatment	Description
	PASSIVE PRIORITY
Adjust cycle length	Reduce cycle lengths at isolated intersections to benefit buses
Split phases	Introduce special phases at the intersection for the bus movement while maintaining the original cycle length
Areawide timing plans	Preferential progression for buses through signal offsets
Bypass metered signals	Buses use special reserved lanes, special signal phases, or are rerouted to non-metered signals
Adjust phase length	Increased green time for approaches with buses
	ACTIVE PRIORITY*
Green extension	Increase phase time for current bus phase
Early start (red truncation)	Reduce other phase times to return to green for buses earlier
Special phase	Addition of a bus phase
Phase suppression	Skipped non-priority phases
	REAL-TIME PRIORITY*
Delay-optimizing control	Signal timing changes to reduce overall person delay
Network control	Signal timing changes considering the overall system performance
	PREEMPTION*
Preemption	Current phase terminated and signal returns to bus phase

Source: Bullard and Nungesser (*28*).

Note: *Any of the listed treatments can be unconditional (occur whenever a request is received) or conditional (priority is granted if other conditions—schedule status, loading, etc.—are met).

TSP treatment is a minor adjustment to signal phase split times. The green indication facing an approaching bus may stay green longer—*green extension*—or start sooner—*red truncation.* The intent is to eliminate or reduce delay to buses at signalized intersections. The additional time given to or taken away from a particular phase is usually no more than 10% of the signal cycle, and is recovered during the following signal cycle(s) so that traffic signal coordination can be maintained along the street. The decision whether TSP is granted can be made locally at the individual intersections, or at a traffic management center coordinating multiple intersections or entire routes. TSP can be applied as a separate preferential treatment or in combination with other physical and operational treatments, such as exclusive lanes and stop consolidation.

Exhibit 6-39 illustrates the red truncation and green extension process associated with an active signal priority implementation. In this exhibit, street-side equipment detects the bus (for example, using a transponder or an optical system), while bus-mounted equipment transmits a request for priority to the signal controller. As discussed later, other methods of monitoring a bus's location relative to an intersection are also feasible.



Source: TCQSM 2nd Edition (*5*).

Exhibit 6-39
Bus Signal Priority Concept—Red Truncation and Green Extension

The importance of the relationship between transit staff and traffic engineering staff cannot be overemphasized. Coordination between these groups is necessary for effective implementation of transit priority measures.

Special Signal Phasing

Another signal preferential treatment strategy is to introduce a transit-only signal or added signal phase into an intersection. This approach typically provides a special left-turn signal at a particular location to allow buses to make turns onto a cross street. Exhibit 6-40 shows two examples of this kind of treatment, (*a*) a bus-only left-turn lane accessed from a general purpose lane and (*b*) a special signal phase allowing left, through, and right bus movements from right-side bus lanes. A bus-only left-turn lane combined with a bus stop in the street median is another possibility.



(a) Bus-only left-turn lane (Portland)



(b) Left turn from right-side bus lane (Vancouver)

Exhibit 6-40
Special Bus Left-Turn Phasing Examples

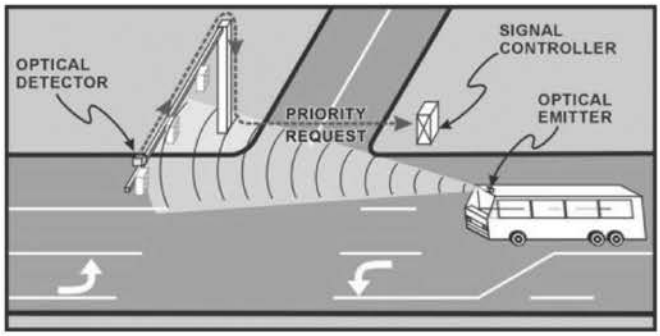
TSP Technology

Signal priority systems vary in complexity. Simple systems that rely on bus operator intervention reduce the amount of on-vehicle technology that is needed. However, automated systems that do not require bus operator intervention are preferable, as operators may not always remember to activate the system at the intersections equipped with signal priority equipment. Furthermore, an automated system, when coupled with two-way data communication and AVL equipment, can be set to activate signal priority only when a bus meets certain conditions for granting priority (e.g., a bus is behind schedule, on route, within a preset area, doors are closed).

A variety of technology is employed for vehicle detection and information transmission:

- Inductive loop systems were used in early TSP applications, where an inductive loop embedded in the pavement detected a transponder mounted on the underside of a bus;
- Optical emitter/detection systems (Exhibit 6-41) have been applied by many U.S. and Canadian transit systems;
- Radio frequency tags, similar to those used by the logistics industry to track packages, interact with wayside reader stations; and
- The combination of global positioning system (GPS) and wireless technology are emerging technologies for TSP application.

Exhibit 6-41
Optical TSP System Example



Source: TCQSM 2nd Edition (*5*).

Feasibility studies have concluded that there is no strong evidence that one technology works best for every situation. The AVL and APC technologies in use at a given transit agency influence the development of TSP, as does the pre-existence of traffic signal infrastructure for other priority applications (e.g., emergency vehicles). If the existing traffic signal control system's capability is not sufficient to accommodate TSP, traffic signal hardware or software updates, or both, may be needed. *TCRP Synthesis 83: Bus and Rail Transit Preferential Treatments in Mixed Traffic* (*14*) summarizes the type of equipment used by some North American transit agencies as of 2010.

Typical Conditions for Application

There are a number of reasons to justify transit signal priority. However, signal priority should only be implemented at intersections whose traffic operations (including pedestrian and bicycle operations) are well understood.

TSP is typically applied when there is significant transit delay along a route at signalized intersections due to signal operation. Studies have found that TSP is most effective at signalized intersections operating within LOS D and E conditions with a volume-to-capacity (v/c) ratio between 0.80 and 1.00. Under LOS A through C conditions, TSP brings limited benefits as the roadway is relatively uncongested and neither major bus travel time or reliability improvements can be achieved. Under oversaturated traffic conditions (v/c greater than 1.00), long vehicle queues prevent transit vehicles from getting to the intersection soon enough to take advantage of TSP without disrupting general traffic operations (*14*). When bus volumes are high enough that TSP would be called for in the majority of signal cycles, passive signal priority or other forms of bus preferential treatment may be preferable, as the traffic signal system may not be able to grant frequent TSP requests.

Ideally, TSP is applied when the net total person delay (on transit and in general traffic) will decrease at a particular intersection or along a corridor, although policy considerations to discourage automobile travel and favor transit use may also apply. Field data collection on traffic and transit operating conditions, as well as an analysis of future conditions (often involving simulation modeling), allows for informed decisions by both transit and transportation engineering staff on the benefits and impacts of potential signal timing changes. *TCRP Report 118: BRT Practitioner's Guide* (*11*) provides a decision-making framework for implementing TSP.

Actual applications have shown that TSP achieves a greater reduction in transit travel time and variability of travel time when transit stops are located on the far side of signalized intersections, as the transit vehicle can activate the priority call, travel through the intersection and then make a stop (*14*).

TCRP Synthesis 83 (*14*) provides cost information for various TSP detection systems, along with typical per-intersection costs for implementing TSP.

Impacts on Transit Operations

The direct benefits of TSP are (*a*) travel time savings and (*b*) improved reliability, which could result in (*c*) capital and operating cost savings. The level of benefit a TSP system provides depends on a complex set of interdependent variables, including whether the signal system along the route was already optimized before TSP application (*14*).

Documented travel time savings from TSP applications in North America and Europe have ranged from 2% to 18%, depending on the length of route, traffic conditions, bus operations, and the TSP strategy deployed. Travel time savings of 8% to12% have been typical. The reduction in bus delay at signals has ranged from 15% to 80% (*14*).

TSP significantly improves schedule adherence, as measured by variability in bus travel times and arrival times at stops relative to the schedule. Bus travel time variability could be reduced by up to 35%. On high-frequency routes, TSP can also help reduce bus bunching headway variability (*14*).

Reductions in bus travel time and travel time variability can result in operating and capital cost savings, when the total time saved from running time reductions and reduced schedule recovery requirements at the ends of routes equals or exceeds the route headway, as fewer buses can then serve the route at the same headway. Even when the time savings are not enough to save a bus immediately, TSP can postpone the day that an extra bus needs to be added to the route to maintain headways, by offsetting some of the increased running time resulting from increased traffic congestion (*29*).

Exhibit 6-42 presents examples of North American TSP applications and their reported benefits.

Exhibit 6-42
Summary of TSP Benefits and Impacts

Location	Transit Mode	# of Intersections	TSP Strategies	Benefit/Impact
Portland (Tualatin Valley Hwy.)	Bus	10	Green extension, red truncation	Bus travel time reduced 1.4–6.4% Bus traffic signal delay reduced 20%
Portland (Powell Blvd.)	Bus	4	Green extension, red truncation, queue jump	Bus travel time reduced 5–8% Bus person delay generally decreased TSP impacts on traffic inconclusive
Seattle (Rainier Ave. at Genesee)	Bus	1	Green extension, red truncation	Bus signal-related stops reduced 50% Bus signal delay reduced 57% Bus travel time variability reduced 35% Average person delay reduced 13.5% Average vehicle delay did not change Side-street impacts insignificant
Toronto	Streetcar	36	Green extension, red truncation	Transit signal delay reduced 15–49% One streetcar removed from service
Chicago (Cermak Rd.)	Bus	15	Green extension, red truncation	Bus travel time reduced 7–20% Improved schedule reliability Average vehicle delay reduced 1.5 s/veh Side-street vehicle delay increased 8.2 s/veh Fewer buses required to operate service Improved passenger satisfaction
San Francisco	Light rail	16	Green extension, red truncation	Transit signal delay reduced 6–25%
Minneapolis (Louisiana Ave.)	Bus	3	Green extension, red truncation, actuated bus phase	Bus travel time reduced 0–38% Average vehicle delay increased 4.4 s/veh Skipping signal phases caused some motorist frustration
Los Angeles (Wilshire and Ventura Blvds.)	Bus	211	Green extension, red truncation, actuated bus phase	Bus travel time reduced 35% Decrease in bus delay at traffic signals

Source: ITS America (*30*).

SITE-SPECIFIC PRIORITY TREATMENTS

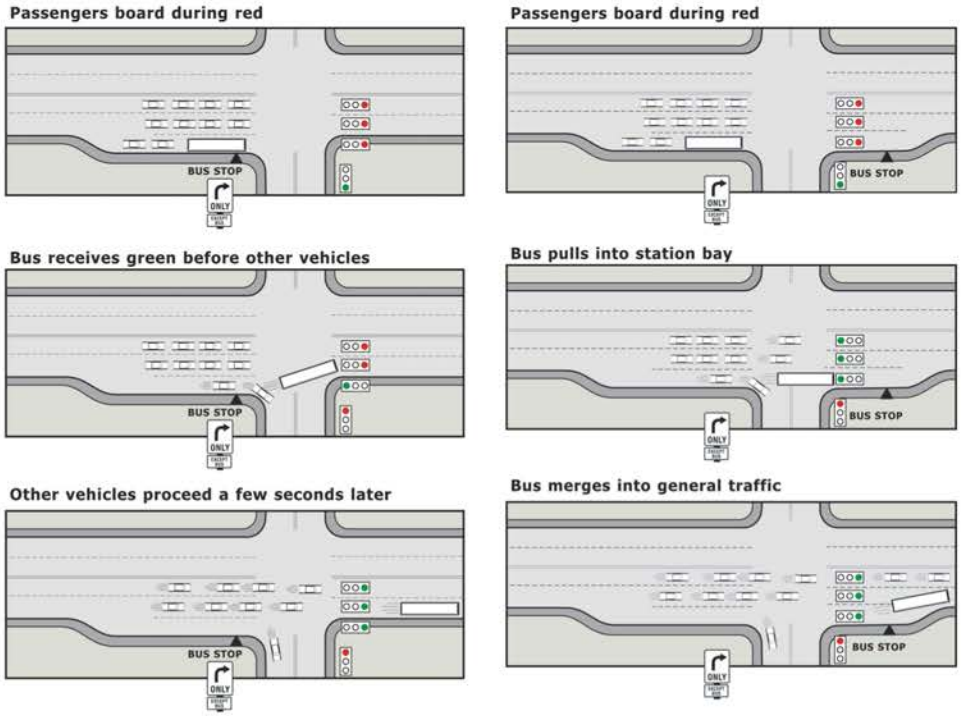
Queue Jumps

Overview

A queue jump lane is a relatively short lane that is available for buses to bypass queues of general traffic at or prior to a signalized intersection, thus reducing delay to bus passengers. Example configurations include:

- Buses enter a right- or left-turn lane (right-turn lanes being the most common) on an intersection approach and are given a green indication at the intersection in advance of general traffic;
- Buses enter an exclusive bus lane developed on the intersection approach and are given a green indication at the intersection in advance of general traffic; and
- Buses use a mid-block traffic signal (or *pre-signal*) coordinated with the downstream signalized intersection to move ahead of general traffic unimpeded.

Exhibit 6-43 illustrates the first type of queue jump lane in situations where TSP is and is not provided. Exhibit 6-44 shows photographs of the second and third types of applications.



(a) With TSP (b) Without TSP

Exhibit 6-43
Right-Turn Lane
Queue Jump Process

Source: *TCRP Report 118* (*11*).

If TSP is provided, a separate, short signal phase is provided to allow the bus (and any turning vehicles in front of it) an early green indication to move into the through lane or bus loading area on the far side of the intersection, ahead of through traffic. If the bus stop is located near side, passenger alighting and boarding could occur during a red signal indication. Immediately after the bus doors close, a signal priority request would be sent to the controller to activate the special signal phase, giving an early green indication to the bus to proceed ahead of the general traffic.

If TSP is not provided, a bus could still use a right-turn lane or right-side bus lane to bypass a general traffic queue. The bus would proceed under the normal through signal phase into a far-side bus zone or bus pullout.

Exhibit 6-44
Example Queue Jump Applications with Bus Lanes



(a) Queue jump at intersection (Copenhagen)



(b) Queue jump at bus lane end (Frederiksberg, Denmark)

In both applications shown in Exhibit 6-44, a special transit signal (e.g., the vertical white bar to the right of the red indication in Exhibit 6-44[a]) is used to indicate that the bus may proceed. Such an indication has been commonly used in Canada and Europe, and has been allowed in the U.S. since the publication of the 2009 *Manual on Uniform Traffic Control Devices* (MUTCD) (*31*) for bus queue jump applications and BRT operating in semi-exclusive or mixed-use alignments. Right-turn-lane queue jump applications in the U.S., such as those illustrated in Exhibit 6-43, have typically used regular traffic signals (with appropriate signing and shielding) to control the bus queue jump movement.

Typical applications of the pre-signal shown in Exhibit 6-44[b] are at a section of reduced right-of-way width where insufficient room exists to continue a bus lane, and to allow buses to transition from a curb bus lane or bus stop to the left-turn lane at a downstream signal. In the example in Exhibit 6-44[b], the roadway width used by the bus lane is needed for a right-turn lane at the downstream intersection, while buses proceed straight through the intersection. In this case, the queue jump allows buses to merge into the through lane ahead of other traffic. The pre-signal is coordinated with the downstream intersection, so vehicles receive a green indication downstream if they have to stop at the pre-signal. These applications can also be combined with mid-block pedestrian crossings, if sufficient pedestrian demand exists and sufficient roadway length exists to queue vehicles without creating operational issues.

Typical Conditions for Application

Conditions that support the application of queue jump lanes include (*14*):

- Right-of-way availability;
- Right-turn (or left-turn) lane availability to serve as a bus bypass lane;
- Sufficient bypass lane length to allow buses to bypass the through traffic queue most of the time, particularly during peak periods;
- Low turning traffic volumes to minimize conflicts between buses and turning vehicles; and
- Availability of a far-side pullout or zone to accept buses, when used in combination with a far-side stop.

Existing utilities or other roadside features could interfere with the application of queue jump lanes.

TCRP Synthesis 83 (*14*) provides a set of questions to assist in making the decision to install queue jump lanes at intersections and provides estimates of installation costs.

Impacts on Transit Operations

Allowing a bus to bypass general traffic queuing at a signalized intersection reduces transit travel time and improves service reliability. The amount of travel time saving depends on multiple factors: (*a*) the length of the general traffic queue, (*b*) the extent the general traffic queue may block the transit vehicle from entering the queue bypass lane, (*c*) whether a free right turn is provided, and (*d*) the interference of right-turning traffic with buses in the queue jump lane.

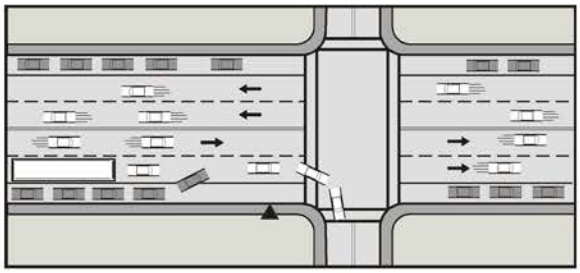
TCRP Report 118 (*11*) shows that bus queue jump lanes result in 5% to 15% reductions in travel time for buses through intersections. Such travel time reduction may also improve service reliability. The greatest reduction in bus delay at intersections resulted with queue jump lane combined with a near-side stop and TSP (*32*). A queue jump lane could cause some delay to right-turning traffic if a separate lane for buses is not provided.

Boarding Islands

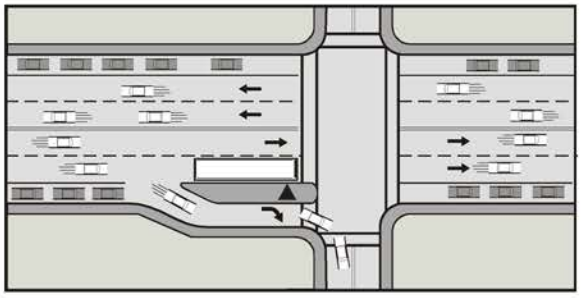
Where significant parking activity, stopped delivery vehicles, heavy right-turning traffic volumes, and other factors slow traffic in the right lane of a multiple-lane street, buses may be able to travel faster in the lane to the left. Boarding islands allow bus stops to be located between travel lanes so that buses can use a faster lane without having to merge into the right lane before every stop. Pedestrian safety issues must be addressed when considering the use of boarding islands. Exhibit 6-45 illustrates the concept of this treatment, along with two applications.

Exhibit 6-45
Boarding Island Example

Before
Traffic congestion in curb lane due to parking and turning maneuvers.



After
Bus travels in faster lane, passengers load and unload at boarding island.



(a) Concept



(b) Application (Washington, DC)



(c) Application (San Francisco)

Source: (a) City of Portland (*27*).

Curb Extensions

Overview

Curb extensions at transit stops (also known as *bus bulbs*) are similar to boarding islands in that they allow transit vehicles to pick-up passengers without moving into the curb lane. Curb extensions, typically applied with bus and streetcar operations, extend the sidewalk into the street (typically into the parking lane) so that transit vehicles do not have to pull out of the travel lane to serve passengers at the curb. This eliminates the clearance time associated with transit vehicles reentering general traffic in the through lane, thereby resulting in travel time savings. Significant travel time savings can be achieved when curb extensions are applied over a series of stops along a route.

Additional advantages of curb extensions include: (*a*) passenger waiting areas clear of the main sidewalk, (*b*) ADA-compliant landing areas for wheeled mobility aid users, (*c*) space for a shelter, and (*d*) reduced pedestrian crossing distance, if located at an intersection or mid-block crosswalk.

Curb extensions are typically applied on the near side of intersections or mid-block. If applied at far-side stops, the traffic queue generated behind the stopped transit vehicle should not block the intersection. Therefore, when far-side curb extensions are used, a second through lane is desirable to allow traffic to move around the stopped transit vehicle.

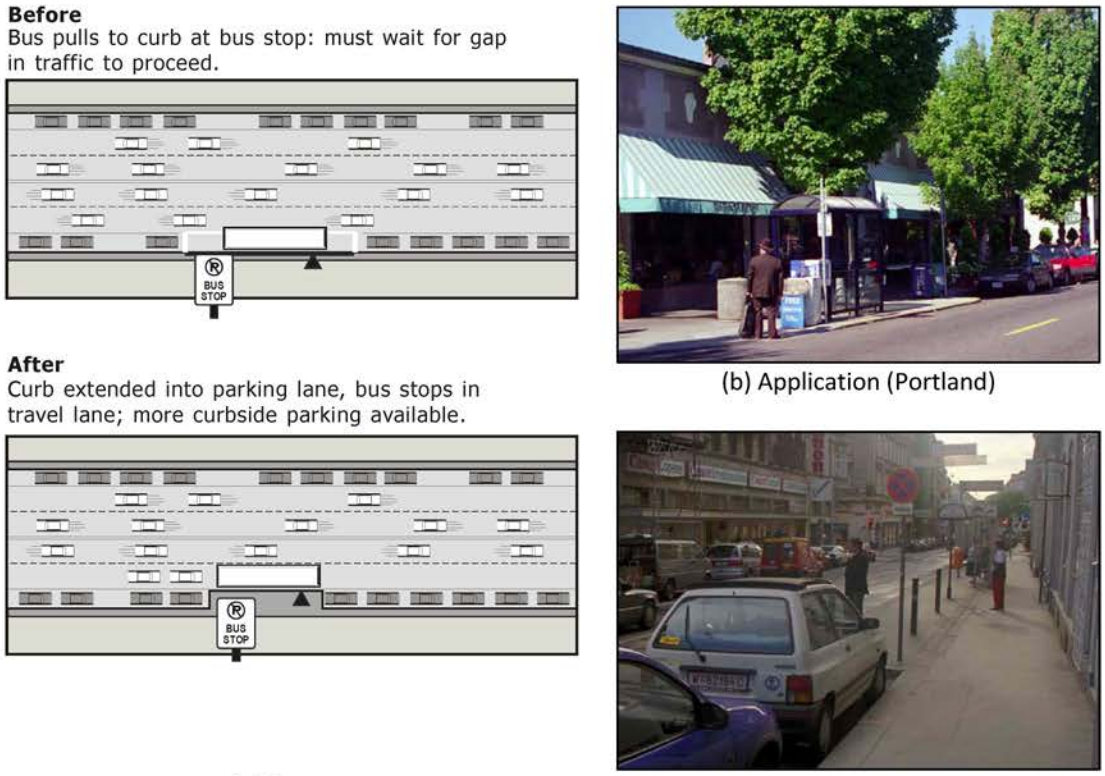
Even though curb extensions are typically created by extending the sidewalk into the parking lane, they can actually create more on-street parking than would exist with

a stop flush with the regular curb line, as the area before or after the bus stop that would otherwise be used by buses to pull in or out of the stop can be used for additional parking.

If bicycle lanes exist, they may need to be routed around the curb extension, creating potential pedestrian/bicycle or auto/bicycle conflicts. Curb extensions can change street drainage patterns, and drainage may need to be reworked to prevent water from ponding in the stop vicinity. They may also restrict some right turns, due to the tighter curb radius associated with this treatment.

Exhibit 6-46 illustrates the use and application of curb extensions.

Exhibit 6-46
Curb Extension Examples



Source: (a) City of Portland (*27*).

Typical Conditions for Application

Curb extensions are typically warranted when buses experience difficulty reentering general traffic flow from stops. Conditions that support the construction of curb extensions related to bus operations include:

- Low street traffic speed,
- Low general traffic volume (fewer than 400 to 500 veh/h),
- Low right-turning traffic volume (particularly for larger vehicles such as trucks),
- High passenger volume at stop or adjacent sidewalk,
- Presence of on-street parking,
- Two travel lanes available (to allow passing of stopped buses),

- Near-side or mid-block stop location,
- Support from local business or property owners for such treatments.

Conditions that require special consideration include:

- Two-lane streets (i.e., no passing opportunity),
- Complex drainage patterns,
- High bicycle traffic along the route,
- High right-turning volume, particularly trucks, for near-side applications.

TCRP Report 65: Evaluation of Bus Bulbs (*33*) provides a set of questions to assist in making the decision to install a curb extension. *TCRP Synthesis 83* (*14*) provides a range of costs for curb extensions, which mainly depend on the cost of providing adequate drainage.

Impacts on Transit Operations

Curb extensions eliminate clearance time, the time a bus waits to reenter traffic flow in the general traffic lane. If curb extensions are implemented in a systematic manner along a route, transit travel time saving accumulates, which may produce operating cost savings. Additional benefits are a shorter pedestrian crossing distance and an increased usable sidewalk width (*14*).

TCRP Report 65(*33*) reports the results of a before-and-after study in San Francisco of the impact of curb extensions. The study found a 7% increase in bus operating speeds along the corridor, and an average11% improvement in the peak-period pedestrian flow rate (ped/min/ft) at one of the bus stops equipped with a curb extension, compared to the original sidewalk with a bus bay. *TCRP Report 65* also developed simulation models to estimate the impact of curb extensions. At near-side stops, simulated traffic speeds were higher on average with curb extensions, compared to bus pullouts, regardless of bus bay design and dwell time, when curb-lane traffic volumes were less than 1,000 veh/h. No significant difference in average simulated traffic speeds was observed with far-side stops.

Curb extensions at intersections prevent the construction of dedicated right-turn lanes. In addition, they may make right-turn maneuvers more difficult for larger vehicles due to the tighter turning radius.

SUMMARY

Exhibit 6-47 summarizes the advantages and disadvantages of the bus preferential treatments presented in this section.

Exhibit 6-47
Bus Preferential Treatments Comparison

Treatment	Advantages	Disadvantages
Exclusive Bus Lanes	• Increases bus speed by reducing sources of delay • Improves reliability • Increases transit visibility	• Traffic/parking effects of eliminating an existing travel or parking lane must be carefully considered • Requires ongoing enforcement
Signal Priority	• Reduces traffic signal delay • Improves reliability	• Risks interrupting coordinated traffic signal operation • Risks lowering intersection LOS, if intersection is close to capacity • Requires interjurisdiction coordination • Cross-street buses may experience more delay than time saved by the favored routes
Queue Bypass	• Reduces delay from queues at ramp meters or other locations	• Bus lane must be available and longer than the back of queue
Queue Jump	• Reduces delay from queues at signals • Buses can leap-frog stopped traffic	• Right lane must be available and longer than the back of queue • Special transit signal required • Reduces green time available to other traffic • Bus drivers must be alert for the short period of priority green time
Curb Extensions	• Eliminates reentry delay • Riding comfort increased when buses don't pull in and out of stops • Increases on-street parking by eliminating need for taper associated with bus pullouts • More room for bus stop amenities • Reduces pedestrian crossing distance	• Requires at least two travel lanes in bus's direction of travel to avoid blocking traffic while passengers board and alight • Bicycle lanes require special consideration
Boarding Islands	• Increases bus speed by allowing buses to use faster-moving left lane	• Requires at least two travel lanes in bus's direction of travel and a significant speed difference between the two lanes • Uses more right-of-way than other measures • Pedestrian/ADA accessibility, comfort, and safety issues must be carefully considered

Sources: City of Portland (*27*) and TCQSM, 1st Edition (*34*).

4. OPERATIONAL TOOLS

OVERVIEW

The previous section focused on infrastructure treatments to improve bus speed and reliability. Those kinds of improvements typically cannot be directly implemented by a transit agency and require coordination with and permission from other agencies, typically those responsible for operating and maintaining the roadways used by buses.

This section focuses on operational treatments over which transit agencies typically have more direct influence. There are a number of options available in the way that bus service is designed and operated that can also provide significant capacity, speed, and reliability benefits.

BUS STOP PLACEMENT

The number and location of bus stops along a route can directly influence bus travel time and reliability and can also influence the effectiveness of transit preferential treatments.

Bus Stop Relocation

The traffic signal systems used on arterial streets are often designed to progress the flow of automobile traffic: the signals at a series of intersections are timed to turn green as a platoon of vehicles approaches each intersection from the preceding intersection. However, signal progression for general traffic may work against buses, as buses will often arrive at the intersection while the signal is green, but by the time passengers using the stop have been served, the signal will have turned red. In this case, the bus will need to wait for the signal to turn green (if the stop is located near side) or the bus will likely arrive at the next signal on red (if the stop is located far side). Ideally, a bus would be able to serve passengers on red while also being able to take advantage of the green as soon as possible (upon arrival at the intersection, or after passenger movement was completed).

It may be possible to relocate bus stops so that buses can take better advantage of the existing signal progression. The combination of archived AVL and APC data can be used to identify signalized intersections where buses must wait for extended periods of time before or after serving passengers. These locations are candidates for moving bus stops from one side of the intersection to the other.

It should be kept in mind that signal timing patterns usually change over the course of the day (for example, favoring the peak traffic direction), so that a bus stop relocation that might be effective during the morning peak might be counter-productive during the afternoon peak. The potential impact of relocations should be evaluated for peak and off-peak periods prior to implementation. It is desirable to coordinate with the agency operating the traffic signals, to make them aware that the bus stop spacing has been optimized for the existing signal timing so they can preserve the bus benefits when they retime their signals. The factors listed previously in Exhibit 6-9 (page 6-13), such as pedestrian access issues and transfer opportunities, should also be considered before relocating stops.

Bus stop relocation can also be a useful technique for reducing the impact of other vehicles on bus operations. For example, when a bus stop is located in an exclusive right-turn lane, queues of turning vehicles may inhibit bus access to the stop. Locations such as this are also candidates for bus stop relocation, and can be identified by talking with bus drivers about problem locations, and through analyzing archived AVL data.

Bus Stop Consolidation

In general, minimizing the number of stops that buses must make will improve overall bus speeds, as buses are able to take better advantage of the signal progression provided to general traffic and will also spend more time in motion instead of being delayed (e.g., decelerating, accelerating, waiting for a traffic signal to turn green, waiting to pull back into traffic) with each additional stop. Furthermore, the more consistently that buses stop at each stop along the route, the more consistent headways between buses will be, because buses will tend to travel in the same pattern along their route from one trip to the next.

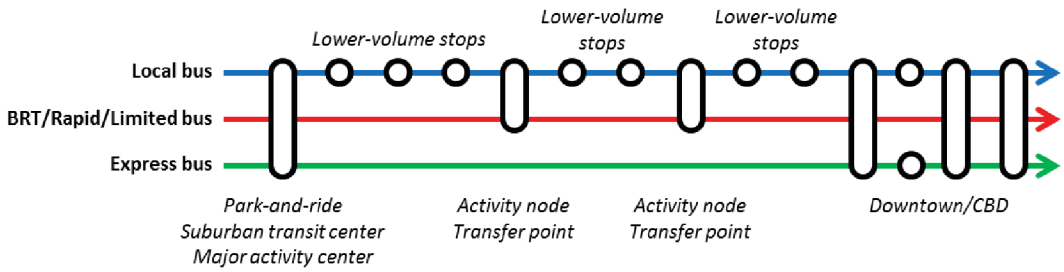
Consolidating bus stops involves trade-offs between the convenience of the passengers using a particular stop, and those passengers already aboard a bus who are delayed each time the bus stops. Requiring passengers—particularly those with mobility difficulties—to walk a long distance to another stop may discourage them from continuing to use transit and may require ADA-eligible passengers to be served with more expensive demand-responsive service. Eliminating a stop can be politically difficult at times when local residents object to having "their" stop removed. Finally, even when the distance to the next bus stop is short, poor or missing pedestrian facilities along the street with bus service may prevent walking access to it.

However, when stops are located close together (e.g., every block), and a consistent, objective process is used to determine which stops are eliminated, consolidating bus stops can provide benefits to all transit users. In these cases, the time spent by individual passengers to walk an extra block to a bus stop will typically be more than recouped by time saved on board the bus because of the improved bus running speed. At the same time, care must be taken that dwell times at critical stops (those stops with the highest dwell time) are not lengthened when a nearby stop is removed and passenger demand is shifted to the critical stop.

Limited-stop and express services as alternatives to consolidating stops in high-ridership corridors.

In high passenger-volume corridors, an alternative to eliminating stops is providing peak-period or all-day *limited-stop* (bypassing minor stops) or *express* (operating non-stop over a significant portion of the route) service in conjunction with local service that serves all stops. Passengers traveling long distances can do so more quickly, and it is easier to convey information to passengers about which stops are made when there are fewer stops. Passengers can transfer between services at shared stops or can choose to walk a little farther to get to their destination rather than wait for a local bus. Implementing limited-stop service can be a first step in the development of a bus rapid transit line. Exhibit 6-48 illustrates the relationship between local, limited and BRT, and express bus stop spacing patterns in a transit corridor. Although this exhibit shows different service types sharing selected stops, it is also possible to provide services with separate stops in the same general vicinity for operational or service branding reasons. The exhibit also shows that stop spacing will typically be farther apart in the suburbs and closer together in higher-density areas, reflective of each area's relative ridership demand.

Exhibit 6-48
Bus Stop Spacing Patterns Illustrated



Impacts on Transit Operations

Several studies report on the travel time savings due to stop consolidation:

- TriMet reported a 5.7% reduction in bus running time attributable to an increase in average spacing of 6% for inbound and 8% for outbound stops (*35*).
- MUNI reported an average bus speed increase of 4.4% to 14.6% when average stop spacing was reduced from 5.9 to 2.5 stops per mile (*7*).
- Los Angeles' first two BRT lines, along the Wilshire–Whittier and Ventura Boulevard corridors, implemented limited-stop service on top of the existing local bus service. These lines provided a 23 to 29% reduction in average running time, two-thirds of which was attributable to the bus stop consolidation (*36*).

Cumulative Impact of Bus Stop Placement with other Preferential Treatments

Moving an intersection from near side to far side, or vice versa, may allow another preferential treatment to be applied or its performance improved. For example, TSP's effectiveness is greatest when bus stops are located on the far side of signalized intersections. On the other hand, queue jumps can be triggered after passenger movement has been completed at a near-side stop (*14*).

BUS STOPPING PATTERNS

These tools organize buses into groups that can make more efficient use of the bus facility.

Skip-Stop Operation

When all buses using a particular street stop at every bus stop, the available capacity is used up more quickly than if buses are spread out among several groups of stops. This technique of spreading out stops among two to four alternating patterns, known as *skip-stop operation,* offers the ability to substantially improve bus speeds and overall facility bus capacity. It works well when bus volumes are heavy and bus stops are initially closely spaced.

TriMet has used skip stops for many years along its 5th and 6th Avenue transit mall in Portland. Exhibit 6-49 shows the pattern used immediately prior to the addition of light rail service to the mall. Bus routes were divided into groups based on their geographic destination. These groups were communicated to passengers via a prominently displayed compass direction (e.g., S, SE) on the bus stop signs, placed alongside color icons (e.g., orange deer, brown beaver) that were included for continuity with an older system of symbolizing the groups. Each group consisted of multiple

routes—for example, 10 TriMet routes plus routes operated by C-Tran were included in the "W" or "West" group illustrated in Exhibit 6-49.

Each block face along the transit mall contained two bus stops, and each group stopped every other block, resulting in four groups in the skip-stop stopping pattern. By spreading buses over four stops, the transit mall was able to accommodate up to 175 buses per hour at its peak (*21*), a total that would be impossible to achieve if all the buses shared the same stops. During construction of light rail tracks on the transit mall, TriMet switched to a basic lettering system to indicate stopping groups (e.g., W-X-Y-Z) on the streets used as the temporary transit mall, and retained this system once buses were reintroduced to the transit mall. Denver uses a similar lettering system to indicate skip-stop groups along the downtown portions of 15th and 17th Streets, which is illustrated in *TCRP Synthesis 83* (*14*).

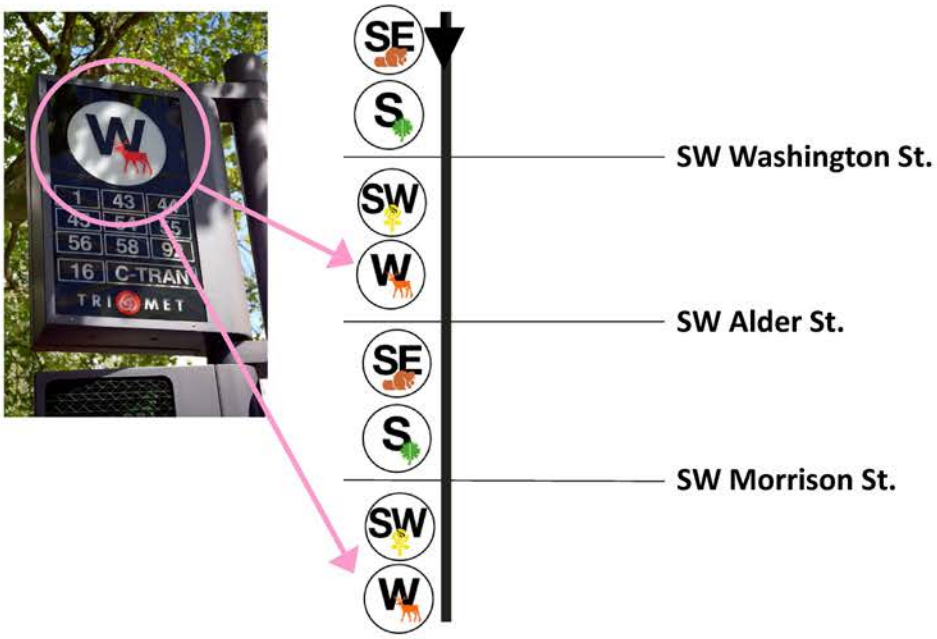


Exhibit 6-49
Example Skip-Stop Pattern and Signing

Skip stops can greatly increase bus facility capacity and average speeds, at the potential expense of added complexity to passengers.

Skip-stopping operations allow a street's bus capacity to nearly equal the sums of the capacities of the individual stops, thereby providing a nearly three- or four-fold increase in capacity, as well as substantially improving average travel speeds. Due to traffic control delays, irregularity of bus arrivals, and other factors, the actual capacity increase will be somewhat less than the theoretical maximum. To maximize these capacity and speed benefits, buses must be able to use the adjacent lane to pass other buses. When the adjacent lane operates at or close to its capacity, buses may not be able to pass other buses easily and the improvement provided by skip-stop operations will be lower.

Platooning

Platooning occurs when a set of buses moves along a street as a group, much like individual cars in a train. Passing activity is minimized, resulting in higher overall travel speeds, and bus stop loading areas are used more efficiently, resulting in a higher capacity. Platoons can be deliberately formed, through careful scheduling and field

supervision; this can be difficult and is a rare practice in North America. More commonly, platoons can be developed by traffic signals, when several buses use the facility at the same time, much as platoons of vehicles form and move down the street together after having been stopped at a traffic signal.

In downtown Ottawa, the city's busways feed into arterial street bus lanes. These lanes have accommodated the scheduled volumes of buses in part because the traffic signal progression on those streets is designed to favor buses (i.e., both bus travel time between stops and dwell times at stops are taken into consideration). The combination of the exclusive lanes and the signal progression naturally forms bus platoons, even though buses might not arrive downtown exactly at their scheduled time (*37*).

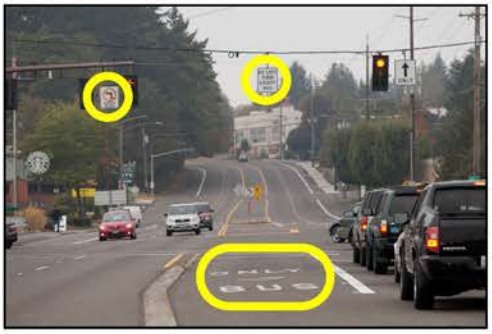
ROUTE DESIGN

Movement Restriction Exemptions

The most direct route for buses may not be possible because of left-turn restrictions at intersections. These restrictions are often implemented when there is insufficient room to develop left-turn lanes or when traffic volumes preclude good intersection operation when traffic signal cycle time is taken away for left-turning traffic. When left-turn restrictions are a result of traffic congestion, rather than safety, it may be feasible to exempt buses from the restriction without unduly impacting intersection operations, as illustrated in Exhibit 6-50(a), particularly when bus arrivals are relatively infrequent.

Traffic calming measures designed to keep through traffic out of neighborhoods, such as traffic diverters that force vehicles to turn at an intersection may create issues for community bus routes that penetrate neighborhoods instead of operating on the major streets. In these cases, providing a bus exemption to the turn restrictions allows buses to continue straight when other vehicles must turn.

In some cases, signing alone is insufficient to prevent cut-through traffic on a street and physical barriers are used to sever the street connection, with the side effect of preventing bus travel along the route. In other cases, development patterns have resulted in no street connection between adjacent land uses that could otherwise be served by a bus route, and local residents may not desire a new connection that could generate cut-through traffic in their neighborhood. To address both of these issues, some European cities have developed *bus gates* that allow bus traffic through a roadway connection (along with pedestrians, bicyclists, and emergency vehicles), but not general traffic. The retractable bollard system shown in Exhibit 6-50(b) would not be MUTCD-compliant, but an alternative system employing gates (such as those used to control access to and from parking lots) could be compliant.



(a) Left-turn exemption (Portland)



(b) Bus gate (Copenhagen)

Exhibit 6-50
Examples of Bus Exemptions from Movement Restrictions

Parking Restrictions

Parking restrictions can be used to implement several of the bus preferential treatments described in Section 3. Parking restrictions are typically required in the vicinity of a curbside stop to allow buses to pull out of the street and up to the curb to load and unload passengers. In areas where high parking turnover interferes with the flow of traffic on a street, parking restrictions may allow restriping to provide a right-turn-only lane that can also be used by buses as a queue jump lane. Part-time parking restrictions can be used to provide part-time exclusive bus lanes. Whenever parking restrictions are being considered, the impacts to general traffic and adjacent land uses from the loss of on-street parking must also be considered. In some instances, parking restrictions are mitigated through stop consolidation, which can increase the overall number of parking spaces in an area.

Design Standards

Developing objective design standards that specify minimum and maximum bus stop spacing, criteria for diverting a route to serve a particular trip generator, and so on can make it easier for transit agencies to improve or at least maintain transit service quality. Having, and consistently applying, these standards can help overcome objections to individual changes and can make larger-scale changes more politically acceptable. For example, having bus stop spacing standards can make it easier to improve service at a later date by justifying the benefits provided by longer stop spacing. Service diversion standards based on person-delay can make a case for or against changes in routing, depending on the net impact on passengers that would result.

YIELD-TO-BUS LAWS

Some jurisdictions, including the states of Florida, New Jersey, Oregon, and Washington, and the provinces of British Columbia and Québec, have passed laws requiring motorists to yield to buses signaling to reenter the street from a bus stop. Depending on motorist compliance with the law, the delay associated with a bus merging back into traffic from a curbside stop can be almost eliminated. Some agencies also view these laws as a way to improve safety for buses and other vehicles. *TCRP Synthesis 49* (*8*) addresses the effectiveness of these laws.

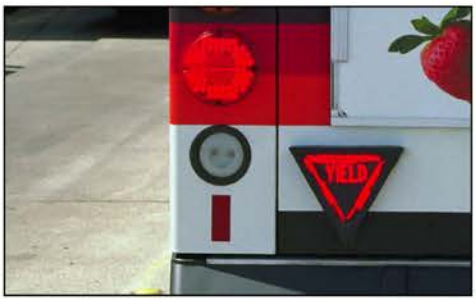
Some jurisdictions (e.g., Québec and Washington) remind motorists of the law through the use of stickers mounted to the back of the bus. Some agencies in areas

without yield-to-bus laws also use similar stickers appealing to motorist courtesy to let the bus back in. Oregon has developed a flashing electronic YIELD sign that has traffic control device status (i.e., motorists must obey it like they would a traffic signal or regulatory sign). Examples of these approaches are shown in Exhibit 6-51.

Exhibit 6-51
Yield-to-Bus Law Notification Examples



(a) Montréal



(b) Portland

SUMMARY

Exhibit 6-52 summarizes the advantages and disadvantages of the operational tools presented in this section.

Exhibit 6-52
Bus Operations Tool Comparison

Treatment	Advantages	Disadvantages
Parking restrictions	• Increases bus speeds • Increases overall street capacity and reduces traffic delays	• May significantly impact adjacent land uses (both business and residential) • Requires ongoing enforcement
Movement restriction exemption	• Reduces travel time by eliminating detours to avoid movement restrictions	• Potentially lowers intersection level of service • Safety issues with turn restrictions must be carefully considered • Potential neighborhood opposition to new street connections, even if bus-only
Bus stop relocation	• Uses existing signal progression to bus's advantage	• May increase walking distance for passengers transferring to a cross-street bus
Bus stop consolidation	• Reduces number of stops, thereby improving average bus speeds	• Increases walking distances for some riders • Pedestrian environment may not support walking to the next closest stop
Skip-stop stopping patterns	• Substantially improves bus speed and capacity	• Unfamiliar riders may be unsure about where to board their bus • Requires available adjacent lane
Platooning	• Reduces bus passing activity	• May be difficult to implement
Design standards	• Service changes to improve operations more easily justified • Supports consistent transit planning and design	• Too rigid an application of standards can be just as bad as not having standards

Sources: City of Portland (*27*) and TCQSM 1st Edition (*34*).

5. BUS CAPACITY METHODOLOGY

INTRODUCTION

This section presents a computational methodology for determining the bus and person capacity of loading areas, stops, and facilities. As discussed in Chapters 2 and 3, bus service can be operated with a variety of service types (e.g., local bus, commuter bus, BRT) and stopping patterns (e.g., all stop, limited stop, express) in a variety of operating environments (e.g., mixed traffic, semi-exclusive, exclusive, grade separated), resulting in dozens of possible combinations of service. Nevertheless, the basic process for determining bus capacity, shown in Exhibit 6-53, is the same for all-stop local bus service in mixed traffic, express BRT service on a grade-separated busway, and every combination in between.

This section's methodology is derived in large part from the research originally presented in *TCRP Report 26: Operational Analysis of Bus Lanes on Arterials* (*21*). Additional contributions to the methodology are referenced in the text at the appropriate points.

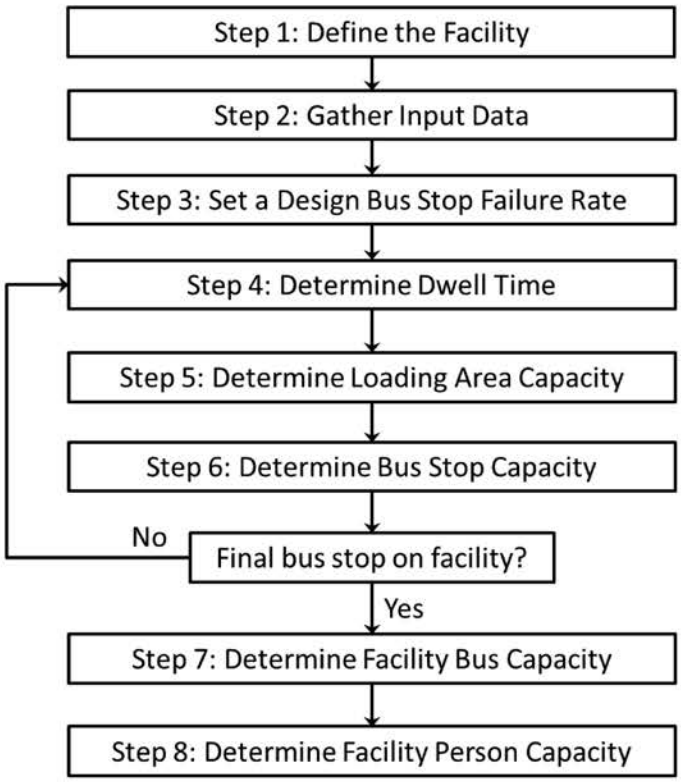


Exhibit 6-53
Bus Capacity Methodology Flowchart

STEP 1: DEFINE THE FACILITY

As introduced earlier in the chapter (Exhibit 6-11, page 6-15), bus capacity is calculated for three key locations:

1. *Bus loading areas (berths),* curbside spaces where a single bus can stop to load and unload passengers;
2. *Bus stops,* consisting of one or more adjacent loading areas; and
3. *Bus facilities,* continuous sections of roadways used by buses that include at least one stop, but typically many more.

For the purposes of conducting a capacity analysis, a facility can be defined very flexibly. It can be a discrete piece of infrastructure (e.g., a median busway), a defined section of roadway (e.g., the portion of a downtown street between two defined cross-streets), or the streets followed by a particular route (e.g., a BRT route). As a result, a facility can include a mix of operating environments (e.g., a mix of bus lanes and mixed-traffic operations) and physical roadways (e.g., a turn from one street to another), and can be used by multiple bus routes using a variety of stopping patterns. However, when two different types of roadways used by buses are located side by side within the same right-of-way (e.g., a median busway used by a BRT route, with local bus service in the adjacent general traffic lanes), these should be treated as two separate facilities.

Importantly, all bus stops located along the defined length of the facility need to be included in the analysis, as individual bus stop characteristics are inputs to the bus speed methodology presented in Section 6. In addition, bus operations issues can occur at any stop, not just the busiest stop, so it is necessary to evaluate each stop along the facility for potential problems.

STEP 2: GATHER INPUT DATA

Bus Stop Demand Data

The following demand data associated with individual bus stops are required to conduct a capacity analysis. All data are for a defined hour (typically a peak hour).

- *Average (mean) dwell time.* As discussed in Step 4, this input can be field measured (preferred for existing conditions); estimated based on passenger volumes, fare collection method, vehicle design, and passenger loads; or estimated based on default values.
- *Dwell time variability,* measured by the coefficient of variation of dwell times (the standard deviation of dwell times divided by the average dwell time). As discussed in Step 3, this input can be field measured or estimated based on default values.
- *Failure rate,* defined as the percentage of buses that arrive at the bus stop to find all available loading areas already occupied. As discussed in Step 3, this input can be field measured, but is more typically applied as a design value to develop a design capacity that reflects a desired level of operational reliability.
- *Passenger demand peak-hour factor (PHF),* defined as the hourly passenger demand at a bus stop (sum of boarding and alighting passengers), divided by four times the passenger demand during the peak 15 min of the hour. This input can be field measured or assigned a default value.

Bus Stop Location Data

- *Position relative to the roadway.* As was illustrated in Exhibit 6-5 (page 6-9), bus stops can be *on-line* (the bus stops in the travel lane) or *off-line* (the bus pulls out of the travel lane to serve a stop).
- *Position relative to an intersection.* As was illustrated in Exhibit 6-8 (page 6-12), bus stops can be *near side* (located immediately prior to an intersection), *far side* (located immediately after an intersection), or *mid-block* (located away from the influence of an intersection).
- *Bus stop design type.* As was illustrated in Exhibit 6-12 (page 6-16), several different bus stop designs are possible. The bus stop design needs to be characterized as *linear* or *non-linear.*
- *Number of loading areas.*
- *Bus facility type,* reflecting the ability of buses to move around other vehicles in their lane. As illustrated in Exhibit 6-54, Type 1 bus lanes do not allow buses to leave their lane. Type 2 bus lanes allow buses to move into the adjacent lane, traffic permitting, to move around other vehicles using the lane. Type 3 bus lanes provide two lanes for the exclusive use of buses.
- *Traffic signal timing,* measured by the ratio of the average green time available for bus movement divided by the traffic signal cycle length, or *g/C* ratio. If transit signal priority is provided, the amount of extra green time potentially provided should be included, as discussed in more detail in Step 6.
- *Curb lane traffic volume,* in vehicles per hour.
- *Right-turning traffic volume and capacity,* in vehicles per hour.
- *Parallel pedestrian crossing volume* conflicting with right-turning traffic, in pedestrians per hour.

Skip-Stop Data

When a skip-stop stopping pattern is used (see Section 4 for a definition and examples), the following additional data are required:

- *Number of stops in the stopping pattern.*
- *Bus arrival pattern* (random, typical, platooned). In a random arrival pattern (typically caused by poor scheduling, poor schedule adherence, or the influence of a nearby timed transfer location), buses arrive in clumps, with large gaps between bus arrivals and significant amounts of passing activity occurring. In a platooned arrival pattern, bus arrivals are spread out and buses tend to travel along the facility as a unit, like cars of a train, with minimal passing activity. In a typical arrival pattern, bus arrivals are scheduled to be spread out, but some passing activity occurs due to imperfect schedule adherence.
- *Traffic volume and capacity of the adjacent lane (i.e., lane to the left of the curb lane),* in vehicles per hour. If there is no adjacent lane, the volume-to-capacity (*v/c*) ratio of the adjacent lane is set to 1.0.

Exhibit 6-54
Bus Lane Types

Type 1






Buses have no use of adjacent lane

- Channelized bus lanes (a, b)
- Contraflow bus lanes (b, c)
- Busway stations without passing lanes (c)
- Mixed-traffic operations with only one travel lane (d)

(a) Denver, (b) Orlando, (c) Eugene, (d) Portland

Type 2






Buses may move into adjacent lane, traffic permitting

- Part-time exclusive bus lanes (e)
- Full-time exclusive bus lanes with passing opportunities (f)
- Mixed-traffic operations with two or more lanes (g, h)

(e) Montréal, (f) Madison, (g) Portland, (h) Milwaukee

Type 3




Buses have full use of adjacent lane

- Dual bus lanes (i)
- Busway stations with passing lanes (j)

(i) New York, (j) Miami

STEP 3: SET A DESIGN BUS STOP FAILURE RATE

Bus loading area capacity is maximized when a bus is available to move into a loading area as soon as the previous bus vacates it. However, this condition is undesirable for several reasons: (*a*) bus travel speeds are reduced, due to the time spent waiting for a loading area to become available; (*b*) bus schedule reliability suffers because of the additional delays; and (*c*) buses block traffic in the street while waiting to enter the bus stop. The more often that bus stop failure occurs, the higher the bus throughput over the course of the hour, but the more severe the operational problems.

Consequently, bus capacity analysis incorporates the concept of a *failure rate* that sets how often a bus should arrive at a stop only to find all loading areas occupied. The selection of a design failure rate sets the bus stop's *design capacity*—the number of buses that can be served in an hour at a desired level of operational reliability. The design failure rate should balance capacity and operational needs. Suggested values are as follows:

- In downtown areas, design failure rates between 7.5 and15% are recommended, reflecting a tradeoff between maintaining bus travel speeds and achieving the higher capacities required in downtown areas. At a 15% failure rate, queues form behind the bus stop for about 10 minute out of the hour, and simulation indicates that bus speeds at capacity are about 20% lower than when scheduled bus volumes are well below capacity (*21*).
- Outside downtown areas , a design failure rate of 2.5% is recommended whenever possible, particularly when off-line stops are provided, as queues will block a travel lane whenever a bus stop failure occurs. However, failure rates up to 7.5% can be accepted (*21*).

Although the failure rate is typically set as a design value, it can also be measured in the field when evaluating bus capacity under existing conditions.

Design capacity is effectively maximized at a 25% failure rate; lower failure rates are recommended for more reliable and higher-speed operation.

Design capacity is effectively maximized at a failure rate of 25% and the capacity achieved with a 25% design failure rate is termed *maximum capacity*. Mathematically, throughput would be highest if a constant queue of buses existed to move into a bus stop (a 100% failure rate); however, the resulting low bus speeds and poor traffic operations would likely be considered unacceptable. Moreover, even with a constant queue of buses, not all of the loading areas could be utilized simultaneously unless each bus's dwell times were tightly managed, allowing a set of buses to enter and exit the stop simultaneously (known as *platooning*), something difficult to achieve consistently in practice. Without platooning, some buses would dwell longer than others and block access to empty loading areas in front of them.

Operating margin.

The failure rate is used in combination with dwell time variability and the average dwell time (both discussed in Step 4) to provide an *operating margin*, the maximum amount of time that an individual bus dwell time can exceed the average dwell time without creating the likelihood of a bus stop failure, when the number of buses scheduled to use the stop approaches the stop's capacity. The lower the design failure rate, the greater the operating margin and schedule reliability, and the lower the loading area capacity. Conversely, the greater the design failure rate, the lower the operating margin and schedule reliability, but the greater the loading area capacity.

Standard normal variable Z.

If a series of dwell time observations were to be plotted, they would form a normal distribution similar to the one shown in Exhibit 6-55(a). A narrower distribution with a higher peak would indicate less variability, while a wider distribution with a lower peak would indicate greater variability. From statistics, the area under and to the right of a given point *Z* on a normal distribution curve (e.g., the shaded area in Exhibit 6-55[a]) represents the probability that any given bus's dwell time will be longer than that amount. The standard normal distribution can also be plotted as a cumulative probability curve as shown in Exhibit 6-55(b). For example, if the desired failure rate is 10% (i.e., a 90% probability that any given dwell time will not cause interference with the following bus), the corresponding *Z* value is 1.28.

The dwell time value t_i corresponding to Z is incorporated in Equation 6-2:

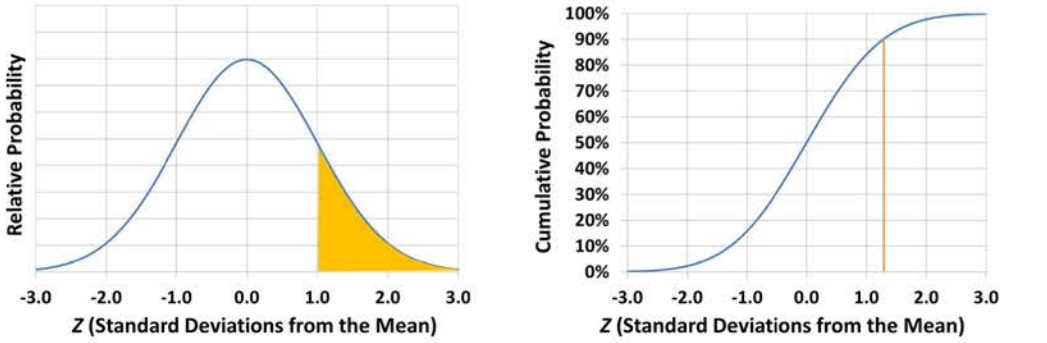
Equation 6-2

$$Z = \frac{t_{om}}{s} = \frac{t_i - t_d}{s}$$

where

Z = standard normal variable corresponding to a desired failure rate,
s = standard deviation of dwell times,
t_{om} = operating margin (s),
t_d = average dwell time (s), and
t_i = dwell time value that will not be exceeded more often than the desired failure rate (s).

Exhibit 6-55
Statistical Basis of Failure Rate



(a) Standard normal distribution (b) Probability of bus stop failure associated with Z

Rearranging Equation 6-2 provides the operating margin required to achieve a particular design failure rate, when a bus stop operates close to its capacity:

Equation 6-3

$$t_{om} = sZ = c_v t_d Z$$

where c_v is the coefficient of variation of dwell times and all other variables are as previously defined.

Exhibit 6-56 provides values of Z corresponding to different design failure rates.

Exhibit 6-56
Values of Z Associated with Given Failure Rates

Design Failure Rate	Z
1.0%	2.330
2.5%	1.960
5.0%	1.645
7.5%	1.440
10.0%	1.280
15.0%	1.040
20.0%	0.840
25.0%	0.675

Source: *TCRP Report 26* (*21*).

Exhibit 6-57 illustrates the relationships between failure rate, operating margin, and loading area bus capacity. For the conditions shown in the exhibit (60-s dwell time and 60% dwell time variability), a 1% failure rate results in a design capacity approximately half of the loading area's maximum capacity (achieved at a 25% failure rate). Achieving this failure rate requires an operating margin of more than 80 s, meaning that dwell

times would normally have to exceed 140 s (60-s average dwell time plus 80-s operating margin) before a queue would develop (assuming that bus arrivals at the stop are spread out over the hour, rather than scheduled to occur at the same times).

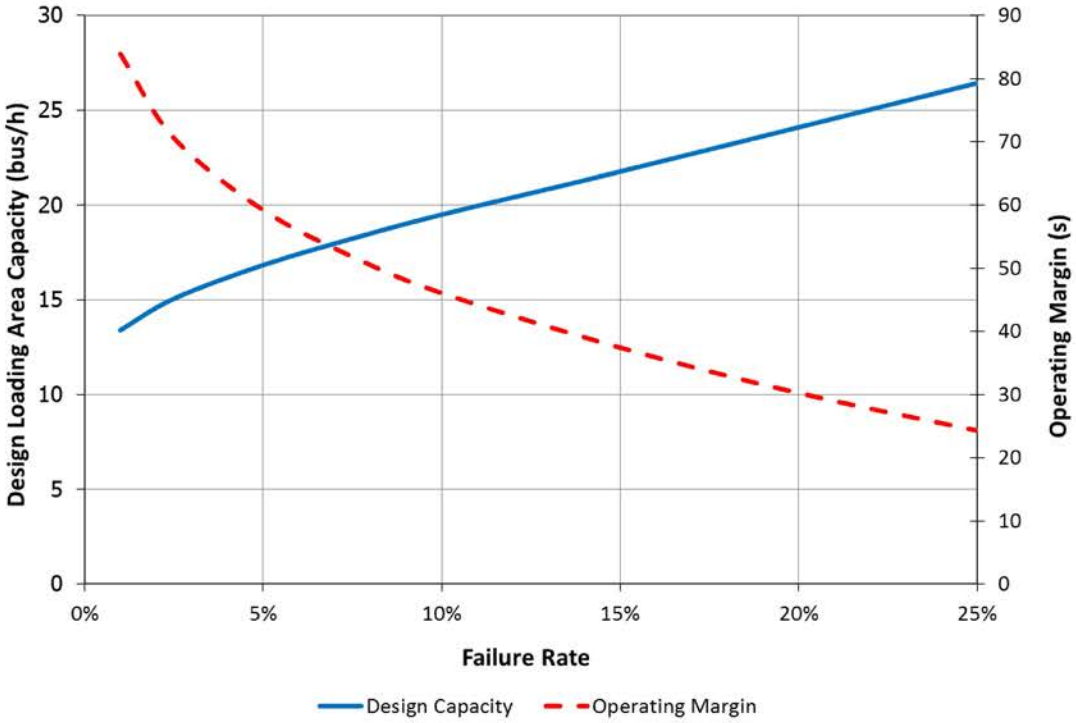


Exhibit 6-57
Illustrative Relationships Between Failure Rate, Operating Margin, and Design Loading Area Bus Capacity

Note: Assumes 60-s average dwell time and 0.6 coefficient of variation of dwell times.

STEP 4: DETERMINE DWELL TIME

Estimating Dwell Time

Three methods can be used to estimate bus dwell times:

1. *Field measurements*—best for evaluating an existing bus route,
2. *Default values*—suitable for future planning when reliable estimates of future passenger boarding and alighting volumes are unavailable, and
3. *Calculation*—suitable for estimating dwell times when passenger boarding and alighting counts or estimates are available.

Method 1: Field Measurements

Best for evaluating existing bus routes. See Appendix B for details.

The most accurate way to determine bus dwell times at a stop is to measure them directly. An average (mean) dwell time and its standard deviation can be determined from a series of observations. Appendix B presents a standardized methodology for measuring bus dwell times in the field.

Archived AVL data can be a valuable source of dwell time, but may require cleaning before use in a capacity analysis. See Appendix C for details.

Archived AVL data can also be used to determine average dwell time and its standard deviation. However, analysts using this method must be aware of the method used by the AVL system to determine dwell time. Many AVL systems are set to record door opening and closing time, which may include time spent not serving passenger movements (e.g., waiting until a traffic signal turns green), whereas the TCQSM defines dwell time solely as the sum of door opening and closing time and passenger service time. Not accounting for time with the doors open, but no passenger movement occurring, can result in overestimated dwell times. Some Dutch transit systems use door sensors to distinguish passenger service time from other time spent waiting at a stop (*38*). *TCRP Report 113* (*38*) provides guidance on setting up and using AVL data to determine dwell times.

Method 2: Default Values

Suitable for future planning when reliable passenger estimates are unavailable.

If field data or passenger counts are unavailable for a bus stop, the following representative values can be used to estimate dwell time: 60 s at a downtown stop, transit center, major on-line transfer point, or major park-and-ride stop; 30 s at a major outlying stop; and 15 s at a typical outlying stop.

Method 3: Calculation

Suitable when passenger counts or estimates are available, or when comparing different fare payment options.

This method requires that hourly passenger counts or estimates be available for the stop, categorized by the number of boarding and alighting passengers and—possibly—by fare collection. This method is also useful for estimating changes in dwell time that could result from changes in the fare collection method.

1. *Determine the average passenger boarding and alighting volumes per bus.* Divide the number of hourly boarding passengers by the number of buses serving the stop during the hour. Repeat the calculation using the number of hourly alighting passengers.

2. *Determine the mix of fare payment methods.* This value can be estimated from (*a*) farebox data specific to the stop, if available, (*b*) a planned fare collection method (e.g., planned proof-of-payment for a BRT route, planned switch to a new fare-collection technology), or (*c*) defaulted from system-level fare payment data.

3. *Assign boarding volumes by bus door channel.* There are a number of possible scenarios; the most common are:

- *Single-channel boarding, all fares paid or inspected upon boarding.* Assign all boarding volume to the front door.
- *Double-channel boarding, all fares paid or inspected upon boarding.* Split the boarding volume into (*a*) those who need to interact with a farebox and (*b*) those who just need a visual inspection of their fare media (e.g., flash pass, paper transfer, mobile phone). Assign smart card users, if any, to the channel(s) equipped with smart card terminals.
- *All-door boarding, free or pre-paid fares.* Use Exhibit 6-58 to determine the boarding volume through the busiest door channel.

Exhibit 6-58
Percent Passengers Using Busiest Bus Door Channel (No Fare Payment)

Available Door Channels	Percent Passengers Through the Busiest Door Channel	
	Boarding	Alighting
2	60%	75%
3	45%	45%
4	35%	35%
6	25%	25%

Source: Derived from Exhibit 4-3 in TCQSM, 2nd Edition (*5*).
Note: It can be assumed that boarding passengers are evenly divided among the remaining door channels. With 2 doors available, assume 25% of alightings through the front door and 75% through the rear door. When the front door has 2 door channels, assume that alighting passengers only use the non-farebox door channel. Assume that the remaining alighting passengers are evenly divided among the remaining door channels.

4. *Assign alighting volumes by bus door channel and adjust boarding volumes if necessary.* Again, there are a number of possible scenarios; the most common are:

- *Single-channel boarding, all fares paid or inspected upon boarding.* In the absence of local information, it can be assumed that 25% of alightings occur through the front door and that the remainder occur via the rear door(s).
- *Double-channel boarding, all fares paid or inspected upon boarding.* In the absence of local information, it can be assumed that 25% of alightings occur through the non-farebox front door channel and that the remainder occur via the rear door(s). Boarding occurs simultaneously through the other front door channel and can use both front door channels once the alighting movement has ended.
- *All-door boarding, free or pre-paid fares.* Use Exhibit 6-58 to determine the alighting volume through the busiest door channel. The busiest alighting door channel may not be the same as the busiest boarding door channel; however, assuming that they are the same produces a conservative result.
- *Pay-on-exit.* Assign all alighting volume to the front door and assume only a single passenger can alight at a time, even if two door channels are available, unless (*a*) the bus interior provides enough circulation space for two passengers to walk side-by-side and (*b*) most fares just need to be visually inspected.

5. *Determine average passenger service times for each bus door channel and movement.* In the absence of local information, use Exhibit 6-4 (page 6-7) to determine appropriate boarding and alighting service times for the conditions existing at each door channel. When a mix of fare payment options are provided, use the information from Step 2 to create a weighted average service time based on the mix of fare media used. The base values given in Exhibit 6-4 are for non-level boarding with no standees on the bus and should be adjusted as shown in the exhibit notes to reflect level boarding conditions (e.g., boarding from the curb onto a low-floor bus, boarding from a high-level platform onto a high-floor bus) and standees, if present. In addition, when more than 25% of the passenger flow through a single door channel is in the opposite direction of the main flow of passengers, increase both boarding and alighting service times by 20% to account for passenger congestion at the door (*39*).

6. *Determine passenger flow time for each bus door channel.* For a given door channel *i*, the passenger flow time is

$$t_{pf,i} = P_{a,i}t_{a,i} + P_{b,i}t_{b,i}$$

Equation 6-4

where

$t_{pf,i}$ = passenger flow time for door channel i (s),

$P_{a,i}$ = alighting passengers through door channel i (p),

$t_{a,i}$ = average alighting passenger service time for door channel i (s/p),

$P_{b,i}$ = boarding passengers through door channel i (p), and

$t_{b,i}$ = average boarding passenger service time for door channel i (s/p).

7. *Determine the boarding lost time.* If a bus stop only consists of one loading area, boarding lost time is zero. From research (*1*), average boarding lost time for three loading areas is 4 s for more crowded waiting conditions (waiting area LOS C or worse) and 4.5 s for less crowded waiting conditions (waiting area LOS A or B, corresponding to 10 ft²/p [0.9 m²/p] or more within an area centered on the front of the second loading area and extending one-half loading area length to either side).

Waiting area LOS is defined in Chapter 10.

Research has not yet developed boarding lost times for two loading areas—the analyst's judgment should be used to determine how often the second loading area would be used to develop a value between 0 and 4 s. Similarly, research has not yet developed boarding lost times for four or more loading areas, but these would be expected to be significantly longer, given passenger uncertainty about where to wait.

Analyst judgment should be used to develop boarding lost times for bus stops with 2, 4, or 5 loading areas.

8. *Calculate the dwell time.* The dwell time is the time required to serve passengers at the busiest door, plus the time required to open and close the doors, plus any boarding lost time:

The longest passenger service time of all doors controls dwell time.

Equation 6-5

$$t_d = t_{pf,max} + t_{oc} + t_{bl}$$

where

t_d = average dwell time (s),

$t_{pf,max}$ = maximum passenger flow time of all door channels (s),

t_{oc} = door opening and closing time (s), 2–5 s typical, and

t_{bl} = boarding lost time (s).

Dwell Time Variability

Not all buses stop for the same amount of time at a stop, depending on fluctuations in passenger demand between buses and between routes. In addition, infrequent events such as wheelchair or bicycle loading have the potential to significantly increase a given bus's dwell time at a stop. As discussed earlier in Step 3, dwell time variability is one of the inputs for developing an operating margin that ensures that bus operations at the stop meet a desired level of reliability, by allowing for longer-than-usual dwell times.

The coefficient of variation of dwell times (c_v) is used to measure dwell time variability.

The *coefficient of variation of dwell times* (c_v), the standard deviation of dwell times divided by the average (mean) dwell time, is used to measure dwell time variability. When c_v is zero, all dwell times are the same. When c_v is 1.0, the standard deviation of dwell times is as large as the mean dwell time, meaning that approximately one in three buses will have a dwell time at least twice as large as the average dwell time.

A recommended default value for c_v is 0.6.

Based on field observations of bus dwell times in several U.S. cities (*21*), c_v typically ranges from 0.4 to 0.8, with 0.6 recommended as an appropriate value in the absence of field data.

Impacts of Infrequent Events on Dwell Time

Impact of Wheelchair Movements on Dwell Time

New transit buses in the United States are equipped with wheelchair lifts or ramps. When a lift is in use, the door is blocked from use by other passengers. Typical wheelchair lift cycle times are 60 to 200 s, while the ramps used in low-floor buses reduce the cycle times to 30 to 60 s (including the time required to secure the wheelchair inside the bus). The higher cycle times relate to a small minority of inexperienced or severely disadvantaged users. When wheelchair users regularly use a particular bus stop, the wheelchair lift time should be incorporated into the average dwell time when dwell times are not measured directly. When wheelchair movements are rare, their impact on dwell time is accounted for by dwell time variability.

Impact of Bicycles on Dwell Time

Many U.S. transit agencies provide folding bicycle racks on their buses. When no bicycles are loaded, the racks typically fold upright against the front of the bus. (Rear-mounted racks, bus-towed bicycle trailers, and allowing bicycles on board are less common options.) When bicycles are loaded, passengers deploy the bicycle rack and load their bicycles into one of the available loading positions (typically two or three are provided). The process takes approximately 20 to 30 s. When bicycle rack usage at a stop is frequent enough to warrant special treatment, average bus dwell time is determined using the greater of the passenger service time or the bicycle loading/unloading time. Otherwise, this effect is accounted for by dwell time variability.

Impact of Timepoint Holding on Dwell Time

Some transit agencies' operating practice is to hold buses at timepoints if they are running ahead of schedule. Holding can significantly increase the time a bus spends stopped at a bus stop, which reduces the stop's capacity; however, this factor is not directly accounted for in the dwell time definition, which only includes time to serve passengers and open and close the bus doors. If many buses have to hold at a stop, consideration should be given to adjusting the schedule to reduce the need to hold. If a relatively small number of buses have to hold, the time spent holding can be treated as additional dwell time for the purposes of calculating dwell time variability.

STEP 5: DETERMINE LOADING AREA CAPACITY

Loading Area Capacity Factors

The bus capacity of a loading area is dependent on operating margin, dwell time, clearance time, and traffic signal timing. The first two factors were determined in Steps 3 and 4, respectively. The remaining two factors are discussed in this subsection. The four factors influence loading area capacity as follows:

- The sum of dwell time and clearance time equals the average time a given bus occupies a loading area.
- The operating margin accounts for longer-than-average dwells to ensure that most buses will be able to immediately use the loading area upon arriving.

Dwell time plus clearance time equals the average time a given bus occupies a loading area.

The operating margin provides extra time needed to account for longer-than-average dwells, so that the design failure rate can be achieved.

- The sum of dwell time, clearance time, and operating margin gives the minimum headway between buses needed to limit bus stop failure to the design level, for a bus stop consisting of one loading area. (Multiple loading areas will be addressed in Step 6.)
- Dividing this headway into 3,600 s/h produces the *loading area capacity,* the number of buses per hour that can use a single loading area at a bus stop at the design failure rate.

Loading area capacity is the number of buses per hour that can use a single loading area at a bus stop at the design failure rate.

When the loading area is located at a traffic signal, buses may not be able to leave the loading area immediately after serving passengers (at near-side stops), or enter it immediately (at far-side stops). This requires a few extra considerations:

- The portion of time that the traffic signal permits bus movement is given by the g/C ratio, the ratio of the time the signal is effectively green for buses to the overall length of the traffic signal cycle. Multiplying the g/C ratio by 3,600 gives the number of seconds in an hour that buses are free to enter or leave the stop.
- Dwell time that occurs during the red phase does not impact capacity, as the bus would not have been able to enter or leave the stop during this time. Therefore, only the portion of the dwell time that occurs during green, on average, is used in calculating capacity.

Mathematically, loading area capacity is expressed as (*21*):

Equation 6-6

$$B_l = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + t_{om}} = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + Zc_v t_d}$$

where

B_l = loading area bus capacity (bus/h);

3,600 = number of seconds in 1 hour;

g/C = green time ratio (the ratio of effective green time to total traffic signal cycle length, equals 1.0 for unsignalized streets and bus facilities);

t_c = clearance time (s) = t_{su} + t_{re};

t_{su} = minimum time for a bus to start up, travel its own length, and the next bus to pull into the loading area (s) (default of 10 s);

t_{re} = reentry delay (s), from Exhibit 6-59 or field measured;

t_d = average (mean) dwell time (s);

t_{om} = operating margin (s);

Z = standard normal variable corresponding to a desired failure rate, from Exhibit 6-56; and

c_v = coefficient of variation of dwell times.

Clearance Time

Clearance time calculation.

Clearance time has two components: (*a*) a fixed minimum amount of time for a bus to start up and travel its own length, and for the next bus to pull in and, for off-line stops, (*b*) a potential added amount of time spent waiting for a gap to pull back into traffic, known as *reentry delay*.

Various studies have examined clearance time, with values ranging from 9 to 20 s (*39*). The start-up component of clearance time is about 10 s for a standard bus (*21*). Reentry delay can be measured in the field, estimated from simulation, or estimated using the method given below, which is based on procedures given in the *Highway Capacity Manual 2010* (HCM, *40*).

Angled loading areas that require buses to back out are rare, but exist. The start-up component of clearance time for these types of loading areas would be considerably longer than 10 s.

Reentry delay only needs to be determined for off-line stops—stops where the bus stops out of the traffic lane and must wait for a gap in traffic to pull back into the lane and continue on its route. The following method produces an estimate of maximum average reentry delay, based on the average wait for a suitable gap in randomly arriving traffic, the wait for the queue of vehicles to clear when a traffic signal turns green, or both. The presence of local yield-to-bus laws (and driver compliance with them), local driver courtesy in allowing buses to reenter the street, the aggressiveness of bus drivers in reentering traffic, and the provision of bus queue jumps (for near-side stops at traffic signals) can reduce or eliminate reentry delay. In addition, for near-side stops, to the extent that buses are not ready to depart when the signal turns green, this method's estimate of clearance time will also include a portion of dwell time.

The calculation of reentry delay depends on the bus stop's location relative to traffic signals that can influence traffic patterns in the lane adjacent to the bus stop. One of the following three cases will apply:

1. **Bus stop away from the influence of traffic signals.** When bus stops are located more than 0.25 mi (400 m) away from the nearest upstream signal and outside the influence of a queue from a downstream signal, traffic is assumed to arrive randomly. Buses wait for a suitable gap in traffic to reenter the street.
2. **Bus stop at a traffic signal.** When bus stops are located at a traffic signal, the signal periodically stops traffic moving in the bus's direction. When the light turns green again, the built-up queue of vehicles is released as a platoon that blocks the bus from leaving the stop until the queue clears. During the remainder of the time, until the signal turns yellow, the bus must wait for a gap in traffic.
3. **Bus stop downstream of a traffic signal.** When bus stops are not located at a signalized intersection, but are located within 0.25 mi (400 m) of an upstream signal, traffic patterns will reflect some traffic signal influence, with that influence growing weaker with increasing distance from the signal. Reentry delay will be between that of Case 1 and Case 2.

The following subsections describe how reentry delay is calculated for each case. Tables providing typical reentry delays are provided as an alternative to the equations.

Case 1: Reentry Delay Away from Traffic Signal Influence

In Case 1, traffic is assumed to arrive randomly and the reentry delay is estimated as the average interval between acceptable gaps in traffic. The HCM's unsignalized intersection procedure (right turn from a minor street) (*40*) is used to estimate this delay:

Equation 6-7

$$d_{re,1} = \frac{3{,}600}{c_{re}} + 900\left[\frac{N_{la}}{c_{re}} - 1 + \sqrt{\left(\frac{N_{la}}{c_{re}} - 1\right)^2 + \frac{\left(\frac{3{,}600}{c_{re}}\right)\left(\frac{N_{la}}{c_{re}}\right)}{450}}\right] - 3.3$$

with:

Equation 6-8

$$c_{re} = v\frac{e^{-vt_{ch}/3{,}600}}{1 - e^{-vt_f/3{,}600}}$$

where

$d_{re,1}$ = average reentry delay for Case 1 (s),
c_{re} = capacity of the reentry movement (veh/h),
N_{la} = number of loading areas at the stop,
v = demand flow rate in the curb (rightmost) travel lane (veh/h),
t_{ch} = critical headway for the reentry movement (s) = 7.0 s default,
t_f = follow-up time for the reentry movement (s) = 3.3 s default,
e = exponential function, and
3,600 = number of seconds in an hour.

The critical headway is the minimum headway between vehicles in the adjacent lane that buses can use to reenter traffic; the follow-up time is the time required by a second bus leaving at the same time. The "– 3.3" term in the delay equation adjusts the HCM's control delay for factors unrelated to reentry delay; it represents the calculated HCM delay with an adjacent lane flow rate of 1 veh/h.

Exhibit 6-59 provides the reentry delay values calculated by Equation 6-7 for various traffic volumes in the lane adjacent to the bus stop.

Exhibit 6-59
Average Bus Reentry Delay (Stops Not Near Traffic Signals)

Adjacent Lane Traffic Volume (veh/h)	Average Reentry Delay (s)
1	0
100	1
200	2
300	2
400	3
500	4
600	5
700	6
800	8
900	10
1,000	12

Source: Based on Equation 6-7 using a critical headway of 7.0 s, a follow-up time of 3.3 s, and one loading area.

Case 2: Reentry Delay at Traffic Signals

In Case 2, reentry delay is calculated from (*a*) the average time to clear the queue of vehicles in the adjacent lane and (*b*) the average delay waiting for a suitable gap in traffic the remainder of the time.

Queue Service Delay

The time g_s required to service a queue of vehicles that has been stopped for a red light at a traffic signal is (*40*):

$$g_s = \frac{Q_r}{(s_f/3{,}600) - q_g} \quad \textbf{Equation 6-9}$$

with:

$$Q_r = q_r r \quad \textbf{Equation 6-10}$$

$$q_r = (1 - p_v) q C / r \quad \textbf{Equation 6-11}$$

where

g_s = queue service time for the adjacent lane (s),
Q_r = queue size at the end of the effective red time (veh),
s_f = saturation flow rate (veh/s),
q_g = arrival flow rate during the effective green time (veh/s) = p_v/qCg,
q_r = arrival flow rate during the effective red time (veh/s),
p_v = proportion of vehicles arriving during the green indication (decimal) = (g/C) for random arrivals,
r = effective red time = $C - g$ (s),
C = traffic signal cycle length (s),
g = effective green time (s),
q = arrival flow rate = $v/3{,}600$ (veh/s), and
v = demand flow rate in the curb (rightmost) travel lane (veh/h).

The saturation flow rate can be calculated using the HCM (*40*) or a default value can be selected from Exhibit 6-60. With random vehicle arrivals, q_r and q_g reduce to the arrival flow rate q; with non-random arrivals, use the HCM to calculate p_v. The queue service delay d_{qs}, in seconds, is the lesser of the queue service time or the effective green time:

$$d_{qs} = min(g_s, g) \quad \textbf{Equation 6-12}$$

where all variables have been defined previously. This equation caps queue service delay as the length of the green interval: at far-side stops, the signal creates a gap in traffic that the bus can potentially use; at near-side stops, the bus is assumed to pull forward into the intersection on green so that it can proceed when the light turns yellow if no gap has appeared before then.

Exhibit 6-60
Default Through Movement Saturation Flow Rates (veh/h of green)

Region Type	CBD	Non-CBD
Metropolitan (250,000+ population)	1,625	1,800
Other (<250,000 population)	1,500	1,650

Source: HCM 2010 (*40*), based on 3% heavy vehicles, 12 buses stopping per hour, and base saturation flow rates of 1,750 and 1,900 veh/h of green for metropolitan and other region types, respectively.

Note: CBD values can be applied to any location with CBD-like conditions (e.g., higher pedestrian and traffic volumes, constrained roadway geometry).

Exhibit 6-61 provides queue service delay values for a range of adjacent lane traffic demands and traffic signal g/C ratios, assuming a 100-s traffic signal cycle length. For other cycle lengths, the delay values given in the exhibit should be increased or decreased proportionately. Shaded values indicate situations where demand exceeds traffic signal capacity and the queue service delay is capped.

Exhibit 6-61
Illustrative Queue Service Delays (s) (100-s Cycle Length)

Adjacent Lane Traffic Volume (veh/h)	g/C Ratio								
	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70
1	0	0	0	0	0	0	0	0	0
100	5	4	4	4	3	3	3	2	2
200	10	9	8	8	7	6	6	5	4
300	16	15	14	12	11	10	9	8	7
400	23	21	20	18	16	15	13	11	10
500	30	29	27	24	22	20	18	16	13
600	30	35	35	32	29	26	23	20	18
700	30	35	40	42	38	34	30	26	23
800	30	35	40	45	48	44	39	34	29
900	30	35	40	45	50	55	50	43	37
1,000	30	35	40	45	50	55	60	56	48

Source: Calculated from Equation 6-9 and Equation 6-12, assuming random arrivals, a 100-s cycle length, and metro CBD conditions.

Note: To calculate queue service delay for other cycle lengths, multiply values in exhibit by (C/100). Shaded values indicate situations where demand exceeds traffic signal capacity and queue service delay is capped by the length of the effective green interval.

Gap-in-Traffic Delay

When a platoon is not present, the situation is similar to Case 1, in that the bus must wait for a suitable gap in traffic. The average delay, in seconds, waiting for a gap in traffic d_{gt} is calculated similarly to reentry delay in Case 1, except that the platooned vehicles over the course of an hour are not included as part of the adjacent lane traffic. An adjusted traffic volume v_{adj}, in vehicles per hour, equal to the total hourly traffic demand in the adjacent lane minus the hourly platooned volume in the adjacent lane, is substituted for v in Exhibit 6-59 or Equation 6-7. Assuming random arrivals, v_{adj} is simply:

$$v_{adj} = v(g/C)$$

Equation 6-13

where all variables have been defined previously.

Reentry Delay for Near-Side Stops

For near-side stops, buses (and traffic in the adjacent lane) can only depart when the signal is green. In this case, reentry delay is the sum of average queue service delay and average gap-in-traffic delay, not to exceed the length of the effective green interval:

$$d_{re,2ns} = \min(d_{qs} + d_{gt}, g)$$

Equation 6-14

where $d_{re,2ns}$ is the reentry delay for near-side stops in Case 2, in seconds, and all other variables are as defined previously.

Reentry Delay for Far-Side Stops

At far-side stops, buses can depart at any time traffic in the adjacent lane permits. Reentry delay is the average of queue service delay and gap-in-traffic delay, weighted by the proportion of time each condition occurs:

$$d_{re,2fs} = d_{qs}\frac{d_{qs}}{C} + d_{gt}\frac{(C - d_{qs})}{C} \quad \textbf{Equation 6-15}$$

where $d_{re,2fs}$ is the reentry delay for far-side stops in Case 2, in seconds, and all other variables are as defined previously.

Case 3: Reentry Delay Downstream from Traffic Signals

In Case 3, traffic patterns are partially influenced by the upstream signal. In this case, reentry delay is calculated from both the Case 1 reentry delay and the Case 2 far-side reentry delay, giving greater weight to the Case 2 delay the closer the bus stop is to the traffic signal:

$$d_{re,3} = d_{re,2fs} - \frac{D_{bs}(d_{re,2fs} - d_{re,1})}{D_{max}} \quad \textbf{Equation 6-16}$$

where

$d_{re,3}$ = reentry delay for Case 3 (s),

$d_{re,2fs}$ = reentry delay for Case 2, far-side stop (s),

$d_{re,1}$ = reentry delay for Case 1 (s),

D_{bs} = bus stop distance from the nearest upstream traffic signal (mi, m), and

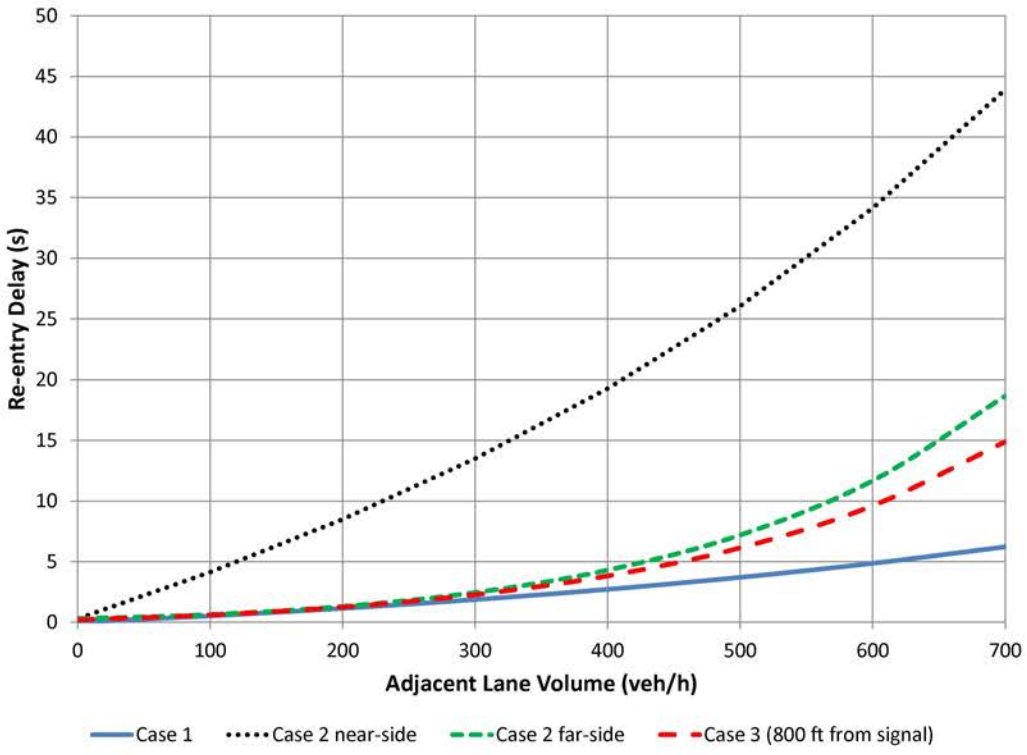
D_{max} = maximum distance for Case 3 (0.25 mi, 400 m).

Summary

Reentry delay is zero when buses stop in the traffic lane to serve passengers, or are provided with a queue jump at a traffic signal. In other situations, reentry delay is lower with any of the following: lower traffic volumes in the adjacent lane, shorter traffic signal cycles, greater green time provided for the bus' direction of travel, and increasing bus stop distance downstream from an intersection.

Exhibit 6-62 illustrates the reentry delay associated with different bus stop locations for the conditions given in the exhibit.

Exhibit 6-62
Illustrative Reentry Delay by Case



Source: Calculated.
Note: Assumes 100-s cycle length, g/C = 0.45, random arrivals, and metro CBD conditions.

STEP 6: DETERMINE BUS STOP CAPACITY

Overview

A bus stop's capacity depends on the capacities of the bus stop's individual loading areas (determined in Step 5), the number of loading areas provided, the design of those loading areas, and the bus stop's position relative to the roadway. It is also dependent on traffic congestion that interferes with a bus's access to the stop and on bus stopping patterns.

Step 6a: Determine the Number of Effective Loading Areas

As discussed earlier in the chapter, the majority of on-street bus stops use linear loading areas. Depending on how closely buses stop near to each other in adjacent linear loading areas, buses *may* be able to exit loading areas independently; however, in constrained situations, they need to wait for the bus(es) in front of them to depart before they can depart. Furthermore, as was illustrated in Exhibit 6-13, upon entering a bus stop consisting of multiple loading areas, a bus will stop at the forward-most available stop. If another bus is occupying one of the stop's loading areas, the arriving bus will need to stop behind it, potentially leaving loading areas farther ahead unoccupied because they cannot be accessed at that point in time.

Because buses can temporarily block loading areas from other buses, there is a diminishing-returns effect when using additional linear loading areas to add capacity to a bus stop. The more loading areas that are added, the more likely that some of them

will be inaccessible at a given point in time. The concept of *effective loading areas* is used to describe this effect, where the second linear loading area provides less capacity than the first, the third adds even less, and so on.

The incremental increase in capacity provided by each additional linear loading area depends on whether the loading areas are located on-line or off-line, as well as on the arrival characteristics of the buses using the stop. Field observations indicate that linear loading areas are used more efficiently when buses enter and exit them as *platoons*, groups of 2 to 3 buses with similar dwell times (or, at least, dwell times short enough to be completed by the time a traffic signal turns green) that travel down the street together. Platoons can be formed by upstream traffic signals or by intentionally scheduling groups of buses to leave the start of a route together, requiring a staging area near the locations where most passengers will board.

Exhibit 6-63 provides efficiency factors for linear loading areas. Non-linear loading areas are 100% efficient—the number of effective loading areas equals the number of physical loading areas. The off-line loading area efficiency factors given in the exhibit were originally developed based on experience at the Port Authority of New York and New Jersey's Midtown Bus Terminal (*17*), but have also been observed on an Australian busway (*1*). The on-line loading efficiency factors are based on simulation (*37*) and European experience (*41*).

Exhibit 6-63
Efficiency of Multiple Linear Loading Areas at Bus Stops

	On-Line Loading Areas				Off-Line Loading Areas	
	Random Arrivals		Platooned Arrivals		All Arrivals	
Loading Area #	Efficiency %	Cumulative # of Effective Loading Areas	Efficiency %	Cumulative # of Effective Loading Areas	Efficiency %	Cumulative # of Effective Loading Areas
1	100	1.00	100	1.00	100	1.00
2	75	1.75	85	1.85	85	1.85
3	70	2.45	80	2.65	75	2.60
4	20	2.65	25	2.90	65	3.25
5	10	2.75	10	3.00	50	3.75

Sources: *TCRP Report 26* (*21*) and *TCRP Research Results Digest 38* (*37*).
Notes: On-line values assume that buses do not overtake each other.
Values apply only to linear loading areas; non-linear designs are 100% effective.

Exhibit 6-63 suggests that four or five on-line linear loading areas provide the effective capacity of no more than three loading areas. When additional capacity is required, other options that can be considered include:

- Constructing sawtooth loading areas, a non-linear design that allows buses to enter and exit loading areas independently of each other. This type of design requires approximately 33% more length per loading area than a linear design, but provides the full capacity benefit of each loading area and also offers the option of assigning specific loading areas to specific routes, which is convenient for passengers and eliminates boarding lost time. This design has been used at some stations on the Miami-Dade Transitway (*7*).
- Splitting the bus stop into two or more adjacent stops, each with 2 to 3 linear loading areas, and assigning particular routes to particular stops, but not to specific loading areas within each stop. This is an example of a skip-stop operation. This design has been used on downtown streets with high bus volumes in Denver, Minneapolis, and Portland, but could also be applied to

busway operations (at the expense of requiring more space and additional signage at each station directing passengers to the appropriate platform).

Step 6b: Adjust Capacity for Traffic Blockage at Traffic Signals

Turning movements at intersections with bus stops reduce bus stop capacity.

Vehicular traffic competes with buses for space at an intersection (Exhibit 6-64). Vehicles turning from the bus' lane (or across the bus' path, at off-line stops) may use up signal green time that would otherwise have been available for bus movement as these vehicles wait for conflicting vehicles and pedestrians to clear before they can complete their turn. The reduced green time available to buses reduces, in turn, the bus stop capacity. The impact on bus stop capacity depends on (*a*) the movement's traffic volume relative to its capacity, (*b*) the bus stop location (e.g., near side, far side), and (*c*) the ability or inability of buses to move around turning vehicles. If other vehicles are not allowed to use the bus facility (e.g., a busway, a freeway managed lane, an exclusive bus lane that does not allow general traffic to turn from the lane), there is no traffic blockage impact on capacity and this step can be skipped. Similarly, if the stop in question is located more than one-half block away from a traffic signal, and outside the influence of a queue of stopped vehicles generated by the signal, this step can be skipped.

Exhibit 6-64
Examples of Auto Turning Conflicts with Buses



(a) Los Angeles (right turn)



(b) Portland (left turn)

The capacity of through movements in the curb lane c_{th} (in vehicles per hour) is the lane's saturation flow rate times the g/C ratio. The saturation flow rate can be calculated using the HCM (*40*) or estimated from Exhibit 6-60.

Exhibit 6-65 can be used to estimate the capacity of right-turn movements c_{rt} based on ranges of conflicting pedestrian volumes and the proportion of effective green time available for traffic.

Exhibit 6-65
Right-Turn Vehicle Capacities c_{rt} for Planning Applications (veh/h)

Conflicting Pedestrian Volume (ped/h)	*g/C* Ratio for Curb Lane					
	0.35	0.40	0.45	0.50	0.55	0.60
0	510	580	650	730	800	870
100	440	510	580	650	730	800
200	360	440	510	580	650	730
400	220	290	360	440	510	580
600	70	150	220	290	360	440
800	*	*	70	150	220	290
1,000	*	*	*	*	70	150

Source: HCM 2010 (*40*), based on 1,450 × (*g/C*) × (1 – (pedestrian volume/2,000)) with PHF=1.
Note: *Vehicles can only turn at the end of green, assume one or two per traffic signal cycle. Values shown are for CBD locations, multiply by 1.1 for other locations.

The curb lane capacity c_{cl}, in vehicles per hour, is the average of the through and right-turn capacities, weighted by their respective volumes. The effects of traffic blockage reduce bus capacity in proportion to the following adjustment factor f_{tb} (*21*):

$$f_{tb} = 1 - f_l\left(\frac{v_{cl}}{c_{cl}}\right)$$

Equation 6-17

where

f_{tb} = traffic blockage adjustment factor;

f_l = bus stop location factor, from Exhibit 6-66;

v_{cl} = curb lane traffic volume at intersection (veh/h); and

c_{cl} = curb lane capacity at intersection (veh/h).

Values of the bus stop location factor f_l are given in Exhibit 6-66. This factor reflects the likely ability of buses to move around right-turning traffic. Where right turns are allowed, the factor ranges from 0.5 (for a far-side stop with the adjacent lane available for buses) to 1.0 (for a near-side stop with all buses restricted to a single lane). A factor of 0.0 is used for Type 3 lanes, as right turns are not allowed by non-transit vehicles from this type of lane, automatically making f_{tb} equal to 1 for Type 3 lanes.

Exhibit 6-66
Bus Stop Location Factor f_l

	Lane Type		
Bus Stop Location	**Type 1**	**Type 2**	**Type 3**
Near side	1.0	0.9	0.0
Mid-block before or after traffic signal	0.9	0.7	0.0
Far side	0.8	0.5	0.0

Source: *TCRP Report 26* (*21*).
Note: f_l = 0.0 for contraflow bus lanes, median busways, and grade-separated busways regardless of bus stop location or lane type, as right turns are either prohibited or do not interfere with bus operations.

Step 6c: Calculate Bus Stop Capacity

Bus stop capacity is the capacity of a single loading area multiplied by the number of effective loading areas and the traffic blockage adjustment factor:

$$B_s = N_{el}B_l f_{tb} = N_{el}f_{tb}\frac{3{,}600(g/C)}{t_c + t_d(g/C) + Zc_v t_d}$$

Equation 6-18

where B_s is the bus stop capacity (bus/h), N_{el} is the number of effective loading areas at the bus stop, and all other variables as defined previously.

STEP 7: DETERMINE FACILITY BUS CAPACITY

Overview

Bus facility capacity is greatly dependent on the exclusivity of the facility—the less interference that buses have from other traffic, the greater the capacity. When the majority of buses make no stops along a facility (e.g., express services to downtown), and passing lanes are provided at any stops that do exist, a bus facility acts like a pipe that can serve hundreds of buses per hour. For example, up to 280 peak-direction buses per hour travel on the busiest portions of Bogotá's TransMilenio BRT system (*42*) and 735 buses per hour operate on the New Jersey approach to the Lincoln Tunnel into New York City (*43*). In these cases, the facility itself does not constrain capacity; rather, the

capacity of other bus facilities before or after the non-stop section (e.g., downtown streets in Ottawa), or the capacity of the bus terminal(s) where the buses end up (e.g., the Port Authority bus terminal in New York City) constrain the number of buses that can be operated on the facility. Use Step 7a to determine the capacity of these facilities.

More typically, even when different service types (e.g., local, limited stop) are operated along a facility, there will be common stops (or groups of stops, with skip-stop operation) served by all buses using the facility. In this case, the facility capacity will be constrained by the capacity of the *critical bus stop*—the bus stop (or group of stops) used by all buses that has the lowest capacity. Use either Step 7b (no skip stops) or Step 7c (skip-stop operation) to determine the capacity of these facilities.

It is also important to compare the capacity of each bus stop along the facility to the number of buses scheduled or planned to use that stop, as operational problems can develop anywhere along a facility when the number of buses stopping at a particular stop exceeds the stop's capacity. Step 7d describes this process.

Step 7a: Non-stop Facility Capacity

Non-stop facilities include freeway managed lanes and busways where passing lanes are provided at stations. Determining the number of buses that can be operated along these facilities requires examining both the facility itself and the facilities and terminals serving it for the constraining location. Potential constraints include:

- A busway station where a passing lane is not provided (e.g., due to right-of-way constraints). Use the procedure given in Step 7b to determine the station's capacity, assigning a zero dwell time to those buses not making passenger stops at the station.
- Facility capacity used by other vehicles (e.g., high-occupancy vehicles on freeway managed lanes). At the time of writing, NCHRP Project 3-96 was developing a method for assessing the capacity and performance of managed lanes. Simulation can also be used to estimate the number of buses and other vehicles that can operate on a managed lane at a desired level of service.
- A low-capacity intersection located before or after the facility being analyzed that constrains bus throughput (for example, a signalized left-turn movement). The HCM (*40*) can be used to evaluate its capacity.
- The combined bus capacity of the terminal(s), transit center(s), and/or streets that buses on the non-stop facility end up. Use the bus stop capacity method given in Step 6 to determine the bus capacity of a terminal or transit center, with appropriate adjustments to dwell time to account for any layover activity that may occur. Use the procedure given in Step 7b to determine the bus capacity of the streets buses serve following the non-stop facility.

The lowest capacity resulting from these checks will serve as the capacity constraint for the non-stop facility.

Step 7b: Facility Capacity without Skip-Stop Operation

When skip-stop operation is not used along a bus facility, the facility capacity is equal to the capacity of the *critical stop* along the facility. When all buses using the facility stop at all stops, the critical stop is the bus stop with the lowest capacity. When a

mix of service types (e.g., local and limited stop) uses the facility, the critical stop will be the bus stop used by all service types that has the lowest capacity.

Step 7c: Facility Capacity with Skip-Stop Operation

When skip-stop operation is used, the bus facility capacity is equal to the sum of the capacities of the critical bus stops of each skip-stop group, multiplied by an adjustment factor f_k reflecting inefficient arrival patterns and the effects of high vehicular traffic volumes in the adjacent lane (*21*):

$$B = f_k(B_1 + B_2 + \cdots + B_n) \quad \textbf{Equation 6-19}$$

where

B = bus facility design capacity (bus/h);
f_k = capacity adjustment factor for skip-stop operations, from Equation 6-20; and
$B_{1...}B_n$ = critical bus stop capacity of a given skip-stop pattern (bus/h);

with

$$f_k = \frac{1 + f_a f_i (N_{ss} - 1)}{N_{ss}} \quad \textbf{Equation 6-20}$$

where

f_a = arrival-type factor, reflecting the ability to fully utilize the bus stops in a skip-stop operation:
= 0.50 for random arrivals (poor scheduling/poor schedule adherence),
= 0.75 for typical arrivals (imperfect schedule adherence), and
= 1.00 for platooned arrivals (buses travel in groups, like cars of a train);
f_i = adjacent lane impedance factor, from Equation 6-21; and
N_{ss} = number of alternating skip stops in sequence;

and with

$$f_i = 1 - 0.8\left(\frac{v_{al}}{c_{al}}\right)^3 \quad \textbf{Equation 6-21}$$

where

v_{al} = traffic volume in the adjacent lane (veh/h); and
c_{al} = capacity of the adjacent lane (veh/h).

A planning-level estimate of the adjacent lane capacity can be made by multiplying the typical downtown lane vehicle saturation flow rate of 1,750 vehicles per lane per hour of green by the g/C ratio of the bus lane. Outside the downtown area, a saturation flow rate of 1,600 vehicles per lane per hour of green may be used. Consult the HCM (*40*) if a more detailed estimate of adjacent lane capacity is required.

The values provided by Equation 6-20 and Equation 6-21 result in added capacity with skip-stop operation, even when the adjacent lane is fully utilized by other vehicles, since non-stopping buses have zero dwell time at the stop. When there is no spreading of stops, there is no increase in capacity rendered by the adjacent lane, as all buses must stop at every stop.

Exhibit 6-67 gives representative values of the adjustment factor f_k for various lane types, bus arrival types, and bus stopping patterns. As indicated previously, these values are applied to the *sum* of the capacities in the sequence of bus stops. Thus, they reflect the actual dwell times at each stop. Exhibit 6-68 gives factors for a Type 2 bus lane with two-block alternating stops.

Exhibit 6-67
Typical Values of Adjustment Factor f_k for Availability of Adjacent Lanes

Condition	Adjacent Lane *v/c*	f_i	N_{ss} - 1	f_a	f_k
TYPE 1 LANE					
Stops every block	0 to 1	0 to 1	0	0.00	1.00
TYPE 2 LANE					
Stops every block	0 to 1	0 to 1	0	0.00	1.00
Alternating 2-block stops, random	0	1	1	0.50	0.75
	1	0.2*	1	0.50	0.55
Alternating 2-block stops, typical	0	1	1	0.75	0.88
	1	0.2*	1	0.75	0.58
Alternating 2-block stops, platooned	0	1	1	1.00	1.00
	1	0.2*	1	1.00	0.60
TYPE 3 LANE					
Alternating 2-block stops, random	0	1	1	0.50	0.75
Alternating 2-block stops, typical	0	1	1	0.75	0.88
Alternating 2-block stops, platooned	0	1	1	1.00	1.00
Alternating 3-block stops, random	0	1	2	0.50	0.67
Alternating 3-block stops, typical	0	1	2	0.75	0.83
Alternating 3-block stops, platooned	0	1	2	1.00	1.00

Source: *TCRP Report 26* (*21*).
Notes: * approximate
v/c = volume-to-capacity ratio.

Exhibit 6-68
Values of Adjustment Factor f_k for Type 2 Bus Lanes with Alternate Two-Block Skip-Stops

Adjacent Lane *v/c*	Arrival Pattern		
	Random	Typical	Platooned
0.0	0.75	0.88	1.00
0.5	0.72	0.84	0.95
0.6	0.71	0.81	0.92
0.7	0.68	0.77	0.87
0.8	0.65	0.71	0.80
0.9	0.60	0.65	0.71
1.0	0.55	0.58	0.60

Source: *TCRP Report 26* (*21*).
Note: *v/c* = volume-to-capacity ratio.

Step 7d: Check *v/c* Ratios of All Stops along the Facility

When a mix of stopping patterns is used, stops other than the critical stop may have capacity problems.

Even when the critical bus stop provides sufficient capacity for the scheduled or planned number of buses using the facility, other bus stops may not provide sufficient capacity to serve even the reduced number of buses using those stops. Therefore, the scheduled or planned volume of buses at each bus stop should be compared to the stop's capacity. If the volume exceeds the capacity, buses will queue behind the stop, resulting in poor bus speeds, schedule reliability problems, and potential traffic operations issues.

The capacities determined in Steps 5–7 are hourly capacities that assume that bus arrivals are spread out over the course of the hour. If bus arrivals are more concentrated during a particular portion of the hour (e.g., peaking over a 15- or 30-min period), volumes and capacities should also be checked during those peak-of-the-peak periods. For example, dividing the hourly capacity by 4 gives the maximum number of buses a loading area, bus stop, or facility can accommodate in a given 15-min period.

Steps 5–7 calculate hourly capacities. It may also be necessary to compare volume to capacity for shorter time periods.

STEP 8: DETERMINE FACILITY PERSON CAPACITY

The final step is to determine how many persons can be served by the bus facility over the course of an hour. As discussed in Section 2, person capacity is influenced by the following:

- The facility's bus capacity,
- Transit agency policy regarding passenger loads,
- Scheduled headways, and
- Passenger demand diversity.

Scheduled Person Capacity

Scheduled person capacity reflects the number of passengers that can be carried through the facility's maximum load section, given the existing schedule and bus model(s) used. If a transit agency's policy is that passenger loading should not exceed P_{max} passengers per bus model *on average* during an hour, scheduled person capacity is calculated as follows:

$$P_s = \sum_{i=1}^{N_{bm}} P_{max,i} N_i \qquad \textbf{Equation 6-22}$$

where

P_s = scheduled person capacity (p/h),

$P_{max,i}$ = maximum schedule load for bus model i (p/bus),

N_{bm} = number of different bus models operated on the facility, and

N_i = number of buses of bus model i scheduled to use the facility during the hour (bus/h).

If a transit agency's policy is that passenger loading should *not regularly exceed* P_{max} passengers per bus model during an hour, scheduled person capacity is calculated as follows:

$$P_s = \sum_{i=1}^{n} P_{max,i}(PHF) N_i \qquad \textbf{Equation 6-23}$$

where *PHF* is the peak-hour factor and all other variables are as defined previously. The addition of *PHF* reduces person capacity to a level that results in buses operating at, but not generally above, the maximum schedule load during the peak 15 min and at somewhat reduced loading levels during the remainder of the hour.

PHF *values range from 0.25 (all passenger demand occurs during a single 15-min period in an hour) to 1.00 (demand is constant throughout the hour).*

Typical peak-hour factors range from 0.60 to 0.95 for transit lines (*39*, *44*). In the absence of other information, 0.75 may be used as a default PHF for bus service where the schedule is not adjusted to accommodate peaks in demand (e.g., when clock headways are used). When headways are adjusted to serve predictable peaks in demand, a PHF of 0.85 may be used as a default.

When available, a *PHF* value representative of actual route- or facility-specific conditions is preferred to a default value. APC data can be used in conjunction with Equation 6-24 to determine a local value for *PHF.* If buses operate at longer than 15-min headways, the denominator of Equation 6-24 should be adjusted appropriately (e.g., $3P_{20}$ for 20-min headways).

Equation 6-24

$$PHF = \frac{P_h}{4P_{15}}$$

where

PHF = peak-hour factor;

P_h = passenger volume during the peak hour (p); and

P_{15} = passenger volume during the peak 15 min (p).

Design Person Capacity

Design person capacity is the number of people that *could* be carried through the facility's maximum load section, if buses were scheduled to use the facility at its full capacity, under a specified set of conditions (e.g., design failure rate, vehicle types, fare collection method). In this case, Equation 6-22 and Equation 6-23 are replaced with the following, depending on whether the loading standard is an average (Equation 6-25) or is not to be regularly exceeded (Equation 6-26):

Equation 6-25

$$P = P_{max}B$$

Equation 6-26

$$P = P_{max}(PHF)B$$

where

P = design person capacity (p/h),

P_{max} = weighted average maximum schedule load for buses using the facility (p/bus), and

B = bus facility design capacity (bus/h).

6. BUS SPEED METHODOLOGY

This section presents a computational methodology for estimating bus speeds on all types of bus facilities except freeway managed lanes. Exhibit 6-69 shows the steps involved in applying the methodology.

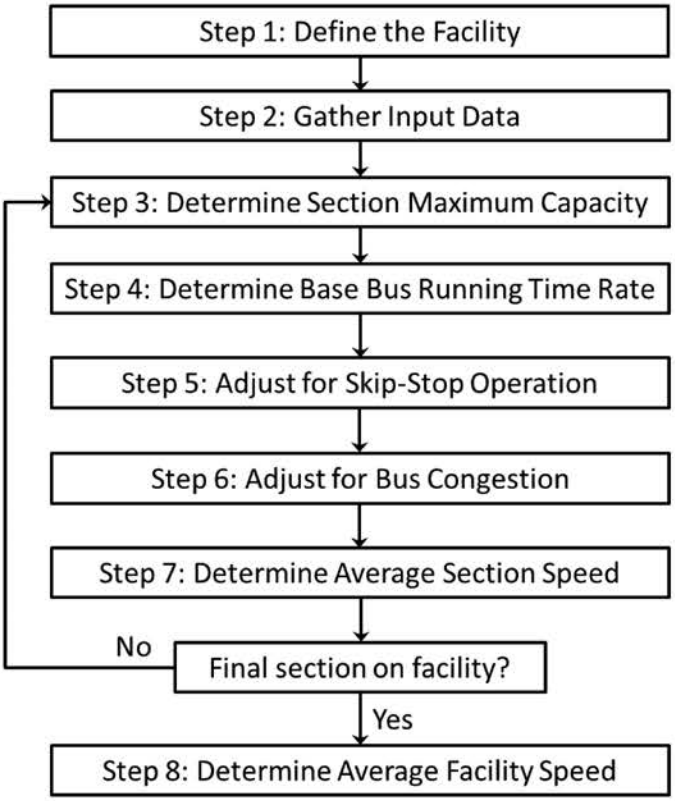


Exhibit 6-69
Bus Speed Methodology Flowchart

The core of the methodology is based on research on arterial street bus lanes presented in *TCRP Report 26* (*21*), which investigated the operation of arterial street bus lanes in a number of North American cities, with modifications made for the TCQSM 3rd Edition to allow unimpeded bus travel time rates to be calculated directly, if desired. The methodology is suitable for developing a planning-level estimate of the average bus speed along a bus facility for a given set of conditions.

If intersection-level traffic volume and traffic signal timing data are available for the facility, the HCM's urban streets methodology (*40*) can be substituted in Step 4 to provide an operations-level estimate of traffic and traffic signal delays, while remaining consistent with the basic TCQSM methodology.

STEP 1: DEFINE THE FACILITY

The facility is defined the same way as described in Section 5, Bus Capacity Methodology. Once the overall facility is defined, it must be divided into sections with similar right-of-way types (e.g., busway with passing lanes, Type 2 arterial bus lane, Type 1 mixed-traffic operation), stop spacing, and dwell times. Average speed will be calculated first for each individual section and then combined into the overall facility speed at the end of the process. Sections should be at least 0.25 mi (400 m) and preferably 0.5 mi (800 m) long.

STEP 2: GATHER INPUT DATA

All of the input data described in Section 5 for calculating bus capacity are required. In addition, the following data are required for each section of the facility:

- Average stop spacing (stop/mi, stop/km);
- Average dwell time (s/bus/stop);
- Scheduled number of buses at the critical stop(s) (bus/h);
- Traffic signal timing and spacing (typical, signals set for bus progression, signals more frequent than bus stops); and
- Traffic interference (general traffic prohibited, bus lane with right-turn lanes, bus lane with traffic/parking blockage, mixed traffic).

STEP 3: DETERMINE SECTION MAXIMUM CAPACITY

In this step, apply the capacity methodology described in Section 5 with the following adjustments:

1. Each section should be treated as its own facility for the purpose of calculating capacity.
2. A 25% failure rate should be used to estimate maximum capacity. The bus–bus interference factor used in Step 6 below adjusts for conditions that might result in bus stop failure.

Use a 25% failure rate when estimating a section's maximum capacity.

STEP 4: DETERMINE BASE BUS RUNNING TIME RATE

The HCM's urban street transit speed estimation method can be substituted for Step 4 when intersection-level traffic volume and signal timing data are available.

Step 4 estimates a travel time rate in minutes per mile or kilometer, based on the bus's running speed between stops, stop spacing, and delays due to traffic interference. Steps 5 and 6 develop adjustment factors that reflect the impacts of skip-stop operation and bus congestion, respectively, and overall bus speeds. As mentioned in this section's introduction, the HCM's urban street transit speed estimation method (*40*) can be substituted for this step when intersection-level traffic volume and signal timing data are available.

Step 4a: Calculate the Unimpeded Bus Running Time Rate

This step calculates the travel time rate a bus would experience if it could travel along the facility without traffic signal or traffic delays. The unimpeded travel time rate incorporates the average dwell time of all bus stops in the section, the acceleration and deceleration delays associated with each stop, and the time spent traveling at the bus's running speed for the facility (typically, the facility's speed limit).

The acceleration and deceleration time per stop is the time spent slowing from the facility's running speed to a stop and accelerating back to running speed.

$$t_{acc} = \frac{c_f v_{run}}{a}$$ **Equation 6-27**

$$t_{dec} = \frac{c_f v_{run}}{d}$$ **Equation 6-28**

where

t_{acc} = acceleration time (s/stop);

t_{dec} = deceleration time (s/stop);

c_f = conversion factor = 1.47 (5,280 ft/mi / 3,600 s/h) or 0.278 (1,000 m/km / 3,600 s/h);

v_{run} = bus running speed on the facility, typically the posted speed (mi/h, km/h);

a = average bus acceleration rate to running speed (ft/s^2, m/s^2); and

d = average bus deceleration rate from running speed (ft/s^2, m/s^2).

These equations assume that buses stop at each stop within the section. In the case of a busway with express bus service where buses slow, but do not stop within each station, ($v_{run} - v_{st}$) can be substituted for v_{run} in Equation 6-27 and Equation 6-28, where v_{st} is the bus travel speed through the station (greater than zero), measured in miles per hour or kilometers per hour. The time required to travel through the station is:

$$t_{sta} = \frac{L_{sta}}{\frac{1}{c_f v_{st}} - \frac{1}{c_f v_{run}}}$$ **Equation 6-29**

where t_{sta} is the station travel time in seconds per stop, L_{sta} is the length of the station speed zone in feet or meters, and all other variables are as defined previously.

The total distance traveled at less than running speed L_{ad} (in feet or meters per stop) associated with each stop or station is:

$$L_{ad} = 0.5at_{acc}^2 + 0.5dt_{dec}^2 + L_{sta}$$ **Equation 6-30**

where all variables have been defined previously. If L_{ad} multiplied by the average stop spacing is greater than 5,280 ft or 1,000 m, then a bus cannot fully accelerate to the selected facility running speed before it must begin decelerating again to the next stop. In this case, a new (lower) value for v_{run} must be selected and the process repeated beginning with Equation 6-27.

Check to make sure that the bus can reach the selected running speed before decelerating to the next stop.

The total distance travelled at running speed per mile or kilometer is:

$$L_{rs} = L_{mk} - N_s L_{ad}$$ **Equation 6-31**

where

L_{rs} = distance traveled at running speed per mile or kilometer (ft, m),

L_{mk} = length of a mile or kilometer (5,280 ft, 1,000 m),

N_s = average stop spacing (stops/mi, stops/km), and

L_{ad} = distance traveled at less than running speed (ft/stop, m/stop).

Finally, the time spent traveling at running speed (t_{rs}, in seconds per mile or kilometer) is:

Equation 6-32

$$t_{rs} = \frac{L_{rs}}{c_f v_{run}}$$

where all variables have been defined previously.

The unimpeded running time rate is the sum of the time spent at running speed plus the sum of the average dwell time and acceleration and deceleration times associated with each bus stop:

Equation 6-33

$$t_u = \frac{t_{rs} + N_s(t_{dt} + t_{acc} + t_{dec} + t_{sta})}{60}$$

where

t_u = unimpeded running time rate (min/mi, min/km),

t_{rs} = time spent at running speed (s/mi, s/km),

N_s = average stop spacing (stops/mi, stops/km),

The average dwell time used here is the average of all stops along the section, rather than the average critical stop dwell time used for capacity analysis.

t_{dt} = average dwell time of all stops within the section (s/stop),

t_{acc} = acceleration time (s/stop),

t_{dec} = deceleration time (s/stop),

t_{sta} = station travel time for buses slowing but not stopping at the bus stop (s/stop), and

60 = number of seconds per minute.

The following three exhibits provide representative values of the unimpeded running time rate for CBD conditions (Exhibit 6-70), suburban conditions (Exhibit 6-71), and busways (Exhibit 6-73).

Exhibit 6-70
Illustrative Unimpeded Running Time Rates (min/mi): CBD

Average Dwell Time (s)	Stops per mile 2	4	5	6	7	8	10	12
10	3.06	3.73	4.06	4.39	4.73	5.06	5.73	6.39
20	3.39	4.39	4.89	5.39	5.89	6.39	7.39	8.39
30	3.73	5.06	5.73	6.39	7.06	7.73	9.06	10.39
40	4.06	5.73	6.56	7.39	8.23	9.06	10.73	12.39
50	4.39	6.39	7.39	8.39	9.39	10.39	12.39	14.39
60	4.73	7.06	8.23	9.39	10.56	11.73	14.06	16.39

Source: Calculated.
Note: Assumes 25 mi/h running speed, 3.4 ft^2/s average acceleration rate, and 4.0 ft^2/s deceleration rate.

Exhibit 6-71
Illustrative Unimpeded Running Time Rates (min/mi): Suburban Arterial

Average Dwell Time (s)	Stops per mile 2	3	4	5	6
10	2.56	2.99	3.42	3.85	4.27
15	2.73	3.24	3.75	4.26	4.77
20	2.90	3.49	4.08	4.68	5.27
25	3.06	3.74	4.42	5.10	5.77
30	3.23	3.99	4.75	5.51	6.27

Source: Calculated.
Note: Assumes 35 mi/h running speed, 2.8 ft^2/s average acceleration rate, and 4.0 ft^2/s deceleration rate.

Exhibit 6-72
Illustrative Unimpeded Running Time Rates (min/mi): Busway

Average Dwell Time (s)	Stops per mile 0.5	1	1.5	2	2.5
0	1.38	1.56	1.75	1.93	2.11
15	1.56	1.88	2.22	2.56	2.90
30	1.75	2.13	2.60	3.06	3.53
45	1.93	2.38	2.97	3.56	4.15
60	2.11	2.63	3.35	4.06	4.78

Source: Calculated.
Notes: Assumes 50 mi/h running speed, 2.2 ft^2/s average acceleration rate, and 4.0 ft^2/s deceleration rate. Use the 0 dwell time row for express buses slowing, but not stopping at stations (25 mi/h station speed limit and 325-ft-long speed zone through station assumed). Assumes passing lane available for non-stopping buses and no at-grade pedestrian crossings within the station.

Step 4b: Calculate Additional Running Time Losses

Step 4b can be skipped when analyzing grade-separated busways.

This step calculates the additional average delay a bus incurs while traveling along a street or bus facility due to traffic signals and interference from other vehicles sharing the lane with the bus. This step can be skipped for grade-separated busways, as these interferences do not exist.

Exhibit 6-73 provides estimates of additional running time losses t_l (in minutes per mile) on urban bus facilities, accounting for the effects of signals and other traffic sharing the bus lane. These values were derived from field observations (*37*). When applying Exhibit 6-73, the additional running time loss selected from a possible range of losses should consider both the quality of traffic signal progression and enforcement efforts (or the lack thereof) to keep non-authorized vehicles out of a bus lane. A calibrated version of this exhibit could be developed for a given city (for example, by analyzing AVL data) by comparing actual bus speeds under selected conditions to the unimpeded speed—the difference in speeds reflects the additional running time loss. In addition, the HCM's urban streets method (*40*) can be used to develop a more precise estimate of traffic and traffic signal delays.

Exhibit 6-73
Estimated Bus Running Time Losses t_l on Urban Streets (min/mi)

Condition	Bus Lane	Bus Lane, No Right Turns	Bus Lane With Right Turn Delays	Bus Lanes Blocked by Traffic	Mixed Traffic Flow
CENTRAL BUSINESS DISTRICT					
Typical		1.2	2.0	2.5–3.0	3.0
Signals set for buses		0.6	1.4		
Signals more frequent than bus stops		1.5–2.0	2.5–3.0	3.0–3.5	3.5–4.0
ARTERIAL ROADWAYS OUTSIDE THE CBD					
Typical	0.7				1.0
Range	0.5–1.0				0.7–1.5

Source: *TCRP Research Results Digest 38* (*37*).
Notes: Traffic delays reflect peak conditions.
A metric version of this exhibit appears in Appendix A.

Step 4c: Calculate the Base Bus Running Time Rate

The base bus running time t_r (in minutes per mile or kilometer) is the sum of the unimpeded running time t_u and the additional running time losses t_l:

Equation 6-34

$$t_r = t_u + t_l$$

STEP 5: ADJUST FOR SKIP-STOP OPERATION

Skip-stop operation spreads buses out among a series of bus stops, allowing for an increase in speeds. The analytical procedure accounts for the skip-stop operations by considering only the bus stops in the skip-stop pattern. For example, if bus stops are located 400 ft (125 m) apart (say a stop at each intersection), a two-block skip-stop pattern provides 800 ft (250 m) between stops for a bus using that pattern. A bus with a two-block stop pattern would be able to proceed faster than a bus with a one-block stop pattern. However, some of this increase will be offset by increases in dwell times, as each stop will have to accommodate more passengers.

The ability of buses to leave the curb lane to pass stopped vehicles is another factor in the ability to attain an increase in speed. This ability depends on the availability of an adjacent lane or the provision of an off-line bus stop. Where dual bus lanes or off-line bus stops are provided, the anticipated bus speed can be calculated using the distance between the bus stops served. Where congestion in the adjacent lane results in essentially no passing-lane availability, the buses will progress as if they were stopping at each stop with a zero dwell time at the intermediate stops. When partial use of the adjacent lane is available, the bus speed will be somewhere in between.

Equation 6-35 expresses the speed adjustment factor for skip-stop operation f_{sp} as a function of both the traffic in the adjacent lane and the buses in the curb lane (*21*). This factor reduces the faster base running time that results from the longer distances between stops used in the skip-stop pattern. If skip stops are not used, f_{sp} = 1.0 and the base running speed is based on the actual stop spacing. The volume v_{al} and capacity c_{al} of the adjacent lane are the same as those used previously for determining the facility capacity with skip-stop operation.

Equation 6-35

$$f_{sp} = 1 - \left(\frac{d_1}{d_2}\right)\left(\frac{v_{al}}{c_{al}}\right)^2\left(\frac{v_b}{B_{max}}\right)$$

where

f_{sp} = stop-pattern adjustment factor,
d_1 = distance for one-block stop pattern (ft or m),
d_2 = distance for multiple-block stop pattern (ft or m),
v_{al} = traffic volume in the adjacent lane (veh/h),
c_{al} = capacity of the adjacent lane (veh/h),
v_b = bus volume in the curb lane (bus/h), and
B_{max} = maximum bus capacity of the curb lane (bus/h).

Exhibit 6-74 illustrates values of the stop-pattern adjustment factor for a two-block stop pattern, for a range of bus lane and adjacent lane volume-to-capacity ratios. As bus volumes, adjacent lane volumes, or both increase, the stop-pattern adjustment factor value decreases, indicating a lower potential for bus speed improvements as a result of the skip-stop pattern. With no traffic in the adjacent lane (i.e., the adjacent lane *v/c* ratio is 0.0) and minimal bus volumes, the adjustment factor is 1.00, indicating that the two-block stop pattern results in a doubling of average bus speeds. When the adjacent lane is fully utilized, so that buses are unable to move into it (i.e., the adjacent lane *v/c* ratio is 1.0), and when the bus lane's maximum capacity is also fully utilized (i.e., the bus volume-to-capacity ratio is 1.0), the adjustment factor is 0.50, indicating that the skip-stop pattern has no effect on average bus speeds (2 × 0.5 = 1.0). Until the volume of adjacent lane reaches approximately half of its capacity (i.e., an adjacent lane *v/c* ratio of 0.5), the ability to achieve a two-fold increase in speed is not significantly reduced.

Speed will need to be estimated separately for each skip-stop pattern. Maximum bus capacity should be based on a 25% failure rate.

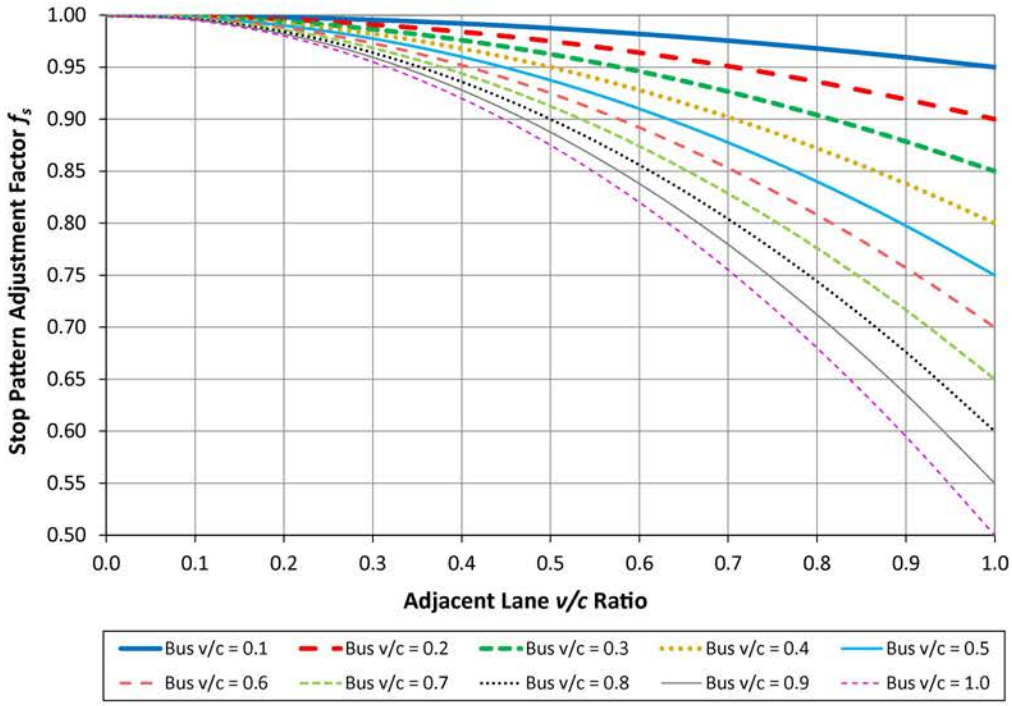


Exhibit 6-74
Illustrative Skip-Stop Speed Adjustment Factor Values

Source: Calculated.

Notes: Assumes two-block skip-stop pattern.
v/c = volume-to-capacity ratio.

STEP 6: ADJUST FOR BUS CONGESTION

Bus speeds within a bus lane along an arterial street decline as the lane becomes saturated with buses. This is because as the number of buses using the lane increases, there is a greater probability that one bus will delay another bus, either by using available loading areas or by requiring passing and weaving maneuvers. Simulation runs reported in *TCRP Report 26* (*21*) as well as observations of actual bus lane operations (*45*) show a sharp drop in bus speeds as bus volumes approach the bus lane's capacity. Exhibit 6-75 presents a bus–bus adjustment factor f_{bb} for speeds based on bus volumes relative to the bus lane capacity. These values were developed through

simulation of Type 1 and Type 2 exclusive bus lanes, using an 80-s traffic signal cycle length, a g/C ratio of 0.5, 400-ft (125-m) block spacing, 20- to 50-s dwell times, and a 33% coefficient of dwell time variation.

Exhibit 6-75
Bus–Bus Interference Factor f_{bb} Values

Bus Volume-to-Capacity Ratio	Bus-Bus Interference Factor
<0.5	1.00
0.5	0.97
0.6	0.94
0.7	0.89
0.8	0.81
0.9	0.69
1.0	0.52
1.1	0.35

Source: *TCRP Report 26* (*21*).
Note: Bus lane capacity should be based on a 25% failure rate (i.e., maximum capacity).

Exhibit 6-10 illustrated the effects of increasing bus volumes on bus speeds. There is no effect on bus speeds until one-half of the bus lane's maximum bus capacity is in use. As scheduled bus volumes increase further, bus speeds begin to drop as buses interfere with the ability of each other to enter and exit bus stops and to pass. When a bus lane's maximum capacity is scheduled, achievable speeds are approximately half of what they could be at lower bus scheduled volumes. (As introduced in Section 5, Bus Capacity Methodology, the failure rate at maximum capacity is 25%, meaning that a bus has a one-in-four chance of being delayed at each bus stop it serves.)

STEP 7: DETERMINE AVERAGE SECTION SPEED

The base bus running time rate from Step 4 is divided by the skip-stop operation and bus–bus interference factors from Steps 5 and 6, respectively, to produce the overall section running time rate:

Equation 6-36

$$t_s = \frac{t_r}{f_{sp} f_{bb}}$$

where t_s is the section running time rate in minutes per mile or kilometer and all other variables are as previously defined. The section running time rate is then divided into 60 minutes per hour to obtain the section speed:

Equation 6-37

$$S_s = \frac{60}{t_s}$$

where S_s is the average section speed in miles or kilometers per hour.

STEP 8: DETERMINE AVERAGE FACILITY SPEED

The travel time rates for each section are multiplied by the respective section lengths and then summed to produce a total travel time for the facility:

$$t_{fac} = \sum_{i=1}^{N_{sec}} t_{s,i} L_i \qquad \text{Equation 6-38}$$

where

t_{fac} = facility travel time (min),
N_{sec} = number of sections forming the facility,
$t_{s,I}$ = section running time rate for section i (min/mi or min/km), and
L_i = length of section i (mi or km).

Finally, the average facility speed is the facility length divided by the facility travel time, multiplied by 60 minutes per hour:

$$S_f = 60\left(\frac{L_{fac}}{t_{fac}}\right) \qquad \text{Equation 6-39}$$

where S_f is the average facility speed (mi/h or km/h), L_{fac} is the facility length (mi or km), and t_{fac} is the facility travel time (min).

7. BUS RELIABILITY

This section presents the state of knowledge about factors that influence bus reliability. The impact of reliability issues on passenger quality of service was discussed in Chapter 4, Quality of Service Concepts.

Studies to date on bus reliability have been limited in scope, typically focusing on single transit routes or demonstrating a proof-of-concept using simulation. Comprehensive research is needed to quantify the effects of both external influences and scheduling and control strategies on bus reliability.

FACTORS INFLUENCING BUS RELIABILITY

Bus reliability is influenced by a number of factors, some under the control of transit operators and some not. These factors include:

- *Traffic conditions* (for on-street, mixed-traffic operations), including traffic congestion, traffic signal delays, parking maneuvers, incidents, etc.;
- *Road construction* and *right-of-way maintenance,* which create delays and may force a detour from the normal route;
- *Vehicle and maintenance quality*, which influence the probability that a vehicle will break down while in service;
- *Vehicle and staff availability*, reflecting whether there are sufficient vehicles available to operate the scheduled trips (some vehicles will be undergoing maintenance and others may be out of service for various reasons) and whether sufficient operators are available on a given day to operate those vehicles;
- *Transit preferential treatments* that partially offset traffic effects on transit operations;
- *Schedule achievability*, reflecting whether the route can be operated under usual traffic conditions and passenger loads, with sufficient layover time provided for operators and sufficient recovery time to allow most trips to depart on time even when they arrived at the end of the route late;
- *Evenness of passenger demand,* both between successive vehicles and from day to day for a given vehicle and run;
- *Differences in operator driving skills*, route familiarity, and adherence to the schedule—particularly in terms of early ("hot") running (*46*);
- *Wheelchair lift and ramp usage,* including the frequency of deployment and the amount of time required to secure wheelchairs;
- *Route length and the number of stops,* which increase a vehicle's exposure to events that may delay it—delays occurring earlier along a route result in longer overall trip times than similar delays occurring later along a route (*47, 48*); and
- *Operations control strategies* used to react to reliability problems as they develop, thus minimizing the impact of the problems (*49*).

The remainder of this section describes techniques for identifying and addressing bus reliability issues.

SCHEDULING AND HOLDING STRATEGIES

A Dutch study (*50*) investigated schedule- and headway-based holding strategies for short headway transit services. Schedule-based holding was found to be more effective than headway-based holding when no maximum holding time was applied. However, with a maximum holding time of 60 s, there was no difference in the effectiveness of the two holding strategies. The effects of vehicle holding on reliability and crowding were also studied; it was found that decreased irregularity due to holding can reduce crowding or enable smaller capacity slack.

Another study (*51*) modeled the operation of a hypothetical route to study optimal running time schedules. Using a performance measure that accounted for passengers' budgeted extra waiting time due to unreliable service and perceived waiting time for late buses, it was found that inserting slack into the schedule at timepoints rather than at the end of the route provided typical equivalent savings of 4.5 min/p of in-vehicle time, with the benefits increasing as the number of timepoints increased. Inserting slack at timepoints did not necessarily increase cycle time, because time spent holding at timepoints could be subtracted from recovery time at the end of the trip. The optimal scheduled route running time was found to be the mean time plus one standard deviation; the optimal route cycle time was found to be the mean plus two or three standard deviations.

A simulation study (*52*) focused on developing optimal bus schedules for taking advantage of TSP found that the best performance was achieved when an aggressive schedule was used (e.g., a majority of buses will be slightly behind schedule), in combination with conditional priority at signals that only grants priority to late buses and a strategy of holding early buses. Average running time, variability of running times and headways, and crowding were reduced with this strategy.

RELATIONSHIPS OF SERVICE CHARACTERISTICS TO RELIABILITY

A Seattle-area study based on AVL data (*53*) studied the impact of service characteristics on bus travel time variability. The most significant segment-level variable was lagged on-time deviation, or the bus already being late. Other significant variables that increased delay included use of high-floor buses, through-routing, presence of standees, severe weather, situations warranting a service alert, number of boarding passengers, and number of passengers onboard. These variables also had a significant negative effect at the route level. At the segment level, express buses and buses using managed lanes had a significant positive effect on decreasing delay.

A study in Beijing, China (*54*) developed estimates of reliability and their correlation to operational characteristics. A high correlation was found between service reliability and the characteristics of route length, headway, distance from the stop to the original terminal, and the provision of exclusive bus lanes. A Dutch study (*55*) also investigated the relationship between the length of a transit line and operational reliability and determined that splitting a line could result in improved reliability.

A study of transit lines in the Zurich region (*56*) considered onboard ticket sales as one factor in route variability. It was found that onboard ticket sales processes vary significantly and can be up to 20% of the total run time for the studied lines, which could significantly impact transit schedule reliability.

APPLICATIONS OF AVL DATA

TCRP Report 113 (*38*) provides information on designing a system to archive AVL data and to apply the collected data to various types of analyses that support a transit agency's operations, scheduling, and management functions. Examples in the report include the development of user-focused performance measures (described in more detail in TCQSM Chapter 5, Quality of Service Methodologies), analysis of short- and long-headway reliability problems, analysis of route travel-time variability, and the application of these analyses to improved route schedules. Several other studies (*57–59*) provide examples of the use of AVL data to support transit agency operations.

FORECASTING RELIABILITY

At the time of TCQSM publication, literature related to forecasting reliability focused on developing models for predicting transit vehicle arrival times for use with real-time information systems, based on archived AVL data (*54, 60*).

8. APPLICATIONS

This section presents examples of the types of real-world situations that this chapter's methods can be applied to.

ALTERNATIVE MODE, FACILITY, AND SERVICE COMPARISONS

The TCQSM bus analysis methods can be applied to a planning study or a formal alternatives analysis process to quickly compare the performance of different alternatives with each other. The information resulting from the analysis can then serve as inputs to ridership estimation, benefit-cost analysis, and alternative prioritization processes. Once one or more promising alternatives have been identified, simulation can be used if desired to confirm the alternative's operating performance. The general steps involved in this process are:

1. Specify the characteristics of each alternative to be compared, including mode, vehicle characteristics, facility type, and all other data needed to estimate the performance measures of interest using TCQSM methods.
2. If transit service already exists in the study corridor, perform a TCQSM analysis of its operating performance as a check on the reasonableness of the results. If necessary, revisit assumed or default input values used in the analysis that impact the performance results and calibrate them as needed to produce results that more closely match actual conditions.
3. Once default inputs have been calibrated, apply the TCQSM methods to each of the alternatives to estimate the performance measures of interest.

Changes in travel time can be used as an input to a ridership estimation process; for example, by applying elasticity factors from *TCRP Report 118: Bus Rapid Transit Practitioner's Guide* (*11*) for bus service. Travel times should be reflective of an average passenger's overall trip (including transfers) and not just of travel time in the corridor.

Speed can be used as an input for determining the number of transit vehicles required to operate service on the route(s) using the corridor, which then becomes an input for estimating operating and capital costs for the alternative. If TSP or bus lanes are part of the alternative, information from Chapter 3 can be used to estimate the change in running time variability associated with the alternative, which may reduce required schedule recovery time and route cycle time.

The capacity procedures can be used directly to develop assumptions about facility size (e.g., platform lengths at a BRT station) that will be required when developing a capital cost estimate for the alternative.

FARE COLLECTION TECHNOLOGY CHANGES

The dwell time calculation method provided in Step 4 of the bus capacity method can be used to evaluate the potential impacts of a change in fare collection technology. The steps involved in this process are as follows:

1. Conduct a study to determine current fare collection times. The process described in Appendix B for determining passenger service times can be followed. When multiple types of fare media are used (e.g., cash fares and

flash passes), the additional step of recording number of fares paid by media type will be required.

2. Compare the results to the TCQSM default values in Exhibit 6-4 to see where the results fall relative to the default value. In some cases—particularly with cash fares—the combination of bills and coins used to pay a fare drives the passenger service time. However, in other cases, vehicle characteristics (e.g., ease of boarding, ease of finding the fare collection device) or passenger characteristics also play a role.
3. Identify the passenger service time default value for the fare collection technology being considered. Consider whether the fare collection device will be retrofitted onto existing buses in addition to existing equipment (in which case, it may be in a less-convenient location that takes more time to access). Also consider the results of Step 2 and select an appropriate service value time value from the range of values given, if passengers appear to board faster or slower than suggested by the default value.
4. Calculate the change in passenger service time (up or down) that would result from the new technology. Combine with passenger count data (for example, from archived APC data) to estimate the change in dwell time along a given route.
5. Apply the TCQSM's speed estimation methodology to determine the resulting change in travel speed for a given route and from this, the change in route cycle time. Identify whether buses would need to be added to, or could be removed from a route, and the resulting operating costs or savings.

ASSESSING THE IMPACT OF TRANSIT PREFERENTIAL TREATMENTS

The information provided in Section 3 can be used in combination with TCQSM methods to evaluate the performance impact of particular treatments. In some cases—such as installing exclusive bus lanes—the treatment is directly accounted for in a TCQSM method. In other cases—for example, installing TSP—the base TCQSM method will need to be adjusted to account for the treatment's effects:

- The impact of TSP is best accounted for by adjusting the effective green time used in the g/C ratio by the average amount of time available to be added over the course of the hour. An HCM analysis will be needed to determine how much green time could be reallocated while meeting other constraints (e.g., intersection level of service standards, minimum pedestrian green time). Analyst judgment will be needed about whether the traffic signal timing and upstream bus stop location makes it more likely that a bus would use green extension or red truncation; this determines the maximum green time benefit a bus would receive. In addition, because of the need to keep intersections in coordination with other nearby intersections, priority is not likely to be granted every signal cycle, but rather every second or third cycle, and the added green time should be reduced proportionately. The TCQSM speed estimation method should then be run with and without TSP effects to estimate the resulting change in average bus speed due to TSP.
- Results of field studies of the effects of queue jumps on intersection bus delay are reported in Chapter 3. Analyst judgment should be applied in determining a

representative delay reduction value. This value should then be reduced to reflect the percentage of bus stops at traffic signals where queue jumps would be installed. (For example, if a 10% intersection delay reduction is determined to be reasonable, and queue jumps would be installed at half the signalized intersections along the facility where bus stops are located, use a 5% reduction to reflect the impact over the facility length.) The resulting value should then be used to reduce the base bus running time loss value from Exhibit 6-73 by the same percentage. Apply the TCQSM speed estimation method with and without TSP effects to estimate the resulting change in average bus speed due to queue jumps.

- Results of a field study (*33*) of the effect of curb extensions on corridor bus delay are reported in Chapter 3, indicating a 7% improvement in bus speeds when applied throughout a corridor. Multiply this value by the percentage of bus stops along the facility that will have this treatment. Apply the TCQSM speed estimation method normally and then increase the result by the calculated percentage.

DIAGNOSING AND TREATING CAPACITY ISSUES

In this application, archived AVL data are used to identify operational issues in the form of bus delays or overall slow running speeds in particular locations. *TCRP Report 113: Using Archived AVL-APC Data to Improve Transit Performance and Management* (*38*) provides guidance on how to do this. Once "hot spots" have been identified, TCQSM methods can then be used to evaluate the potential effectiveness of treatments at those locations (e.g., adding stop capacity, adding a transit preferential treatment).

SIZING BRT FACILITIES FOR A GIVEN DEMAND

If future demand for a BRT or other bus facility has already been estimated (for example, from a regional planning model), TCQSM methods can be used to develop to estimate the required size of stations along the facility, as well as identify any bus capacity constraints along the facility. The process involves these steps:

1. Assumptions will be needed about the vehicle type(s) that will use the facility, particularly the number of doors per vehicle and a design passenger load.
2. Assumptions about the types of service on the facility will also be needed—multiple-route operation such as in Pittsburgh, Ottawa, and Brisbane requires more attention to individual route demand characteristics than a single BRT route serving a facility that serves all stops.
3. Determine the number of vehicles required by route to serve the estimated hourly demand. For BRT service, use of a peak-hour factor is recommended (locally generated or a default of 0.75) to avoid overcrowded buses during peak 15-min conditions.
4. Determine the number of buses stopping at each station during the analysis hour.
5. Estimate the average dwell time based on passenger boarding and alighting demand at the station and assumptions about the fare payment method.

6. Apply the TCQSM to determine (*a*) the capacity of a single loading area, based on the dwell time determined above and then (*b*) the number of physical loading areas required to provide sufficient loading areas to serve the number of buses serving the station. If scheduled demand will be 70% or more of capacity, consider adding additional capacity (e.g., adding another loading area, implementing fare-paid platforms to reduce dwell times) to reduce bus interference effects that reduce bus speeds.
7. Repeat steps 4–6 as needed along the facility length.

The resulting station sizes can then be provided as inputs to a cost-estimation process.

9. CALCULATION EXAMPLE

THE SITUATION

Calculation results have been updated as needed to reflect changes in the methodology or the example problem assumptions; these are not specifically marked as changes.

Carroll City, the central city in a region of 750,000 people, is examining opportunities to improve transit service through its downtown core as part of a Downtown Circulation Plan. Existing bus service to downtown is concentrated on Carroll Street and George Street, a one-way couplet just over one mile in length. Both streets have two through lanes, with on-street parking provided on both sides of the street.

The couplet is served by six transit routes operated by Carroll City Transit (CCT), with combined peak-hour frequency of 26 buses per hour. Buses stop every block, with average block lengths of 660 ft. On-street parking is removed at bus stops to allow buses access to the curb, and buses must exit the traffic stream to serve passengers. Traffic signals are located at each intersection along the downtown couplet.

The city is considering two options for operational changes and two options for design changes to the Carroll Street/George Street couplet, with the intention of improving the quality of transit service in the downtown area:

Operational Options

1. Implement a "pay-on-exit" fare payment system. Outbound passengers from the CBD will pay their fare when exiting the bus.
2. Implement skip-stop operations, such that each route stops every other block. Each transit stop would serve three of the six downtown routes under this scenario.

Design Options

1. Install curb extensions (bus bulbs) at stops to allow buses to serve passengers without leaving the traffic stream. Note that this option also provides additional space for passenger amenities and reduces pedestrian crossing distance, changes that may also impact the facility's quality of service as well.
2. Remove on-street parking along one side of the street, narrow the existing two through lanes, and install a bus lane. Right turns will be allowed from the bus lane. Buses will be allowed to exit the bus lane and travel in the adjacent travel lane if needed (gaps in traffic permitting).

For the sake of this example, the design options are mutually exclusive, but in actual application, a pay-on-exit system could be implemented with either design option, and skip-stop operations could be implemented in tandem with a curbside bus lane.

THE QUESTION

What is the potential bus capacity in vehicles per hour, and what are the travel time impacts of the options described above (and their combinations) during the p.m. peak period?

BUS CAPACITY

Step 1. Define the Facility

Under both existing conditions and Design Options 1 and 2, the facility consists of the one-way couplet of Carroll Street and George Street through the downtown core.

Step 2. Gather Input Data

Bus Stop Demand Data

The following demand data associated with individual bus stops are required to conduct a capacity analysis. All data are for a defined hour (typically a peak hour).

- *Coefficient of variation of dwell times* (c_v) = 0.62, based on an analysis of CCT's archived AVL data.
- *Passenger demand peak-hour factor* (*PHF*) = 0.75, based on an analysis of CCT's archived APC data for the p.m. peak hour. Passenger boarding and alighting volumes are also available from the APC system.

Bus Stop Location Data

- All stops are *off-line*, as buses exit the travel lane to access the curb.
- All stops along the couplet are *far side*.
- Bus stop design is *linear*.
- Two *loading areas* (*N*) are provided at bus stops in the central portion of the couplet by removing additional on-street parking at the stop. This reflects the higher passenger demand at these stops. Other stops have only one loading area. See Exhibit 6-76 for stop-by-stop details.
- The downtown street network is a one-way grid, with signals on every block. Signals operate on 80-s cycles, with both streets at a given intersection receiving the same amount of green time. Accounting for traffic signal lost time, this results in a *g/C* ratio of 0.45 for buses on the couplet. The posted speed is 25 mi/h.
- *Curb travel lane traffic volume (v)* varies from 450 to 650 veh/h. See Exhibit 6-76 for stop-by-stop details.
- *Right-turning traffic volume* varies from 0 to 160 veh/h. See Exhibit 6-76 for stop-by-stop details.
- *Parallel pedestrian crossing volume* varies from 40 to 400 ped/h. See Exhibit 6-76 for stop-by-stop details.

	Carroll Street Bus Stops							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Number of loading areas	1	1	2	2	2	2	1	1
Curb-lane volume (veh/h)	450	500	500	550	600	650	600	600
Right-turn volume (veh/h)*	75	110	0	160	0	60	80	75
Pedestrian volume (ped/h)	40	70	140	120	280	400	120	80
	George Street Bus Stops							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Number of loading areas	1	1	2	2	2	2	1	1
Curb-lane volume (veh/h)	650	600	550	550	550	500	450	450
Right-turn volume (veh/h)*	80	120	60	0	160	0	90	130
Pedestrian volume (ped/h)	110	140	80	300	340	170	130	140

Note: *Included as part of the curb lane volume.

Exhibit 6-76
Calculation Example: Summary of Existing Bus Stop Characteristics

Step 3. Set a Design Bus Stop Failure Rate

The TCQSM recommends a design failure rate of 7.5 to 15% for downtown areas. Based on the policies of CCT and the Carroll City Public Works Department, 15% is selected as the design bus stop failure rate for the analysis.

Step 4: Determine Dwell Time

All bus routes operate using 40-ft low-floor buses that have a wide (two-channel) front door and a narrower (one-channel) rear door. Boarding occurs through the front door. Passengers purchasing single-ride or daily fares must use the farebox, but passengers with a monthly pass can bypass the farebox by showing their pass to the operator. Agency data show that approximately 55% of passengers use the heavily discounted monthly passes. Alighting passengers may use either door, but favor the rear door to avoid conflicts with boarding passengers. Standees are not normally present.

Three methods are given in Step 4 for determining dwell time: field measurements, default values, and calculation. When possible, field measurements are preferred; however, for the sake of example, the calculation method is illustrated below.

Exhibit 6-77 summarizes the average boardings and alightings per bus by stop.

	Carroll Street Bus Stops							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Boarding passengers	3	5	10	5	12	8	3	6
Alighting passengers	3	2	7	8	7	3	0	0
	George Street Bus Stops							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Boarding passengers	2	4	8	10	6	12	4	3
Alighting passengers	2	4	6	6	8	4	2	0

Exhibit 6-77
Calculation Example: Average Boardings and Alightings per Bus by Stop

Assign Boarding and Alighting Volume by Door Channel

The current boarding scenario reflects *double-channel* boarding, in which 45% of passengers use the farebox (channel 1) and the remaining 55% use the front door but bypass the farebox (channel 2).

No alighting passengers will use channel 1 (as it will be occupied by boarders using the farebox). Assume that 25% of alighting passengers exit from the front door via

channel 2 (default value), with the remaining 75% of passengers using the rear door (channel 3).

Exhibit 6-78 shows the resulting average boarding and alighting volumes by door channel. Fractional numbers of people are used here, as these *average* volumes will be combined with average individual passenger service times to determine an overall average passenger service time by door channel. Rounding to whole passengers at this point would end up either over- or underestimating service times for a given combination of fare payment method and boarding direction, depending on which way the number was rounded, which would then result in the average dwell time being inaccurately estimated.

Exhibit 6-78
Calculation Example: Average Boardings and Alightings by Door Channel—Existing Conditions

	Door Channel	Carroll Street Bus Stops 1	2	3	4	5	6	7	8
Boardings	1	1.4	2.3	4.5	2.3	5.4	3.6	1.4	2.7
	2	1.7	2.8	5.5	2.8	6.6	4.4	1.7	3.3
	3	0	0	0	0	0	0	0	0
Alightings	1	0	0	0	0	0	0	0	0
	2	0.8	0.5	1.8	2.0	1.8	0.8	0	0
	3	2.3	1.5	5.3	6.0	5.3	2.3	0	0
	Door Channel	**George Street Bus Stops 1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Boardings	1	0.9	1.8	3.6	4.5	2.7	5.4	1.8	1.4
	2	1.1	2.2	4.4	5.5	3.3	6.6	2.2	1.7
	3	0	0	0	0	0	0	0	0
Alightings	1	0	0	0	0	0	0	0	0
	2	0.5	1.0	1.5	1.5	2.0	1.0	0.5	0
	3	1.5	3.0	4.5	4.5	6.0	3.0	1.5	0

Determine Average Passenger Service Time for Each Bus Door Channel

Exhibit 6-4 provides suggested default values for passenger service time based on the observed range. For the scenario under consideration, the following service times apply:

- Boardings through Channel 1: 4.5 s (exact change into farebox)
- Boardings through Channel 2: 2.0 s (visual fare inspection)
- Alightings through Channel 2: 2.5 s (front door)
- Alightings through Channel 3: 1.75 s (rear door)

In addition, when minor-direction flow through a door channel is more than 25% of the total flow through the door channel, boarding and alighting times should be increased by 20% to account for the congestion at the door. Two-directional flows occur in door channel 2, and minor-direction flow is more than 25% of the total flow at stops 1 and 4 on Carroll Street and at stops 1, 2, 3, and 5 on George Street.

Determine Passenger Flow Time for Each Bus Door Channel

Using Equation 6-4, calculate the average passenger flow time for each door channel. The calculations are shown in their entirety for Stop #1 on Carroll Street below.

$t_{pf,i} = P_{a,i}t_{a,i} + P_{b,i}t_{b,i}$

$t_{pf,1} = 0 + (1.4)(4.5) = 6$ s (rounded)

$t_{pf,2} = (0.8)(2.5 \times 1.2) + (1.7)(1.75 \times 1.2) = 6$ s

$t_{pf,3} = (2.3)(1.75) + 0 = 4$ s

Exhibit 6-79 shows the average passenger flow time for each door channel resulting from the calculations.

Exhibit 6-79
Calculation Example: Average Passenger Flow Time by Door Channel (s)—Existing Conditions

	Carroll Street Bus Stops							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Channel 1 ($t_{pf,1}$)	6	10	20	10	24	16	6	12
Channel 2 ($t_{pf,2}$)	6	7	15	13	18	11	3	7
Channel 3 ($t_{pf,3}$)	4	3	9	11	9	4	0	0
Maximum ($t_{pf,max}$)	6	10	20	13	24	16	6	12
	George Street Bus Stops							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Channel 1 ($t_{pf,1}$)	4	8	16	20	12	24	8	6
Channel 2 ($t_{pf,2}$)	4	8	15	15	14	16	6	3
Channel 3 ($t_{pf,3}$)	3	5	8	8	11	5	3	0
Maximum ($t_{pf,max}$)	4	8	16	20	14	24	8	6

Determine the Boarding Lost Time

Stops 1, 2, 7, and 8 on both Carroll Street and George Street have only one loading area each, and therefore have no boarding lost time.

Assume that boarding lost time is equal to 2 s for the remaining stops, each of which have two loading areas. While there is no research specific to boarding lost time at stops with two loading areas, it is assumed that it would be less than the average boarding lost time of 4–4.5 s for stops with three loading areas.

Calculate the Dwell Time

Using Equation 6-5, calculate the average dwell time for each bus stop. The calculation is shown for Stop #1 on Carroll Street below, using an assumed door opening and closing time t_{oc} of 4 s.

$t_d = t_{pf,max} + t_{oc} + t_{bl}$

$t_d = 6 + 4 + 0 = 10$ s

Exhibit 6-80 shows the average dwell time for each of the study facility stops.

Exhibit 6-80
Calculation Example: Average Dwell Time by Stop (s)—Existing Conditions

	Bus Stop							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Carroll Street	10	14	26	19	30	22	10	16
George Street	8	12	22	26	20	30	12	10

Step 5: Determine Loading Area Capacity

Determine the Clearance Time

Because the stops on the corridor are off-line, the clearance time is equal to 10 s (the minimum time for a standard bus to start up and travel its own length, and for the next

bus to pull in) plus reentry delay. The calculation of reentry delay varies depending on the bus stop location relative to traffic signals; since all bus stops in the corridor are located at signalized intersections, Case 2 applies to all stops.

The first step is to determine the queue service time g_s, which represents time that buses are unable to leave the bus stop because a platoon of vehicles is discharging from the upstream traffic signal. Equation 6-9 through Equation 6-11 are used to determine this time. This process is illustrated for Stop #1 on Carroll Street, using a value of 1,625 veh/h for the saturation flow rate s_f, from Exhibit 6-60:

$$g_s = \frac{Q_r}{(s_f/3{,}600) - q_g} = \frac{q(C-g)}{(s_f/3{,}600) - q} = \frac{(v/3{,}600)(C-g)}{(s_f/3{,}600) - (v/3{,}600)}$$

$$g_s = \frac{(450/3{,}600)(80 - (0.45)(80))}{(1{,}625/3{,}600) - (450/3{,}600)}$$

$$g_s = 16.9\ s$$

The queue service time g_s is then compared to the effective green time g (equal to $g/C \times C$) and the smaller value is used as the queue service delay d_{qs}, per Equation 6-12. Since 16.9 s is smaller than (0.45 × 80 = 36 s), it is used as the queue service delay.

Next, the average delay that a bus experiences waiting for a gap in traffic is calculated, for the times that a platoon is not passing by the bus stop. The volume of traffic conflicting with bus movements during these times is given by Equation 6-13. For Stop #1 on Carroll Street, $v_{adj} = v(g/C) = 450\ 0.45 = 203$ veh/h. This adjusted volume is then used in for Case 2 $c_{re,2}$. Assuming default values of 7.0 s and 3.3 s for critical headway and follow-up time, respectively, $c_{re,2}$ is calculated as follows for Stop #1 on Carroll Street:

$$c_{re,2} = v_{adj} \frac{e^{-vt_{ch}/3{,}600}}{1 - e^{-vt_f/3{,}600}}$$

$$c_{re,2} = 203 \frac{e^{-(203)(7.0)/3{,}600}}{1 - e^{-(203)(3.3)/3{,}600}}$$

$$c_{re,2} = 804\ veh/h$$

Equation 6-7 is then used to calculate the average delay waiting for a gap in traffic before a bus can exit the bus stop:

$$d_{re,2} = \frac{3{,}600}{c_{re,2}} + 900\left[\frac{N_{la}}{c_{re,2}} - 1 + \sqrt{\left(\frac{N_{la}}{c_{re,2}} - 1\right)^2 + \frac{\left(\frac{3{,}600}{c_{re,2}}\right)\left(\frac{N_{la}}{c_{re,2}}\right)}{450}}\right] - 3.3$$

$$\mathrm{d_{re,2}} = \frac{3{,}600}{804} + 900\left[\frac{1}{804} - 1 + \sqrt{\left(\frac{1}{804} - 1\right)^2 + \frac{\left(\frac{3{,}600}{804}\right)\left(\frac{1}{804}\right)}{450}}\right] - 3.3$$

$$\mathrm{d_{re,2}} = 1.2\ \mathrm{s}$$

Because all stops are far-side stops, Equation 6-15 is used to calculate the reentry delay. This value is the average of the queue service delay and the gap-in-traffic delay,

weighted by the proportion of time a platoon of vehicles is and is not present, respectively. For Stop #1 on Carroll Street, the calculations are as follows:

$$d_{re,2fs} = d_{qs}\frac{d_{qs}}{C} + d_{gt}\frac{(C - d_{qs})}{C}$$

$$d_{re,2fs} = 16.9\frac{16.9}{80} + 1.2\frac{(80 - 16.9)}{80}$$

$$d_{re,2fs} = 4.5\ s$$

Finally, the clearance time t_c is the reentry delay (4.5 s) plus the minimum bus start-up and movement time (10 s), or 14.5 s. Exhibit 6-81 provides reentry and clearance times for all stops in the corridor.

Exhibit 6-81
Calculation Example: Reentry and Clearance Times by Stop (s)—Existing Conditions

	Carroll Street Bus Stops							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Reentry time t_{re} (s)	5	6	6	7	9	12	9	9
Clearance time t_c (s)	15	16	16	17	19	22	19	19
	George Street Bus Stops							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Reentry time t_{re} (s)	12	10	8	8	8	6	5	5
Clearance time t_c (s)	22	20	18	18	18	16	15	15

Calculate the Loading Area Capacity

Use Equation 6-6 to calculate the loading area capacity for each stop. Using Exhibit 6-56, the standard normal variable Z associated with the design failure rate of 15% is 1.04. The calculation of loading area capacity for Stop #1 on Carroll Street is shown below.

$$B_l = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + t_{om}} = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + Zc_v t_d}$$

$$B_l = \frac{3{,}600(0.45)}{14.5 + 10(0.45) + (1.04)(0.60)(10)}$$

$$B_l = \frac{1{,}620}{25.24} = 64 \text{ bus/h}$$

Exhibit 6-82 shows the loading area capacity for each stop.

Exhibit 6-82
Calculation Example: Loading Area Capacity by Stop (bus/h)—Existing Conditions

	Bus Stop							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Carroll Street	64	53	37	48	31	36	54	44
George Street	53	50	40	36	42	34	59	64

Step 6: Determine Bus Stop Capacity

Determine the Number of Effective Loading Areas

Use Exhibit 6-63 to estimate the number of effective loading areas N_{el} at each stop. Stops with one loading area will 1.00 effective loading areas, while stops with two loading areas will have 1.85 effective loading areas (as the stops are off-line).

Adjust Capacity for Traffic Blockage

Use Equation 6-17 to calculate the traffic blockage adjustment factor f_{tb}. The bus stop location factor f_l is 0.5 because stops are located far side and buses are able to move into the adjacent travel lane as needed.

The capacity of the curb lane through movement c_{th} is estimated as 1,625 × (g/C), or 731, based on the saturation flow values in Exhibit 6-60. The capacity of the right-turn movement c_{rt} is estimated as 1,450 × (g/C) × (1-(pedestrian volume/2,000)), using the equation accompanying Exhibit 6-65. For Stop #1 on Carroll Street, c_{rt} equals 639 veh/h. The curb lane capacity is the volume-weighted average of the through and right-turn capacities:

$$c_{cl} = 731\frac{(450-75)}{450} + 639\frac{75}{450} = 716 \text{ veh/h}$$

The traffic blockage adjustment factor calculation for Stop #1 on Carroll Street is as follows:

$$f_{tb} = 1 - f_l\left(\frac{v_{cl}}{c_{cl}}\right)$$

$$f_{tb} = 1 - 0.5\left(\frac{450}{723}\right) = 0.69$$

Exhibit 6-83 shows the traffic blockage adjustment factor for each stop.

Calculate Bus Stop Capacity

Use Equation 6-18 to calculate the bus stop capacity, rounding down the result to the nearest whole number. The calculation for Stop #1 on Carroll Street is shown below.

$$B_s = N_{el}B_l f_{tb} = (1.0)(64)(0.69) = 44 \text{ bus/h}$$

Exhibit 6-83 shows the bus stop capacity for each stop on the facility.

Exhibit 6-83
Calculation Example: Bus Stop Capacity—Existing Conditions

	Carroll Street Bus Stops							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Loading area capacity B_l (bus/h)	64	53	37	48	31	36	54	44
Effective loading areas N_{el}	1.00	1.00	1.85	1.85	1.85	1.85	1.00	1.00
Blockage factor f_{tb}	0.69	0.65	0.66	0.61	0.59	0.54	0.58	0.58
Bus stop capacity B_s	44	33	44	53	34	35	31	25
	George Street Bus Stops							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Loading area capacity B_l (bus/h)	53	50	40	36	42	34	59	64
Effective loading areas N_{el}	1.00	1.00	1.85	1.85	1.85	1.85	1.00	1.00
Blockage factor f_{tb}	0.55	0.58	0.62	0.62	0.59	0.66	0.68	0.68
Bus stop capacity B_s	29	28	45	41	45	41	40	43

Step 7: Determine Facility Bus Capacity

As skip-stop operations are not used on this facility, the facility bus capacity is simply equal to the capacity of the critical bus stop (i.e., the bus stop with the lowest capacity). The critical bus stop on Carroll Street is Stop #8, with a capacity of 25 buses per hour, and the critical bus stop on George Street is Stop #2, with a capacity of 28 buses per hour. Because 26 buses are currently scheduled in the peak hour in each

direction, the result of 25 buses per hour for the design capacity on Carroll Street indicates that the desired 15% failure rate cannot be achieved and that buses will experience less reliable operations than planned.

BUS SPEED

Step 1: Define the Facility

Under the existing conditions and Design Options 1 and 2, the facility consists of the one-way couplet of Carroll Street and George Street through the downtown core.

Step 2: Gather Input Data

The input data needed to calculate bus speed are largely available from the bus capacity analysis described above. In addition, the following input data are required:

- Average stop spacing is eight stops per mile in each direction.
- There are 26 buses per hour scheduled at the critical bus stop in each direction.
- Traffic signals are located every block (approximately 8 signals per mile). The signals are not timed specifically for bus operations.

Step 3: Determine Maximum Capacity

Maximum capacity is determined by recalculating the capacity of the critical stop in each direction using a 25% failure rate, instead of the 15% used previously to determine design capacity. The critical bus stop on Carroll Street was Stop #8, and its maximum capacity is 28 buses per hour. The critical stop on George Street was Stop #2, and its maximum capacity is 30 buses per hour. The scheduled number of buses (26 per hour) is less than the maximum capacity in both directions.

Step 4: Determine Base Bus Running Time

Calculate the Unimpeded Bus Running Time Rate

Because the conditions in the study area (typical signal timing, posted speed of 25 mi/h) match those used to develop Exhibit 6-70, the exhibit can be used directly to estimate bus speeds. Using the results of the dwell time calculations given previously (Exhibit 6-80), it is determined that the average dwell time of all stops is 18.4 s on Carroll Street and 17.5 s for George Street. From Exhibit 6-70, the unimpeded bus running time rates for 10- and 20-s dwell times are 5.06 min/mi and 6.39 min/mi, respectively. Interpolating between these values for dwell times of 18.4 and 17.5 s gives unimpeded bus running time rates of 6.18 and 6.06 min/mi for Carroll Street and George Street, respectively.

These running time rates could also be calculated directly using Equation 6-27 through Equation 6-33. The time spent decelerating from running speed to a stop, assuming a standard bus deceleration rate of 4.0 ft/s^2, is given by Equation 6-28:

$$t_{dec} = \frac{c_f v_{run}}{a} = \frac{(1.47)(25)}{(4)} = 9.2\ s$$

Similarly, the time spent accelerating back to running speed from a stop, assuming an average standard bus acceleration rate of 3.4 ft/s² to 25 mi/h, is calculated from Equation 6-27:

$$t_{acc} = \frac{c_f v_{run}}{d} = \frac{(1.47)(25)}{(3.4)} = 10.8\ s$$

As this is not a busway operation, the time t_{sta} and distance L_{sta} spent by express buses passing through stations at a reduced speed are set to zero. The total distance travelled per stop while accelerating or decelerating is given by Equation 6-30:

$$L_{ad} = 0.5at_{acc}^2 + 0.5dt_{dec}^2 + L_{sta}$$

$$L_{ad} = (0.5)(3.4)(10.8)^2 + (0.5)(4.0)(9.2)^2 + 0$$

$$L_{ad} = 368\ ft$$

The total distance travelled at running speed per mile or kilometer is the length of a mile (5,280 ft) minus the product of the number of stops per mile and the acceleration/deceleration distance per stop, as given by Equation 6-31:

$$L_{rs} = L_{mk} - N_s L_{ad} = 5{,}280 - (8)(368) = 2{,}336\ ft$$

Because this result is greater than zero, buses can reach the assumed running speed between stops and no adjustment to the assuming running speed is required.

The time spent travelling at running speed in each mile is the distance travelled at running speed divided by the running speed (converted from mi/h to ft/s), as given by Equation 6-32:

$$t_{rs} = \frac{L_{rs}}{c_f v_{run}} = \frac{2{,}336}{(1.47)(25)} = 63.6\ s$$

Finally, the unimpeded running time rate is the sum of the time spent at running speed plus the sum of the average dwell time and acceleration and deceleration times associated with each bus stop, as calculated by Equation 6-33. For Carroll Street:

$$t_u = \frac{t_{rs} + N_s(t_{dt} + t_{acc} + t_{dec} + t_{sta})}{60}$$

$$t_u = \frac{63.6 + 8(18.4 + 10.8 + 9.2 + 0)}{60}$$

$$t_u = 6.18\ min/mi$$

Similarly, the unimpeded running time rate for George Street is calculated as 6.06 min/mi. These values match those obtained using Exhibit 6-70.

Calculate Additional Running Time Losses

Exhibit 6-73 is used to determine the base bus running time loss t_l, representing delay due to traffic signals and traffic interference. Both Carroll Street and George Street are mixed-traffic facilities in the CBD with typical signal operations; Exhibit 6-73 gives a value of 3.0 min/mi for t_l under these conditions.

Calculate the Base Bus Running Time Rate

Equation 6-34 is used to calculate the base bus running time, which is simply the sum of the unimpeded running time rate t_u and the additional running time losses t_l. The

base bus running time is 9.18 min/mi for Carroll Street and 9.06 min/mi for George Street.

Step 5: Adjust for Skip-Stop Operations

As skip-stop operations are not being used under existing conditions, no adjustment needs to be made (i.e., $f_{sp} = 1$).

Step 6: Adjust for Bus Congestion

The bus volume-to-capacity ratio is determined by dividing the scheduled number of buses per hour (26) on each street by the street's maximum capacity, calculated earlier in Step 3 (28 and 30 bus/h for Carroll and George Street, respectively). The results are bus *v/c* ratios of 0.93 and 0.87 for Carroll and George Streets, respectively.

These *v/c* ratios are then used as inputs in Exhibit 6-75 to determine Interpolating from the exhibit gives factors of 0.64 and 0.73 for Carroll and George Streets, respectively.

Step 7: Determine Average Section Speed

Equation 6-36 and Equation 6-37 are used to calculate the section running time rate t_s and speed S_s. For Carroll Street:

$$t_s = \frac{t_r}{f_{sp} f_{bb}} = \frac{9.18}{(1)(0.64)} = 14.34\ min/mi$$

$$S_s = \frac{60}{t_s} = \frac{60}{14.34} = 4.2\ \text{mi/h}$$

Similarly, for George Street:

$$t_s = \frac{t_r}{f_{sp} f_{bb}} = \frac{9.06}{(1)(0.76)} = 11.92\ min/mi$$

$$S_s = \frac{60}{t_s} = \frac{60}{11.92} = 4.8\ \text{mi/h}$$

OPTIONS ASSESSMENT

As described in the introduction to this example, there are several operations and design options under consideration to improve bus service through the downtown core. The capacity and speed effects of each option are evaluated here in more detail. It is assumed that other considerations (e.g., potential drainage issues associated with curb extensions, potential increase in walking distances to bus stops with skip stops) have already been evaluated and the options determined to be feasible, or that these considerations will be evaluated at a later stage of the evaluation.

For each option, calculations are shown only for the portions of the capacity and speed methodologies that change with each option (e.g., the change to a fare-free zone affects only the dwell time calculations). In addition, the effect of each option on overall capacity and speed is discussed.

Operations Option 1: Implement Pay-on-Exit

Under Operations Option 1, CCT would implement a "pay-on-exit" fare payment system. Passengers boarding in the CBD could use any door and would pay their fare on exiting the bus. (Inbound passengers to the CBD would pay their fare on boarding, as usual). One hoped-for outcome of such a change would be to reduce dwell times at the busy CBD stops by allowing passengers to board more quickly.

Operations Option 1 directly affects only Step 4, Determine Dwell Times, of the bus capacity methodology, and does not directly impact the procedures for bus speed at all (although the change in average dwell time will of course require that bus speeds be recalculated). The impacts on dwell time are described below.

Capacity Step 4: Determine Dwell Times

Assign Boarding and Alighting Volume by Door Channel

The change to a fare-free zone would result in all-door boarding along the facility. Passengers would have the option of boarding through the rear door, resulting in three door channels.

Using Exhibit 6-58, assign 45% of boarding passengers to the busiest door channel and 45% of alighting passengers to the busiest door channel. To be conservative, assume that the busiest door channel for boarding passengers is that same as that for alighting passengers.

Exhibit 6-84 shows the resulting boarding and alighting volumes by door channel.

Exhibit 6-84
Calculation Example: Average Boardings and Alightings by Door Channel (s)—Pay-on-Exit

	Door Channel	Carroll Street Bus Stops 1	2	3	4	5	6	7	8
Boardings	1	1.4	2.3	4.5	2.3	5.4	3.6	1.4	2.7
	2	0.8	1.4	2.8	1.4	3.3	2.2	0.8	1.7
	3	0.8	1.4	2.8	1.4	3.3	2.2	0.8	1.7
Alightings	1	0	0	0	0	0	0	0	0
	2	0.8	0.5	1.8	2.0	1.8	0.8	0	0
	3	2.3	1.5	5.3	6.0	5.3	2.3	0	0
	Door Channel	**George Street Bus Stops 1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Boardings	1	0.9	1.8	3.6	4.5	2.7	5.4	1.8	1.4
	2	0.6	1.1	2.2	2.8	1.7	3.3	1.1	0.8
	3	0.6	1.1	2.2	2.8	1.7	3.3	1.1	0.8
Alightings	1	0	0	0	0	0	0	0	0
	2	0.5	1.0	1.5	1.5	2.0	1.0	0.5	0
	3	1.5	3.0	4.5	4.5	6.0	3.0	1.5	0

Determine Average Passenger Service Time for Each Bus Door Channel

Exhibit 6-4 provides suggested default values for passenger service time based on the observed range. For the all-door boarding, the following service times apply:

- Boardings: 1.75 s,
- Alightings through Channels 1 and 2: 2.5 s (front door), and
- Alightings through Channel 3: 1.75 s (rear door).

As before, passenger service times are increased by 20% for door channels where the minor flow is more than 25% of the total passenger flow through the door.

Determine Average Passenger Flow Time for Each Bus Door Channel

Equation 6-4 is used to calculate the passenger flow time for each door channel. Exhibit 6-85 shows the passenger flow time for each door channel resulting from the calculations.

Exhibit 6-85
Calculation Example: Average Passenger Flow Time by Door Channel (s)—Pay-on-Exit

	Carroll Street Bus Stops							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Channel 1 ($t_{pf,1}$)	2	4	8	4	10	6	2	5
Channel 2 ($t_{pf,2}$)	4	4	11	9	12	7	1	3
Channel 3 ($t_{pf,3}$)	7	6	17	16	18	9	1	3
Maximum ($t_{pf,max}$)	7	6	17	16	18	9	2	5
	George Street Bus Stops							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Channel 1 ($t_{pf,1}$)	2	3	6	8	5	10	3	2
Channel 2 ($t_{pf,2}$)	3	5	9	10	10	8	4	1
Channel 3 ($t_{pf,3}$)	5	9	15	12	20	11	5	3
Maximum ($t_{pf,max}$)	5	9	15	12	20	11	5	3

Comparing Exhibit 6-85 to Exhibit 6-79, passenger service times increased by 1 s at three stops, and by 3 s and 6 s at one stop each. Service times decreased at the other eleven stops, with reductions ranging from 1 s to 13 s. Overall, service times are reduced by an average of 3 s per stop, and the longest service times on both streets are both reduced. The variable effect is due to the different mixtures of boarding and alighting passengers at each stop; stops with higher boarding volumes will benefit most from the change, while stops with more alightings than boardings may actually experience increased passenger boarding time due to the increased passenger congestion at the doors.

As a result, the impact on bus capacity and speed resulting from a switch to a pay-on-exit system will depend heavily on the mix of boarding and alighting passengers at the critical bus stop along the facility.

Determine the Boarding Lost Time

Boarding lost time does not change with all-door boarding.

Calculate the Dwell Time

Equation 6-5 is used to calculate the average dwell time for each bus stop, using the same average door opening and closing time (4 s) as before. Exhibit 6-86 shows the average dwell time for each of the study facility stops.

Exhibit 6-86
Calculation Example: Average Dwell Time by Stop (s)—Pay-on-Exit

	Bus Stop							
	1	2	3	4	5	6	7	8
Carroll Street	10	10	23	21	24	15	6	9
George Street	9	13	21	18	26	17	9	7

Assessment of Capacity and Speed Impacts

Exhibit 6-87 shows the bus capacity and speed impacts results associated with Operations Option 1. This exhibit shows mixed results for the operational impacts of the pay-on-exit system, with a moderate increase in capacity and speed for Carroll Street, but a small reduction in capacity and no change in speed on George Street. The lack of improvement on George Street is a result of the pay-on-exit system resulting in a small increase in dwell time at the critical stop (Stop #2). In this case, the critical stop was not the stop with the longest dwell time, but the stop with the longest dwell time among the four stops with only one loading area.

Exhibit 6-87
Calculation Example: Summary of Impacts—Pay-on-Exit

	Existing Conditions		Operations Option 1			
	Capacity (bus/h)	Speed (mi/h)	Capacity (bus/h)	Speed (mi/h)	% Change in Speed	Minutes Saved per Bus
Carroll Street	25	4.2	32	5.8	+38%	4.0
George Street	28	4.8	27	4.8	+0%	0.0

Operations Option 2: Implement Skip-Stop Operations

The option under consideration would have buses stop every other stop, resulting in a two-stop skip pattern.

Capacity Step 4: Determine Dwell Time

Because each bus is stopping half as frequently as it used to, dwell times at the remaining stops will be twice as high as before, assuming no loss of ridership due to the longer walking distances to stops for some passengers.

Capacity Step 7: Determine Bus Facility Capacity

Use Equation 6-21 to calculate the adjacent lane impedance factor f_i. Use an average volume of 550 veh/h for both Carroll Street and George Street for the adjacent lane volume based on the information shown in Exhibit 6-76.

$$f_i = 1 - 0.8\left(\frac{v_a}{c_a}\right)^3 = 1 - 0.8\left(\frac{550}{731}\right)^3 = 0.66$$

Use Equation 6-20 to calculate the capacity adjustment factor f_k. Assume that scheduled bus arrivals will be spread out throughout the peak hour, but that actual bus arrivals will deviate somewhat from the schedule (but not excessively), and set f_a = 0.75.

$$f_k = \frac{1 + f_a f_i (N_{ss} - 1)}{N_{ss}} = \frac{1 + (0.75)(0.66)(2 - 1)}{2} = 0.75$$

Determine the individual capacity of the two bus stops (B_1 and B_2) using the individual bus stop capacity results shown in Exhibit 6-83. Assume that B_1 consists of stops 1, 3, 5, and 7, and that B_2 consists of stops 2, 4 , 6, and 8. Exhibit 6-88 shows the bus stop group capacities.

Exhibit 6-88
Calculation Example: Bus Stop Group Capacities (bus/h)—Skip Stops

		Bus Stop 1/2	3/4	5/6	7/8	Minimum
Carroll Street	B_1	35	28	22	29	22
	B_2	26	40	26	21	21
George Street	B_1	22	28	29	27	22
	B_2	20	25	24	30	20

Use Equation 6-19 to calculate design bus facility capacity:

$$Carroll\ Street: B = f_k(B_1 + B_2) = (0.75)(22 + 21) = 32 \text{ bus/h}$$

$$George\ Street: B = f_k(B_1 + B_2) = (0.75)(22 + 20) = 31 \text{ bus/h}$$

Speed Step 4: Determine Base Bus Running Time Rate

With a two-stop skip-stop pattern, each bus will stop at half as many stops as it did before. As a result, the bus stop spacing within each pattern is reduced from 8 stops/mi to 4 stops/mi and the average dwell time increases to 36.8 and 35.0 s for Carroll and George Streets, respectively. Therefore, the base bus running time rate needs to be recalculated. Interpolating from Exhibit 6-70, the new unimpeded bus running times are 5.51 and 5.39 min/mi for Carroll Street and George Street, respectively. The running time losses remain the same at 3 min/mi for both streets, resulting in base bus running time rates of 8.51 and 8.39 min/mi for Carroll and George Streets, respectively.

Speed Step 5: Adjust for Skip-Stop Operations

Use Equation 6-35 to calculate the stop pattern adjustment factor f_{sp} for each stop group. This factor reflects how The calculation for stop group 1 on Carroll Street is shown below. The values for d_1 and d_2 are 660 feet and 1,320 feet, respectively, based on 8 total stops per mile and 2 stop groups. Assume that the routes are split such that half of the total number of buses scheduled per hour use each group.

Maximum bus facility capacity will also need to be determined by recalculating bus facility capacity using a 25% failure rate. These capacities are 38 and 35 bus/h for Carroll and George Street, respectively.

The calculation of the stop pattern adjustment factor is shown for Carroll Street:

$$f_{sp} = 1 - \left(\frac{d_1}{d_2}\right)\left(\frac{v_{al}}{c_{al}}\right)^2\left(\frac{v_b}{B_{max}}\right)$$

$$f_{sp} = 1 - \left(\frac{660}{1{,}320}\right)\left(\frac{550}{731}\right)^2\left(\frac{26}{38}\right)$$

$$f_{sp} = 1 - (0.5)(0.75)^2(0.68)$$

$$f_{sp} = 0.81$$

Similarly, the stop pattern adjustment factor is 0.79 for George Street.

Speed Step 6: Adjust for Bus Congestion

Skip-stop operations increase a bus facility's maximum capacity and thereby reduce bus-bus interference. On Carroll Street, the bus volume-to-capacity ratio is (26 / 38) or 0.68; the corresponding bus–bus interference factor from Exhibit 6-75 is 0.90. For

George Street, the bus volume-to-capacity ratio is 0.74 and the corresponding bus–bus interference factor is 0.86.

Assessment of Capacity and Speed Impacts

Exhibit 6-89 shows the bus capacity and speed impacts results associated with implementing a two-block skip-stop pattern on Carroll Street and George Street. This exhibit shows moderate improvements in bus speeds on the two streets associated with the conversion to skip-stop operations. Even though dwell times increased at the remaining stops served by each bus, the reduction in the number of stops made by a given bus resulted in a net positive speed benefit. However, this benefit need to be weighed against a potential decrease in pedestrian access to buses associated with the longer stop spacing. Although the maximum additional walk for passengers is one block and downtown areas typically have good sidewalk networks, those passengers who would need to walk an extra block (660 ft, approximately 3 min) would experience a longer overall trip.

Exhibit 6-89
Calculation Example: Summary of Impacts—Skip Stops

	Existing Conditions		Operations Option 2			
	Capacity (bus/h)	Speed (mi/h)	Capacity (bus/h)	Speed (mi/h)	% Change in Speed	Minutes Saved per Bus
Carroll Street	25	4.2	38	5.1	+21%	2.5
George Street	28	4.8	35	5.8	+21%	2.2

Design Option 1: Install Curb Extensions

Installing curb extensions reduces the clearance time for buses when leaving stops by eliminating the reentry delay component of clearance time (i.e., the stops will be converted from off-line to on-line stops).

Step 5: Determine Loading Area Capacity

Exhibit 6-81 shows the clearance time associated with off-line stops under existing conditions. With on-line stops, the clearance time would be equal to 10 s for every stop, as reentry delay would be eliminated. The calculation for Stop 1 on Carroll Street is shown below.

$$B_l = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + t_{om}} = \frac{3{,}600(g/C)}{t_c + t_d(g/C) + Zc_v t_d}$$

$$B_l = \frac{3{,}600(0.45)}{10 + 10(0.45) + (1.04)(0.60)(10)}$$

$$B_l = \frac{1{,}620}{20.74} = 78 \text{ bus/h}$$

Exhibit 6-90 shows the loading area capacity for each stop.

	Bus Stop							
	1	2	3	4	5	6	7	8
Carroll Street	78	65	43	62	38	48	78	60
George Street	87	71	48	43	52	38	71	78

Exhibit 6-90
Calculation Example: Loading Area Capacity by Stop (bus/h): Design Option 1

The remainder of the bus capacity and speed procedures are performed as shown previously for existing conditions, with the exception that the number of effective loading areas should be recalculated using Exhibit 6-63 using the "on-line, random arrivals" column, resulting in the stops with two physical loading areas providing 1.75 effective loading areas.

Assessment of Capacity and Speed Impacts

Exhibit 6-91 shows the bus capacity and speed impacts results associated with Design Option 1, taking the average of the two bus groups for Carroll Street and George Street. This exhibit shows moderate improvements in bus speeds associated with the addition of curb extensions along the corridor.

	Existing Conditions		Design Option 1			
	Capacity (bus/h)	Speed (mi/h)	Capacity (bus/h)	Speed (mi/h)	% Change in Speed	Minutes Saved per Bus
Carroll Street	25	4.2	34	5.9	+40%	4.1
George Street	28	4.8	40	6.3	+31%	3.0

Exhibit 6-91
Calculation Example: Summary of Design Option 1 Impacts

Design Option 2: Implement Curbside Bus Lanes

The bus lanes being considered will allow other vehicles to enter the bus lane to make right turns at intersections and will allow buses to enter the adjacent lane as needed to move around other vehicles in the bus lane. Thus, these will be Type 2 bus lanes.

Capacity Step 5: Determine Loading Area Capacity

One of the parking lanes is being removed and the existing travel lanes are being narrowed to provide room for a curbside bus lane. Buses will stop in the bus lane at stops; thus, the stops will be on-line. The procedures for adjusting the loading area capacity to reflect on-line stops are described above for Design Option 1 and remain the same under Design Option 2.

Capacity Step 6: Determine Bus Stop Capacity

The capacity of the right-turn movement is calculated based on Exhibit 6-65. Exhibit 6-76 provides pedestrian volumes for each stop. The calculation is shown for Stop 1 on Carroll Street below:

$$c_{rt} = 1{,}450(g/C)\left\{1 - \frac{(\text{peds/h})}{2{,}000}\right\}$$

$$c_{rt} = 1{,}450(0.45)\left\{1 - \frac{40}{2{,}000}\right\} = 639 \text{ veh/h}$$

The capacity of the through movement c_{th} is 731 veh/h, as before. The curb lane capacity is the volume-weighted average of the through and right-turn capacities, with

the through volume reflecting the scheduled number of buses and the right-turn volume reflecting the values given in Exhibit 6-76.

$$c_{cl} = 731\frac{(101-75)}{101} + 639\frac{75}{101} = 663 \text{ veh/h}$$

The traffic blockage adjustment factor calculation for Stop #1 on Carroll Street is as follows:

$$f_{tb} = 1 - f_l\left(\frac{v_{cl}}{c_{cl}}\right)$$

$$f_{tb} = 1 - 0.5\left(\frac{101}{663}\right) = 0.92$$

Exhibit 6-92 shows the right-turn capacity, curb lane capacity, and traffic blockage adjustment factor by stop.

Exhibit 6-92
Calculation Example: Traffic Blockage Factor f_l by Stop (veh/h)

	Carroll Street Bus Stops							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Right-turn capacity, c_{rt} (veh/h)	639	630	607	613	561	522	613	626
Curb lane capacity, c_{cl} (veh/h)	663	649	731	630	731	585	642	653
Traffic blockage adjustment factor, f_{tb}	0.92	0.90	0.98	0.85	0.98	0.93	0.92	0.92
	George Street Bus Stops							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Right-turn capacity, c_{rt} (veh/h)	617	607	626	555	542	597	610	607
Curb lane capacity, c_{cl} (veh/h)	645	629	658	731	568	731	637	628
Traffic blockage adjustment factor, f_{tb}	0.92	0.88	0.93	0.98	0.84	0.98	0.91	0.88

Speed Step 4: Determine Base Bus Running Time Rate

Exhibit 6-73 is used to determine the base bus running time loss t_l. For Type 2 bus lanes in the CBD with typical signal operations, t_l is 2.0 min/mi.

The steps involved with the remainder of the speed calculation remain the same as before.

Assessment of Capacity and Speed Impacts

Exhibit 6-93 shows the bus capacity and speed impacts results associated with Design Option 2. The bus lanes results in substantial improvements in speed and capacity.

Exhibit 6-93
Calculation Example: Summary of Design Option 2 Impacts, No Skip-Stop Operation

	Existing Conditions		Design Option 2			
	Capacity (bus/h)	**Speed (mi/h)**	**Capacity (bus/h)**	**Speed (mi/h)**	**% Change in Speed**	**Minutes Saved per Bus**
Carroll Street	25	4.2	55	7.3	+74%	6.1
George Street	28	4.8	62	7.4	+54%	4.4

COMMENTS

The design options used in this example focused on facilitywide improvements, for the sake of illustrating the TCQSM's bus speed and capacity calculation methods. In actual practice, an agency could also evaluate smaller-scale options focusing on improving conditions at the critical stop(s). Such an effort could produce reasonable benefits at a considerably lower implementation cost.

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APPENDIX A: EXHIBITS IN METRIC UNITS

Exhibit 6-7m
Estimated Average Bus Speeds on Grade-Separated Busways (km/h)

Average Stop Spacing (km)	Average Dwell Time (s) 0	15	30	45	60
80 km/h RUNNING SPEED					
1.0	54	42	36	31	28
1.5	61	50	44	39	35
2.0	65	55	49	45	41
3.0	69	61	57	53	49
4.0	71	65	61	57	54
90 km/h RUNNING SPEED					
1.0	57	43	36	32	28
1.5	65	52	45	40	36
2.0	70	58	52	47	43
3.0	75	66	61	56	52
4.0	79	71	66	61	58
100 km/h RUNNING SPEED					
1.0	59	43	37	32	28
1.5	68	53	47	41	37
2.0	74	61	54	48	44
3.0	81	70	63	58	54
4.0	85	75	70	65	61

Note: Assumes average 0.67 m/s^2 acceleration and 1.2 m/s^2 deceleration rate (12-m standard diesel bus). Use the zero dwell time column for express buses slowing, but not stopping at stations (40 km/h station speed limit and 100-m-long speed zone through station assumed). Assumes passing lane available for non-stopping buses and no at-grade pedestrian crossings within the station.

Exhibit 6-73m
Estimated Base Bus Running Time Losses, t_l (min/km)

Condition	Bus Lane	Bus Lane, No Right Turns	Bus Lane With Right Turn Delays	Bus Lanes Blocked by Traffic	Mixed Traffic Flow
CENTRAL BUSINESS DISTRICT					
Typical		0.7	1.2	1.5-1.8	1.8
Signals Set for Buses		0.4	0.8		
Signals More Frequent Than Bus Stops		0.9–1.2	1.5–1.8	1.8–2.1	2.1–2.4
ARTERIAL ROADWAYS OUTSIDE THE CBD					
Typical	0.4				0.6
Range	0.3–0.6				0.4–0.9

Source: Derived from *TCRP Report 26* (*21*).
Note: Traffic delays reflect peak conditions.

APPENDIX B: DWELL TIME DATA COLLECTION

INTRODUCTION

As discussed in Section 2, passenger service times (and dwell times) can vary greatly depending on many factors. For example, the average passenger boarding times shown in Exhibit 6-4 for level boarding ranged from 1.6 to 8.4 s. For this reason, it is recommended that field data be collected when estimating passenger service times and dwell times for a given system.

Although a transit vehicle's passenger service time may be affected by many factors, most of these factors are constant for a given system. For this reason, the principal determinants of service time typically include aspects of passenger demand. Therefore, for a given transit system with constant operating characteristics (i.e., fare collection system, number and width of doors, number of steps to board/alight, etc.), the major factors affecting service time will be

- The number of passengers boarding,
- The number of passengers alighting, and
- The number of passengers on board.

This appendix presents methodologies for measuring passenger service times and dwell times in the field for buses and light rail transit (LRT).

PASSENGER SERVICE TIMES

Passenger movements at most stops are small, typically one or two passengers boarding or alighting per stop. In these situations, dwells are relatively independent of passenger service times and it is not possible to collect statistically useful data. To determine passenger service times for use in evaluating the differences between systems (such as single- and dual-stream doors, high- and low-floor buses, or alternate fare collection systems), data collection should be done only at high-volume stops. These stops are typically downtown or at major transfer points. The data collection effort will require one or two persons, depending on the number of passengers.

The following are steps that may be used to collect field data on passenger service times. An example of a data collection sheet is shown in Exhibit 6-B1.

1. From a position at the transit stop under study, record the identification number and run number for each arriving vehicle.
2. Record the time that the vehicle comes to a complete stop.
3. Record the time that the doors have fully opened.
4. Count and record the number of passengers alighting and the number of passengers boarding.
5. Record the time that the major passenger flows end. (Note: This is somewhat subjective but essential to correlate flows per unit of time. The time for stragglers to board or exit should not be included.)
6. When passenger flows stop, count the number of passengers remaining on board. (Note: If the seating capacity of the transit vehicle is known, the

number of passengers on board may be estimated by counting the number of vacant seats or the number of standees).

7. Record the time when the doors have fully closed.
8. Record the time when the vehicle starts to move. (Note: Leave time should exclude waits at timepoints or at signalized intersections where the vehicle must wait for a traffic signal to turn green.)
9. Note any special circumstances. In particular, any wheelchair movement times should be noted.

The passenger service time for each transit vehicle arrival is computed by taking the difference between the time that the door opens and the time that the main flow stops. The service time per passenger is computed by dividing the number of passengers boarding (or alighting) by the total service time.

Exhibit 6-B1
Sample Passenger Service Time Data Collection Sheet

Passenger Service Time Data Sheet #____

Date _____ **Time** _____

Route _____ **Location** _____ **Direction** _____

Bus Run #	Arrival Time	Doors Open	Main Flow Stops	Doors Close	Bus Leaves	Passengers Boarding		Passengers Alighting		Passengers Departing On Board	Notes
						Front	Rear	Front	Rear		

DWELL TIMES

The procedure for determining dwell times is similar to that for estimating passenger service times, except that dwell times are best determined with ride checks. With ride checks, the observer rides the transit vehicle over the entire route for several runs at different times of day. A single observer can usually monitor both doorways on a 40-ft (12-m) bus. While it is more difficult for a single observer to handle articulated buses that have three doorways, it is possible with an experienced checker. For LRT vehicles, at least one observer per car will be required. Automated equipment can also monitor dwell times, possibly in conjunction with automatic passenger counting equipment.

Usually a given route will have similar equipment. Where equipment types such as single or double doors, rigid or articulated bodies, or high- or low-floor cars are intermixed, separate data sets should be obtained for each type of equipment. A sample data collection sheet is shown in Exhibit 6-B2. This sheet can be adapted to also record traffic and intersection delays. Where passenger service times are not needed, the doors

open, end of passenger flow, doors close columns can be omitted. The following are steps that may be used to collect field data for estimating dwell times:

1. From a position on the transit vehicle, record the stop number or name at each stop.
2. Record the time that the vehicle comes to a complete stop.
3. Record the time that the doors have fully opened.
4. Count and record the number of passengers alighting and the number of passengers boarding.
5. Record the time that the major passenger flows end.
6. When passenger flows stop, count the number of passengers remaining on board. (Note: If the seating capacity of the transit vehicle is known, the number of passengers on board may be estimated by counting the number of vacant seats or the number of standees).
7. Record the time when doors have fully closed.
8. Record the time when the vehicle starts to move. (Note: Waits at timepoints or at signalized intersections where the dwell is extended due to a red traffic signal should be noted but *not* included in the dwell time. A delay due to a driver responding to a passenger information request is an everyday event and *should* be included in the dwell time calculation. Time lost dealing with fare disputes, lost property, or other events should *not* be included.)
9. Note any special circumstances. In particular, any wheelchair movement times should be noted. Whether this is included in the mean dwell time depends on the system. Dwell times due to infrequent wheelchair movements are often not built into the schedule but rely on the recovery time allowance at the end of each run.

The observer must use judgment in certain cases. At near-side stops before signalized intersections, the driver may wait with doors open as a courtesy to any late-arriving passengers. The doors will be closed prior to a green light. This additional waiting time should *not* be counted as dwell time but as intersection delay time.

Dwell Time Data Sheet #____

Date _____ Time _____ Bus No. _____ Bus Type_____

Route _____ Run No. _____ Direction _____

Stop # and Name	Arrival Time	Doors Open	Main Flow Stops	Doors Closed	Bus Leaves	Passengers Boarding		Passengers Alighting		Passengers Departing On Board	Notes
						Front	Rear	Front	Rear		

Exhibit 6-B2
Sample Dwell Time Data Collection Sheet

APPENDIX C: BUS BUNCHING AND PERSON CAPACITY

Transit services are typically designed with sufficient buses to ensure that an agency's maximum schedule load is not exceeded. Agency policies differ on whether this maximum load applies to every bus or to the average load of all buses on a route during a specified time period (e.g., one-half hour), but in any event, no pass-ups should occur.

Predictable surges in demand may be accommodated by adjusting headways or adding an extra bus. Tweaking the schedule is less effective for handling random surges.

If passengers arrived evenly throughout the course of an hour, the number of buses per hour required to serve those passengers would be simply the hourly passenger demand divided by the maximum schedule load per bus. More typically, more passengers will arrive for some buses than for others, due to the normal randomness of passengers' travel from day to day and from predictable surges at certain times (e.g., from a school letting out). If passenger demand requires frequent service and if buses are scheduled as though passengers arrive at an even rate, the result will be that some buses will experience overcrowding. The number of buses per hour required to accommodate typical peak 15-min loads can be determined as follows:

Equation 6-40

$$f_{min} = \frac{P_h}{P_{max}(PHF)}$$

where

f_{min} = minimum frequency to accommodate peak 15-min passenger demands without overcrowding (bus/h),

P_h = hourly passenger volume (p/h),

P_{max} = maximum schedule load per bus (p/bus), and

PHF = peak-hour factor.

For example, if 600 passengers must be served during the peak hour and if the maximum schedule load is 60 passengers per bus, 10 buses per hour would be needed if passengers arrived at an even rate (i.e., PHF=1.00). If the peak15-min passenger demand were 20% higher than the average demand over the peak hour (i.e., PHF=0.83), the number of buses required to avoid overcrowding would be 12. Adjusting scheduled headways to respond to regular peaks in demand is another option that can reduce the number of extra buses required to avoid overcrowding (*C-1*).

In practice, the extra passengers would cause dwell times to be longer than normal, the first bus will fall further and further behind schedule, and the following bus will tend to run early.

The PHF concept can be extended to address crowding issues on routes experiencing a moderate amount of bunching. If, as a simplified example, buses are scheduled to arrive every 10 min, passengers arrive at an even rate, and one bus operates 5 min late, that bus will pick up all of its normal passengers at a stop, plus half of the passengers that would normally take the following bus. The late bus will experience overcrowding, carrying more passengers than the schedule assumes, while the following bus will pick up half of its normal load, and some of its offered capacity will go unused.

As an extreme example, imagine that buses are scheduled to arrive every 5 min but that actually two arrive in close succession every 10 min. The effective frequency of the route in this case is 10 min, as that is the average interval between bus arrivals. The effective frequency can be determined from the following:

$$f_{eff} = \frac{f}{1 + c_{vh}}$$ **Equation 6-41**

where

f_{eff} = effective frequency (bus/h),
f = scheduled frequency (bus/h), and
c_{vh} = coefficient of variation of headways (standard deviation of headways divided by the mean headway).

The coefficient of variation of headways should be calculated using the population standard deviation; this produces a c_{vh} of 1.0 when two buses always arrive together and a c_{vh} of 0.5 when buses are consistently one-half headway off-headway, as in the previous examples.

The average loading of late buses during the peak 15 min can be calculated as shown in Equation 6-42. Dividing the average hourly passenger demand by the peak-hour factor gives the average peak 15-min load; dividing the result by the effective frequency gives the average load per late bus during the peak 15 min.

$$P_l = \frac{P_h}{(PHF) f_{eff}}$$ **Equation 6-42**

where P_l is the average load per late bus during the peak 15 min (p/bus) and other variables are as defined previously.

Research is required to develop procedures to estimate the effects of various factors (e.g., traffic, transit priority, bus operator experience) on headway adherence. Adding additional buses to address overcrowding may not have an effect on the most crowded buses, if the added buses end up bunched as well. Since the added buses entail added operating costs for an agency, other measures to improve reliability, such as those discussed in Section 7, could prove to be more cost effective for relieving overcrowding.

REFERENCE

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CHAPTER 7
DEMAND-RESPONSIVE TRANSIT

1. User's Guide
2. Mode and Service Concepts
3. Operations Concepts
4. Quality of Service Concepts
5. Quality of Service Methods
6. Bus Transit Capacity
7. **Demand-Responsive Transit**
8. Rail Transit Capacity
9. Ferry Transit Capacity
10. Station Capacity
11. Glossary and Symbols
12. Index

CONTENTS

1. INTRODUCTION 7-1
How to Use This Chapter 7-1
Other Resources 7-1

2. DRT CAPACITY 7-3
Capacity Factors 7-3
Capacity Calculation Procedures 7-6
Importance of Ridership Demand for Estimating DRT Capacity 7-8

3. REFERENCES 7-10

1. INTRODUCTION

Transit capacity deals with the movement of people and vehicles, depends on the size of the transit vehicles and how often the vehicles operate, reflects the interaction between passenger concentrations and vehicle flow, and reflects operating policies of the transit service provider. For bus transit, capacity must specifically address bus routes, bus lanes, and bus terminals in terms of persons carried. In short, it is a complex topic.

DRT capacity addresses how many vehicles and service hours are needed to serve a given passenger demand and service area.

Demand-responsive transit (DRT) capacity is also complex but it is a different proposition than bus capacity. For DRT, the issues relate to how many vehicles and vehicle service hours are required to accommodate a given passenger demand and service area. Similarly to bus transit, DRT capacity also depends on vehicle size and the operating policies of the DRT service provider, such as the length of the on-time window. DRT capacity may also depend on the provider's policy regarding how much capacity to deploy. This, in turn, may relate to available funding or other local circumstances.

Chapter 7 of the *Transit Capacity and Quality of Service Manual* summarizes the state of knowledge regarding DRT capacity and ridership demand (Section 2) and provides a list of references used in developing the chapter (Section 3).

HOW TO USE THIS CHAPTER

Chapter 7 is short, covering the following three topics:

- The "Capacity Factors" section describes the factors specific to DRT that influence the available capacity. This section provides a good introduction to DRT operating issues for those new to planning, operating, or studying DRT service.
- The "Capacity Calculation Procedures" section describes different techniques that are available for estimating DRT capacity, depending on DRT system characteristics and available data. No computational methods are provided; instead, readers are referred to other sources for guidance on implementing the methods.
- Although the TCQSM is not a ridership estimation tool, DRT ridership demand is a key factor for estimating DRT capacity. Therefore, an "Importance of Ridership Demand" section is provided that summarizes the contents of four TCRP reports and documents on the subject, links to which are provided in full on the accompanying CD-ROM.

OTHER RESOURCES

Other TCQSM material related to DRT includes:

- The "What's New" section of Chapter 1, User's Guide, which describes the changes made in this chapter from the 2nd Edition.
- Chapter 2, Mode and Service Concepts, which summarizes the development of DRT as a transit mode, highlights the different types of DRT service, and gives

typical ranges of productivities for those services, and describes the different DRT service patterns in use.

- Chapter 5, Quality of Service Methods, which includes a section on evaluating the quality of DRT service.
- The TCQSM's CD-ROM, which includes links to electronic versions of all of the TCRP reports referenced in this chapter.

2. DRT CAPACITY

CAPACITY FACTORS

DRT passengers are generally provided a seat, unlike fixed-route service where standees may increase vehicle capacity.

For most types of DRT service with a dispersion of origins and destinations, the number of vehicles and vehicle service hours required is dependent on a number of factors, including ridership demand, passenger characteristics, peak-period demand, service area size and characteristics (e.g., railroad crossings, topographic features, traffic congestion), DRT trip pattern (e.g., many-to-many, many-to-few), and service policies that affect DRT operations. Generally, DRT passengers are provided a seat for service, unlike fixed-route service where standees may increase vehicle capacity.

Ridership Demand

Ridership demand is one of the most important factors. The demand for DRT service in terms of one-way passenger trips should be determined or estimated as one key factor for the calculation of needed capacity. These data should be determined on an average weekday basis as well as a peak-period basis. If the peak-period demand is significantly greater than off-peak, the number of vehicles that are needed will be determined by the peak demand. If the peak-period demand is significantly greater than off-peak, additional capacity will be needed during peak time periods. Given that DRT vehicles carry only a limited number of passenger trips each hour, fluctuations in ridership demand can have a large effect on the amount of capacity required and the resulting costs for service.

Passenger Characteristics

ADA complementary paratransit regulations are given in 49 CFR Part 37, Subpart F. See http://fta.dot.gov/civilrights/12325_3884.html.

Passenger characteristics are also important in determining capacity. Is the DRT service designed for general public users, or a specialized group, such as older adults and people with disabilities? Or is the service Americans with Disabilities Act (ADA) complementary paratransit?

DRT service that functions as ADA paratransit cannot limit its capacity for eligible riders.

Significantly, a DRT service that functions as ADA paratransit cannot limit its capacity for eligible riders. This is a key difference between ADA paratransit and all other types of DRT service. The ADA prohibits any "capacity constraints" for complementary paratransit service. Capacity constraints are defined as restrictions on the number of trips that an eligible person may request, waiting lists for service, and operational practices that result in substantial numbers of significantly late trips, substantial numbers of denied or missed trips, and substantial numbers of excessively long trips (as measured by travel time). Excessive telephone hold times to reserve trips are included among operational practices that restrict capacity and are not allowed.

To meet the requirement prohibiting capacity constraints, ADA paratransit providers must constantly monitor their ridership demand and ensure adequate capacity. Many ADA paratransit providers have established a standard of zero denials for service. The ADA does not require zero denials; the regulations and subsequent court interpretations require that ADA paratransit providers meet all expected demand, with recognition that there may be an insubstantial number of trip denials as long as such denials are not attributable to the design of the paratransit service.

Non-ADA providers of DRT service do not have any federal requirements regarding capacity. Such providers may offer capacity according to local policy and funding levels, and may adopt service policies affecting capacity—for example, prioritizing limited capacity to serve specific trip purposes such as medical, school, and work.

Providers of non-ADA DRT service do not have any federal requirements regarding capacity.

Differences in passenger characteristics that impact wait times and dwell times also influence DRT capacity. Wait time refers to the amount of time a DRT operator will wait for a scheduled passenger to appear for boarding. Dwell time refers to the amount of time required for the passenger to safely board the vehicle and either take a seat or access securement for a wheelchair. A general public DRT service will typically have quite short wait times for riders at pick-up locations (1 to 2 min, for example). Dwell times are also relatively short. However, specialized DRT services designed for riders with disabilities will have longer wait times (5 to 10 min and in some cases longer) and dwell times are also longer. Increased wait and dwell times mean that fewer passenger trips can be carried per hour, translating to lower productivity and the need for additional vehicles to provide needed capacity.

Higher wait and dwell times, longer passenger trip lengths, and slower vehicle speeds all result in a greater number of DRT vehicles needed to provide a given capacity.

Peak-Period Demand

Peak-period demand is an important factor. Where DRT systems have peaked ridership demand, additional capacity is required at those peak times. Unlike a fixed-route bus that is able to accommodate additional passengers during peak times by filling all seats and allowing standees, a DRT vehicle does not generally carry more passengers during peak times than off-peak. (An exception is when operating characteristics change during peak times to become more productive, e.g., from many-to-many during off-peak to many-to-few or many-to-one during peaks.) When there is a significant difference between peak and off-peak demand, DRT providers may offer more service during peak times to meet the extra demand. Providing additional service during peak times can be accomplished in a number of ways, such as deploying additional DRT vehicles, supplementing DRT service with non-dedicated service such as taxis, and improvements to the DRT vehicle schedules to ensure adequate capacity during peak times.

The DRT provider's policy for scheduling trips is particularly important in relation to peak-period capacity needs. The extent to which a DRT provider can manage its peak-period demand will affect the amount of capacity that is needed. A DRT provider of ADA paratransit, for example, can "negotiate" trip times within one hour before or after a rider's requested time to help address peaking demand or to make more efficient driver schedules (as long as such negotiation does not jeopardize time constraints for the rider, e.g., requiring the rider to arrive late for work). Non-ADA paratransit DRT providers may be able to "spread" some of the peak-period trips to the shoulders of the peak or to the off-peak by encouraging alternative travel times for riders, by using a longer pick-up window for scheduling trip pick-ups, or by only offering trip pick-ups that can be handled.

Whether a DRT provider can manage demand during peak periods will affect capacity needs.

Service Area Size

Service area size has a critical influence on DRT capacity. The DRT provider may divide the service area into zones or distinct smaller geographic areas, depending on travel patterns and to ensure capacity for shorter trips. Zones are often established to offer connections to the fixed-route network at a bus stop or rail station but may also

serve neighborhoods with short trips from residences to local destinations such as shopping centers, medical clinics, or community centers. The number of vehicles assigned to each geographic area will depend on the number of passengers from that area that need to be accommodated at a given time.

Service Area Characteristics

Service area characteristics also impact capacity. Those characteristics that delay travel will have a similar effect as a large service area, resulting in longer travel times, lowered productivity, and the need for additional DRT capacity to serve the demand. Locations of major bridges and railroad crossings, and the geographic shape and topographic features of the service area are some of the service area characteristics that may constrain travel and increase travel times.

DRT Trip Pattern Type

DRT services that can group riders will carry more passenger trips per vehicle each hour and day than services where origins and destinations are dispersed.

The trip pattern type (e.g., many-to-many, many-to-few) offered by the DRT provider will affect capacity. A DRT service that is able to group more riders through a many-to-one, many-to-few, or few-to-few type of service will have higher productivity, with each DRT vehicle carrying more passenger trips. Conversely, a many-to-many type of DRT service is not able to group as many passenger trips per vehicle given the greater dispersion of origins and destinations, and therefore each vehicle carries fewer passenger trips with a resulting need for additional capacity.

Operating Policies

Operating policies may also impact capacity. A policy that establishes a short on-time window—for example, a 15- or 20-min window—and requires high on-time performance standards will mean less grouping of passenger trips, which, in turn, limits productivity and requires additional vehicle capacity. The policies that increase the time to serve each passenger trip, such as a 10-min wait time for riders at pick-up location, will increase riders' travel times, with a similar effect as long-trip travel times, that is, lowering productivity with a need for additional capacity.

Summary

Summary of factors affecting DRT capacity.

To summarize, various factors affect DRT capacity, including:

- The demand for DRT service—estimated in terms of one-way passenger trips;
- DRT provider policies—particularly the amount of capacity to be deployed, which may be affected by available funding or other local issues;
- Passenger characteristics—whether the service is provided for the general public or specialized rider groups;
- Peak-period demand—when demand during peak periods is significantly greater than off-peak, additional capacity may be needed;
- Service area size and characteristics—in particular, a large service area results in longer passenger trips, lowering productivity with additional capacity needed to serve the demand;

- Trip pattern type—many-to-few, many-to-one and few-to-few DRT services can group passenger trips, achieving higher productivities and requiring fewer vehicles than a service that operates many-to-many; and
- Service policies, such as the size of the on-time window—the shorter the window, the more the window constrains scheduling, with a resulting need for additional vehicles.

Importantly, if the DRT service is an ADA paratransit program, the service must provide enough capacity to meet the demand. ADA paratransit capacity cannot be limited by a provider's policies on how much capacity to deploy or by other factors that could limit eligible riders' access to service, including, among others, waiting lists for service, substantial numbers of significantly late or missed trips, or excessive telephone hold times to book trips.

CAPACITY CALCULATION PROCEDURES

Links to TCRP reports referenced in this section are available on the accompanying CD-ROM.

There are various ways that the number of vehicles and vehicle service hours for a DRT system can be estimated.

Analogy Method

The analogy method estimates capacity needs based on the experiences of comparable DRT systems.

The number of vehicles and vehicle service hours for a DRT system can be estimated using data from a similar DRT system or several similar DRT systems operating in a comparable community or area. This is the *analogy* method, which, while straightforward and simple, can provide useful information to help assess the number of passenger trips per day and per service hour that can be served with a given number of vehicles. These data can then be used to estimate capacity for the community or area where DRT service is being planned.

DRT Resource Estimation Model

This model estimates the fleet size and market share served at a user-defined level of service quality.

A second approach is to use the DRT resource estimation model, developed through a TCRP project and published as *TCRP Report 98: Resource Requirements for Demand-Responsive Transportation Services* (*1*). This report and its software tool on an accompanying CD provide a model that roughly estimates the number of vehicles needed to operate a DRT service. The model can be used for planning a new DRT service or for expanding an existing DRT service. For DRT providers, there is trade-off between high service quality and cost, with costs driven by fleet size and operating labor. With more vehicles (capacity), a DRT provider can serve more people or a larger service area, or the same market area with a higher service quality. The model is designed to show the trade-off between fleet size and share of the market served at a level of service quality that is defined by the model user. Inputs for the model include a definition of the service area using census of 2000 geographic units, the type of riders to be served, vehicle capacity, hours of service, the pick-up and drop-off windows, and the expected number of trip requests per day (demand). With data specific to the defined service area, the model then "assigns" trip requests to the vehicles, with the number of vehicles increasing until all trip requests are met. In addition to the information on fleet size, the model estimates vehicle miles and vehicle hours and other summary statistics.

Analytical Model

The analytical model incorporates peak-period demand characteristics and desired service quality data into its estimate of vehicle needs.

Another approach is an analytical model (*2*) that estimates fleet requirements and system capacity as well as quality of service measures for specific operating conditions. This model is built on the relationship between minimum fleet size and DRT system characteristics. That is, the minimum number of vehicles needed (capacity) is directly related to trip demand and service area and inversely related to acceptable passenger ride times and average travel speed as well as dwell times. The model also incorporates an on-time window, an important factor for measuring DRT timeliness and level of service to the riders. A smaller on-time window increases the fleet requirements. The model additionally introduces consideration of peak period demand, an important factor for most DRT systems. With a peak-trip rate, the model accounts for the fact that the maximum fleet size depends primarily on the peak-period demand. The model does not, however, include other factors important for determining fleet and capacity requirements such as the spatial distribution of trip demand and vehicle size.

Non-dedicated DRT Service

Non-dedicated DRT services include taxis and other vehicles that serve both DRT riders and other riders not affiliated with the DRT service.

For those DRT providers interested in determining how they might provide capacity with taxis or other transportation resources that are not solely serving the provider's passengers, *TCRP Report 121: Toolkit for Integrating Non-Dedicated Vehicles in Paratransit Service* (*3*) provides guidance and a software tool. *Dedicated* providers are those that only serve the DRT riders, while *non-dedicated* providers (such as taxis) serve both DRT riders and other riders unaffiliated with the DRT program. The TCRP report and accompanying spreadsheet-based model help DRT providers assess the optimum split between dedicated and non-dedicated service. While the intent of the research was not primarily to address DRT capacity, use of non-dedicated service is an attractive strategy to consider for dealing with common DRT capacity issues, including excess peak-period demand and long, out-of-the-way trips that are difficult to group with other trips and therefore costly to provide with dedicated vehicles.

This model estimates the optimum split of passenger trips between dedicated and non-dedicated vehicles, along with cost and efficiency information.

The report's model relies on two component models. The first is a driver/run optimization model developed by the research project to determine the most cost-effective schedules for the DRT-dedicated vehicles, given a specified ridership demand pattern in the service area. This first model optimizes the driver/run structure regardless of whether taxis or other non-dedicated vehicles are used. The second model is the analytical model described above (*2*) that estimates DRT capacity. Data inputs for the report's model include service supplied (e.g., number of dedicated vehicles, revenue vehicle hours and miles), non-dedicated vehicles available for DRT use, operating costs, ridership demand, and service area characteristics. Results from the model show not only the optimum split of passenger trips between dedicated and non-dedicated vehicles, but also the efficiency of the dedicated vehicles and cost impacts of the optimum split.

Rural DRT

The rural DRT model determines the total area that can be served with a given budget, for a particular set of demand characteristics.

A 2002 paper (*4*) presents a methodology for determining the capacity of a rural DRT system using an economic constraint model and spatial data for the DRT service area. The basis of the methodology is the economic notion of diminishing returns—the point at which providing transit service to a larger area causes a decrease in the overall trip rate, resulting in an inefficient operation. Variables needed include the operational

costs (calculated on a cost per mile basis), transit need (calculated as the number of likely users of the DRT service), the charge for the service (the rider fare and any subsidy allotted for the service), and distance to each stop (defined as the total distance from the vehicle garage to each passenger pick-up location (calculated as the center of the census block upon which the transit need is determined, using GIS). The model determines the total area that the rural DRT agency can serve without losing money, and the percent of the total area that can be served with the existing fleet.

IMPORTANCE OF RIDERSHIP DEMAND FOR ESTIMATING DRT CAPACITY

DRT ridership demand is a key factor for estimating DRT capacity.

Since DRT ridership demand is a key factor for estimating DRT capacity, several TCRP projects that provide guidance on estimating demand are identified as resources and summarized below.

TCRP Report 119: Improving ADA Complementary Paratransit Demand Estimation

TCRP Report 119 *provides tools for estimating ADA paratransit service demand.*

TCRP Report 119 (*5*) provides several tools for estimating the demand for ADA paratransit service, including a spreadsheet that estimates demand based on (*a*) user-provided data on a paratransit system's policies and service characteristics and (*b*) data tables from 28 representative ADA paratransit systems for comparison purposes.

TCRP Web-Only Document 49: Methods for Forecasting Demand and Quantifying Need for Rural Passenger Transportation

TCRP Web-Only Document 49 *provides a tool for estimating rural transit demand at a planning level, particularly in areas without current service.*

This report (*6*) is an interim product of TCRP Project B-36, "Methods for Forecasting Demand and Quantifying Need for Rural Passenger Transportation." The project was still active at the time of writing. The web-only document is a workbook with an accompanying online spreadsheet that estimates the need for public transit services in rural areas and estimates demand (defined as annual ridership) for rural transit service. The methods are intended to evaluate areawide need and demand at a planning level, particularly in situations where there is no current service. The methods are not suitable for estimating the need and demand for specific routes or neighborhoods.

TCRP Report 158: Improving ADA Paratransit Demand Estimation: Regional Modeling

TCRP Report 158 (*7*) builds upon the research presented in *TCRP Report 119* (*5*), using an analysis of a survey of 800 ADA paratransit riders in the Dallas–Fort Worth region and application of the region's travel demand model. The report provides two models for estimating travel demand by ADA paratransit–eligible persons by travel mode, trip purpose, and destination:

- The report's spreadsheet-based *sketch-planning model* is specific to the Dallas–Fort Worth region and forecasts changes in trip making by the region's ADA-eligible population in response to changes in regional income, regional senior population, regional household size, paratransit travel times, trips made within a particular time window, and paratransit fares.
- The report's *regional model* is designed to be used in conjunction with an existing regional travel demand model. While also specific to the Dallas–Fort Worth region, it can be adapted for use in other regions by collecting new survey data or by adjusting the model's "expansion factors" to match the characteristics of the local ADA-eligible population.

Both models produce demand estimates that correspond to the demand generated by ADA complementary paratransit service that fully meets—but does not exceed—ADA requirements.

TCRP Report 95: Traveler Response to Transportation System Changes, Chapter 6—Demand Responsive/ADA

Chapter 6 TCRP Report 95 *provides a limited set of data on ridership impacts from new service or changes to DRT service.*

The *TCRP Report 95* series provides readily accessible, interpretive documentation of results and experience from around the country of different types of transportation system changes and policy actions and of alternative land use and site development design approaches. The report focuses on assessment of travel demand changes, and it is intended as a general guide for preliminary screening, not for regional or project-specific ridership demand estimation. *Chapter 6* (*8*) addresses demand-responsive transportation, including ADA paratransit as a type of DRT service. The report notes the scarcity of data on ridership impacts resulting from new or changes to DRT services. Despite this caveat, *Chapter 6* provides ridership data from a range of DRT strategies, including implementation of new service, replacement of fixed-route service with DRT, and use of DRT as feeder service to fixed route.

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CHAPTER 8
RAIL TRANSIT CAPACITY

1. User's Guide
2. Mode and Service Concepts
3. Operations Concepts
4. Quality of Service Concepts
5. Quality of Service Methods
6. Bus Transit Capacity
7. Demand-Responsive Transit
8. **Rail Transit Capacity**
9. Ferry Transit Capacity
10. Station Capacity
11. Glossary and Symbols
12. Index

CONTENTS

1. INTRODUCTION 8-1
How to Use This Chapter 8-1
Other Resources 8-2

2. RAIL CAPACITY FUNDAMENTALS 8-3
Overview 8-3
Line Capacity 8-3
Person Capacity 8-9
Design Capacity 8-13
Speed 8-15
Positive Train Control 8-16
Reliability 8-16

3. TRAIN CONTROL AND SIGNALING 8-18
Overview 8-18
Fixed-Block Systems 8-18
Cab Signaling 8-19
Moving-Block Systems 8-19
Hybrid Systems 8-20
Automatic Train Operation 8-21
Automatic Train Supervision 8-21
On-Street Preferential Treatments 8-21

4. TRAIN OPERATIONS 8-24
Overview 8-24
Doorway Flow Rates 8-24
Operating Margins 8-27
Skip-Stop and Express Operation 8-31
Passenger-Actuated Doors 8-31
Train and Platform Screen Doors 8-32
Fare Payment 8-32
Station and Platform Design 8-33
Wheelchair Accommodations 8-34
System Design 8-40

5. RAIL SYSTEM CAPACITY METHODOLOGIES 8-44
Introduction 8-44
General Methodology 8-44
Commuter Rail Capacity 8-67
Automated Guideway Transit Capacity 8-75
Ropeway Capacity 8-77

6. APPLICATIONS 8-81
Designing for Future Growth 8-81
Planning-Level Analysis 8-81
Transit Operations Planning 8-89
Role of Simulation 8-91
Application of Simulation 8-99
Sketch-Planning Tools 8-102
Best Practices for the Use of Simulation Models and Sketch-Planning Tools 8-105

7. CALCULATION EXAMPLES 8-108
Calculation Example 1: High-Capacity Heavy Rail 8-108
Calculation Example 2: Heavy Rail Line with Junction 8-111
Calculation Example 3: Heavy Rail with Long Dwell 8-112
Calculation Example 4: Light Rail with Single-Track Section 8-115
Calculation Example 5: Commuter Rail with Limited Train Paths 8-117
Calculation Example 6: AGT with Short Trains 8-118
Calculation Example 7: AGT with Off-Line Stations 8-119
Calculation Example 8: Aerial Ropeway 8-120

8. REFERENCES 8-124

APPENDIX A: EXHIBITS IN METRIC UNITS 8-126

LIST OF EXHIBITS

Exhibit 8-1 Basic Train Signal Operation 8-4
Exhibit 8-2 Distance–Time Plot of Two Consecutive Trains 8-5
Exhibit 8-3 Turnback Operation with Crossover Located in Advance of Station 8-6
Exhibit 8-4 Types of Rail Junctions 8-7
Exhibit 8-5 At-Grade ("Flat") Junction Operation 8-7
Exhibit 8-6 Illustrative Peak-Hour Passenger Distribution Between Cars of Trains 8-10
Exhibit 8-7 Example A.M. Train Loads, Toronto 8-11
Exhibit 8-8 Example A.M. Train Loads, Vancouver 8-11
Exhibit 8-9 Illustrative Capacity as a Function of Speed for a Rail Transit Line 8-15
Exhibit 8-10 Conceptual Reliability–Throughput Relationship 8-17
Exhibit 8-11 On-Street Rail Preferential Treatment Examples 8-23
Exhibit 8-12 Selection of Rail Transit Door Flow Times (1995) 8-25
Exhibit 8-13 Summary of Rail Transit Average Door Flow Times 8-26
Exhibit 8-14 SkyTrain (Vancouver) Door Flow Rate Comparisons 8-26
Exhibit 8-15 Observed Rail Headways and Dwell Times 8-28
Exhibit 8-16 Dwell and Headway Data Summary of Surveyed Rail Transit Lines Operating at or Close to Capacity (1995) 8-29
Exhibit 8-17 Headway Components of Surveyed Heavy Rail Transit Lines Operating at or Close to Capacity (1995) 8-30
Exhibit 8-18 Onboard Fare Collection 8-33
Exhibit 8-19 High-Platform Station and Adjustable Door Height Examples 8-36
Exhibit 8-20 Low-Floor Car Examples 8-36
Exhibit 8-21 Mini-High Platforms 8-37
Exhibit 8-22 Profiled Light Rail Platform Providing for One Accessible Door 8-37
Exhibit 8-23 ADA Maximum Platform Slopes 8-38
Exhibit 8-24 Profiled Light Rail Platform with Slide-Out or Fold-Down Step 8-38
Exhibit 8-25 Car-Mounted Lifts 8-39
Exhibit 8-26 Commuter Rail Wheelchair Loading Examples 8-40
Exhibit 8-27 System Design Features for Accommodating Disabled Trains 8-42
Exhibit 8-28 Minimum Train Control Separation Parameters 8-46
Exhibit 8-29 Typical Minimum Train Separation Versus Train Length 8-46
Exhibit 8-30 Typical Station Headways for Lines at Capacity 8-47
Exhibit 8-31 Maximum Speed Limits on Curves 8-47
Exhibit 8-32 Speed Limits on Turnouts 8-48
Exhibit 8-33 Typical Stopping Distance as a Function of Speed 8-48
Exhibit 8-34 Typical Effect of Grade on Station Headway 8-49
Exhibit 8-35 Typical Headway Changes with Voltage 8-49

Exhibit 8-36 Typical Moving-Block Station Headways Compared with Conventional Fixed-Block Systems 8-51
Exhibit 8-37 Peak-Period Station Dwell Times for Heavily Used Systems (1995) 8-53
Exhibit 8-38 Default Data Values for Single Track LRT Travel Time 8-56
Exhibit 8-39 Light Rail Travel Time Over Single-Track Section 8-56
Exhibit 8-40 Light Rail Platform Options at a Crossing 8-58
Exhibit 8-41 Flat Junction Dimensions 8-60
Exhibit 8-42 Key Turnback Dimensions 8-61
Exhibit 8-43 Turnout Numbers 8-62
Exhibit 8-44 Light Rail Single-Track Terminus with Separate Unloading Platform 8-63
Exhibit 8-45 Observed Rail Transit Peak-Hour Factors (1994–95) 8-66
Exhibit 8-46 Effect of P/W Ratio on Train Acceleration to 80 mi/h (128 km/h) 8-68
Exhibit 8-47 Multiple-Platform Commuter Rail Terminal Examples 8-71
Exhibit 8-48 U.S. Railroad Track Classes 8-73
Exhibit 8-49 Average Commuter Rail Operating Speeds 8-74
Exhibit 8-50 AGT Minimum Train Separation Times 8-76
Exhibit 8-51 Suggested AGT Separation Calculation Default Values 8-76
Exhibit 8-52 Typical Cabin Sizes of Ropeway Modes 8-80
Exhibit 8-53 Rail Transit Performance Assumptions for Planning Applications 8-82
Exhibit 8-54 Capacity of Light Rail Systems Designed for Minimum Planned Headway 8-83
Exhibit 8-55 Grade-Separated Line Capacity—Cab Signaling 8-84
Exhibit 8-56 Grade-Separated Person Capacity—Cab Signaling 8-84
Exhibit 8-57 Grade-Separated Line Capacity—Moving-Block Signaling 8-85
Exhibit 8-58 Grade-Separated Person Capacity—Moving-Block Signaling 8-85
Exhibit 8-59 Single-Track Line Capacity—Two-Car Light Rail Trains 8-86
Exhibit 8-60 Single-Track Person Capacity—Two-Car Light Rail Trains 8-86
Exhibit 8-61 Light Rail Line Capacity—Exclusive Lane Operation 8-87
Exhibit 8-62 Light Rail Person Capacity—Exclusive Lane Operation 8-87
Exhibit 8-63 Reversible Ropeway Person Capacity 8-88
Exhibit 8-64 Gondola Person Capacity 8-89
Exhibit 8-65 Example String-Line Chart: Metro North Penn Station Access 8-92
Exhibit 8-66 Example Dynamic Dispatch Animation: Washington Union Station 8-93
Exhibit 8-67 Example Speed Profile 8-97
Exhibit 8-68 Example Track Occupancy Chart 8-98
Exhibit 8-69 Dynamic Dispatch Animation Example: Penn Station New York 8-99
Exhibit 8-70 Example Simulated Interlockings 8-101
Exhibit 8-71 Example Network Graphic with Crossovers 8-101
Exhibit 8-72 Example Network Graphic with Passing Sidings 8-102

Exhibit 8-73 Example Sketch-Plan String-Line Diagram (Charlotte North Corridor Commuter Rail) 8-103
Exhibit 8-74 Example Sketch-Plan Track-Occupancy Diagram (Washington Union Station) 8-104
Exhibit 8-75 Example Sketch-Plan Timetable (California High Speed Rail) 8-104
Exhibit 8-76 Example Sketch-Plan Train Loading Chart (California High Speed Rail) 8-105
Exhibit 8-77 List of Calculation Examples 8-108
Exhibit 8-78 Calculation Example 1: Input Data 8-109
Exhibit 8-79 Calculation Example 2: Input Data 8-112
Exhibit 8-80 Calculation Example 3: Input Data 8-113
Exhibit 8-81 Calculation Example 4: Input Data 8-115
Exhibit 8-31m Maximum Speed Limits on Curves 8-126
Exhibit 8-33m Typical Stopping Distance as a Function of Speed 8-126
Exhibit 8-36m Typical Moving-Block Station Headways Compared with Conventional Fixed-Block Systems 8-127
Exhibit 8-39m Light Rail Travel Time Over Single-Track Section 8-127
Exhibit 8-49m Average Commuter Rail Operating Speeds 8-128
Exhibit 8-51m Suggested AGT Separation Calculation Default Values 8-128
Exhibit 8-59m Single-Track Line Capacity—Two-Car Light Rail Trains 8-129
Exhibit 8-60m Single-Track Person Capacity—Two-Car Light Rail Trains 8-129
Exhibit 8-63m Reversible Ropeway Person Capacity 8-130

1. INTRODUCTION

Many factors contribute to the number of trains that can be operated and the number of people that can be carried over a given time period on a rail transit line or railroad corridor—the fundamental determinant of the capacity of the line. These factors are related to vehicles, station characteristics, signaling system technology, and operational characteristics.

Organization of Chapter 8.

Chapter 8 of the *Transit Capacity and Quality of Service Manual* (TCQSM) presents methods for calculating the capacity of a variety of rail modes and right-of-way types.

- Section 2 introduces the fundamental concepts and factors associated with rail capacity.
- Section 3 describes the basic operation of train control and signaling systems and their relationship to the minimum train headway.
- Section 4 describes operational measures and platform design aspects that can improve train capacity, speed, and reliability.
- Section 5 provides the computational methods for calculating rail capacity for various modes and configurations of rail transit systems, including methods for measuring or estimating input values.
- Section 6 presents potential applications of this chapter's methods and describes the role of simulation in rail capacity analysis.
- Section 7 provides examples of applying this chapter's computational methods.
- Section 8 is a list of references used to develop the material in this chapter.
- Appendix A provides substitute exhibits in metric units for Chapter 8 exhibits that use U.S. customary units only.

The majority of the material in this chapter first appeared in *TCRP Report 13: Rail Transit Capacity* (*1*). Although written in the mid-1990s, this report remains the leading reference on the topic. The basic principles of rail capacity have not changed, although improvements to rail vehicles and technology have occurred and continue to occur, and the methodologies presented here are flexible enough to accommodate these changes.

HOW TO USE THIS CHAPTER

At a minimum, be familiar with the content of Sections 2 and 3 before applying this chapter's computational methods.

Sections 2–4 of this chapter build upon the general transit capacity, speed, and reliability concepts presented in Chapter 3, Operations Concepts, providing information specific to rail transit. Readers will ideally be familiar with the contents of Sections 2 and 3 before trying to apply this chapter's computational methods. Section 4 provides information about rail system design and operations that are useful to consider when planning a potential new rail system (e.g., as part of an alternatives analysis).

Section 5 begins with a general methodology for estimating the capacity of a rail transit line in terms of both trains and persons per hour. Although some of the equations may look complicated, the calculations are straightforward substitutions of input values for each variable in the equation. The majority of the effort is in selecting appropriate values to apply to the equations; this section provides guidance in this area, but assumes familiarity with the basic rail capacity concepts from Sections 2 and 3.

Refinements to the general methodology are subsequently presented for commuter rail and automated guideway transit (AGT) lines, and a separate method is presented for estimating the capacity of ropeway modes (e.g., aerial trams and funiculars). Section 7 provides examples of performing the computations associated with these methods.

Section 6 describes potential applications of this chapter's methods to planning applications. When greater detail is required, or the operations of a rail line are more complex (e.g., lines merging or crossing, mixed freight and passenger operations), simulation is typically used to evaluate operations and determine maximum reliable train throughput. Section 6 includes sections on the role of simulation and provides examples of its application to rail capacity analysis.

OTHER RESOURCES

Other TCQSM material related to rail transit capacity includes:

- The "What's New" section of Chapter 1, User's Guide, which describes the changes made in this chapter from the 2nd Edition.
- The "Rail Transit" subsection of Chapter 2, Mode and Service Concepts, which defines and describes the various rail submodes.
- Chapter 3, Operations Concepts, which presents general capacity concepts applicable to all transit modes, including rail.
- The "Passenger Load" subsection of Chapter 5, which presents a detailed method of estimating railcar passenger capacity applicable to any railcar dimensions, seating arrangement, and transit agency loading policy. The length-based method presented in Chapter 8 assumes generic light rail and heavy rail car dimensions and relatively comfortable standing passenger loads, which may not be applicable to specific situations.
- Chapter 10, Station Capacity, which presents methods for sizing station platforms and their exits. Crowded platforms can slow down passenger boarding and alighting, which increases dwell times and potentially reduces a rail line's capacity.
- The manual's CD-ROM, which includes spreadsheets for applying the general rail capacity method and for estimating the capacity of single-track bi-directional operation. It also includes links to electronic versions of all the TCRP reports referenced in this chapter.

The CD-ROM accompanying the manual includes spreadsheets for evaluating rail transit capacity.

2. RAIL CAPACITY FUNDAMENTALS

OVERVIEW

Ideally, station dwell time and the minimum train separation produced by the signaling system will control line capacity, but other factors may need to be considered.

Rail transit systems encompass a variety of technologies, vehicle sizes, and applications. Despite these variations, a few basic factors—in particular, dwell times and train signal control systems—typically control the number of trains that can be operated along a section of a line during an hour. The number of cars per train and the diversity of passenger demand control how many people those trains can carry.

LINE CAPACITY

Line capacity and vehicle capacity, both relating to the number of trains that can be operated per hour, are equivalent terms for rail capacity.

Line capacity is the maximum number of trains that can be operated over a section of track in a given period of time, typically 1 h. Ideally, the combination of the train signaling system being used and the station with the longest dwell time will control the line capacity. However, under less than ideal conditions, any of a number of other factors may control line capacity. These include:

- Signaling systems designed for the minimum planned train headway, rather than the maximum capacity practical;
- Speed restrictions due to sharp curves or steep downgrades on the approach to the station with the longest dwell time;
- Line crossings and merges, particularly at-grade track junctions;
- Time required to turn back a train at a terminal station; and
- Mode-specific issues, such as light rail trains operating in mixed traffic or commuter rail trains sharing tracks with freight trains.

Propulsion power constraints can also limit line capacity.

The factor providing the lowest capacity—the weakest link—will constrain the capacity of a given section of a line.

Train Control and Signaling

Streetcars and portions of some light rail systems that operate at low speeds do not use train signals. Multiple trains may be allowed to berth at stations where space permits.

Most rail modes rely on signaling systems to maintain safe separation between trains. The minimum distance between trains must be long enough for a train to come to a complete stop, with a suitable safety margin between it and the train ahead. All urban rail transit train control systems are based on dividing the track into sections known as *blocks* and ensuring that trains are separated by a suitable and safe number of blocks. The longer the time required for a train to traverse (pass through) a block—whether due to long block lengths, low train speeds, or station dwell time—the longer the minimum headway between trains, and the lower the line capacity. Train control is discussed in detail in Section 3. Exhibit 8-1 illustrates the operation of a typical three-aspect (red/yellow/green) signal system.



Note: R = red, Y = yellow, G = green.

Exhibit 8-1
Basic Train Signal Operation

Dwell Time

Dwell time is frequently the dominant factor in determining the minimum train headway and, thus, the line capacity. The three main components of dwell time are:

Dwell time at the station with the highest passenger volumes often will control line capacity.

- Door open and close time, and time waiting to depart once the doors close;
- Passenger flow time; and
- Time the doors remain open after passenger flow ceases.

Of these three factors, passenger flow time is the largest and the hardest to control. It depends on passenger volumes at stations, the number of doors on a train, the door widths, the level of crowding inside the train and on the platform, and congestion between boarding and alighting passengers at the train door. The other two factors are, to a great degree, under an agency's control. Minimizing the time spent in a station without passenger flows occurring is important in maintaining reliable train operations, particularly when a line is operating near capacity.

Operating Margin

When a rail system is operating close to its capacity, small irregularities in service can lead to delays, as a train is not able to approach a station until the train ahead departs. These irregularities can be caused by variations in station dwell times, variations in train performance, and—on manually driven systems—variations between operators. To compensate for these variations, when creating a minimum headway, most rail systems add an operating margin to the combination of the signal system's minimum train separation time and the critical station dwell time. The operating margin is, in effect, the amount of time a train can run behind schedule without interfering with

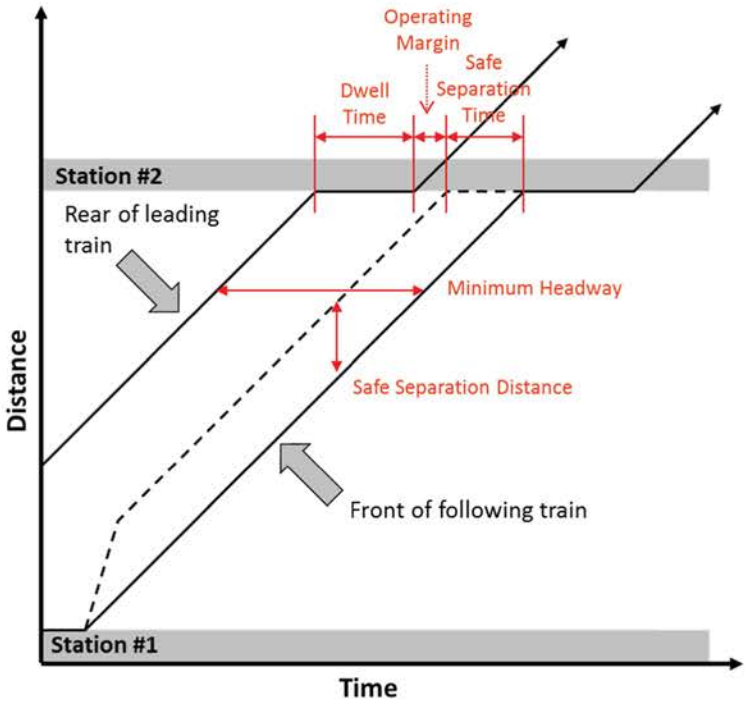
An operating margin is "slack time" built into the minimum headway to accommodate small irregularities in service. If a train is late by more than the operating margin, following trains will be delayed.

the following trains and, consequently, is an important component of line capacity. Operating margins are discussed further in Section 5.

Non-interference Headway

In most cases, the combination of the safe separation time imposed by the train control and signaling system, the longest (or *critical*) average dwell time along the line, and the operating margin will determine the minimum headway that can be operated along the route. This minimum headway is known as the *non-interference headway,* because as long as it can be maintained (i.e., actual dwells do not exceed the average dwell plus the operating margin), following trains will be able to proceed from one station to the next without stopping or slowing for preceding trains, as shown in Exhibit 8-2.

Exhibit 8-2
Distance–Time Plot of Two Consecutive Trains



Source: *TCRP Report 13* (*1*).
Note: Acceleration and braking curves omitted for clarity.

If a train's dwell exceeds the average dwell plus operating margin, however, the following train will need to slow or stop to maintain the required safe separation distance and will not be able to approach the next station at its planned speed. This delay, in turn, will force the next train to slow or stop to maintain its required separation, creating a cascade of delays to following trains that will be extremely difficult to resolve as long as trains continue to arrive at the minimum headway.

As can be seen, train operation at the minimum headway can be easily disrupted. Transit agencies that operate rail lines at or near the minimum headway therefore try to manage station dwell times—for example, through the use of timers visible to train

operators, and through passenger education efforts to encourage passengers to step aside to allow others to exit the train first and to not hold train doors open.

Guideway Characteristics

Turnbacks

A typical terminal station will have a center (island) platform, allowing passengers to board trains on either side. A number of designs are possible, but a common, lower-cost (but also potentially capacity-constraining) design is to locate a crossover in advance of the station. This crossover allows entering trains to be sent to either platform, and exiting trains to be sent to the correct departure track. When a line operates at short headways, the amount of time required to load and unload passengers, and for the operator to change ends, inspect the train, and check train integrity and braking will be longer than the headway between trains. As a result, a second train will arrive and occupy the other platform while the first train is still preparing to depart. A capacity constraint will result if the first train is unable to clear the crossover before a third train arrives to use the platform that the first train is vacating. Exhibit 8-3 shows this process.

Alternative terminal station designs are discussed in Section 4.

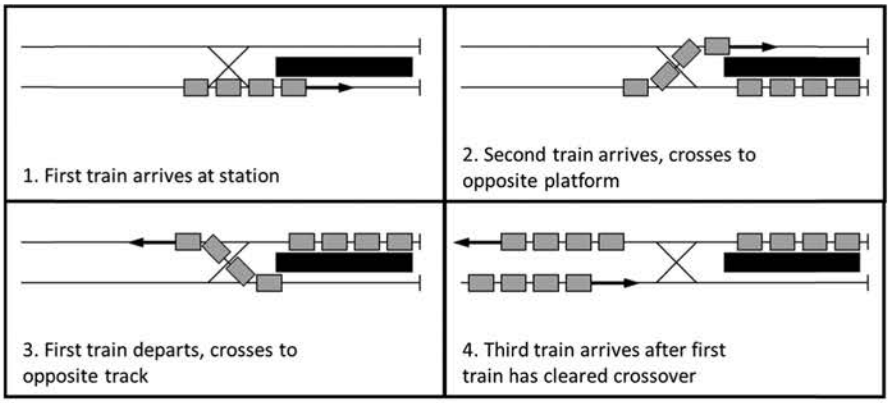


Exhibit 8-3
Turnback Operation with Crossover Located in Advance of Station

Alternative configurations also are possible, including far-side crossovers and tail tracks beyond the terminal station, turning loops, and turning pockets (a third track in between the two mainline tracks, for turning selected trains at a point before the end of the line).

As described in Section 5, when turnbacks are correctly designed and operated, they should not control capacity on a new rail system. However, turnbacks can be a constraint on older systems, where physical constraints—particularly in subways—may have resulted in less-than-optimal designs, or when passenger demand has generated the need for more service than the system was originally designed for.

Junctions

Locations where lines merge, diverge, or cross at-grade can constrain capacity, or introduce the likelihood of interference, when scheduled headways approach 2 to 2.5 min. Two trains may need to use the space where the tracks cross, but only one train can occupy that space at a time. The minimum interval between trains on a given line at an at-grade ("flat") junction is a combination of:

1. The time required for an opposing train to move through the junction,
2. The time required to move ("throw") and lock the switches,
3. The delay incurred in decelerating from and accelerating to line speed, and
4. The minimum headway imposed by the signaling system on the line.

Conceptually, the process is similar to that used for calculating headway based on dwell time at a station, in that both headways are based on the minimum train separation on the lines plus the time a train is stopped. In this case, time stopped is spent waiting for another train at a junction rather than waiting to serve passengers.

It is not desirable for one train to have to wait for another. When more capacity is required, grade-separated ("flying") junctions are typically used. Exhibit 8-4 depicts the two types of junctions. Exhibit 8-5 illustrates the operation of a flat junction. Section 5 discusses junctions in more detail.

Exhibit 8-4
Types of Rail Junctions

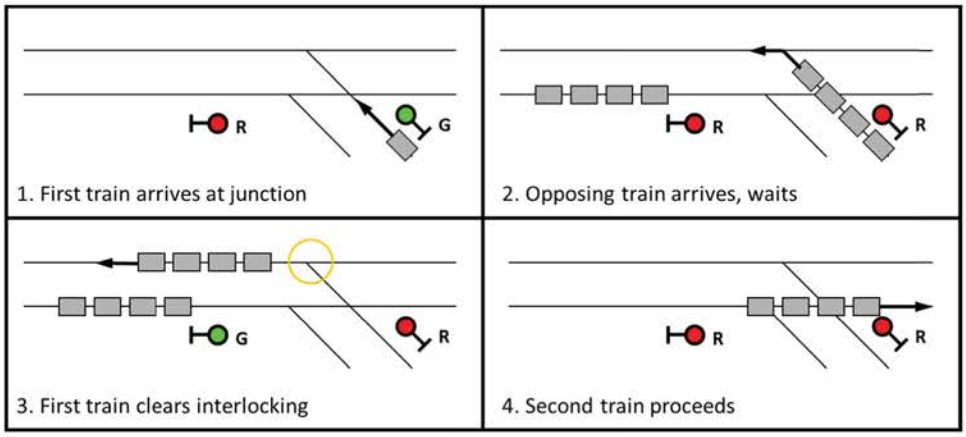


(a) Flat (Pittsburgh)



(b) Flying (Paris)

Exhibit 8-5
At-Grade ("Flat") Junction Operation



Note: R = red, G = green.

Vehicle–Platform Interface

The performance of trains while stopped at stations has a significant effect on overall line capacity and can, in many cases, be the controlling element. Factors affecting dwell times include:

- The volumes of passengers boarding and alighting from trains during peak hours;

- The physical configuration of the platform: its width, length, curvature, usable area for passenger queuing and circulation, and configuration and capacity of vertical circulation;
- The rate at which passenger alight from and board the train;
- The extent of any horizontal gaps between train door sill and the platform edge or differences in elevation between the platform and the car floor—which affects the rate at which passengers board and alight;
- The time required to open and close the train doors; and
- Operational procedures affecting the boarding process.

Ideally, platforms should have tangent (straight) edges, with the surface of the platform at the same level as the train vestibule, to meet the requirements of the Americans with Disabilities Act (ADA) for level boarding with no more than a three inch gap between train door and platform edge. Platforms also should extend the full length of the train, so that doors on all cars open onto the platform. This configuration optimizes the flow capacity of the train doors and minimizes the length of time required to unload and board a train's passenger loads. Platforms should be wide enough to allow boarding passengers to queue on the platform while allowing adequate lanes for alighting passengers to exit the train and walk to the vertical circulation elements. Stairs, escalators, ramps, and/or elevators should be provided in sufficient numbers and spaced along the platform to allow the platform to be cleared of arriving passengers prior to the arrival of the next train. However, level boarding is not always possible or practical, especially on existing commuter rail and light rail systems not designed for level boarding.

Vehicle Characteristics

The characteristics of the rolling stock also affect line capacity. Doorway flow rates are a function of the number, size, and spacing of doors on the train and the interior vestibule space available to passengers boarding and alighting. These flow rates, in turn, influence dwell time.

Mode-Specific Issues

The line capacity factors identified above are applicable to most major rail modes, particularly heavy rail (rail rapid transit), and one of these factors will generally control line capacity. Sometimes, though, issues unique to a particular mode may need to be considered as well:

- *Light Rail*—single-track operations, on-street operations (either in mixed traffic or in an exclusive right-of-way), street-level boarding, and the characteristics of traffic signal priority.
- *Commuter Rail*—mixed freight and passenger operations, limits on the number of trains imposed by the owner of the tracks being used, differences in locomotive power, single-track operations, and boarding from low-level platforms.
- *Automated Guideway Transit*—widely varying technology, potential for off-line stations that allow trains to bypass stations and other trains.
- *Ropeway*—line length, line speed, vehicle or carrier spacing.

PERSON CAPACITY

Person capacity defined.

Person capacity is the maximum number of people that can be carried in one direction over a section of track in a given period of time, typically 1 hour, under specified operating conditions without unreasonable delay, hazard, or restriction, and with reasonable certainty.

The definition of person capacity is less absolute than the definition of line capacity, as it depends on the number of trains operated, the length of those trains, passenger loading standards, and variations in passenger demand between trains and between individual cars of a given train.

The theoretical capacity is the number of cars per hour per direction, times the maximum design load of each car.

Person capacity accounts for variations in passenger arrivals and distribution, and is lower than the theoretical capacity.

This last factor, known as *loading diversity,* provides an important distinction between a line's theoretical capacity and a more realistic person capacity that can actually be achieved on a sustained basis. The theoretical capacity assumes that all the offered capacity can be used by passengers. In practice, this only occurs when a constant queue of passengers exists to fill all available seats and standing room—a situation that is undesirable in a transit operation, as it leads to crowded platforms and passenger delay. Transit passengers generally do not arrive at an even rate over the course of an hour, and generally do not distribute themselves evenly among the cars of a train. Accounting for loading diversity allows one to determine the number of people that can be accommodated during an hour without pass-ups occurring.

How many people can be carried vs. how many people could be carried.

Constraints on staff and equipment resources must also be considered. Line capacity considers how many trains *could* be operated, assuming no constraints on the supply of cars to form trains, nor any constraints on the number of operators available to drive those trains. Knowing, and designing for, a line's ultimate person capacity is often important in long-term planning. However, it may be just as important to know in the short term how many trains *can* be operated and the person capacity of those trains, given existing resources.

Passenger Loading Standards

The passenger-carrying capacity of a transit or rail car, for both seated and standing passengers, is a critical element of person capacity. Peak train loads are estimated based on loading standards that are either developed by the operating agency, based on equipment specifications and assumptions about appropriate design loads, or derived from rules of thumb. For rail transit systems, design capacity includes full occupancy of any seats, plus an allowance for a certain number of standees at a reasonably comfortable quality of service. For commuter rail systems, nominal capacity typically assumes full seated capacity without standees. Chapter 5, Quality of Service Methods, provides guidance on determining appropriate design loads.

See Chapter 5 for guidance on passenger loading levels.

Loading standards are typically based on maximum design loads—the maximum number of people that can be accommodated at a specified quality of service. Crush loading represents the physical capacity of the vehicle to accommodate passengers and loads greater than the maximum design load. The former is expected to be a regular everyday occurrence, while the latter may be tolerable for short periods on an infrequent basis when delays occur or when trains are cancelled—as the system recovers to its normal operating state—or when extraordinary holiday or special event loadings occur.

Loading Diversity

Passengers do not load evenly into cars and trains over the peak hour. Three different types of loading diversity have to be considered: (*a*) loading diversity within a car, (*b*) loading diversity among cars of a train, and (*c*) unevenness of passenger demand during the peak hour.

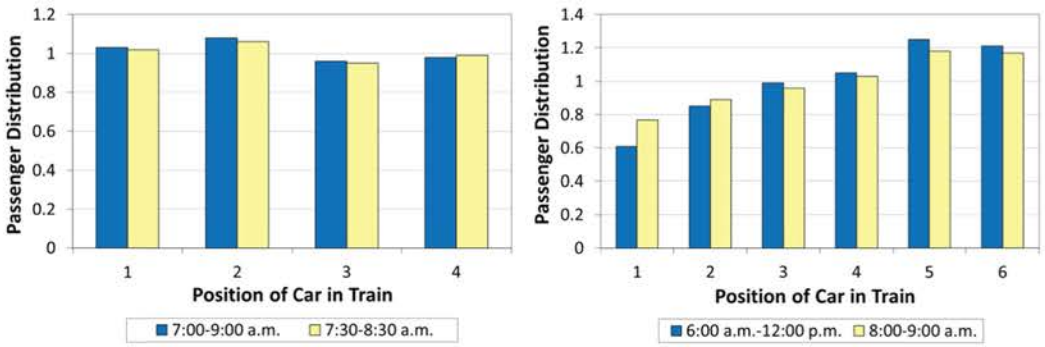
Loading diversity within a car.

The first type of loading diversity is within a car. In individual cars, the highest standing densities occur around doorways while the lowest densities occur at the ends of the cars. Several European urban rail systems add doors, sometimes only single-stream, at the car ends to reduce this unevenness.

Loading diversity within a train.

A second type of diversity occurs in uneven loading among cars of a train. Cars that are closer to station exits and entrances will be more heavily loaded than more remote cars. This inefficiency can be minimized by staggering platform entrances and exits between ends, centers, and third points of the platforms. This is not always possible or practiced. Even so, relatively even loading often occurs due to the duress factor that encourages passengers to spread themselves along the platform during heavily traveled times—or risk being unable to get on the next arriving train.

Vancouver TransLink (formerly BC Transit) has measured car loadings at a station where passengers are regularly passed up, as shown in Exhibit 8-6(a).



(a) Vancouver, SkyTrain (Broadway Station) (b) Toronto, Yonge Subway (Wellesley Station)

Exhibit 8-6
Illustrative Peak-Hour Passenger Distribution Between Cars of Trains

Source: *TCRP Report 13* (*1*).
Notes: 1.0 represents an individual car load equal to the average load of all cars in the train.
Vancouver data collected inbound direction Oct. 27, 1994, 50 trains, 6,932 passengers.
Toronto data collected southbound direction Jan. 11, 1995, 99 trains, 66,263 passengers.

In Vancouver, there is no significant variation in the average loading diversity between cars of a train in either the peak hour or the peak 2-hour period, both of which are within the range of +5% of an average (mean) load to -6%. However, the imbalance between cars on individual trains ranges from +61% to -33%. The average evenness of loading can be attributed to four factors: short trains, wide platforms, close headways, and dispersed entrance/exit locations among the system's stations.

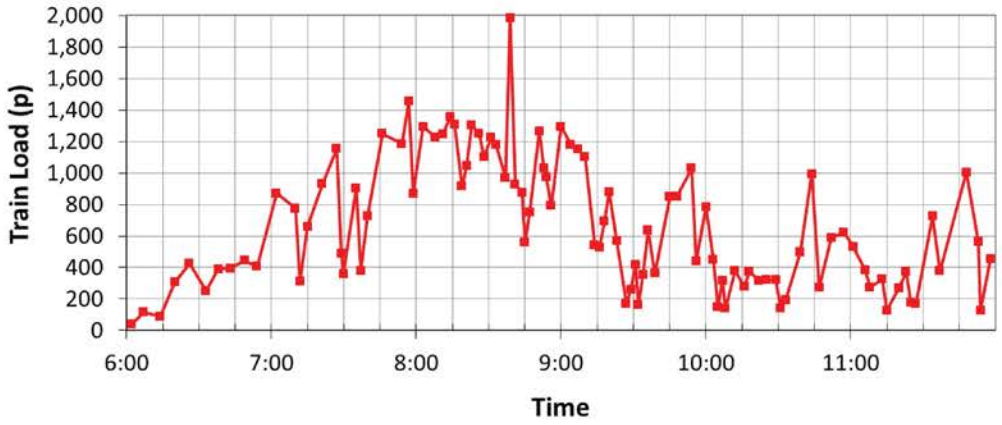
Toronto's Yonge Street subway has a more uneven average loading between cars than Vancouver, as seen in Exhibit 8-6(b). During the morning peak period, the rear of the train is consistently more heavily loaded. This pattern reflects the dominance of the major transfer station at Bloor Street, with the interchange occurring at the rear (northern) end of the Yonge subway platform. As would be expected, there is less

variation in the average car loading diversity between the peak hour and the peak morning period due to the pressures on passengers to spread along the platforms at busy times. The average diversity of individual car loading over the peak period has a range of +26% to -39%. The imbalance for cars on individual trains ranges from +156% to -89%.

Loading diversity within the peak hour.

The third and most important type of diversity is the unevenness of passenger demand over the peak hour. Passengers do not arrive evenly and uniformly on any rail transit system, as shown dramatically over the extended peak period in Exhibit 8-7 for Toronto's Yonge Street subway. This exhibit shows the realities of day-to-day rail transit operation. The morning peak 15 min has a pronounced abnormality at 8:35 a.m. following a short gap in service. The different loading, train by train, is significant, and it is difficult to visually pick out the peak hour or the peak 15 min.

Exhibit 8-7
Example A.M. Train Loads, Toronto

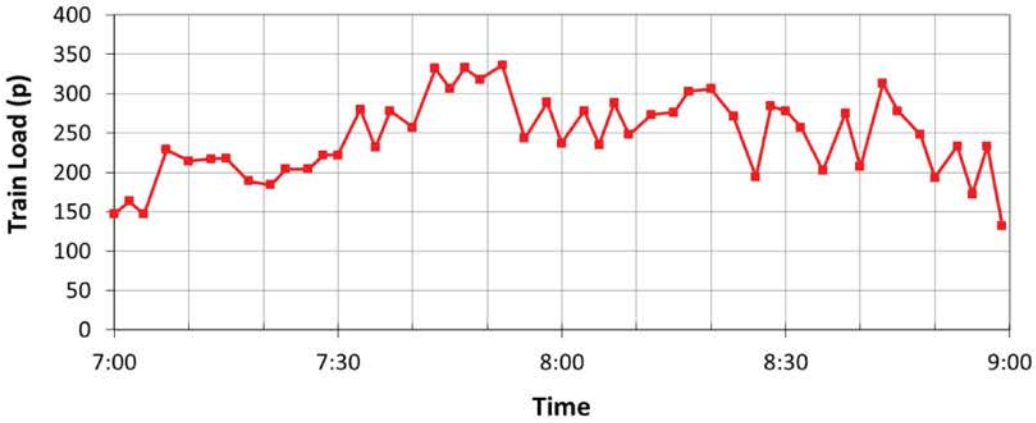


Source: *TCRP Report 13* (*1*).
Note: Data collected January 11, 1995 at Wellesley Station in the southbound direction.

Short-turn services turn back before the end of the line, providing more frequent service in the middle of the line than at the ends.

Exhibit 8-8 shows an a.m. peak period for Vancouver's SkyTrain that, although without major delays, shows the irregular loading from train to train due to the interlace of short-turn trains with regular service from 7:30 a.m. onward.

Exhibit 8-8
Example A.M. Train Loads, Vancouver



Source: *TCRP Report 13* (*1*).
Note: Data collected October 27, 1994 at Broadway Station in the inbound direction.

Number of Cars

The number of cars in a train is a major determinant of person capacity—the longer the train, the more people it can carry. However, there are limits to how many cars can be added to a train, set by the lengths of platforms, the supply of cars, and (for light rail) city block lengths.

Platform Lengths

Station platforms are designed for the longest train the system plans to operate. When platforms are located above or below grade, they are difficult to lengthen once constructed. In some instances, for example, at New York's South Ferry subway station (before it was rebuilt) and some older commuter rail stations, the platform is shorter than the train length, and passengers wishing to exit trains must do so from selected cars only at the front or rear of the train. However, this kind of operation is not generally desirable and is not typical practice for new systems.

Car Supply

Even when the platform design allows for longer trains, a shortage of rail cars may preclude operating longer trains. This kind of constraint is typically financial—new rail cars averaged $1.9 to 3.6 million each in 2010–2011, depending on the rail mode and type of car (*2*); additional staff are also required to maintain added cars.

Maintenance and Yard Storage Facilities

The capacity of facilities where rail cars are maintained and stored when not in service can constrain the number of cars available to form trains. Capacity-enhancement plans that consider lengthening station platforms also need to consider the potential need to expand rail yards and enlarge maintenance facilities. For many existing systems, lengthening yard tracks may be infeasible, difficult, or expensive.

Propulsion Power

For commuter rail systems that employ locomotives, the number of cars that can be accommodated on the train is limited by the horsepower and other performance characteristics of the locomotive. Many traditional locomotives in commuter service are capable of handling trains of up to eight cars. Some newer models of high-horsepower locomotives are capable of pulling 10- to 12-car trains.

For electric traction rail modes, power supply limitations can constrain the number of cars and trains that can use a given track section. Electrical substations are located at intervals along a line, each of which is capable of powering only a certain number of cars within its section of track. Therefore, even though the train control system may provide the capability of operating short headways continually, the electrical system may only support that capability for short periods of time (i.e., until the number of cars that one substation can power in a given track section has been reached).

Street Block Lengths

Street block lengths can be a major limitation for at-grade systems that operate on-street. Most jurisdictions are unwilling to allow stopped trains to block intersections and so require that trains not be longer than the shortest street block where a stop is likely. This issue is especially noteworthy in Portland, where unusually short street

blocks of 200 ft (65 m) in the downtown area limit trains to two cars. Sacramento has been an exception to the street block length rule and can operate four-car trains in the peak hours. These long trains block one intersection when stopped. This situation arose as the single-track nature of the original Sacramento line (since addressed by double-tracking) imposed a minimum headway of 15 min on the service. The capacity limitation of this headway restriction was therefore partially made up by the operation of relatively long trains.

Exclusive lanes can mitigate street block length constraints.

Street block length is also an issue when another vehicle occupies the lane used by light rail trains. If a vehicle in the lane would cause the rear of the train to protrude into an intersection, then the train would need to wait for the lane to clear before advancing. This issue provides a strong argument for providing an exclusive light rail transit lane where street running with long trains occurs. Indeed, as a result of this concern, operation with mixed traffic is very rare on new light rail transit systems, although it does occur on modern streetcar lines in the U.S., which typically operate one-car trains. Where buses and light rail transit trains operate alongside each other, such as in downtown Calgary and Portland, the rail stations, bus stops, and lanes are laid out to cause minimum interference between the modes.

DESIGN CAPACITY

The generally accepted methods by which capacity is calculated define the maximum possible throughput of trains on a line as the theoretical capacity. Several factors contribute to the design capacity of a line being a somewhat lower level of throughput. Research on following headways for a high-density rail operation in tunnels approaching New York City (*3*) provides a good overview of the factors that go into the estimation of theoretical and design capacity. The results of this research are summarized below.

Train signaling systems are discussed in detail in Section 3.

For capacity measurement purposes, the theoretical headway at a specific signal location is the shortest time a following train can pass that signal location at the same speed as the first train. It generally assumed that the speed is the maximum speed allowed by the best available signal aspect (or speed code if a cab signaling system is employed). For fixed-block signal systems, both cab and wayside, the theoretical headway at a signal or for a signal block is determined by calculating the time required for a train traveling at line speed to clear the signal block, plus an additional *clearing time,* which is defined to be the time it takes for the signal aspect or cab-signal code to return to its highest-speed signal aspect or code after the first train passes (typically on the order of 3 s), plus an allowance for the reaction time of the engineer or operator of the following train to recognize that the preceding signal has cleared (typically 3–4 s).

The clearing time at a given signal is determined by both constant (fixed) and variable factors. Fixed factors include the block length, design speed through the block, and the worst-case train safe-braking distance. The variable factors in determining signal clearing time include the speed and station stopping pattern of the first train as it passes through the control line of that signal. If there are multiple train types and station-stopping patterns, a clearing time can be calculated for each one. This can either be done in the field with a stopwatch or by using a train performance calculator programmed with the line's civil characteristics (grades, curves, civil speed restrictions, maximum speed allowed by the signal code or aspect, and any underspeed

assumptions), the unique acceleration and braking characteristics of each train type, and the dwell times at each scheduled station stop within the span of the control line.

Train capacity at a given signal location is calculated by dividing one hour (3,600 s) by the theoretical signal headway (seconds per train), which includes both signal clearing time and engineer reaction time as noted above, to give a maximum throughput expressed in trains per hour. Where there are multiple train types and stopping patterns, a weighted average headway is calculated based on the proportion of each train type relative to the total number of trains.

In commuter rail, just as the signal with the longest clearing time will define segment line capacity, the slowest moving train in a segment will define line capacity, because it will block trains behind it, preventing the faster trains from clearing at optimal speed unless passing sidings or additional tracks are available to prevent delays to the faster trains. These issues arise in local/zone-express type operating patterns, and also in mixed freight/commuter corridors.

It should be noted that the capacity calculated for each signal location assumes that a following train is arriving at that signal ready to accept the newly cleared code or aspect 3 s after it clears. Where a line segment has multiple signals, the longest clearing time defines the capacity of that segment. While some signals in a given segment may clear faster than others, trains operating on close headways cannot take advantage of these fast-clearing signals because their natural progression will reflect the slowest clearing signal.

The capacity of a given line segment, therefore, is based on the *theoretical line headway,* which is the maximum of the headways calculated (or observed) at each signal on the line—sometimes referred to as the *ruling* or *constraining headway.* Throughput is calculated by dividing the theoretical line headway into one hour in the same manner as for an individual signal block.

Typically, plotting capacity with respect to speed results in a bell-shaped curve in which capacity is low at low speeds due to the long time it takes to traverse fixed blocks, high at speeds in the 45–60 mi/h (75–100 km/h) range when supported by appropriate intermediate-speed signal aspects or codes, and tapering down again at higher speeds, which require longer safe braking distances. Braking distances increase with the square of the speed, resulting in much longer signal blocks at higher speeds.

Normally the longest clearing time for a train making station stops is associated with a signal whose control line extends into a station platform. Station dwell time is usually the factor limiting capacity in such cases.

Where there are multiple train types or stopping patterns, an average theoretical line headway is derived from the longest clearing time for each combination of train type and stopping pattern, with a weighted average calculated based on the proportion of each type. In cases where the longest clearing times are at different signal locations for different stopping patterns, the weighting of clearing times is based on the number of times trains of one unique pattern follow trains of another unique pattern.

In addition to the two major variables of train type and stopping pattern, there are other variable factors that determine the actual clearing time behind each train, namely variations in engineer and equipment performance that affect rates of acceleration, deceleration, and maximum speed. These are not typically included in clearing time calculations, but any measure of capacity must account for them in some way.

Calculated capacity at a given signal that does not factor in these variable elements is often referred to as the calculated or theoretical capacity at that signal location.

Each of the variables not included in theoretical capacity can have a negative effect on capacity in one of two ways:

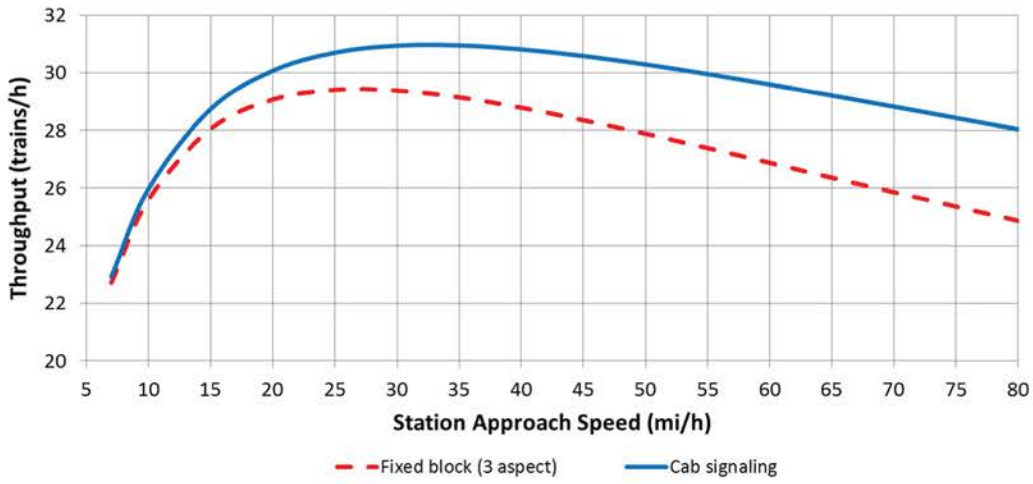
1. By slowing a train as it approaches the ruling signal, making it unavailable to take immediate advantage of the clear signal when it becomes available. In the absence of an operating margin (schedule slack) between trains, this effect will cause every subsequent train that attempts to follow at the theoretical ruling headway to be late by the same amount of time that the first train was delayed.
2. By slowing or delaying a train within the ruling control line such that the signal takes longer to restore to its best aspect or code.

A capacity measure that includes all of the variable factors not included in theoretical capacity can be considered design or practical capacity. For line segments where trains are operating at close to the maximum authorized speed, design capacity generally is estimated to be in the range of 75 to 80 percent of theoretical capacity (i.e., a reduction in theoretical capacity by 20 to 25 percent). This is a rule of thumb that is commonly applied to rail systems for purposes of developing train schedules, projecting future growth requirements, and performing capacity analyses.

SPEED

The capacity of a transit line in terms of train throughput is affected by the speed at which the transit vehicles travel. As speed increases, the distance and time required to safely stop a train also increases, which means that trains need to be spaced further apart in order to operate safely. This relationship between speed and throughput capacity is illustrated in Exhibit 8-9. Cab signal systems and communications-based train control systems are able to more efficiently track the position of trains on a line and therefore offer slightly more line capacity than traditional fixed-block signal systems. The actual relationship between speed and throughput capacity will be a function of the specific design characteristics of the signaling system, so the graph should be considered as illustrative.

Exhibit 8-9
Illustrative Capacity as a Function of Speed for a Rail Transit Line



Source: Calculated with this chapter's methods.
Note: Assumes 45-s average dwell time and 20-s operating margin.

For rail transit systems, the speed at which capacity is maximized is in the range of 25 to 30 mi/h (40 to 50 km/h, usually significantly lower than the allowable top speed), and the peak throughput usually is in the range of 30 trains per hour (equivalent to an approximate 2-min headway). At speeds higher than this, maximum speed and throughput are inversely proportional to each other. Operating at a lower speed for the sake of higher throughput may be acceptable for a heavy rail or light rail transit line in an urban environment but these speeds generally are slower than desired for commuter rail or express transit operations. As a result, these latter systems may intentionally be operated at a lower design capacity than could otherwise be achieved, in order to achieve safe operations at higher speeds.

Some transit systems (e.g., PATH) achieve throughput greater than 30 trains per hour.

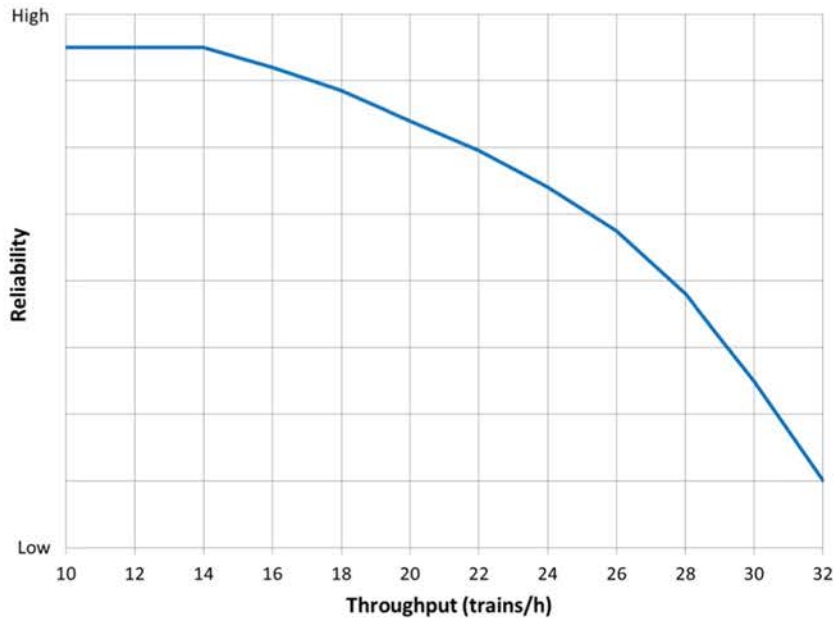
POSITIVE TRAIN CONTROL

Commuter rail systems, which operate on the national railroad network, are subject to federal regulations for positive train control (PTC), a system that improves the safe operation of trains by overriding the discretion of the train engineer to pass a stop signal or operate at a higher-than-permissible speed. At the time of writing, the regulations and associated system design concepts continue to be under development. The effect of such systems on capacity is unclear. Well-designed systems should be able to implement PTC without a significant degradation of capacity, particularly for passenger-only systems or systems with relatively few types of trains in operation. Complex systems with mixed freight and passenger operations and multiple types of trains may see a decrease in capacity, since the PTC system would need to protect against reasonable worst-case operating conditions. The costs, difficulties, and impacts of retrofitting PTC to existing systems also are unclear, but will need to be part of the analysis for projects that change the traffic mix or seek to increase the capacity of an existing system. Simulation models, described in Section 6, provide a tool by which the capacity impacts associated with implementing PTC can be determined and factored into a capacity analysis.

RELIABILITY

The design capacity of a rail line is also related to the desired level of operational reliability. If the frequency of service is relatively low, individual trains have time to recover from minor delays without impacting other trains on the line. As a line approaches its capacity, however, it becomes vulnerable to the condition in which a delay to a single train causes additional delays that cascade or propagate to other trains. The magnitude of the total delay and the time required to recover to normal operating conditions increases as the density of traffic increases, as shown in Exhibit 8-10. There are several ways in which operational reliability can be measured, and a quantitative relationship between reliability and design capacity is difficult to measure, so the reliability axis on the chart is not dimensioned. The shape of the curve, however, is generally considered to be roughly as shown.

Exhibit 8-10
Conceptual Reliability–Throughput Relationship



Transit and rail lines that are asked to deliver a level of throughput close to their theoretical capacity can expect to be less reliable than those that are planned to operate at longer headways. Systems for which predictable, highly reliable service is paramount should be planned for a lower design capacity to better ensure the line's ability to recover from individual train delays.

3. TRAIN CONTROL AND SIGNALING

OVERVIEW

Functions of signaling.

The role of signaling is to safely separate trains from each other and protect specific paths through interlockings (switches) at junctions and crossovers. Additional functions include automatic train stops, should a train run through a stop signal, and speed control to protect approaches to junctions, sharp curves, and approaches to terminal stations where tracks end at a solid wall.

Early forms of surface rail transit, such as streetcars, operated without signal systems—on a *line-of-sight* basis—where the operator of the transit vehicle was responsible for maintaining a safe distance from the preceding vehicle. Some existing systems that operate at relatively low speeds continue to operate on a line-of-sight basis, which can deliver a relatively high vehicle throughput with the trade-off of a top speed lower than rail transit operations equipped with signaling systems.

Signaling technology is very conservative, but signaling cannot protect from every eventuality.

Rail transit signaling maintains high levels of safety based on emergency brake applications and fail-safe principles ensuring that no single failure—and often multiple failures—should allow an unsafe event. The rigor with which fail-safe principles have been applied to rail transit has resulted in an exceptional safety record. However, the safety principles do not protect against all possibilities, including possible human error. An increasing inability to control the human element—responsible for three-quarters of rail transit accidents or incidents—has resulted in new train control systems using automation to reduce or remove the possibility of human error.

Automatic train control adds further features to the train protection of basic signaling, including automatic driving and train supervision that regulates service.

Automatic train control.

This section describes and compares the separation capabilities of the following types of rail transit train control systems: fixed block, cab, and moving block. It is applicable to the main rail transit grouping of electrically propelled, multiple-unit, grade-separated systems.

FIXED-BLOCK SYSTEMS

Track circuits.

In a fixed-block system, trains are detected by the wheels and axles of a train shorting a low-voltage current inserted into the rails. The rails are electrically divided into blocks. The blocks will be short where trains must be close together (e.g., in a station approach), and can be longer between stations where trains operate at speed.

Fixed-block systems provide a coarse indication of train location.

The signaling system only knows the position of a train by the simple measure of block occupancy. It does not know the position of the train within the block; it may have only a fraction of the train, front or rear, within the block. At block boundaries, the train will occupy two blocks simultaneously for a short time.

A minimum of two empty blocks is required between trains for a two-aspect fixed-block system.

In the simplest two-aspect (red/green) block system, the signals display only stop (red) or go (green). A minimum of two empty blocks must separate trains and these blocks must be long enough for the braking distance plus a safety distance. The simplest system can accommodate a throughput approaching 24 trains per hour. This does not provide sufficient capacity for some high-volume rail lines. Higher capacity can be obtained from combinations of additional signal aspects, shorter block lengths, and

A three-aspect system (red/yellow/green) is typical; four-aspect systems (red/yellow/flashing yellow/green) are also found on some commuter rail systems.

overlay systems that electronically divide blocks into shorter "phantom" sections—for trains equipped for this overlay.

Conventional train control systems can support a throughput of 30 trains/track/hour.

In this way, conventional train control systems can support a throughput of up to 30 trains per hour with typical train lengths, performance, controlling station dwells, and operating margins. Overlay systems can increase this throughput by 10 to 15%. A notable exception to this is in Russia where conventional signaling routinely handles 40 metro trains per hour. This is achieved by tightly controlling station dwells to a maximum of 25 s and rigorous adherence to schedule using digital clocks in each station to display the seconds from the departure of the previous train. Newer Moscow metro lines have been designed for 44 and 48 trains per hour—by far the closest train spacing on any rail system, irrespective of technology.

Requiring a driver to control a train's speed and commence braking according to multiple-aspect color light signaling requires considerable precision to maximize throughput. Cab signaling provides assistance in this regard and reduces capital and maintenance costs.

CAB SIGNALING

Cab signaling sets authorized, safe train speeds.

Cab signaling uses electronic codes inserted into each track circuit and detected by an antenna on each train. The code specifies the maximum allowable speed for the block occupied and may be termed the *reference* or *authorized* speed. This speed is displayed in the driver's cab—often so that the authorized speed and actual speed can be seen together.

The authorized speed can change while a train is in a block, as the train ahead proceeds, allowing drivers to adjust train speed close to the optimum with less concern about overrunning a trip stop. Problems with signal visibility on curves and in inclement weather are reduced or eliminated. Cab signaling avoids much of the capital and maintenance costs of multiple-aspect color light signals, although it is prudent and usual to leave signals at interlockings and occasionally on the final approach to and exit from each station.

Reducing the number of color light signals makes it economically feasible to increase the number of aspects and it is typical, although not universal, to have the equivalent of five aspects on a cab signaling system. A typical selection of reference speeds would be 50, 40, 30, 20, and 0 mi/h (80, 70, 50, 35, and 0 km/h).

MOVING-BLOCK SYSTEMS

Moving-block signaling systems are also called *transmission-based* or *communication-based* signaling systems. A moving-block signaling system can be compared to a fixed-block system with very small blocks and a large number of aspects. However, a moving-block signaling system has neither blocks nor aspects. The system is based on continuously or frequently calculating the clear (safe) distance ahead of each train and then relaying the appropriate speed, braking, or acceleration rate to each train.

Moving-block signaling is based on the use of target points.

This system requires continuous or frequent two-way communication with each train, and precise knowledge of a train's location, speed, and length, and of fixed details of the line—curves, grades, interlockings, and stations. With this information, a computer can calculate the next stopping point of each train—the *target point*—and can

command the train to brake, accelerate, or coast accordingly. The target point will be based on the normal braking distance for that train plus a safety distance.

The safety distance is the maximum distance a train can travel after it has failed to act on a brake command before automatic override (or overspeed) systems implement emergency braking.

Without track circuits to determine block occupancy, a moving-block signaling system must have an independent method to accurately locate the position of the front of a train, and then use look-up tables to calculate its end position from the length associated with that particular train's identification. The first moving-block systems used a wire laid alongside or between the running rails, periodically transposed from side to side. The wire transmitted signals to and from antennas on the train, while counting the transpositions determined location.

The use of exposed wayside wires is a maintenance problem and refinements use inert transponders located periodically along the track. These are interrogated by a radio signal from each train and return a discrete location code. Positioning between transponders relies on the use of a tachometer. Communications to and from the train are then radio-based, with protocols to ensure safety and reliability and that messages are received by, and only by, the train they are intended for.

Communication can be made secure.

The computers that control a moving-block signaling system can be located on each train, at a central control office, dispersed along the wayside, or a combination of these. The most common arrangement is a combination of onboard and central control office locations.

Safety Issues

Safety on rail transit is a primary consideration when rail systems are designed. It encompasses all aspects of design, maintenance, and operations. In fixed-block signaling, electrical interlockings, switch, and signal setting are controlled by relay logic. A rigorous discipline has been built around this long-established technology, for which processor-based controls are now finding a role.

A moving-block signaling system is inherently processor-controlled. Processor-based train control systems intrinsically cannot meet the fail-safe conventions of traditional signaling. Computers, microprocessors, and solid-state components have multiple failure opportunities and cannot be analyzed and tested in the same way as conventional equipment. Instead, an equivalent level of safety is provided based on statistical failure modes of the equipment. Failure analysis is not an exact science. Although not all failure modes can be determined, the statistical probability of an unsafe event can be predicted.

HYBRID SYSTEMS

There are times when an urban rail transit system shares tracks with other services, such as long-distance passenger trains, whose equipment is impractical or uneconomic to equip with the moving-block signaling system. Hybrid or overlay systems are available that allow use by unequipped trains—with longer separation—while still obtaining the close headway of the moving-block system for the urban or short-distance trains.

Hybrid systems can allow equipment not equipped for moving block operation to operate on lines signaled with moving blocks.

AUTOMATIC TRAIN OPERATION

Automatic acceleration has long been a feature of rail transit, where relays, and more recently microprocessors, control the rate of acceleration smoothly from the initial start to maximum speed. Linking this feature to onboard commands from the signaling system provides automatic train operation.

Automated train operation systems often also provide for manual operation.

The driver or attendant's role is typically limited to closing the doors, pressing a train start button, and observing the line ahead, with limited manual operating capabilities to deal with certain failures. Dispensing entirely with a driver or attendant was controversial when introduced but has demonstrated its economy and safety on numerous automated guideway transit (AGT) systems, and on selected rail systems in Europe and Canada.

Automatic train operation (ATO), with or without attendants or drivers, allows a train to follow the optimum speed envelope more closely and commence braking for the final station approach at the last possible moment. This reduces station-to-station travel times, and, more importantly, from the point of capacity, it minimizes the critical station *close-in time*—the time from when one train starts to leave a station until the following train is berthed in that station. This can increase total line capacity by 2 to 4 percent.

Automated train operation may provide a 2 to 4% capacity increase.

AUTOMATIC TRAIN SUPERVISION

Automatic train supervision (ATS) is generally not a safety-critical aspect of the train control system. At its simplest, it does little more than display the location of trains on a mimic board or video screen in the central control or dispatcher's office. Increasing levels of functionality are available.

Corrective measures to correct late running trains.

In more advanced systems where there is ATO, computer algorithms are used to attempt to automatically correct lateness. These are rare in North America and are generally associated with the newer moving-block signaling systems.

Predictive control.

A further level of ATS strategies is possible: predictive control, when a computer looks ahead to possible conflicts (for example, a merge of two branches at a junction). The computer can then adjust terminal departures, dwell times, and train performance to ensure that trains merge evenly without holds.

The non-vital ATS system can also be the host for other features such as onboard system diagnostics and the control of station and onboard information through visual and audio messages, including those required by the Americans with Disabilities Act (ADA).

ON-STREET PREFERENTIAL TREATMENTS

Rail preferential treatments on city streets constitute a more limited set of treatments than treatments to accommodate buses, given the constraints posed by a dedicated trackway for streetcars and at-grade light rail transit. This limits the total freedom of vehicle movement that trains can achieve, to take advantage of bypass maneuvers and sudden shifts in vehicle routing. In addition, light rail trains are longer than buses and can have a greater impact on signal operations and the ability to provide effective transit signal priority. Given the higher cost of streetcar and at-grade light rail transit operation, greater emphasis is placed on providing a dedicated right-of-way within a street section if possible. This includes a predominance for light rail transit for median transitways, which can be provided separate from adjacent general traffic, as

opposed to shared-use lanes with general traffic. While streetcars can also operate in separate transitways, most streetcar operations share lanes with general traffic and tend to institute transit signal priority in a similar manner as buses due to their shorter train length (typically only one vehicle).

Transitways

A variety of light rail and streetcar transitway types can be placed within a street right-of-way, providing different levels of protection from other street users. These transitway types can be broadly divided into three groups: (*a*) exclusive, (*b*) semi-exclusive, and (*c*) non-exclusive. Allowable train speeds are higher and potential conflicts with other roadway users are fewer at higher levels of exclusivity (*4*).

An *exclusive transitway* provides complete separation of transit vehicles and other street users. The transitway can be located completely above or below grade, or can run mostly at-grade (with barriers or fences protecting the transitway) with under- or overpasses used at major cross streets.

A *semi-exclusive transitway* allows access across the transitway at controlled locations. Examples of this type of transitway include light rail tracks in the street median, in a protected right-of-way along one side of the street, and along transit malls. Traffic signals are used at locations where cross-street traffic is allowed, and pedestrians and bicycles cross at designated locations only.

A *non-exclusive transitway* allows uncontrolled access onto or across the transitway. Examples include light rail tracks operating in transit-only lanes that can be crossed by turning vehicles at driveways and unsignalized intersections, and mixed-traffic operation (typical streetcar operation).

Examples of these transitway types are provided in the Operating Environments section of Chapter 2, Mode and Service Concepts.

Traffic Signal Priority for Transit Vehicles

Traffic signal priority for LRT or streetcars can be applied under certain signal and traffic operating conditions, more applicable to isolated signalized intersections or where the signal timing in a closely spaced set of intersections (such as in downtown areas) can provide a window for some green extension for transit. Given the typical longer train length for LRT compared to individual bus lengths, a signal preemption strategy may be considered as an alternative to signal priority (including extension of green time), particularly at isolated signalized intersections. Streetcars are shorter than LRT trains—often with just one car per train in U.S. applications—and therefore have the potential to employ signal priority strategies similar to those for buses.

Special traffic signal phases for trains (Exhibit 8-11[a]) can be inserted when LRT vehicles or streetcars turn or queue jump in front of parallel motor vehicle traffic. In many of these cases, the train or streetcar will be operating on the right side of street (whether in a side-of-road alignment or in mixed traffic, and because of the greater turning radius requirement of the vehicles, greater green time associated with the special phase will be required.

When traffic signal priority is applied, stations located near intersections are preferably located on the far (departure) side of the intersection, such that trains can take advantage of the green extension or added signal phase to proceed through the

intersection before servicing the station. In these cases, there should preferably be at least one lane available for parallel general traffic, so that motorized vehicles do not queue up behind a stopped train and block the intersection.

Exhibit 8-11
On-Street Rail Preferential Treatment Examples



(a) Queue jump (Seattle)



(b) Curb extension (Little Rock)

Curb Extensions/Boarding Islands

If LRT vehicles or streetcars are running on the curb side of the street, either curb extensions (Exhibit 8-11[b]) or boarding islands can be applied as pedestrian refuge areas to serve as stations. Boarding islands are typically provided where there is a right turn lane and hence the need for a raised pedestrian refuge area between the right turn lane and adjacent through lane where the train or streetcar is operating. In either configuration, the length and width of the station should be adequately sized to accommodate the design train and design passenger demand.

4. TRAIN OPERATIONS

OVERVIEW

The previous section focused on the effects of train control and signaling on the capacity of a rail transit line. This section discusses additional operating issues affecting capacity.

Uniformity of train performance.

There is considerable uniformity of performance of the electrical multiple-unit trains that handle more than 90% of all U.S. and Canadian rail transit, and this uniformity can be further assisted by the widespread introduction of electronic controls and automatic driving. However, there still can be up to a 10% difference in performance between otherwise identical trains due to manufacturing tolerances, aging of components, and variances in set-up parameters, and—particularly on manually driven systems—due to variations in driving techniques between drivers.

Operating margins.

To accommodate these routine irregularities, two allowances are made in rail transit operations planning and scheduling. An *operating margin* is added to the minimum train separation time and maximum load point station dwell time to create a minimum headway. This operating margin is, in effect, the amount of time a train can run behind schedule without interfering with the following trains. The operating margin is an important component in determining the design capacity.

Schedule recovery.

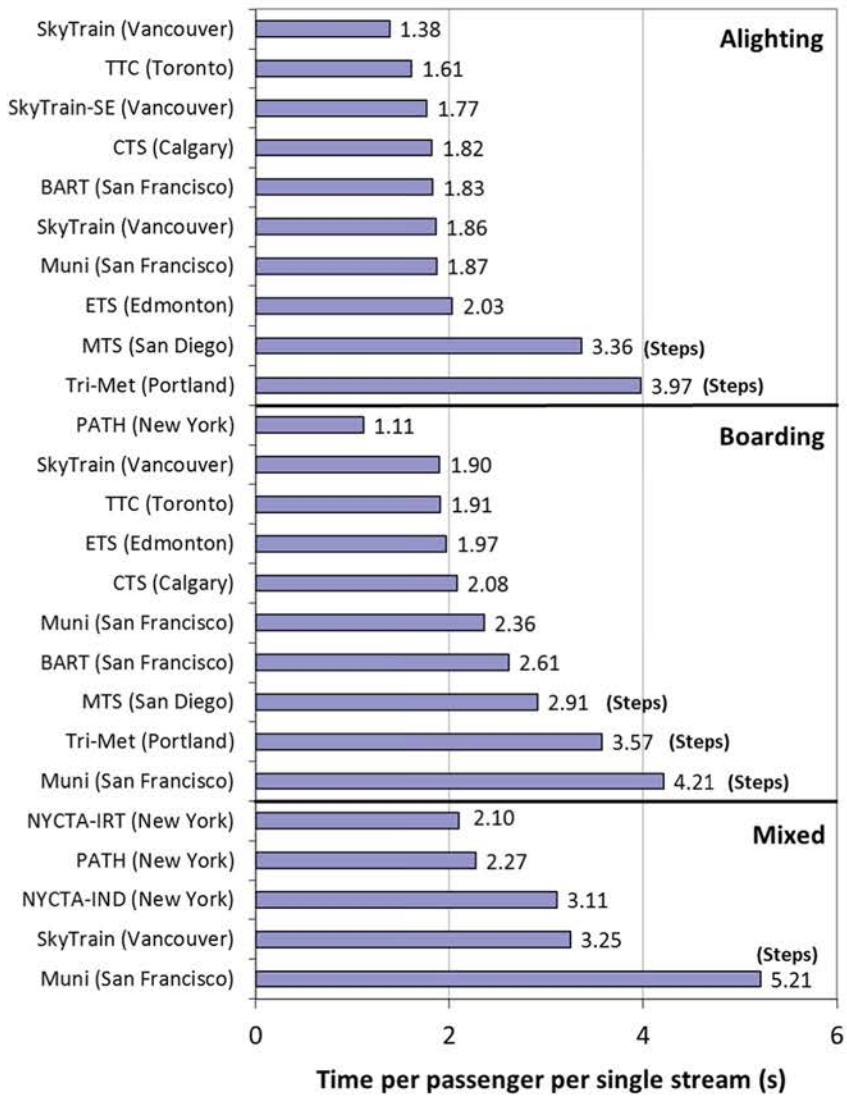
The second allowance is *schedule recovery,* an amount of time added to the terminal turn-around time to allow for recovery from accumulated delays on the preceding trip. Schedule recovery time has some effect on capacity and also has economic implications, as it can increase the number of trains and staff required to transport a given volume of passengers.

DOORWAY FLOW RATES

Flow time is the time in seconds for a single entering or exiting passenger to cross the threshold of the rail transit car doorway, per single stream of doorway width. Extensive rail transit door flow rate data collection took place in 1995 as part of *TCRP Report 13: Rail Transit Capacity* (*1*). Data were collected from a representative set of high-use systems and categorized by the type of entry—level entry being the most common, followed by light rail with door stairwells, with and without fare collection at the entrance. The data sets were partitioned into mainly boarding, mainly alighting, and mixed flows. This work was supplemented in the early 2000s with data collection specific to low-floor light rail cars as part of the development of the TCQSM 2nd Edition (*5*). The results are summarized in Exhibit 8-12.

Exhibit 8-12
Selection of Rail Transit Door Flow Times (1995)

Data in this exhibit are illustrative of the range of values that are possible. Analyses of actual systems should utilize recent empirical data from the lines being analyzed, where available.



Source: *TCRP Report 13* (*1*).
Note: Level boarding, except up or down steps where indicated.

Passengers ascend steps into a light rail vehicle faster than they descend them on exit.

An interesting result is that passengers enter high-floor light rail vehicles faster from street level than they exit. The overall fastest flow rate, 1.11 seconds per passenger per single stream, was observed on PATH when passengers were boarding empty trains at the Journal Square station in Newark in the morning peak. These flow data are consolidated and summarized by type of flow in Exhibit 8-13.

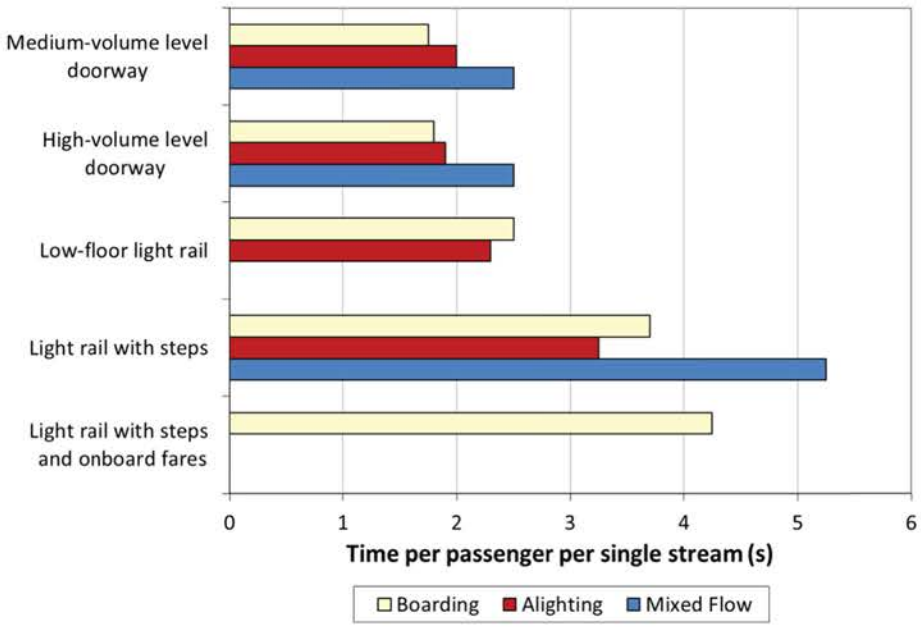


Exhibit 8-13
Summary of Rail Transit Average Door Flow Times

Sources: *TCRP Report 13* (*1*) and TCQSM 2nd Edition (*5*).

The results show that, in these averages, there is little difference between the high-volume systems —older East Coast heavy rail transit—and the medium-volume systems—newer light rail and heavy rail transit. Doorway steps approximately double times for all three categories: mixed flow, boarding, and alighting. Manual fare collection adds about 1 to 3 s per passenger transaction (for specific values, refer to Exhibit 6-4 in Chapter 6, Bus Transit Capacity, page 6–7).

Doorway steps double boarding and alighting times.

While most of the field data collection on doorway flow rates was done during peak periods, off-peak and special event flows were observed on Vancouver's SkyTrain and compared with peak-period flows, as summarized in Exhibit 8-14.

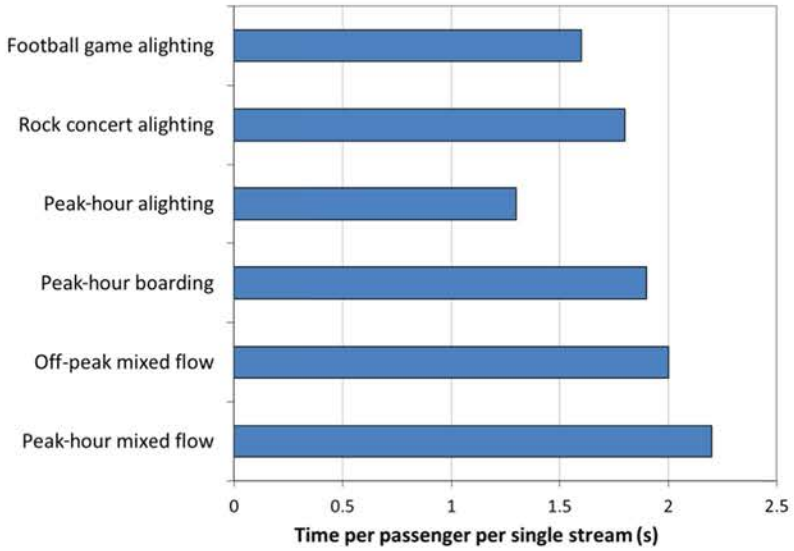


Exhibit 8-14
SkyTrain (Vancouver) Door Flow Rate Comparisons

Source: *TCRP Report 13* (*1*).

Special event passenger rates were found to be slower than weekday peak rates.

Special event flows were observed before a football game, before a rock concert, and on a busy suburban station in the early afternoon base period. The resultant data are contrary to the supposition that special event crowds move faster and that off-peak flows are slower than in the peak hour. BC Transit (now TransLink) has also measured car occupancy differences between normal peak hour operation and after service delays. In the ensuing pressure to travel after a delay, passenger space dropped almost by half from a mean of 3.8 ft^2 per passenger to 2.2 ft^2 per passenger (2.8 p/m^2 to 5 p/m^2).

OPERATING MARGINS

Examples of North American Operating Margins

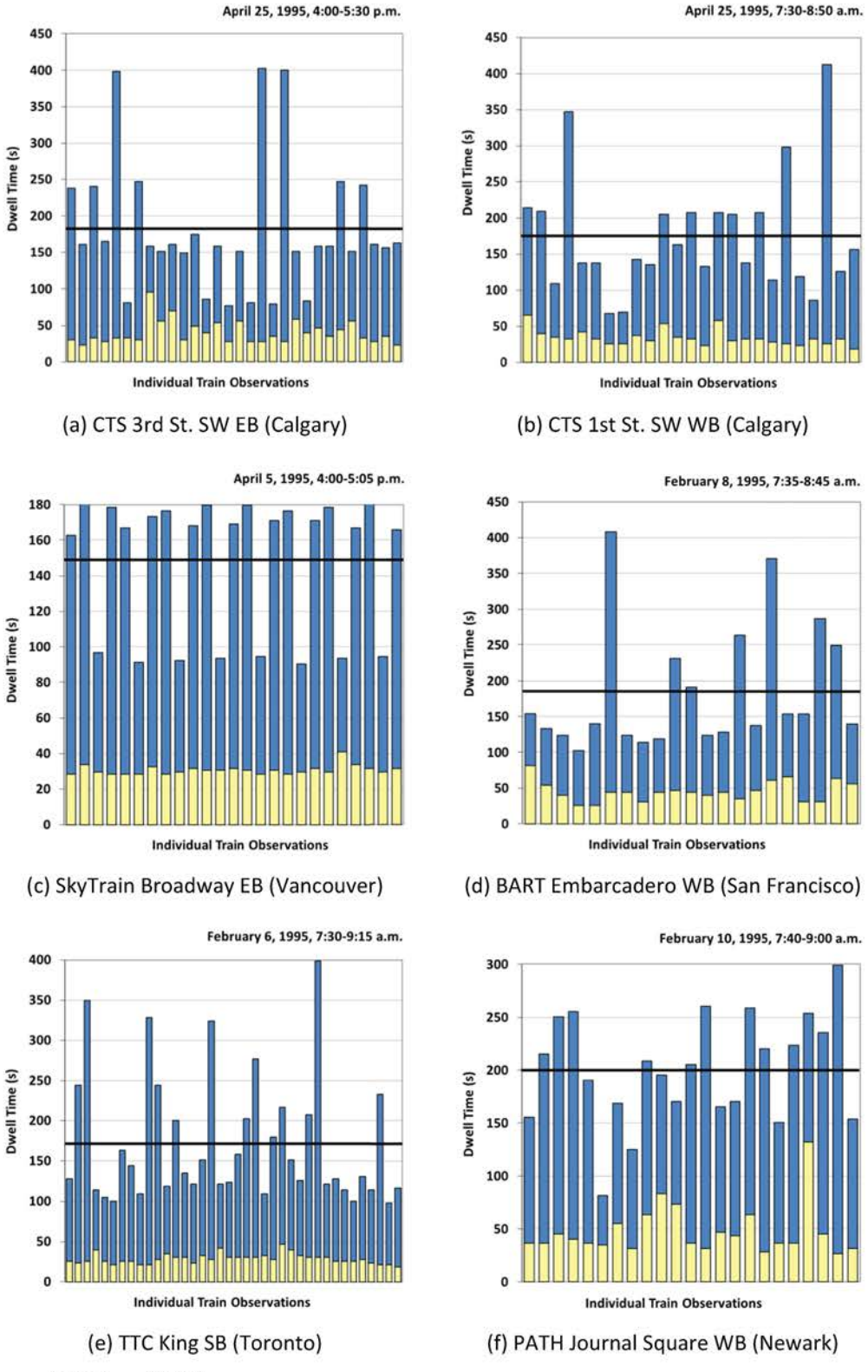
As a starting point for recommending a suitable operating margin, the operating margins incorporated into the schedules of existing systems can be reviewed. The maximum load point, peak period, station dwell time, and headways for several rail transit lines are presented in Exhibit 8-15.

Operating margin examples.

The headways in Exhibit 8-15 for Calgary are all multiples of the 80-s traffic signal cycle. The seemingly erratic headways in Calgary are misleading as three routes, forming two interlaced services, shared this downtown bus and light rail mall. The exhibit also shows the dwell and headway regularity of interlaced services on Vancouver's fully automatic SkyTrain. San Francisco's BART is also automatic, but allows drivers to control when the doors close; it shows a relatively regular headway pattern, but more irregular dwell times.

The final two charts in Exhibit 8-15 show the range of dwell and headway irregularities on manually driven systems. These are not typical of most heavy rail lines throughout the day, but represent lines at or near capacity at the peak point in the peak period. It is at these times that operating margin and schedule recovery times are most needed to correct service irregularities.

Exhibit 8-16 shows the headway components with the final column indicating the residual time that is a surrogate for the operating margin.



Source: *TCRP Report 13* (*1*).
Note: EB = eastbound, WB = westbound, SB = southbound.

Exhibit 8-15
Observed Rail Headways and Dwell Times

Dwell Time (s)
Headway (s)
Avg. headway (s)

Light rail headways on observed systems were generally sufficiently long that any irregularities reflected problems other than schedule interference between trains. One of the closest on-street headways is in Calgary, shown at the top. Note that the scales of the graphs vary.

Additional examples of these dwell/headway charts are contained in Chapter 6 of TCRP Report 13 (*1*).

Exhibit 8-16
Dwell and Headway Data Summary of Surveyed Rail Transit Lines Operating at or Close to Capacity (1995)

System and City	Station and Direction	Average Station Dwell (s)	Dwell Standard Deviation (s)	Average Headway (s)	Dwell as % of Headway	Train Control Separation (s)	Estimated Operating Margin (s)
BART San Francisco	Embarcadero WB	49.9	15.7	201.7	24.7	90.0	30.4
CTS Calgary	1st St. SW WB	34.6	11.1	176.6	19.6	80.0	39.9
CTS Calgary	3rd St. SW EB	40.0	16.2	181.4	22.1	80.0	28.9
CTS Calgary	City Hall EB	36.8	20.6	191.4	19.2	80.0	33.4
Muni San Francisco	Montgomery WB	34.4	11.0	146.0	23.6	60.0	29.6
NYCTA New York	Queens Plaza WB	40.7	17.3	134.7	30.2	53.0	6.4
NYCTA New York	Grand Central SB	64.3	16.7	164.7	39.0	53.0	14.1
NYCTA New York	Grand Central NB	53.9	14.8	184.1	29.3	53.0	47.5
PATH Newark	Exchange Place EB	23.3	7.4	115.8	20.1	55.0	22.6
PATH Newark	Journal Square WB	47.3	23.4	199.7	23.7	55.0	50.6
SkyTrain Vancouver	Broadway EB	30.2	2.6	145.6	20.7	40.0	70.2
SkyTrain Vancouver	Burrard WB	26.7	2.5	150.7	17.7	40.0	79.0
SkyTrain Vancouver	Metrotown EB	37.8	10.4	241.3	15.7	40.0	142.8
TTC Toronto	Bloor NB	43.0	15.3	145.5	29.4	55.0	17.0
TTC Toronto	King SB	28.1	5.9	168.3	16.7	55.0	73.4

Source: *TCRP Report 13* (*1*).
Note: NB: northbound, SB: southbound, WB: westbound, EB: eastbound.

Exhibit 8-17 shows the headway components graphically, with the operating margin as the end component of each bar. The bars are arranged in order of increasing headway. Note that the bar at the top is the only off-peak data set. It is included only for comparison and shows the large operating margin available when a system is not at capacity. The operating margins range widely and bear little relationship to system, technology, or loading levels.

Headway coefficient of variation.

A proxy for service reliability is the *headway coefficient of variation*—the standard deviation divided by the mean. There may be the expectation of a relationship between operating margin and service reliability; however, *TCRP Report 13: Rail Transit Capacity* (*1*) found no such relationship. Some inference can be drawn in that the system with the best headway adherence identified in *TCRP Report 13,* Vancouver's SkyTrain, also has the most generous operating margins.

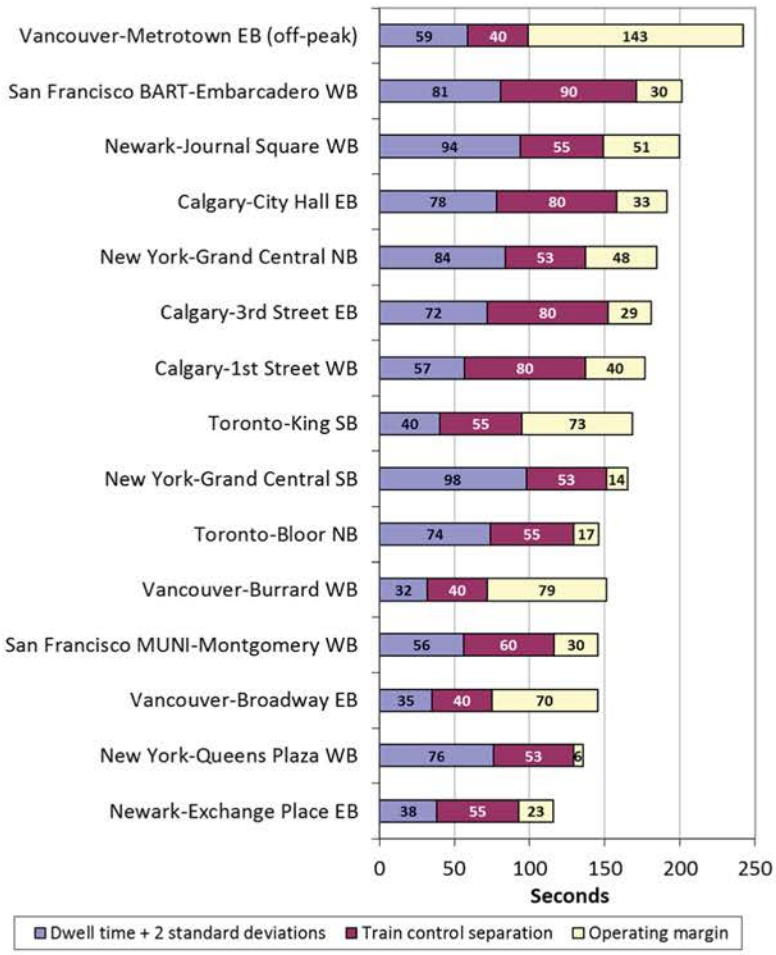


Exhibit 8-17
Headway Components of Surveyed Heavy Rail Transit Lines Operating at or Close to Capacity (1995)

Source: *TCRP Report 13* (*1*).
Note: NB: northbound, SB: southbound, WB: westbound, EB: eastbound.

Estimating Operating Margins

Although there is no clear relationship between existing rail transit operating margins and other operating criteria, this important factor, and the related terminal recovery or layover time, cannot be discounted. The inevitable headway irregularities and the need for reasonable operating flexibility require the greatest possible operating margin and recovery time to ensure reasonably even service and to achieve maximum capacity. Selecting a recommended operating margin is a dilemma, as too much reduces design capacity, but too little incurs sufficient irregularity that it may also serve to reduce capacity.

It is recommended that a range be considered for an operating margin. A reasonable level for a system with more relaxed loading levels, where all of the capacity is not needed, should be 35 s. On systems where headways prohibit such margin, a minimum level of 10 s can be used with the expectation that headway interference is likely.

Suggested operating margin range.

In between these extremes is a tighter range of 15, 20, or 25 s that is recommended. This range is used in estimating design capacity in this manual and is recommended as a default value for computations using the detailed procedures.

SKIP-STOP AND EXPRESS OPERATION

Skip-stop operation increases average speed but not capacity.

Skip-stop service (where a given train stops at every other station) is used on several of the heavy rail transit operations in Japan, New York, and Philadelphia. Skip stops provide faster travel times for most passengers, and require less equipment and fewer staff. They do not increase capacity as the constraint remains the dwell time at the maximum load point station at which all trains must stop. In fact, capacity can be slightly reduced as the extra passengers transferring between *A* and *B* trains at common stations can increase dwell times. Skip-stop operation is only applicable if the headways are sufficiently short that the "up to two-headway wait" at minor stations is acceptable to passengers.

Skip-stop service tries to balance loads between the "A" and "B" trains.

The common stations on the Japanese skip-stop operations have multiple platforms, typically two island platforms allowing passengers to transfer across the platform between *A* and *B* or between local and express trains.

Some light rail lines operate a form of express service, where a following train skips stops to catch up to—but not pass—the train in front.

Light rail operations may also skip stations when an *on-demand* operating policy is adopted. This requires that an onboard passenger signal to stop the train. Drivers must observe whether there are any waiting passengers as they approach each station. This is a particularly efficient way to increase line schedule speed and reduce operating costs. However, at higher capacity levels all trains will stop at all stations and so the practice has no effect on line capacity. Demand stops are rare on new North American light rail systems, even where there are clearly some low-volume stations where during off-peak times on-demand stops could contribute to lower energy consumption, lower maintenance costs, and a faster, more attractive service.

New York's Lexington Avenue express tracks carry 80% the number of trains of the local tracks, making it one of the most efficient four-track lines.

Directional capacity with express service.

Most trunk routes in New York have three or four tracks, while the Broad Street subway in Philadelphia and the North Side elevated in Chicago have four tracks. The capacity of four-track lines is not a simple multiple of two single tracks and varies widely with operating practices such as the merging and diverging of local and express services and trains holding at stations for local-express transfers. The result is that four tracks rarely increase capacity by more than 50% over a double-track line—and often less. A third express track does not necessarily increase capacity at all when restricted to the same station close-in limitations at stations with two platform faces.

PASSENGER-ACTUATED DOORS

Most new light rail systems have passenger-actuated doors, which increase comfort by retaining interior heat or air conditioning and reducing wear and tear on door mechanisms. The practice can extend station dwell time but is of little value at higher frequencies or busy stations where the use of all doors is generally required. Consequently, some systems use the feature selectively and allow the train operator to override passenger actuation and control all doors when appropriate.

Door cycle times.

A typical heavy rail transit car door will open and close in 5 s. Certain light rail doors associated with folding or sliding steps can take double this time to operate. A door opening initiated at the end of a station dwell will extend the dwell time by the door opening and closing time, plus any added passenger movement time. A system approaching its capacity could not tolerate such dwell extensions but would, in any event, be using all doors and might just as well be under driver control—avoiding any last-minute door opening and closing.

TRAIN AND PLATFORM SCREEN DOORS

Many AGT systems and newer heavy rail transit systems have platforms that are enclosed and separated by screens from the guideway, with doors that open directly adjacent to the train doors when the train stops at the platform. The door opening mechanisms are coordinated so that the platform and train doors open and close simultaneously. Examples include the Jubilee Line extension in London, underground stations on the Copenhagen Metro, the JFK AirTrain in New York, and virtually all on-airport people mover systems in the U.S. Platform doors provide superior safety and (potentially) climate control on the station platform by physically separating the platform zone from the trackway. Rapid transit systems in Hong Kong, Taipei, and Singapore use platform screen doors (some half-height, some full-height) and sometimes platform conductors at busier stations to control dwell time. Some platform screen doors are manually operated: the driver closes the platform doors first to shut off the crowds, and closes the train doors simultaneously if there is no obstruction, or holds the train doors open a little longer if needed to ensure everyone is safely inside the train. The platform conductor uses lightsticks and a whistle to indicate to passengers that train is ready to depart and the boarding process should stop.

Generally, these systems require automatic train operation to ensure that the train stops at exactly the right location on the platform for the train doors to line up with the platform doors. They also require uniform rolling stock with precisely-specified door locations.

FARE PAYMENT

Onboard light rail fare payment.

Fare payment can be a constraining factor on light rail systems that use manual on-board payment, although the trend for new systems is towards proof-of-payment fare collection systems that avoid the need for onboard fare payment. Manual fare payment adds an average of 1 to 3 s per boarding passenger. This is an inefficiency that increases running time, station by station, day by day.

However, the far more drastic impact of manual onboard fare collection is the restriction of boarding to a single staffed door. Not only do all passengers take more time to board individually, the efficiency of loading several passengers at once through multiple doors is lost, resulting in dwell times that are potentially three to four times as long as they would be without onboard fare collection. Exhibit 8-18(c) shows an extreme case of platform congestion resulting from manual onboard fare collection and a surge of passengers from a nearby tourist attraction. A system using manual onboard fare collection, and restricting boardings to driver-attended doors only, cannot achieve its maximum capacity.

A few systems provide onboard fare machines, combined with random fare checks. These machines allow passengers to board through all doors and then make their way inside the car to the fare machine. This addresses the dwell time issue, but can substitute a crowding and circulation issue inside the car, in the vicinity of the fare machine. On low-volume lines, or mainly pre-paid lines, congestion within the car may not be an issue. However, on high-volume systems with onboard fare machines, it can be an issue.

Exhibit 8-18
Onboard Fare Collection



(a) Farebox (Pittsburgh)



(b) Self-service machine (Portland Streetcar)



(c) Farebox, with passenger surge (Cleveland)



(d) Smart card reader (San Francisco)

Platform width.

Stations with high mixed flows must also have platforms of adequate width to accommodate the flows. Platform width is also a factor in making it easy for passengers to distribute themselves along the length of a train and to improve the peak-hour factor.

STATION AND PLATFORM DESIGN

Inadequate platform exit capacity can reduce line capacity, as dwell times of following trains increase.

Many station-related factors can influence demand. Poor location, inconvenient transfers to connecting modes, and inadequate or poorly located kiss-and-ride or park-and-ride facilities may all deter usage. However, the only factor that has a potential effect on the line capacity of a rail transit line is the rate of exiting from a platform. Adequate passageways, stairways, and escalators must be provided to ensure that a platform can clear before the arrival of the next train. Inadequacies in passenger access to a station may reduce demand but not capacity.

Chapter 10 of the TCQSM covers NFPA station exit requirements in greater detail.

Station exiting requirements are specified by the U.S. National Fire Protection Association (NFPA) Standard 130 for fixed-guideway transit systems (*6*). Exits, emergency exits, and places of refuge must be adequate to allow a platform with one headway's worth of passengers plus the entire complement of a full-length fully loaded train to be able to be evacuated to a safe location within 4 min. These regulations ensure that in all but the most unusual circumstances—where there is a disproportionate reliance on emergency exits—full capacity loads can leave the platform before the next train arrives.

NFPA 130 requirements may not be met on older systems. Additional exits must be provided to ensure that exit throughput is not constrained by platform back-ups. Rates of flow are established for passageways and for up and down stairs and escalators according to width. In emergencies, exit fare payment devices can be placed in a free passage mode. This is not the case in normal operation when adequate exit-fare control checks must be provided on those systems with distance-related fares.

Out-of-service fare gates and escalators have the potential to create station platform congestion if the remaining in-service equipment does not have sufficient capacity.

Even when NFPA 130 requirements are met, constraints posed by out-of-service fare gates, escalators, or other station components can potentially create congestion that could cause passenger queues to back up onto station platforms if these components are being operated close to their capacity. Chapter 10 of the TCQSM provides procedures for calculating the passenger-handling capacity of various station components.

WHEELCHAIR ACCOMMODATIONS

Since dwell times are one of the most critical components of headway, the time for wheelchair movements is important. Measured lift times run 2 to 3 min, with some as low as 60 s. The movement of wheelchairs on level surfaces is generally faster than walking passengers except where the car or platform is crowded. Level loading is essential to achieve high capacity. Where high platforms or low-floor cars cannot be provided, mini-high or high-block loading arrangements for wheelchairs, described later in this section, have the least impact on capacity. The vertical and horizontal gap between the edge of platform and the door is often a major problem for passengers in wheeled mobility aids.

An unknown is the number of customers in wheelchairs who will elect to use mainstream rail transit when all ADA measures have been implemented. A 1995 survey of heavily used rail transit systems indicated an average of 1 wheelchair use per 20,000 passengers (*1*). Other estimates range from 1 in 5,000 to 1 in 10,000. However, usage is usually dependent on other streetscape amenities and demographic factors as well. The usage of lifts can be three to five times higher than these rates due to use by other passengers not using wheeled mobility aids.

In addition to any boarding and alighting delays, the time for a wheelchair to move to a securement position and use any required securement or restraint systems can be considerable, particularly if the rail car is crowded. However, experienced users can be remarkably quick in boarding and alighting, and passenger movement times are often lower than for lift-equipped buses, as there is more room to maneuver wheelchairs, walkers, and scooters within rail vehicles. Off-vehicle fare collection also helps to speed loading for mobility limited and able-bodied passengers alike. The least loss of time occurs when the wheelchair position is close to the doorway and requires neither a folding seat nor the use of a securement system. Some systems have experienced passenger conflicts over mobility device seating priority when other passengers occupy the folding seats provided to create space for wheelchairs and other mobility devices.

Some agencies are overly cautious in adapting bus securement procedures to light rail service. Consideration of wheelchair securement is necessary for light rail vehicles operating on-street, due to the possibility of rapid braking as a result of traffic. However, many systems' experience indicates that wheelchair securement systems are not necessary for off-street rail service, as braking and acceleration is closely controlled and ride quality is smooth.

Impact of wheelchairs on line capacity.

There are many other types of boarding and alighting delays from passengers, other than those in wheelchairs, and generally these are accommodated in the operating margins and schedule recovery times. There is insufficient information to quantify the impact of wheelchair accessibility on line capacity. Indications are that in the short term, wheelchair lift and bridging plate use on light rail may cause delays, but this use is generally on systems with long headways (6 min and above) and have minimal impact on capacity at these levels. In the longer term, other accessibility requirements of the ADA and the move to level boarding with low-floor cars, or mini-high and profiled platforms, should sufficiently improve boarding and alighting movements to offset any negative impact of wheelchair use.

Wheelchair Boarding Methods

High-level loading is invariably used on heavy rail systems and automated guideway transit systems. The relative rarity of level loading with high-level platforms on other rail modes has resulted in a variety of methods to allow wheelchair access to rail vehicles. Each of the methods is outlined by mode in the sections that follow.

It should be noted that both mobility-impaired passengers and transit agencies prefer access methods that do not single out people with mobility impairments for special treatment. Lifts and special ramps cause delays that reduce the reliability of the service while isolating people with mobility impairments from other passengers. Mechanical devices such as lifts can also fail and put a train out of service. For these reasons, the popularity of lifts and other special devices for use by people with mobility impairments is decreasing in favor of more reliable and less exclusionary methods such as low-floor cars.

Light Rail

High Platforms

High platforms allow level movement between the platform and the car floor. This allows universal access to all cars of a train and removes the reliability and exclusionary effects associated with lifts, ramps, and special platforms. Passenger flow is sped up for all passengers since there are no steps to negotiate on the car. High-platform stations can be difficult to fit into available space, because of the need for an ADA-accessible sloped ramp to get between street level and platform level, which can increase costs. The use of high platforms on the transit mall portion of Calgary's light rail lines illustrates the difficulty accommodating this preferred loading method in on-street locations.

Mixed use of high and low platforms.

High platforms are also used at LRT stations in Buffalo, Pittsburgh, and San Francisco in combination with low-level loading at other stops. Buffalo is unusual in that a subway with high platforms serves the outer portion of the line, while the downtown segment is on a transit mall with low-level loading using fold-out steps combined with high-platform stubs for wheelchair access. Pittsburgh has separate doors for each platform level, while the San Francisco Muni uses cars fitted with steps that can be mechanically raised to floor height at high-platform stations.

Examples of high-platform stations and vehicles used in mixed high- and low-platform environments are shown in Exhibit 8-19.



(a) On-street station in median (San Francisco)



(b) Partial platform (Buffalo)



(c) Adjustable vehicle steps (San Francisco)



(d) Separate door levels (Pittsburgh)

Exhibit 8-19
High-Platform Station and Adjustable Door Height Examples

Low-Floor Cars

Low-floor cars offer a straightforward solution to the need for universal access to light rail vehicles. By bringing the floor height down to just above the railhead, boarding is simplified for all passengers, as steps are no longer required. Small, extendible ramps and slight increases in platform edge height allow passengers using wheeled mobility aids to board without the aid of lifts or special platforms. Boarding by persons with strollers, bicycles, and luggage, and by persons who have difficulty climbing steps is also greatly simplified. Exhibit 8-20 presents examples of low-floor light rail cars.

Low-floor cars improve access for everyone, not just persons using mobility aids.



(a) Portland, Oregon (light rail)



(b) Jersey City, New Jersey

Exhibit 8-20
Low-Floor Car Examples

Low-floor cars provide much of the benefit of level loading without the need for high platforms. The typical floor height is 14 in. (350 mm), about double the height of a normal curb. Medium- or intermediate-height platforms are therefore still required for no-step boarding, but long ramps are unnecessary. Buttons located at a lower height than the separate passenger-actuated door buttons on the inside and outside of the car allow wheelchair users to deploy the ramp on demand to bridge the gap between the car and the platform.

While low-floor cars have operated in Europe since the mid-1980s, the first North American operation began on Portland's light rail system in 1997. Portland's low-floor cars are compatible with the system's older high-floor fleet, allowing two-car trains to be formed from one high-floor and one low-floor car. Low-floor cars have subsequently been placed in service on many new North American light rail lines.

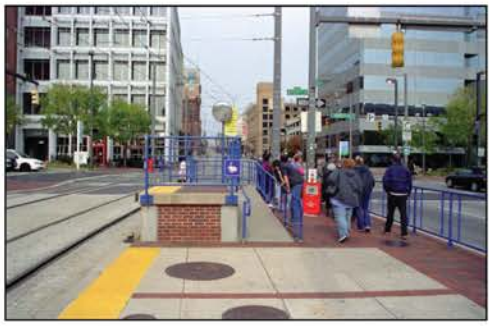
Mini-High Platforms

The most common wheelchair access methods to high-floor light rail cars are *mini-high* platforms that provide level loading to the accessible door of the train. This method is mechanically simple and often uses a folding bridgeplate, manually lowered by the train operator, to provide a path over the stepwell between the platform edge and vehicle floor. The mini-high platform is reached by a ramp or, where space limitations require, a small lift. A canopy is sometimes provided over the ramp. Exhibit 8-21 provides examples of mini-high platforms used in North America.

Exhibit 8-21
Mini-High Platforms



(a) San Francisco



(b) Baltimore

Profiled platform as an alternative to mini-high platforms.

An alternative to the mini-high platform is the Manchester-style profiled platform, shown in Exhibit 8-22. This platform has an intermediate height and is profiled up to a section that is level with one doorway for wheelchair access. Maximum platform slopes are shown in Exhibit 8-23.

Exhibit 8-22
Profiled Light Rail Platform Providing for One Accessible Door



Source: *TCRP Report 13* (*1*).

Maximum Rise		Maximum Slope	
Rise ≤ 3 in.	Rise ≤ 7.5 cm	1:4	14.04°
3 in. < Rise ≤ 6 in.	7.5 cm < Rise ≤ 15 cm	1:6	9.46°
6 in. < Rise ≤ 9 in.	15 cm < Rise ≤ 22.5 cm	1:8	7.13°
Rise > 9 in.	Rise > 22.5 cm	1:12	4.76°

Exhibit 8-23
ADA Maximum Platform Slopes

Folding steps and profiled platforms.

Most of the platform is only slightly higher than a sidewalk. Where the street arrangement permits, the profiled platform can be raised so that its mid-section—taking up most of the length—is raised one step, providing single-step entry to most doors. Alternatively, cars can have a slide-out or fold-down step as shown in Exhibit 8-24.

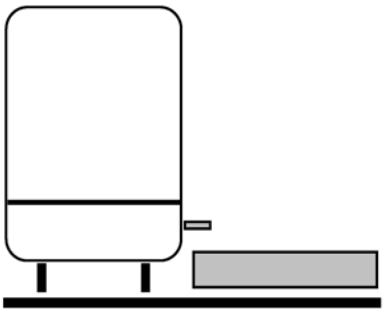


Exhibit 8-24
Profiled Light Rail Platform with Slide-Out or Fold-Down Step

Source: *TCRP Report 13* (*1*).

Car-Mounted Lifts

Car-mounted lifts, illustrated in Exhibit 8-25, were introduced on the San Diego Trolley, one of the first light rail transit systems to be wheelchair accessible. In San Diego, lifts are mounted in older high-floor cars so that the first door on the right side of every train is lift-equipped. When not in use, the lift is stored in a vertical position that blocks the doorway from use by other passengers. The Kenosha, Wisconsin, vintage trolleys use a car-mounted lift that folds flat against the side of the door when not in use, which allows other passengers to use the door when the lift is not in use. Trains used on New Orleans' Waterfront and Canal Street lines use car-mounted lifts located at a high-level door not used by other passengers.

Dwell times with car mounted lifts.

Boarding and alighting times with the car-mounted lifts are around 1 min for each passenger movement. However, the need for the train operator to leave the cab to operate the lift adds to the time required and can mean the total station dwell time extends to 1.5 to 2 min when the lift is used. If the operator is required to assist in securing the wheelchair, the dwell can be further extended.

Exhibit 8-25
Car-Mounted Lifts



(a) San Diego



(b) Kenosha



(c) New Orleans

Platform-Mounted Lifts

Platform mounted lifts were originally used on the San Jose and Portland light rail systems. They offer advantages over car-mounted lifts in that all car doors are left available for other passengers when the lift is not required, the lift is not subject to car vibration, and the failure of a lift need not remove a car from service. Disadvantages include increased susceptibility to vandalism and an increase in the distance that the train operator must walk to operate the lift. Wheelchair boardings using platform lifts took 2 to 3 min, giving a total train delay (including loading and unloading) of 4 to 6 min per passenger requiring the lift. These delays could easily consume a train's scheduled terminal recovery time. Both systems removed their platform lifts after introducing low-floor cars to their fleet.

Commuter Rail

Bridgeplates are often used to span the gap between platform and train.

Commuter rail systems use many of the same kinds of access methods as light rail systems. The main difference is that these methods are often supplemented with a bridgeplate to span the gap between platform and train when a form of level boarding is used. The vertical and/or horizontal gap between the train and platform for "level" boarding typically is greater for commuter rail than for light rail. The bridgeplate can be portable or built into the train.

High-level platforms are usually not possible on lines shared with freight trains.

High-level platforms provide the easiest and fastest boarding for all passengers. The Electric Division of Chicago's Metra, MTA-Long Island Rail Road, and MTA-Metro North Railroad are among the commuter rail lines that use high-level platforms. However, it is often not possible to provide high-level platforms on lines that are shared with freight trains, as freight wide-loads will need to be accommodated (*1*).

Mini-high platforms, combined with a bridgeplate (Exhibit 8-26), are a frequently used option on lines with low-level platforms. Platform lifts are used by CalTrain in the San Francisco Bay Area and at some New Jersey Transit commuter rail stations. Metra's diesel-powered lines in Chicago provide cars with onboard lifts.



(a) Vancouver



(b) Seattle

Exhibit 8-26
Commuter Rail Wheelchair Loading Examples

Ropeway Modes

Inclined Planes

Because each inclined plane in North America is unique, so are the means of providing access; due to their age, many inclined planes are not accessible as a result of the vehicle and/or station design.

Access is much easier to provide when the car floor is level, rather than when the seats are tiered (as is the case on most inclined planes). Johnstown, Pennsylvania, has level loading from each end. The Horseshoe Curve funicular, near Altoona, Pennsylvania, provides level loading from each side of the car.

Several access methods have been developed for tiered cars. The funicular at the Industry Hills Resort in California was designed to carry golf carts and has a series of terraced ramps leading to each car tier. Pittsburgh's Monongahela Incline has an elevator inside the lower station to take wheelchairs to the top tier loading area; wheelchairs exit on the level at the upper station. Los Angeles' Angels Flight uses an inclined platform lift (like those used on stairways) to bring wheelchairs to the top car level at the lower station; wheelchairs exit on the level at the upper station.

Aerial Ropeways

In the past, gondola access required that the entire system be brought to a stop to load and unload wheelchairs because boarding normally occurred as the carriers circulated through the station while moving (typically at 50 ft/min or 15 m/min) and there was a vertical gap between the cabin floor and the platform that needed to be overcome. Newer designs provide a trench in the platform floor that the gondola passes through, allowing level loading. Clutching equipment allows an individual carrier to be brought to a near-stop to load wheelchairs, without stopping the entire system. Aerial tramways provide level boarding from the platform into the cabin; however, elevators or ramps may be needed to access the platform.

SYSTEM DESIGN

Although the capacity estimation procedures in Section 5 are focused on normal operating conditions, it is prudent to consider the impacts of abnormal conditions. Three areas in particular to consider are (*a*) the potential impacts of disabled trains on

system operation, (b) routine track maintenance, and (c) the handling of special event crowds.

Disabled Trains

When a train needs to be taken out of service, it is desirable to get it off the main line as quickly as possible. In a typical two-track operation, this means moving it to a place where it can be temporarily stored, moving it into a yard, or turning it back on the opposite track. The train will likely not be able to move at its normal speed, which means that the trains following it will catch up to it and be delayed. The longer the disabled train remains on the line, the more trains will be delayed. Because the disabled train, and the ones delayed behind it, will occupy signal blocks for longer periods of time, train headways will increase and line capacity will decrease. The longer headways mean that more passengers will accumulate on platforms between trains, potentially leading to platform crowding. In addition, passengers on a disabled train will need to be off-loaded; the station where they off-load will have passengers of its own on the platform waiting to board the train, and the platform should be designed to accommodate all of those passengers. Finally, when a system operates close to capacity, any significant delay will use up a train's terminal recovery time, resulting in potential delays later on in the reverse direction. As can be imagined, a disabled train can quickly cause delays and crowding that ripple along the line, and which may take a long time to clear up.

Exhibit 8-27 shows examples of ways that a rail system can be designed to accommodate disabled trains. Trains can be stored off the main line in a pocket track accessible to both main tracks (allowing the train to be reversed later if needed), on a siding accessible to only one direction, or in a storage track beyond a terminal station. If a yard is convenient to the train's location, it can be removed from the line altogether. Finally, a train can be turned back at a crossover—either to get to a storage track or to move it in a direction where it will delay fewer people. Crossovers can also be used to short-turn trains in advance of their scheduled terminus—this can help to fill a gap in the sequence of trains in the reverse direction, helping to reduce the time needed to recover from the delay, at the expense of further delaying passengers traveling beyond the station at which the train makes its short turn.

Crossovers can be used to short-turn trains to help recover from delays.

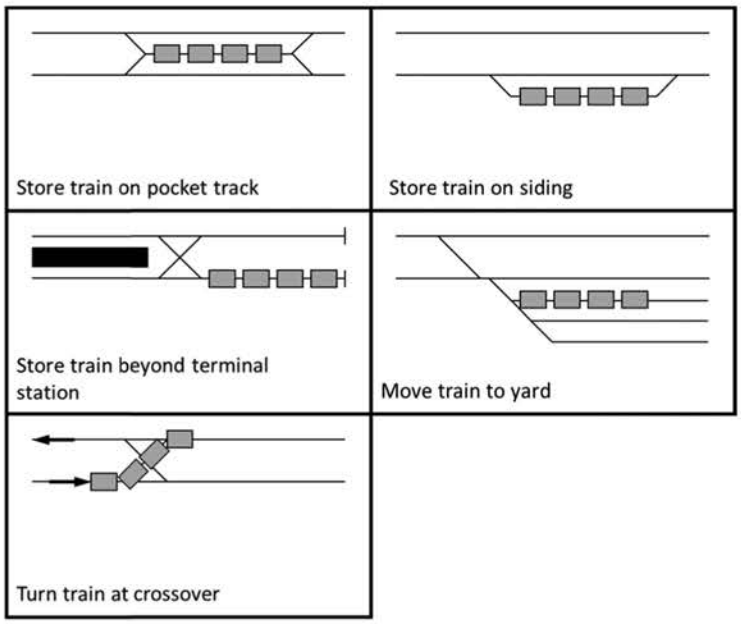


Exhibit 8-27
System Design Features for Accommodating Disabled Trains

The spacing of storage tracks and crossovers requires balancing initial capital costs when constructing the system with the amount of delay a system is willing to tolerate when a train breaks down. Physical constraints, particularly when tracks are elevated or underground, must also be considered. Train headways and the resulting line capacity as a result of a disabled train can be estimated from agency experience, or by using an assumed disabled train operating speed, the resulting block traversal time, and increased dwell times for subsequent trains resulting from the longer headways and greater passenger accumulations in stations.

Guidance on estimating line capacity with a disabled train.

Track Maintenance

Many rail systems do not operate 24 hours a day because ridership levels do not warrant it. Overnight closure provides a window of time to conduct routine track maintenance when the tracks are out of service (e.g., from 1 a.m. to 4 a.m.). However, some projects may require more time than this window allows, or an agency may have a need for 24-hour operation. An alternative means of moving passengers must be developed when a track needs to be taken out of service during regular service hours.

If passenger demand is low, the remaining in-service track can be used in single-track operation to move trains around the work area if signaling is provided for the wrong-side direction. However, the capacity of both directions will be greatly reduced. The single-track capacity procedures presented in Section 5 can be used in these circumstances, given a known distance between crossovers.

Single-track rail operation.

If single-track operation does not provide sufficient capacity to meet passenger demand, another alternative is to provide a bus bridge. In this situation, trains are turned back on either side of the work area, and passengers transfer to buses to meet a train on the other side of the work area or to reach a destination station within the work area.

Bus bridges.

Use of express tracks.

MTA-New York City Transit is able to take advantage of the third and fourth tracks that exist on many of its major lines to close tracks for maintenance and maintain two-direction operations.

Special Events

Special events—such as sporting events, concerts, and community festivals—can generate very large passenger demands during a short span of time. While passengers are willing to tolerate longer delays and greater levels of crowding under these circumstances than they might otherwise, system design should still consider any special train storage needs in order to make sure that crowds can be transported away from the event site in a reasonable period of time. San Diego, for example, designed its football stadium station with storage for 18 cars—enough room for five three- to four-car trains. For Super Bowl XXXII, San Diego closed the Mission San Diego station, at the time a terminal station located one station east of the stadium, which allowed storage on the main tracks for twenty-one three- to four-car trains. Light rail was able to transport 29,800 passengers—30% of the Super Bowl's attendance—within 2 hours following the end of the game (*7*).

Crowd management.

Crowd management is another issue requiring consideration. Security personnel are usually needed to keep passengers off tracks and to limit platform access to avoid overcrowding problems. Providing pre-sold return tickets and/or providing mobile ticket sales outlets minimizes crowds and delays at ticket machines. Platforms should be sized to accommodate expected special event crowds, and additional temporary space may be required to queue passengers when there are constraints on platform space. For example, Muni's 2nd & King light rail station, adjacent to San Francisco's baseball stadium, is located in a street median and has little platform room for large event crowds. Instead, passengers are queued using portable fences in the adjacent closed-off street following games and are allowed onto the platform when a train arrives. San Diego's football stadium station has three platforms, allowing trains to be loaded from both sides, minimizing dwell time.

Demand management.

Demand management measures can be used to spread out passenger demand following sporting events, and thus minimize platform crowding. During the sold-out first season at their new baseball stadium, for example, the Seattle Mariners provided post-game trivia contests and a ceremonial closing of the stadium's retractable roof to encourage a portion of the fans to linger after the game.

5. RAIL SYSTEM CAPACITY METHODOLOGIES

INTRODUCTION

Except for the simplest of operations, or for operations that have a long history of experience, there are no "one-size-fits-all" formulas for calculating the capacity of a rail corridor. There are many variables involved (train characteristics, speed limits, train and siding lengths, signal system characteristics, etc.), which means that a simple approach may not yield precise and accurate results. Rules of thumb and deterministic formulas that estimate minimum headways and capacities based on operational performance measures provide useful surrogates that can be used to estimate the capacity of a line or system for planning purposes. However, complex networks, terminals, and systems with complicated train operating patterns are difficult to analyze using sketch methods because of their complexity and the fact that increasing operational and physical complexity tends to either reduce the capacity of each individual element of the network or reduce the reliability of the system when it is operated close to its capacity. As a result, capacity analyses for complex networks and operating plans, where a high level of accuracy is required, are able to utilize detailed operations simulation models and methods. These are discussed in Section 6.

Methodologies presented in this section are suitable for planning purposes. Simulation is typically used for more detailed operations analyses.

This section is divided into four main subsections: a general methodology suitable to many types of rail transit operations (e.g., heavy rail, light rail, and commuter rail not sharing trackage with non-commuter trains); a discussion of the challenges of determining commuter rail capacity using deterministic methods when tracks are shared with freight or intercity passenger trains; guidance on adapting the general methodology for AGT; and a methodology for determining the capacity of ropeway modes.

GENERAL METHODOLOGY

Overview

The general methodology seeks to identify the weakest link along the rail line that will ultimately control train throughput by setting the minimum headway that can be operated between trains. The following are the potential weak links:

- Dwell time at the controlling station along the line;
- Minimum train separation allowed by the train control system;
- Right-of-way characteristics (e.g., single-track operation);
- Turnbacks;
- Junctions;
- Power supply constraints;
- Train length limitations; and
- Track configuration within terminals.

On a new system, the sum of the controlling dwell time, the minimum train separation, and the operating margin will typically control the line capacity. However, with older systems or with newer systems built to minimize initial costs, one of the

other factors may turn out to control capacity. Newer systems can often be designed to accommodate future projects to eliminate these initial constraints, but it may be costly to upgrade older systems for which allowances were not originally made to address built-in capacity constraints.

A spreadsheet that implements the general rail capacity methodology is provided on the accompanying CD-ROM.

The general methodology can be applied using hand calculations or by using the spreadsheet on the accompanying CD-ROM. When there is uncertainty about input values to these equations or where several of the performance variables are unknown (e.g., the technology or specific vehicle has not been selected), then the use of this procedure is not recommended. The planning graphs found in Section 6 provide *generic design capacity ranges* with less effort and potentially as much accuracy as the general methodology in which one or more input factors will have to be estimated.

Consider using the planning graphs in Section 6 when input variables must be defaulted.

Step 1: Determine the Non-Interference Headway

Step 1a: Determine the Maximum Load Point Station

Traditionally, the maximum load point station is the principal downtown station, or the downtown station where two or more rail transit lines meet. However, this is not always the case. With increasingly dispersed urban travel patterns, some rail transit lines do not serve the downtown. Los Angeles' Green Line and extensions to Vancouver's SkyTrain are examples.

Ridership models.

A regional transportation model will usually produce ridership data by station, both boardings and alightings and direction of travel. Such data are usually for a peak-hour or a multiple-hour peak period and rarely for the preferable 15-min period. Depending on the number of zones and nodes in the model, data accuracy at the station level can be poor—particularly if there is more than one station in a zone. Nevertheless, this is often the sole source of individual station volumes, and without it the selection of the maximum load point station requires an educated estimate. Present and future CBD employment sometimes can be used to estimate the reasonableness of ridership forecasts.

Step 1b: Determine the Control System's Minimum Train Separation

This step determines the minimum train separation associated with three types of train control systems, each providing progressively increased throughput:

- Three-aspect fixed-block signaling system,
- Multiple-command cab signaling, and
- Moving-block signaling system.

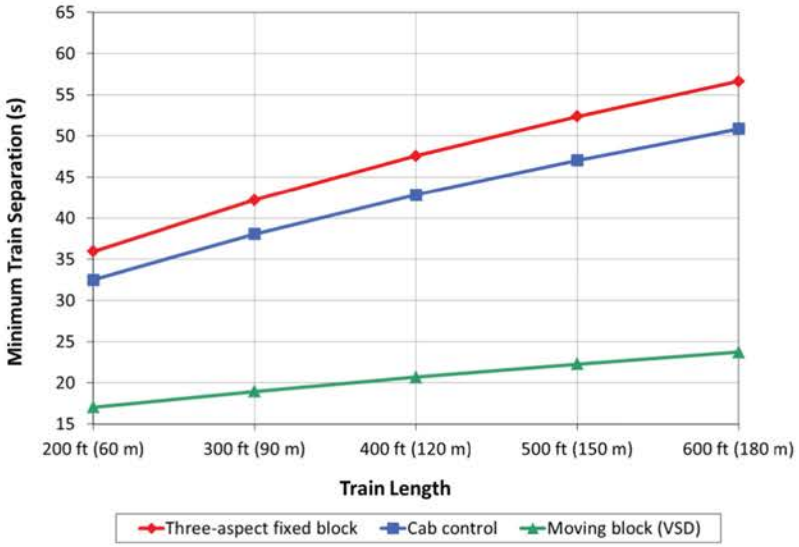
Although the equations that follow appear long, the arithmetic is simple and can be implemented using basic functions in a spreadsheet. However, before going to this effort, check the availability of the required input parameters in Exhibit 8-28. Parameters can be adjusted for system specific values or left at their default value. Train length is the most important variable. If most parameters are left at their default values, it would be easier to refer to Exhibit 8-29, which shows the minimum train control separation against train length for the three types of train control systems.

Exhibit 8-28
Minimum Train Control Separation Parameters

Default Value	Term	Description
Calculated	t_{cs}	train control separation (s)
650 ft, 200 m	L_t	longest train length (ft, m)
35 ft, 10 m	d_{eb}	distance from the front of stopped train to start of station exit block (ft, m)
Calculated	v_a	station approach speed (ft/s, m/s)
88 ft/s, 27.8 m/s	v_{max}	maximum line speed (88 ft/s = 60 mi/h, 27.8 m/s = 100 km/h)
75%	f_{br}	braking safety factor—worst-case service braking is f_{br}% of specified normal rate—typically 75% (decimal)
2.4–three-aspect, 1.2–cab, 1.0—moving block	b	separation safety factor—equivalent to number of braking distances (surrogate for blocks) that separate trains
3.0 s	t_{os}	time for overspeed governor to operate on automatic systems—to be replaced with driver sighting and reaction times on manual systems
0.5 s	t_{jl}	time lost to braking jerk limitation
1.5 s	t_{br}	brake system reaction time
4.3 ft/s^2, 1.3 m/s^2	a	initial service acceleration rate (ft/s^2, m/s^2)
4.3 ft/s^2, 1.3 m/s^2	d	service deceleration rate (ft/s^2, m/s^2)
32 ft/s^2, 10 m/s^2	a_g	acceleration due to gravity (ft/s^2, m/s^2)
0%	G_i	grade into station, downgrade = negative (decimal)
0%	G_o	grade out of station, downgrade = negative (decimal)
90%	l_v	line voltage as percentage of specification (decimal)
20.5 ft, 6.25 m	P_e	positioning error—moving block only (ft, m)
165 ft, 50 m	S_{mb}	moving-block safety distance—moving block only (ft, m)

Source: *TCRP Report 13* (*1*).

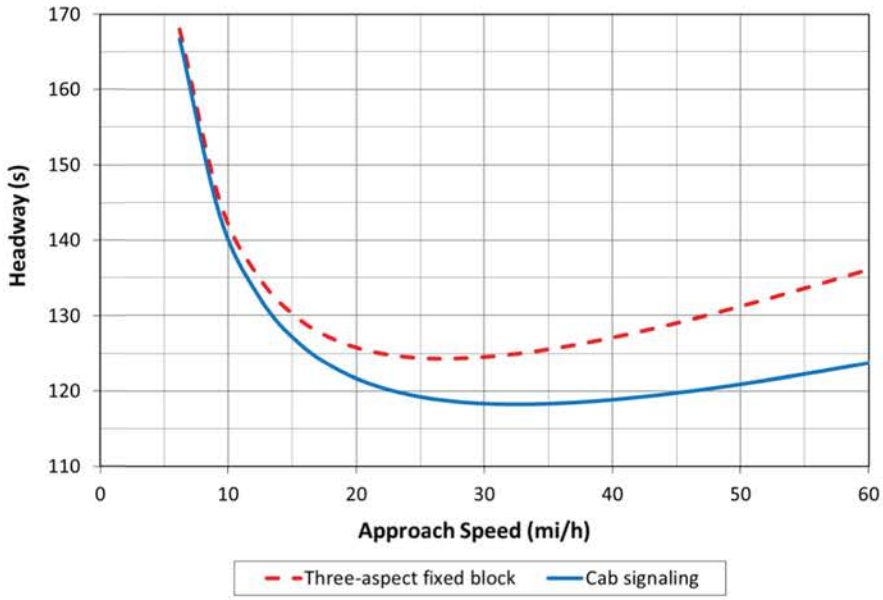
Exhibit 8-29
Typical Minimum Train Separation Versus Train Length



Source: *TCRP Report 13* (*1*).
Note: VSD = variable safety distance.

Exhibit 8-30 shows minimum station headways achieved using the typical values shown in Exhibit 8-28, derived from the equations presented later in this section, and including an assumed dwell time and operating margin. The optimum approach speeds shown in this exhibit should be compared with the maximum speeds imposed by switches and curves in the vicinity of the maximum load point station.

Exhibit 8-30
Typical Station Headways for Lines at Capacity

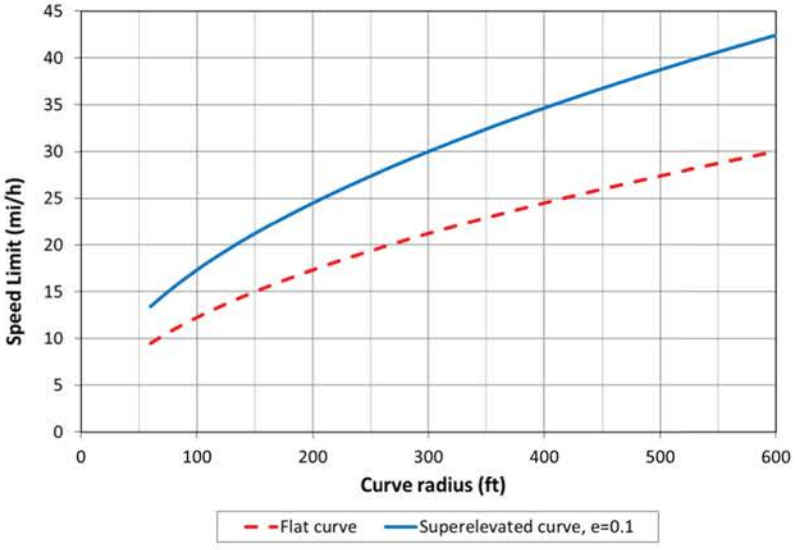


Source: *TCRP Report 13* (*1*).
Note: Assumes 45-s average dwell time and 20-s operating margin.

Exhibit 8-30 shows that the optimum approach speed for three-aspect fixed-block signaling in this situation is 28 mi/h (45 km/h), while, for cab signaling, the optimum approach speed is 32 mi/h (52 km/h). If special work (interlockings) or curves restrict approach speeds below these values, then the lower values must be calculated and used. Typical speed limits for curves and turnouts (switches) are shown in Exhibit 8-31 and Exhibit 8-32, respectively. Determine any such station approach speed restrictions and their distance from the station stopping point. Next, compare this speed restriction with the normal approach speed at that distance from the station as shown in Exhibit 8-33. The most restrictive approach speed is used in the equations presented in this section.

Exhibit 8-31
Maximum Speed Limits on Curves

Curves and turnouts (switches) impose speed restrictions.

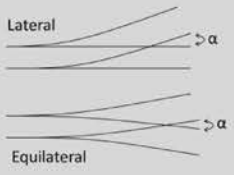


Source: *TCRP Report 13* (*1*).
Notes: Transition spirals are not taken into account. A metric version of this exhibit appears in Appendix A.

Turnout Number	Lateral Turnout		Equilateral Turnout	
	mi/h	km/h	mi/h	km/h
#6	15	24	21	34
#8	20	32	28	45
#10	25	40	35	57
#20	50	81	70	113

Source: *AREMA Manual for Railway Engineering* (*8*).
Notes: Speeds shown are based on freight trains using level turnouts with curved switch points. Intercity passenger and rail transit cars are designed for greater roll through curves and can operate comfortably at somewhat higher speeds than shown. Many transit agencies have their own speed limits for turnouts that differ from those shown.

Exhibit 8-32
Speed Limits on Turnouts



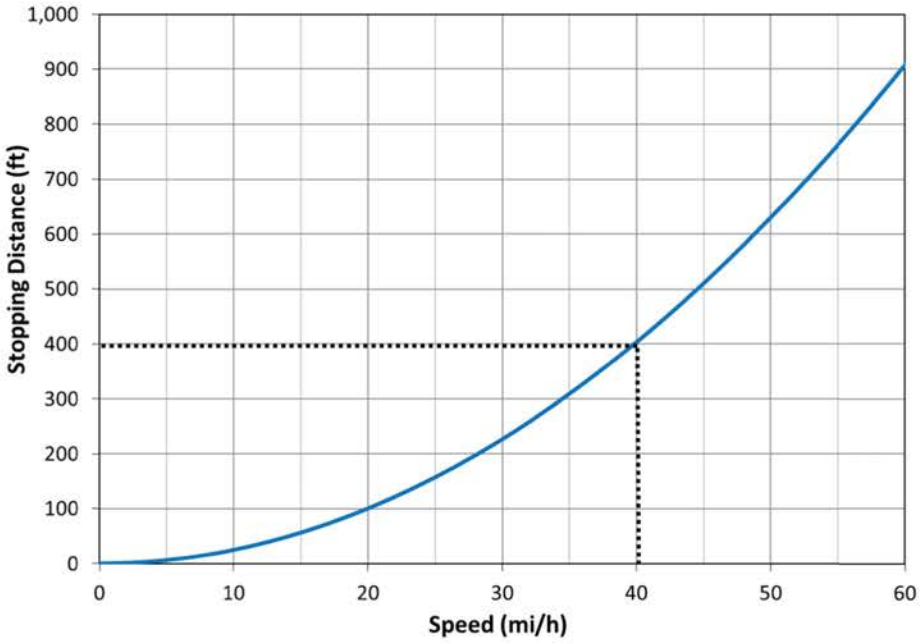


Exhibit 8-33
Typical Stopping Distance as a Function of Speed

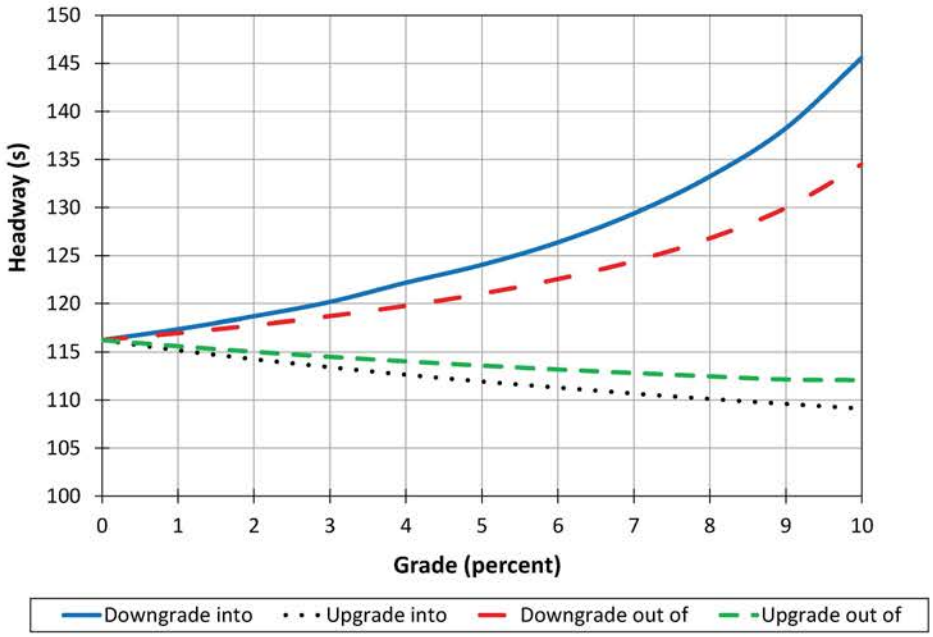
Use this chart to find how far from the station a computed optimal approach speed will occur, then determine if there is a lower speed limit at that location.

Source: *TCRP Report 13* (*1*).
Note: A metric version of this exhibit appears in Appendix A.

The dotted line example in Exhibit 8-33 shows that at 400 ft (120 m) from a station, expressed as the distance from the front of the approaching train to the stopping point, the approaching train will have a speed of 40 mi/h (64 km/h). If there is a speed limit at this point that is lower than 40 mi/h (64 km/h), then the minimum train separation, t_{cs}, must be calculated with the approach speed v_a set to that limit.

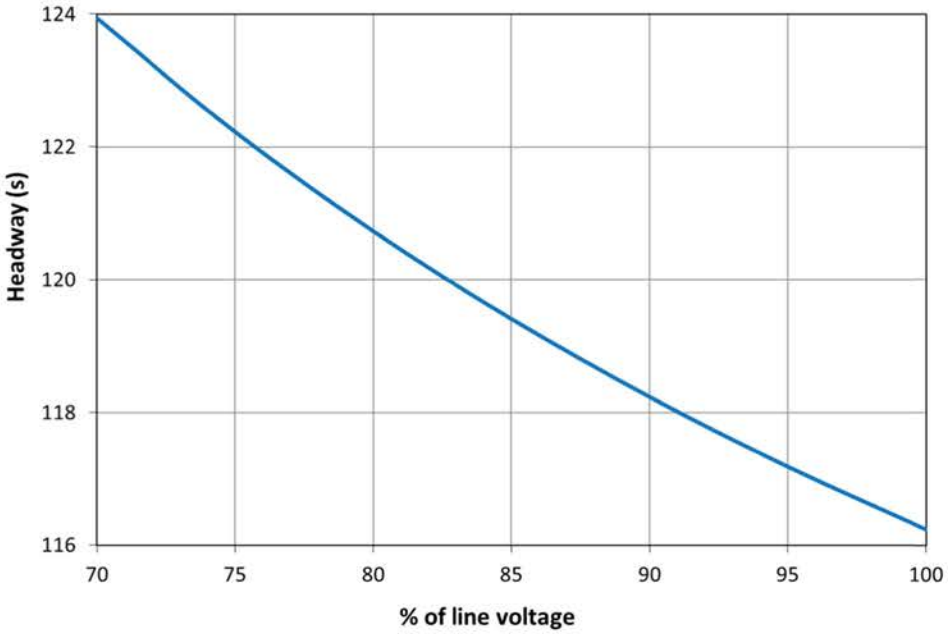
Two other factors affect minimum headways. Grades into or out of a station will change the acceleration and braking rates. Line voltage will drop below the nominal value on heavily used systems and reduce train performance. The results of grades and voltage drops are shown in Exhibit 8-34 and Exhibit 8-35, respectively. The calculations of these effects are complex and best left to a computer simulation. If a simulation model is not available, then the approximate headway changes can be read from Exhibit 8-34 and Exhibit 8-35, and the calculations adjusted by the appropriate number of seconds.

Exhibit 8-34
Typical Effect of Grade on Station Headway



Source: *TCRP Report 13* (*1*).
Note: Assumes cab signals, 45-s dwell time, and 20-s operating margin.

Exhibit 8-35
Typical Headway Changes with Voltage



Source: *TCRP Report 13* (*1*).

Fixed-Block and Cab Signaling Throughput

The minimum train control separation for fixed-block and cab signal systems is given by Equation 8-1, with variables as shown in Exhibit 8-28:

$$t_{cs} = \sqrt{\frac{2(L_t + d_{eb})}{a + a_g G_o}} + \frac{L_t}{v_a} + \left(\frac{1}{f_{br}} + b\right)\left(\frac{v_a}{2(d + a_g G_i)}\right) + \frac{(a + a_g G_o) l_v^2 t_{os}^2}{2v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$

Equation 8-1

This equation should be solved for the minimum value of t_{cs}. The approach speed v_a that produces this minimum value must then be checked against any speed restrictions approaching the station from Exhibit 8-33.

Compare the approach speed producing the minimum train separation to any speed restrictions on the station approach.

Moving-Block Throughput

Moving-block signaling systems replace separation by fixed blocks with a moving block based on the braking distance to a target point plus a safety separation distance. The safety separation distance can be fixed for a given system and type of rolling stock or can be continually adjusted with speed and grades.

Moving-block train separation safety distances can be fixed or variable.

Equation 8-2 determines the train control separation for a moving-block signaling system with fixed safety separation, with variables as given in Exhibit 8-28. Note that the time for the overspeed governor to operate is incorporated into the safety distance and so does not appear in the equation.

$$t_{cs} = \frac{L_t + S_{mb}}{v_a} + \frac{1}{f_{br}}\left(\frac{v_a}{2d}\right) + t_{jl} + t_{br}$$

Equation 8-2

Note that this equation is not affected by either line voltage or station grade. Lower voltages increase the time for a train to clear a station platform. In moving-block systems this time does not affect throughput. When a train starts to leave a station, the target point of the following train is immediately advanced accordingly. The worst-case approach grade is included in the determination of the safety distance. This can result in sub-optimal minimum train separation.

Higher throughput is usually obtained with a moving-block signaling system with a variable safety distance consisting of the braking distance at the particular speed plus a runaway propulsion allowance. The minimum train control headway of such a system is given by Equation 8-3, with variables and default values as given in Exhibit 8-28.

$$t_{cs} = \frac{L_t + P_e}{v_a} + \left(\frac{1}{f_{br}} + b\right)\left(\frac{v_a}{2(d + a_g G_i)}\right) + \frac{(a + a_g G_o) l_v^2 t_{os}^2}{2v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$

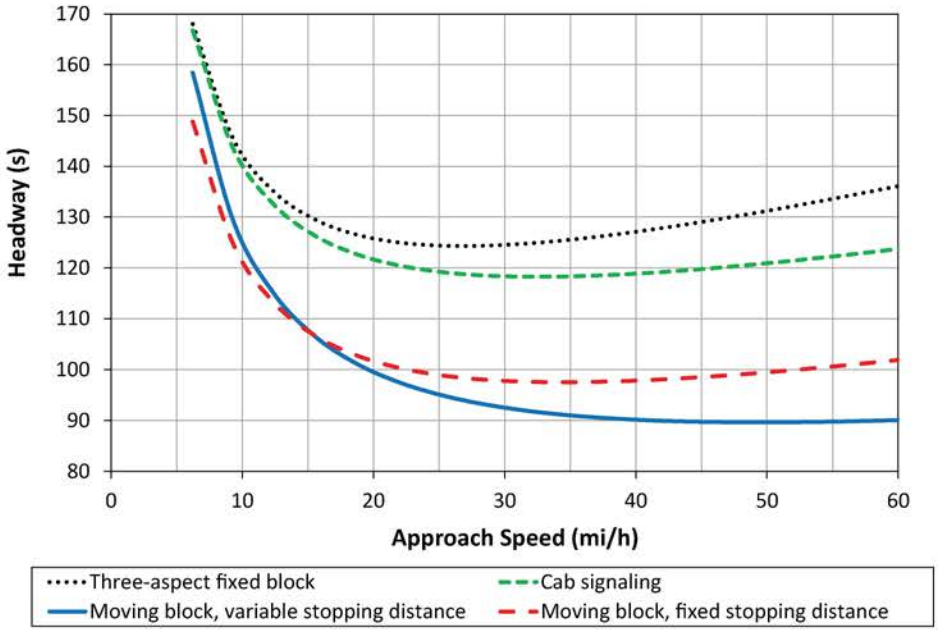
Equation 8-3

Equation 8-3 adjusts the safety separation entering a station due to any grade. A downgrade will increase the braking distance and so require a longer safety separation—and vice versa.

The results of Equation 8-2 and Equation 8-3 are shown in Exhibit 8-36. The resultant minimum station headway of 97 s occurs at an approach speed of 35 mi/h (56 km/h). The respective curves for a conventional three-aspect fixed-block signaling system and a cab signaling system are included for comparison. As would be expected, a moving-block system with a speed variable safety distance shows the lowest overall headway. The difference between the two methods of determining the safety distance represents an 8-s difference in the minimum headway. Voltage fluctuations have little effect on moving-block headways as the time to clear the platform is not a component in calculating the moving-block signaling system headway.

Exhibit 8-36
Typical Moving-Block Station Headways Compared with Conventional Fixed-Block Systems

Capacity is higher with a moving-block signaling system.



Source: *TCRP Report 13* (*1*).
Notes: Assumes 45-s dwell time and 20-s operating margin. A metric version of this exhibit appears in Appendix A.

The appropriate equation above should be solved for the minimum value of t_{cs}. The approach speed, v_a, that produces this minimum value must then be checked against any speed restrictions approaching the station from Exhibit 8-33.

Check Results

Compare the approach speed producing the minimum train separation to any speed restrictions on the station approach.

Compare the results obtained from the above equations with Exhibit 8-29. The calculated minimum train separation should be close to or moderately greater than the values charted. If lower, there is probably an error, as the charted values are the minimums using typical maximum rail transit performance criteria without applying any corrections for grades or speed restrictions into or out of the station.

Step 1c: Determine the Average Dwell Time at the Critical Station

The train close-in time at the critical station depends on a train's physical performance and length, as well as other fixed-system characteristics, and therefore can be calculated with some precision. Station dwell time cannot be determined with the same exactitude. Virtually all the literature references related to rail transit capacity assigns a set time to dwell time. Many simulation models do likewise, using typical figures of 15 to 20 s for lesser stations and 30 to 45 s for major stations. The main constituents of dwell time are as follows:

- Passenger flow time at the busiest door,
- Remaining (unused) door-open time, and
- Waiting to depart time (with doors closed).

Four methods of estimating controlling dwell.

Four methods of estimating dwell time or controlling dwell time are provided in this section. The first method is the one used in most of the literature references—simply assigning a reasonable figure to the critical station. The second method uses field data reported in *TCRP Report 13* (*1*), allowing the selection of a controlling dwell time from the critical station of rail transit lines with similarities to the one being analyzed. These two methods are suitable where information on passenger flows at the critical station is not available.

The third method is only suitable for new lines in cities with existing rail transit systems. In this case, using the mean dwell time plus two standard deviations is suggested, based on a comparable station on the existing network. The fourth and final method uses a statistical approach of determining station dwell times based on peak-hour passenger flows. This method, detailed in *TCRP Report 13* (*1*), is complex and still requires an estimate of the ratio of the busiest door to average door flow.

None of these methods are entirely satisfactory. This explains why practitioners over a period of several decades have resorted to simply assigning a reasonable value to station dwell time.

Method 1: Assigning a Value

Existing rail transit systems operating at or close to capacity have median station dwell times over the peak hour that range from 30 to 50 s with occasional exceptional situations—such as the heavy peak hour mixed flow at NYCT's Grand Central Station of more than 60 s. A tighter range of dwell time values—35 to 45 s—was used to develop the capacity graphs that appear in Section 6.

Method 2: Using Existing Dwell Time Data

Examples of existing dwell time data from the highest-use station on lines that are close to capacity are summarized in Exhibit 8-37. Selection of a dwell time from this table is less arbitrary than Method 1 and allows some selectivity of mode and the opportunity to pick systems and stations with similar characteristics to those of the one under examination.

The selected median station dwell times range from 27.5 to 61.5 s. The highest values are mainly alighting and mixed-flow records from manually operated systems with two-person crews. Most station dwell times in Exhibit 8-37 fit into the 35 to 45 s range suggested in the previous method.

Exhibit 8-37
Peak-Period Station Dwell Times for Heavily Used Systems (1995)

System & City	Station	Passengers Observed	Mean Dwell (s)	Mean Headway (s)
BART (San Francisco)	Embarcadero WB	2,298	48.0	155.0
CTS (Calgary)	1st St. WB (LRT)	298	33.0	143.0
CTS (Calgary)	3rd St. WB (LRT)	339	38.0	159.0
CTS (Calgary)	City Hall EB (LRT)	201	34.0	161.0
NYCT (New York)	Grand Central SB (4&5)	3,488	61.5	142.5
NYCT (New York)	Queens Plaza WB (E&F)	634	36.0	121.0
PATH (Newark)	Journal Square WB	478	37.0	204.0
Muni (San Francisco)	Montgomery WB (LRT)	2,748	32.0	129.0
SkyTrain (Vancouver)	Broadway EB	257	30.0	166.0
SkyTrain (Vancouver)	Metrotown EB (off-peak)	263	34.0	271.5
TTC (Toronto)	King SB	1,602	27.5	129.5
TTC (Toronto)	Bloor NB	4,907	44.0	135.0

Source: *TCRP Report 13* (*1*).
Note: NB: northbound, SB: southbound, EB: eastbound, WB: westbound

Method 3: Using Dwells from the Same System

This method only applies where a line of the same mode is being added to an existing system, in which case the controlling dwell time from an existing, similar, peak-point station can be used. Where passenger volumes at the critical station of the new line are different from the equivalent station on an existing line, the flow component of dwell time can be adjusted in proportion to hourly passenger movements in the station. Alternatively, the dwell time from an existing station with similar passenger volumes can be used.

Care should be taken if the train control system or operating procedures are different. If this is the case, consideration should be given to adjusting both the station dwell time and the operating margin.

Method 4: Calculating Dwells from Passenger Flows

TCRP Report 13 (*1*) provides regression equations to relate passenger flow times to the number of boarding, alighting, or mixed-flow passengers, and, in turn, to convert this flow time to dwell time. These regression equations can be used to estimate the dwell time from hourly passenger flows into the maximum load point station. However, the best regression fit involves logarithmic functions and the estimation of a constant for the ratio between the highest doorway and the average doorway passenger flow rate. The mathematics are complex and it is uncertain if the results provide any additional accuracy that merits this complexity—particularly if the hourly station passenger volumes by direction are themselves somewhat uncertain.

This method is best suited to new lines in locations without rail transit and with a sufficiently refined and calibrated regional transportation model that can assign hourly passenger flow, by direction, to individual stations. This method is not detailed further in this manual.

Step 1d: Select an Operating Margin

Section 4, Train Operations, introduced the need to add an operating margin to the minimum train separation and dwell time to create the closest sustainable headway without interference.

The closer the trains operate, and the busier they are, the more chance there is of minor incidents delaying service due to an extended station dwell time, stuck door, or late train ahead. It is never possible to ensure that delays do not create interference between trains, nor is there any stated test of reasonableness for a specific operating margin. A very small number of rail transit lines in the United States and Canada operate at capacity and so can accommodate little or no operating margin. On such lines, operations planners face the dilemma of scheduling too few trains to meet the demand, resulting in extended station dwell times and erratic service, or adding trains to the point that they interfere with one another. Striking a balance is difficult and the tendency in practice is to strive to meet demand—equipment availability and operating budget permitting. While the absolutely highest capacity is so obtained, it is poor planning to omit such an allowance for new systems.

The greater the operating margin that can be incorporated in the headway the better; systems running at design capacity have little leeway. The recommended procedure is to aim for 25 s and back down to 20 or even to 15 s if necessary to provide sufficient service to meet the estimated demand. Where demand is unknown or uncertain in the long-term future—when a rail line in planning reaches capacity—then 25 s should be used.

When a line already exists, the operating margin can be selected to accommodate 95% of dwells that occur at the critical station. This value can be estimated as twice the standard deviation of dwell times during the analysis hour (*1*).

When level boarding is not provided (i.e., high platform to high-floor car or low platform to low-floor car), the time required to operate to operate wheelchair lifts or deploy bridgeplates (discussed previously in Section 4) can be incorporated into the operating margin when the goal of the analysis is to determine the minimum headway that can be operated without causing train interference.

Step 1e: Determine the Non-Interference Headway

The non-interference headway is the sum of the train control separation determined in Step 1b, the average dwell time at the critical station determined in Step 1c, and the operating margin selected in Step 1d:

$$h_{ni} = t_{cs} + t_{d,crit} + t_{om} \qquad \textbf{Equation 8-4}$$

where

h_{ni} = non-interference headway (s),

t_{cs} = train control separation (s),

$t_{d,crit}$ = average dwell time at the controlling station (s), and

t_{om} = operating margin (s).

Step 2: Determine the Minimum Headway Associated with the Right-of-Way Type

In some cases—most often with light rail transit lines—characteristics of the right-of-the-way may constrain the minimum headway that can be operated. A rail line that is completely grade separated and double tracked can skip this step. However, most light rail transit lines use a combination of right-of-way types. This step addresses three specific right-of-way types that create capacity constraints. These types are discussed in order of their decreasing relative importance for most systems. This order is as follows:

- Single track with two-way operation,
- On-street operation with traffic signal control, and
- Station departures adjacent to grade crossings.

Only the right-of-way types in this list that already exist or that are being evaluated need to be addressed in this step.

Step 2a: Single-Track, Two-Way Operation

Single track reduces capital costs but can add a serious capacity constraint.

This constraint only applies to two-way operation, not to one-way operation, such as on a downtown one-way street grid.

Single-track sections with two-way operation are the greatest capacity constraint on rail transit lines where they are used extensively. Single-track sections are used primarily to reduce construction costs. Some lines have been built with single track as a cost-saving measure where the right-of-way would permit double track. In other areas single track has been built because widening the right-of-way and structures is cost prohibitive. Single-track sections can be very short in order to bypass a particular obstacle, for example, an overpass of a highway.

While determining the potential extent of single-track construction is possible, the exact layout is highly system-specific. Estimates can be made of the number of track miles or kilometers required for a certain number of route miles or kilometers once the intended headway is known (*9*). While this does not tell the user *where* the single-track sections can be used, it can provide assistance in determining the possible extent of single track for use in cost estimates.

Gauntlet track interlaces the four rails without using switches.

Single-track sections greater than 0.25 to 0.30 mi (400 to 500 m) are a particularly restrictive capacity constraint. The minimum headway associated with single track is twice the time for trains to traverse the single-track section, including an allowance for switch throw and lock—unnecessary for spring switches or gauntlet track—and an operating margin to minimize the potential wait of a train in the opposite direction.

The time to cover a single-track section is:

Equation 8-5

$$t_{st} = S_m \left[\left(\frac{N_{st} + 1}{2} \right) \left(\frac{3v_{max,st}}{d} + t_{jl} + t_{br} \right) + \frac{L_{st} + L_t}{v_{max,st}} \right] + N_{st} t_d + t_{sw} + t_{om}$$

where

t_{st} = time to cover single-track section (s),
L_{st} = length of single-track section (ft, m),
L_t = train length (ft, m),
N_{st} = number of stations on the single-track section,
t_d = average station dwell time (s),
$v_{max,st}$ = maximum speed on single-track section (ft/s, m/s),
d = deceleration rate (ft/s², m/s²),
t_{jl} = jerk limitation time (s),
t_{br} = operator and braking system reaction time (s),
S_m = speed margin,
t_{sw} = switch throw and lock time (s), and
t_{om} = operating margin (s).

The speed margin is an allowance for out-of-specification equipment and train operators that do not drive at exactly the maximum permitted speed. It typically ranges from 1.08 to 1.20.

The minimum single-track headway is:

$$h_{st} = 2t_{st}$$

Equation 8-6

where

t_{st} = time to cover single-track section (s), and

h_{st} = minimum single-track headway (s).

Default values for light rail transit for use with Equation 8-5 are given in Exhibit 8-38. The results of applying these default values are depicted in Exhibit 8-39. A spreadsheet that calculates the single-track capacity is included on the accompanying CD-ROM.

A spreadsheet for calculating single-track capacity is included on the accompanying CD-ROM.

Exhibit 8-38
Default Data Values for Single Track LRT Travel Time

Term	Symbol	Value
Jerk limitation time	t_{jl}	0.5 s
Brake system reaction time	t_{br}	1.5 s
Dwell time	t_d	15–25 s
Switch throw-and-lock time	t_{sw}	6 s
Service braking rate	d	4.3 ft/s^2 (1.3 m/s^2)
Speed margin	S_m	1.1 to 1.2
Operating margin time	t_{om}	10–30 s

Source: *TCRP Report 13* (*1*).

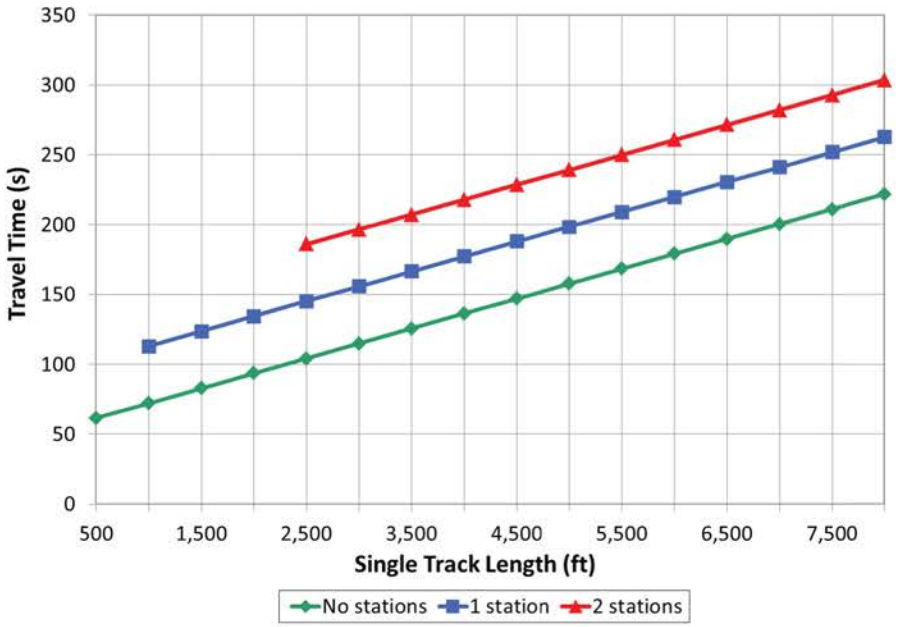


Exhibit 8-39
Light Rail Travel Time Over Single-Track Section

The minimum single-track headway is twice the time given in this exhibit.

Source: *TCRP Report 13* (*1*).
Notes: Assumes speed limit of 35 mi/h, 180-ft train length, 20-s dwell time, 20-s operating margin, and other data as per Exhibit 8-38. *The recommended closest headway is twice the time given in the exhibit.* A metric version of this exhibit appears in Appendix A.

The value used for the maximum single-track section speed should be the appropriate speed limit for that section. A speed of 35 mi/h (55 km/h) is a suitable value for most protected, grade-separated light rail lines. If the single-track section is on-street, then a speed below the traffic speed limit should be used. If there are signalized intersections, an allowance of half the signal cycle should be added to the travel time for each such intersection, adjusted for any improvements possible from traffic signal priority.

Scheduling for single track.

Trains should be scheduled from their termini such that passing locations are not close to the single-track sections. Where there is more than one single-track section, this can become difficult but not impossible.

Passing sections.

Lengthy single-track sections can severely limit headways and capacity and may require one or more double-track passing sections within the single-track section. These should, wherever possible, be of sufficient length to allow opposing trains to *pass on-the-fly* and allow some margin for off-schedule trains. Obviously, trains should be scheduled to meet at these locations.

Step 2b: On-street Operation

Reserved lanes for light rail vehicles and streetcars.

Historically, streetcar operation has achieved throughput in excess of 125 cars per hour on a single track in many North American locations, assuming relatively short one-car trains and line-of-sight operations. Some high-density systems continue to operate, such as the Queen Street Line in Toronto, where the Toronto Transit Commission operates single and articulated streetcars from multiple lines over a stretch of downtown streets at close headways. The price of this relatively high throughput capacity, however, is a low average operating speed, congestion, irregular running, and potential passenger confusion at multiple-car stops.

Despite this record, on-street operation is often raised as a major capacity constraint for modern light rail systems, yet this is rarely the case on contemporary lines. This is particularly true on most newer lines, where light rail trains have exclusive use of road lanes or a reserved center median where they are not delayed by other traffic making turns, queuing at signals, or otherwise blocking the path of the trains. Exclusive lanes for light rail are also being instituted on some of the older streetcar systems.

The capacity of streetcars operating in mixed traffic is determined similarly to the capacity of buses.

Single streetcars in classic mixed-traffic operation can be treated as similar to buses with capacity determined from the procedures of Chapter 6, Bus Transit Capacity, with suitable modifications reflecting longer vehicle lengths and differences in dwell time variability.

Where, as is often the case, light rail train lengths approach the downtown street block lengths, then the maximum train throughput is simply one train per traffic signal cycle, provided the track area is restricted from other traffic. When other traffic, such as queuing left-turning vehicles, prevents a train from occupying a full block, throughput drops as not every train can proceed upon receiving a green indication at a traffic signal. Similarly, longer-than-normal dwell times can cause a train to be unable to proceed on green, requiring the train to wait an additional traffic signal cycle to proceed. Therefore, a common rule of thumb is that the minimum sustainable headway is double the longest traffic signal cycle on the on-street portions of the line.

Equation 8-7 can be used to determine the minimum headway between trains operating on-street in exclusive lanes or mixed traffic (*1, 10*).

$$h_{os} = max\begin{cases} \dfrac{t_c + (g/C)t_d + Zc_v t_d}{(g/C)} \\ 2C_{max} \end{cases}$$

Equation 8-7

where

h_{os} = minimum on-street section train headway (s);

g = effective traffic signal green time (s);

C = traffic signal cycle length (s) at the stop with the longest dwell time;

Some transit agencies use the signal cycle time (C) as the minimum clearance time.

C_{max} = longest traffic signal cycle length in the line's on-street section (s);

t_d = average dwell time (s) at the critical stop;

t_c = clearance time between trains (s), defined as the sum of the minimum clear spacing between trains (typically 15–20 s or the signal cycle time) and the time for the cars of a train to clear a station (typically 5 s/car);

Z = standard normal variable corresponding to a desired failure rate, from Exhibit 6-56 (page 6-65); and

c_v = coefficient of variation of dwell times (typically 40% for light rail, 60% for streetcars).

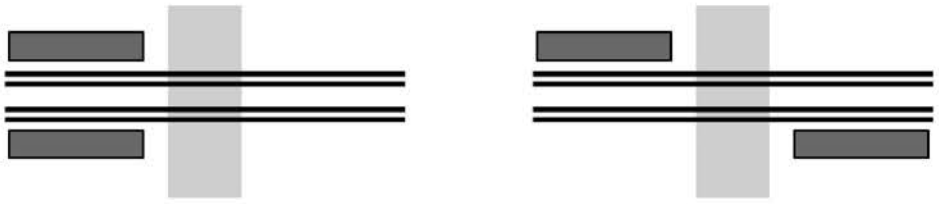
Step 2c: Station Departures Adjacent to Grade Crossings

Grade crossings adjacent to stations.

Grade crossing activation and occupancy times can be affected by the presence of a station adjacent to the crossing. If the train must use the crossing after stopping at a station, the activation of the crossing signals is often premature and the crossing is unavailable to other traffic for more than the optimum time. In this case the train is also starting from a stop and so must accelerate through the crossing, adding to the total delay. Where the station platform is on the far-side of the crossing, the arrival time at the crossing can be predicted consistently and premature activation of the crossing is not a factor. The train is also either coasting or braking through the crossing from cruising speed and so will occupy it for less time.

Stations can be designed to place both platforms on one side of the crossing or to locate one platform on each side of the crossing such that trains use the crossing before stopping at the station. Both arrangements are shown in Exhibit 8-40. Using far-side platforms is advantageous for the operational reasons given above, for reduced right-of-way requirements, and, for median operation, allowing left-turn bays to be readily incorporated into the street.

Far-side platforms can be advantageous.



(a) Facing (b) Far-side

Exhibit 8-40
Light Rail Platform Options at a Crossing

Source: *TCRP Report 13* (*1*).

Additional time may need to be allowed when grade crossings adjacent to station exits are manually activated.

Delays to other roadway users caused by premature activation of crossing gates and signals at near-side stations can be reduced using wayside communication equipment. This can be done with the operator being equipped with a control to manually start the crossing cycle before leaving the station (as in Portland) or by an automatic method. An extra 10 s is an appropriate allowance when station departures are adjacent to grade crossings, and train operators manually initiate the crossing cycle after passenger movements at the station have finished. If the extra dwell time is required at a station with a dwell time equal or close to the critical dwell time along the line, then this station may end up controlling the headway:

Equation 8-8

$$h_{gc} = t_{cs} + t_{d,maxgc} + t_{gca} + t_{om}$$

where

h_{gc} = non-interference headway associated with stations with grade crossings on departure (s),

t_{cs} = train control separation (s),

$t_{d,maxgc}$ = longest average dwell time of stations with grade crossings on departure (s),

t_{gca} = minimum time from when the crossing cycle is manually activated to when a train can depart (s), and

t_{om} = operating margin (s).

An example of the automatic approach can be found on the San Diego Trolley. The trolley shares some of its track with freight trains and uses a communication device that identifies light rail trains to crossing circuits located on the far side of stations. If the crossing controller identifies a train as a light rail train, a delay to allow for station dwell time is added before the crossing is activated. This ensures that the crossing remains open for cross traffic for most of the time that the light rail train is stopped in the station. If the controller cannot identify the train as a light rail train, it assumes the train is a freight and activates the crossing gates without delay.

Other systems use an inductive link between the light rail train and wayside to activate signal preemption, switches, and ADA-mandated information requirements. The lowest-cost detection approach is the classic overhead contactor. Trolleybus technology using radio signals from the power collection pick-up to coils suspended on the overhead wires is also applicable to light rail but is not used in the United States or Canada.

Step 2d: Determine the Minimum Headway Associated with the Right-of-Way Type

The minimum headway associated with the right-of-way type h_{row} is the highest of the headways calculated in Steps 2a, 2b, and/or 2c:

Equation 8-9

$$h_{row} = \max(h_{st}, h_{os}, h_{gc})$$

where h_{row} is expressed in seconds and all other variables are as previously defined.

Step 3: Determine the Limiting Junction Headway

Junctions should not constrain capacity.

Correctly designed junctions should not be a constraint on capacity. Where a system is expected to operate at close headways, high-use junctions perform more reliably and at higher levels of capacity if they are grade separated. At such *flying junctions*, the merging and diverging movements can all be made without conflict and the only impact on capacity is the addition of the switch throw and lock times, typically 3 to 6 s. Speed limits, imposed in accordance with the radius of curvature and any superelevation, may reduce the schedule speed but should not raise the minimum headway—unless there is a tight curve close to a headway limiting station.

Key dimensions of a flat junction are shown in Exhibit 8-41.

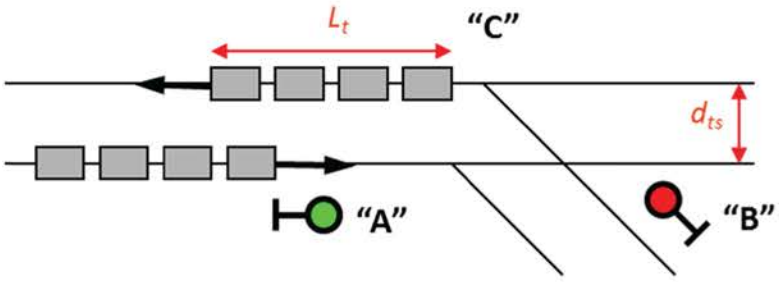


Exhibit 8-41
Flat Junction Dimensions

Source: *TCRP Report 13* (1).

The worst case is based on a train (lower left) held at signal "A" while a train of length L_t moves from signal "B" to clear the interlocking at "C." The minimum operable headway is the train control separation of train "A" (imposed by the line's signaling system), plus the time required for the conflicting train to clear the interlocking, plus the extra time for train "A" to brake to a stop and accelerate back to line speed. Ignoring specific block locations and transition spirals, this can be expressed approximately as:

$$h_j = t_{cs} + \sqrt{\frac{2(L_t + 2f_{sa}d_{ts})}{a}} + \frac{v_{max}}{a+d} + t_s + t_{om}$$

Equation 8-10

where *[typical heavy rail values shown in brackets]*

h_j = limiting headway at junction (s);

t_{cs} = train control separation time (s); *[32 s]*

L_t = train length (ft, m); *[650 ft, 200 m]*

d_{ts} = track separation (ft, m); *[33 ft, 10 m]*

Higher-speed turnouts have smaller angles between the diverging tracks. They require a longer distance for the tracks to separate from each other, but trains can move onto the branch at a higher speed.

f_{sa} = switch angle factor (see also Exhibit 8-43):
- —5.77 for #6 turnout,
- —6.41 for #8 turnout, and
- —9.62 for #10 turnout;

a = initial service acceleration rate (ft/s², m/s²); *[4.3 ft/s², 1.3 m/s²]*

d = service deceleration rate (ft/s², m/s²); *[4.3 ft/s², 1.3 m/s²]*

v_{max} = maximum line speed (mi/h, km/h); *[60 mi/h = 91 ft/s, 100 km/h = 27.8 m/s]*

t_s = switch throw and lock time (s); and *[6 s]*

t_{om} = operating margin time (s).

Although 120-s headways are possible, junctions generally should be grade separated for headways below 150–180 s.

Substituting the typical values shown above into the equation results in a junction limiting headway of 102 s. An operating margin should then be added to this headway. While in theory a flat junction should allow a 120-s headway, it does not leave a significant operating margin and there is a probability of interference headways. General guidance in rail transit design is that junctions should be grade separated for headways below 150 to 180 s.

Advantage of sophisticated supervision to reduce junction conflicts.

An exception is with a moving-block signaling system incorporating an automatic train supervision system with the capability to look forward. This system adjusts train performance and station dwells to avoid conflicts at the junction. That is, trains will not have to stop or slow down at the junction except for the interlocking's track design speed limit. In this case, the junction interference headway drops to 63 s, allowing 120-s, or slightly lower, headways to be sustained on a flat junction—a potentially significant cost savings associated with a moving-block signaling system.

Step 4: Check Power Supply Constraints

The power supply for a new rail line will presumably be designed to accommodate the number of trains planned to be operated, if not for the long term, then at least for some time into the future. However, the power supply for an existing line that is being considered for improved headways may not be capable of supporting the additional number of trains without being upgraded. The average headway imposed by a given substation will be a function of the number of trains the substation can power at a time and the time required for a train to traverse the track section powered by the substation, including station stops.

Step 5: Determine the Controlling Headway

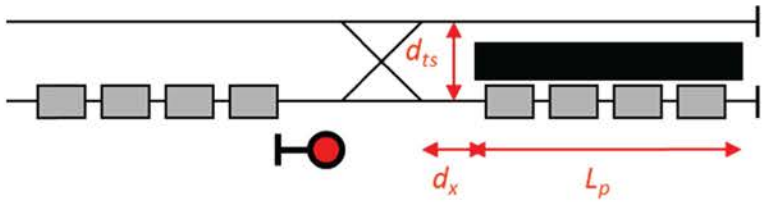
The controlling headway will be the highest of the non-interference headway h_{ni} (Step 1), the headway imposed by the right-of-way type h_{row} (Step 2), the highest limiting headway at a junction h_j (Step 3), and the minimum headway supported by the power supply system (Step 4). Assuming that turnbacks are not a capacity constraint (checked in Step 6), the controlling headway will be the minimum headway that can be consistently operated on the line.

Step 6: Determine Terminal Layover Time

Turnbacks should not be a constraint on capacity.

Correctly designed and operated turnbacks should not be a constraint on capacity. Key dimensions of a typical terminal station arrangement with a center (island) platform (preferred as passengers do not need to be directed to a particular platform; only a particular side of the same platform) are shown in Exhibit 8-42.

Exhibit 8-42
Key Turnback Dimensions



Source: *TCRP Report 13* (*1*).

The worst case is based on the arriving train (lower left) being held at the cross-over approach signal while a train departs. It must, moving from a stop, traverse the crossover and be fully berthed in the station before the next exiting train (lower right) can leave. The exiting train must then clear the crossover and the interlockings must be reset before another train can enter the station. The difference between the scheduled headway and the time required to make these maneuvers, doubled for a two-berth station such as the one illustrated, is available for terminal layover. The terminal layover time must be sufficient to accommodate passenger movements, and allow time for the driver to change ends, inspect the train, and check train integrity and braking. The maximum time available per track for terminal layover is given by Equation 8-11.

$$t_{tl} \leq 2\left(h - t_s - \sqrt{\frac{2(L_p + d_x + f_{sa}d_{ts})}{a + d}} - \sqrt{\frac{L_p + d_x + f_{sa}d_{ts}}{2a}}\right)$$

Equation 8-11

where *[typical heavy rail values shown in brackets]*

t_{tl} = terminal layover time (s);

h = train headway (s); *[120 s]*

t_s = switch throw and lock time (s); *[6 s]*

L_p = platform length (ft, m); *[660 ft, 200 m]*

d_x = distance from cross-over to platform (ft, m); *[65 ft, 20 m]*

d_{ts} = track separation (ft, m),

= platform width + 5.25 ft (1.6 m); *[33 ft, 10 m]*

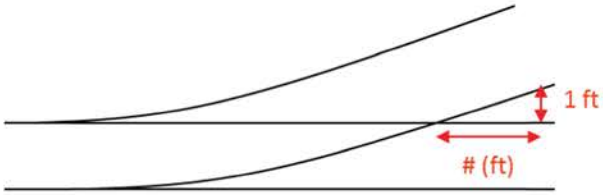
f_{sa} = switch angle factor (see also Exhibit 8-43):
—5.77 for #6 turnout,
—6.41 for #8 turnout, and
—9.62 for #10 turnout;

a = initial service acceleration rate (ft/s², m/s²); and *[4.3 ft/s², 1.3 m/s²]*

d = service deceleration rate (ft/s², m/s²). *[4.3 ft/s², 1.3 m/s²]*

Turnout numbers are based on the ratio of the number of feet moved longitudinally per foot moved out at the "frog" (device located where the tracks cross). The higher the number, the smaller the departure angle and the higher the permitted speed.

Exhibit 8-43
Turnout Numbers



Source: Wilson (*11*).

Terminal layover time can be calculated using the typical parameters given in the brackets above, including a headway of 120 s. The terminal layover time t_{tl} is less than or equal to 175 s per track. This value would increase by 9 s if the incoming train did not stop before traversing the crossover. While this is not a generous amount of time, particularly to contain a schedule recovery allowance, many systems maintain such close headways with minimal delays.

This analysis assumes that any speed restrictions in the terminal approach and exit are below the speed a train would reach in the calculated movements—approximately

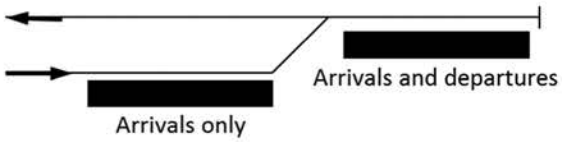
21 mi/h (34 km/h) on a stop-to-stop approach, and 29 mi/h (47 km/h) as the end of the train leaves the interlocking on exit. Normally there would be no restrictions so low, but following London Transport's Moorgate disaster—when a fully loaded train accelerated into the wall at the end of a terminal station—some systems have imposed low entry speeds, occasionally enforced with speed control signaling.

The maximum permitted terminal time can be calculated for the specific system and terminal parameters, using the controlling headway as the value for h in Equation 8-11. This time should then be compared to the time required to load and unload passengers, perform necessary checks, and have the driver walk to the opposite end of the train. There are numerous corrective possibilities when the terminal time is insufficient. These include moving the crossover as close to the platform as possible; however, structures can restrict the crossover location in subways.

Toronto's streetcars face terminal design problems in which two or more routes share a common terminal and single-track turning loop. This is the case at the Broadview and Dundas West subway stations where there is heavy transferring activity between the subway and streetcars. The high volumes of transit vehicles and passengers can cause delays to the following streetcars while passengers board and alight from the preceding car. Scheduled recovery time for the streetcar operator is hard to accommodate in these conditions as the volume of the following cars precludes layover time.

The Baltimore light rail line also uses single-track termini but the train frequency is not high enough for these to be a capacity limitation. However, some terminals are designed to allow an arriving train to unload passengers before the departing train ahead leaves. This is accomplished through the use of an extra platform as shown in Exhibit 8-44. This arrangement allows the location of a station in a relatively narrow right-of-way since the platforms are not adjacent to each other and a wider center platform is not required.

Exhibit 8-44
Light Rail Single-Track Terminus with Separate Unloading Platform



Source: *TCRP Report 13* (*1*).

Dual-faced platforms and loops can reduce dwell times.

If passenger dwell is a limiting factor, then this issue can be reduced with the use of dual-faced platforms. At terminals with exceptionally heavy passenger loading, multiple-track layouts may be needed. Another alternative, used at SEPTA's 69th Street, New York's South Ferry, and Chicago's Howard and Forest Park termini, are loops—however, these are rare luxuries for heavy rail transit. However, some older streetcar-based light rail lines still incorporate terminal loops.

At a leisurely walking pace of 3 ft/s (1 m/s), it takes 200 s for an operator to walk the length of a 650-ft (200-m) heavy rail train, more if the operator is expected to check the interior of each car for left-behind objects or passengers. Obviously, this cannot be accommodated reliably in a 175-s terminal layover time. The turnaround time can be expedited with *fall-back* or *set-back crewing*, where an extra engineer or operator is positioned at the rear end of the terminal platform as a train enters the station. The fallback engineer enters the rear cab of the train as the train's incoming engineer exits

the front cab. Once the train has been readied for departure and received its boarding passengers, it can depart without further delay. In this type of operation, each engineer drops back to the following train at the terminal station, so only one additional engineer per shift is required to make such an operation work. Such a strategy can improve equipment utilization and reduce the car requirements associated with special events, and can also be productive during normal peak periods at high-volume terminal stations.

Allowances should be made to prevent common delays from disrupting terminal operations.

Terminal arrangements should accommodate some common delays. An example would be the typical problems of a train held in a terminal for a door sticking problem, waiting for police to remove an intoxicated passenger, or for a cleaning crew to perform minor cleaning. Alternatively, one track may be preempted to store a disabled train. On these occasions, the terminal is temporarily restricted to a single track and the maximum terminal layover time is reduced to 61 s with the above parameters (70 s without an approach stop). This may be sufficient for the passenger dwell but cannot accommodate changing ends on a long train and totally eliminates any schedule recovery allowance.

Alternative solutions for terminals include single-track terminals (which limit the overall throughput capacity), turnback loops, which are prevalent among many older streetcar systems, and terminal stations with far side crossovers and tail tracks (the arriving train pulls into one platform, then pulls into one of the tail tracks, changes direction and then returns to pick up passengers from the other platform).

More expensive ways to improve turnbacks include multi-track or grade-separated terminals, or extending tracks beyond the station and providing crossovers at both ends of the station. This permits a storage track or tracks for spare and disabled trains—a useful, if not essential, failure management facility. With crossovers at both ends of the station, on-time trains can turn beyond the station with late trains turning in front of the station—providing a valuable recovery time of about 90 s at the price of additional equipment to serve a given passenger demand.

If terminal time is insufficient and none of the corrective measures discussed above can be implemented, then the terminal becomes the capacity constraint and the value of h that produces a sufficient terminal time then becomes the controlling headway.

Step 7: Determine Train Throughput

The maximum number of trains per hour T (line capacity) is simply the number of seconds in an hour divided by the controlling headway determined from Step 5 (or Step 6, if for some reason a turnback constrains capacity):

$$T = \frac{3{,}600}{h_c}$$

Equation 8-12

where

T = line capacity (trains/h),

3,600 = number of seconds in an hour, and

h_c = controlling headway (s/train).

Step 8: Determine Person Capacity

The person capacity of a rail route at its maximum load section *under prevailing conditions* is determined by multiplying the number of cars operated during the peak hour by the agency's scheduled design load for each car and by a peak-hour factor that reflects loading diversity:

Equation 8-13

$$P = P_c C_h (PHF)$$

where

P = design person capacity (p/h),
P_c = maximum design load per car (p/car),
C_h = cars operated per hour (car/h), and
PHF = peak-hour factor.

Where an agency operates a mix of cars along the line (e.g., a mix of high-floor and low-floor cars), a weighted average design load should be used, based on the proportion of each car type used. If the transit agency has established a loading standard for its rail cars, this value should be used. Otherwise, the procedures given in the Passenger Load section of Chapter 5, Quality of Service Methods, may be used to estimate a maximum design load based on a car's exterior dimensions and interior seating arrangement.

The person capacity of a rail route at its maximum load section *when operated at line capacity* is determined by multiplying the number of trains per hour by the number of cars per train, the agency's scheduled design load for each car, and a peak-hour factor:

Equation 8-14

$$P = TN_c P_c (PHF)$$

where

P = design person capacity (p/h),
T = line capacity (trains/h),
N_c = number of cars per train (cars/train),
P_c = maximum schedule load per car (p/car), and
PHF = peak-hour factor.

The peak-hour factor reflects the diversity of demand over the course of a peak hour and produces a person capacity that reflects the number of people that can consistently be served day after day at the desired loading (quality of service). It is defined as:

Equation 8-15

$$PHF = \frac{P_h}{4P_{15}}$$

The PHF ranges from 0.25 (all volume occurs during the peak 15 min) to 1.00 (volumes are even throughout the hour).

When 30-min peak periods are used, P should represent 30-min volumes, and $2P_{30}$ should be substituted for $4P_{15}$.

where

PHF = peak-hour factor,
P_h = passenger volume during the peak hour (p), and
P_{15} = passenger volume during the peak 15 minutes (p).

PHFs observed at many U.S. and Canadian rail systems in the mid-1990s are tabulated in Exhibit 8-45, illustrating the variations in peak-hour loading diversities that can occur among rail transit systems. Use of current local data is recommended

whenever possible; when these data are not available, the following default PHF values for specific modes can be used instead:

- 0.80 for heavy rail,
- 0.75 for light rail, and
- 0.60 for commuter rail operated by electric multiple-unit trains.

Exhibit 8-45
Observed Rail Transit Peak-Hour Factors (1994-95)

System (City)	# of Routes	Peak Hour Factor
Commuter Rail		
AMT (Montréal)	2	0.71
CalTrain (San Francisco)*	1	0.64
GO Transit (Toronto)*	7	0.49
Long Island Rail Road (New York)	13	0.56
MARC (Baltimore)*	3	0.60
MBTA (Boston)*	9	0.53
Metra (Chicago)	11	0.63
Metro-North (New York)	4	0.75
NICTD (Chicago)	1	0.46
New Jersey Transit*	9	0.57
SCRRA (Los Angeles)*	5	0.44
SEPTA (Philadelphia)	7	0.57
VRE (Washington, D.C.)*	2	0.35
Light Rail		
CTS (Calgary)	2	0.62
RTD (Denver)	1	0.75
SEPTA (Philadelphia)	8	0.75
TriMet (Portland)	1	0.80
Rapid Transit		
SkyTrain (Vancouver)	1	0.84
CTA (Chicago)	7	0.81
MARTA (Atlanta)	2	0.76
Metrorail (Miami)	1	0.63
NYCT (New York)	23	0.81
PATH (New Jersey)	4	0.79
STM (Montréal)	4	0.71
TTC (Toronto)	3	0.79

Source: *TCRP Report 13* (*1*).
Note: *Mainly diesel-hauled—not electric multiple unit.

When the specific vehicle type has not yet been selected (e.g., when planning a new rail system), vehicle length can be used as a proxy for the passenger capacity of a rail car. Passenger loadings for typical North American light rail cars range from 1.5 to 2.4 passengers per foot of car length (5.0 to 8.0 p/m length). The lower level of 1.5 passengers per foot length (5.0 p/m length)—with a standing space per passenger of 4.3 ft^2 (0.4 m^2)—corresponds to a standing load without body contact, while the upper level provides 3.2 ft^2 (0.3 m^2), corresponding to a standing load with some body contact.

Chapter 5, Quality of Service Methods, describes passenger conditions at different loading levels.

For heavy rail, the 75-ft (23-m) cars used in more than 12 U.S. and Canadian cities range from 2.1 to 3.5 passengers per foot of car length (7.0 to 11.5 p/m of car length). The higher end of this range approaches crush-loaded conditions. The lower end of the range, at 2.1 to 2.4 passengers per foot length (7 to 8 p/m length)—with a standing

space per passenger as low as 3.2 ft² (0.3 m²)—is an appropriate and tight range for higher use systems. A lower figure of 1.8 p/ft length (6 p/m length) provides a more comfortable loading level and is appropriate for a higher quality of service on new systems. In either case, a reduction by 0.3 p/ft length (1.0 p/m length) should be used for smaller, narrower cars (*1*). Actual passenger loading standards in use at some agencies may differ from these values and should be used for analyses related to those systems.

COMMUTER RAIL CAPACITY

Overview

Commuter rail ridership in North America is dominated by the systems in the New York area where the busiest routes use electric multiple-unit trains on dedicated tracks with little or no freight service. The capacity of such systems can be estimated using the generalized rail transit methodology presented above, with suitable adjustments to input parameters to account for the sometimes lower vehicle performance and lower throughput of signaling systems where these are based on railroad rather than rapid transit practices. These high levels of throughput generally are limited to the commuter rail systems feeding Grand Central Terminal and Penn Station in New York City. Other commuter rail systems, such as those feeding Chicago, Washington, D.C., Boston, Philadelphia, Los Angeles, and San Francisco, operate at relatively short headways into and out of the major terminals—but at a level of peak-hour throughput per track significantly below the New York systems.

Push-pull commuter rail operation.

Outside of New York, with the exception of SEPTA's Philadelphia lines, Chicago's Metra Electric and South Shore lines, and Montréal's Deux-Montagnes line, commuter rail uses diesel locomotive-hauled coaches and follows railroad practices. Most of these commuter systems operate in *push-pull* mode, where the locomotive always remains at the same end of the train, and a cab control car is positioned at the other end of the train. In *pull* mode, the engineer operates the train in the "normal" forward direction, from the locomotive at the front of the train. In *push* mode, the train engineer operates the train from the front of the cab car and the locomotive is at the rear end of the train. The top speed of commuter trains in push mode is limited by the crashworthiness of the cab car and can be capped at 100 mi/h (160 km/h) or, in some cases, slightly higher. Push-pull operations reduce train layover times, minimize operating costs, and increase the available capacity at terminals.

Electric locomotive-hauled coaches are also used by SEPTA and New Jersey Transit on routes that also run electric multiple-unit cars. Dual-powered (electric and diesel) locomotives are used by the Long Island Rail Road (LIRR) and Metro-North Railroad in the New York area. Most new starts are likely to use diesel locomotive-hauled coaches; however, three of Denver's new commuter rail lines (under construction at the time of writing) will use electric multiple-unit cars.

For non-electric lines, there is no easy answer for calculating capacity. Unlike rapid and light rail transit, whose vehicles have similar performance characteristics within their respective modes, the performance of diesel locomotives used by various U.S. commuter operations varies considerably. This performance, measured by the *power-to-weight (P/W) ratio,* ranges from 2 to 10 for commuter rail operations, which makes it difficult to develop a "standard" commuter rail locomotive performance for use in

capacity calculations. For comparison, a typical diesel Amtrak intercity train has a P/W ratio of 4 to 6, while electric high-speed corridor trains (such as the Metroliner used in the Washington-New York-Boston corridor) have P/W ratios of 10 and higher (*12*). Exhibit 8-46 shows the effect of different P/W ratios on the time and distance needed to accelerate from a stop, and the delay incurred as a result.

Exhibit 8-46
Effect of P/W Ratio on Train Acceleration to 80 mi/h (128 km/h)

	Power-to-Weight (P/W) Ratio				
	2	4	6	8	10
Distance to accelerate (mi)	23.0	7.3	3.6	2.5	1.9
Distance to accelerate (km)	37.0	11.8	5.8	4.0	3.1
Acceleration time (min)	23.7	7.7	4.3	3.0	2.3
Time lost (min)	3.7	2.3	1.6	1.2	1.0

Source: Galloway (*12*).

Other issues affect commuter rail capacity that make it difficult to provide a simple analytical technique. First, many smaller commuter rail lines do not own the tracks they use, and therefore the number of trains they can operate will depend on negotiations with the owning railroad. Second, the mix of users of the tracks—and their impacts on capacity—will vary greatly from location to location. Generally, simulation is the only tool available for calculating the capacity of these commuter rail lines. Finally, the number of platforms available at terminal stations may constrain capacity. Consequently, this section does not present any equations for calculating commuter rail capacity. Instead, it focuses on the factors that impact capacity and potential means of improving capacity.

Simulation is often the only tool available for calculating commuter rail capacity.

Track Ownership and Usage

For commuter rail lines that use tracks owned by another railroad, the number of trains that can be operated in the peak hour depends on negotiations with the owning railroad. As the number of trains using a track increases—particularly when only a single track is available—the average speed of all trains decreases. Train meets have a compounding impact on capacity: each meet produces delay to the train that must wait, and each delay produces an increased probability of additional future meets. The impact of meets is even more severe when different classes of trains with different characteristics (e.g., passenger and freight trains) share the same tracks (*13*).

One concern that a freight railroad will have when passenger trains are proposed to be added to its tracks will be the impacts on train running times. Train crews have a maximum permitted number of hours they can work at a time, and an increase in train travel time may put them at risk of exceeding that limit if any unexpected delay occurs. Freight railroads may also need to reserve capacity (paths) for freight trains to service local customers during hours that passenger service is being contemplated, or to get trains to a certain location by a certain time (*14*).

There are a number of consumers of track capacity, some recurring but most not. The most common consumers of capacity are (*13*)

- Trains (not all use the same amount),
- Track patrols,
- Track maintenance,

- Track deterioration requiring temporary speed restrictions,
- Passenger station stops,
- Industrial switching,
- Freight yard interactions,
- Train or train control system failures,
- Incidents (e.g., crossing accidents, deer, and trespassers), and
- Weather.

Trains will be assigned different levels of priority, and there may be different levels of priority within a particular class of trains. For example, passenger train types can include high-speed intercity, conventional intercity, commuter zone express, commuter local, and deadhead (non-revenue) passenger trains. Freight train types include intermodal, manifest, bulk commodity, and local freight. An individual train's priority may also be raised or lowered depending on special circumstances. For example, early trains will have lower priority, trains whose crews are nearing their legal work hour limit will have higher priority, and heavy trains may be given higher priority, particularly on grades, because of the time required to regain their speed after a stop. The relative priority of each train will determine which one is delayed when two trains meet or one overtakes another (*14*).

Although freight railroads are becoming more receptive to accommodating commuter rail services—and the revenue and capital upgrading they produce—they have the upper hand and obtaining paths for commuter trains at a reasonable cost can require difficult and protracted negotiations.

Transit agency ownership of track used for commuter rail.

There are an increasing number of exceptions where the operating agency has purchased trackage and/or operating rights and so has more, or total, say in the operation and the priority of passengers over freight. The two New York commuter railroads own the great majority of track on which they operate; however, in the case of MTA-Metro North Railroad, priorities must be determined between Metro North's commuter operations and Amtrak's Northeast Corridor services. New Jersey Transit, SEPTA in Philadelphia, MBTA in Boston, Metra in Chicago, and Metrolink in Los Angeles, among others, also own substantial portions of the trackage they use. Some transit agencies have leverage with the freight railroads, as they own tracks used by the freight carriers. However, even when an agency owns track or trackage rights, there may still be strict limits on the number of trains that can be operated because of interlockings and grade crossings with other railroads.

Train Throughput

Determining train throughput requires consulting the railroad agreement or the railroad or agency signaling engineers to determine the maximum permitted number of commuter trains per hour. Generally these numbers will be based on a train of maximum length.

A definitive answer may not always be obtained, particularly with single-track sections that are shared with freight. Freight traffic can be seasonal and available commuter rail trips can vary. Usually the agreement will ensure a minimum number of commuter rail trips per hour. These may be unidirectional—that is, all trains must platoon in one direction in each peak period. This is generally not a capacity problem

but rather an efficiency issue with respect to equipment and staff utilization. Unidirectional operation is an issue on lines where reverse commuting to suburban work sites is important. For example, Chicago's Metra has services aimed specifically at the growing reverse commuter market.

Signal blocks for freight trains are considerably longer than for rail transit operations, due to the length of the trains, and the amount of time and distance required to bring a long, heavy freight train to a stop. Trains are the only means of land transport that cannot stop within their range of vision (*15*). Because of these long stopping distances and the resulting longer block lengths, and the lower speed of freight trains compared with rail transit, both commuter and freight trains take longer to traverse a signal block than their rail transit counterparts. This longer block transit time translates into significantly longer headways between trains and, therefore, lower capacity.

Line Capacity Range

Train throughput where commuter rail has exclusive occupancy of the track.

The number of commuter rail trips available per hour may range from one to the double digits. Ten or more trains per hour is at the upper range of traditional railroad signaling and will exceed it if long, slow freights must be accommodated. At the upper end of this range, commuter rail is effectively in sole occupancy of the line for the peak period and is approaching levels where the generalized rail transit capacity methodology can be considered. The input values should be adjusted using suitably lower braking and acceleration rates and longer train lengths, and by adjusting the separation safety factor *b* from the suggested value of 2.4 for a rapid transit three-aspect signaling system to 3 or 4. This equation and the associated equation for junction throughput do not apply in locations and times where freight and commuter rail trains share trackage or where the signaling system is designed solely for freight with long signal blocks.

Operating practices and patterns.

Additional complications are raised by the variety of commuter services operated and the number of tracks available. The busier commuter rail lines tend to offer a substantial number of stopping patterns in order to minimize passenger travel times and maximize equipment utilization. A common practice is to divide the line into zones with trains serving the stations in a zone and then running express to the station(s) in the CBD. Through local trains provide connections between the zones. A number of lines in the Chicago and New York areas are operated this way—Metra's Burlington Northern line to Aurora operates with five zones in the morning peak, Metro-North's New Haven line (including the New Canaan Branch) operates with seven zones. Such operating practices are made possible with three or more tracks over much of the route and the generous provision of interlockings to allow switching between tracks. Grade-separated junctions are also common where busy lines cross or converge. The capacity of this type of operation is hard to generalize and should be considered on a case-by-case basis. Such heavy operations are similar to grade-separated rapid transit in many ways, but have some notable exceptions, such as the wide range of services operated.

Station Constraints

Train storage at downtown terminals.

Another principal difference between commuter rail and the other rail transit modes is that commuter rail trains are often stored at the downtown terminals during the day. This reduces the need for track capacity in the off-peak direction and allows a higher level of peak-direction service to be operated. Metro-North in New York, with 42

platform tracks in use at Grand Central Terminal, is thus able to use three of its four Park Avenue tunnel tracks in the peak direction. Even when one of the tunnel tracks was closed for reconstruction, 23 trains per hour were handled on the remaining two peak-direction tracks.

The situation at New York's Penn Station is less relaxed. The LIRR has exclusive use of five tracks and shares four more with Amtrak and New Jersey Transit. At the time of writing, the LIRR operated the East River tunnels with two tracks inbound and two tracks outbound, with an average peak headway of approximately 3 min per track. With limited station capacity, many LIRR trains continue beyond Penn Station to the West Side Yard during rush hours. However, the yard cannot accommodate the full complement of peak trains, and some trains must be turned in the station. This can be done in as little as 3.5 min in a rush, but a minimum of 8 min is generally scheduled for turning trains.

Station Dwells

Dwells are less critical for commuter rail than for heavy rail transit.

Station dwell times on commuter rail lines are generally not as critical as they are on rapid transit and light rail lines, as frequencies are lower and major stations have multiple platforms, such as those shown in Exhibit 8-47. In most cases, the longest dwells are at the multiple-platform downtown terminals where the train is not blocking others while passenger activity takes place.

Exhibit 8-47
Multiple-Platform Commuter Rail Terminal Examples



(a) Toronto



(b) Philadelphia

Platform level and commuter rail car door layout.

Passenger flows are generally unidirectional and so are not slowed by passengers attempting to board while others alight and vice-versa. Exceptions are locations where major transferring activity takes place between trains but these are limited. Jamaica station on the LIRR is one of the few examples of a station with major transfers as it serves as a funnel where eight lines converge from the east and two major lines diverge to the west. Most transfers are made cross platform and are scheduled for 2 or 3 min. SEPTA's four-track regional rail tunnel through Center City Philadelphia—where train schedules incorporate both dwell and schedule recovery time—and the FrontRunner line in Salt Lake City are among the few North American locations where commuter trains run through from one line to another without terminating downtown.

Commuter rail station dwell times depend on the platform level and car door layout. The busiest lines are equipped with high platforms and remotely controlled sliding doors, as on rapid transit cars. Single-level cars often use conventional traps for high- and low-platform stations but these are time consuming to operate and require a large operating crew. Cars used on lines with both high and low platforms can be fitted with conventional trap doors at the car ends and sliding doors for high-platform use at the

center of the car, as on New Jersey Transit, the South Shore in Chicago, and the Deux-Montagnes line in Montréal. Most bi-level and gallery cars are designed for low platforms and have the lowest step close to the platform for easy and rapid boarding and alighting. Bi-level cars of the type popularized by GO Transit feature two automatic sliding double stream doors per side allowing cars to be emptied in 1 to 2 min. Gallery cars usually feature one exceptionally wide door (6.5 ft or 2 m) at the center of each side to allow rapid boarding and alighting with multiple passenger streams.

Means of Increasing Line Capacity

If the line capacity is determined to be insufficient for the desired level of commuter rail operations, there are three main ways that capacity can be increased: (*a*) add another track, (*b*) reduce running times between sidings, and (*c*) reduce the delay resulting from train meets and overtakes (*1*).

Methods that do one or more of these things are described below, along with a qualitative discussion of each method's potential benefits and potential constraints. Simulation will be required to quantify the effects of a particular method for increasing capacity.

Double Tracking

Double tracking allows some trains to meet without having to stop. Double-track sections can be formed by joining or extending existing sidings, but need to be at least three signal blocks (4.5 to 7.5 mi or 7 to 12 km) long in order to be effective. Longer double-track sections should provide crossovers to allow both meets and overtakes to occur within the double-track section (*1*).

Avoid ending sidings and double-track sections

- *On or near grades,*
- *On curves, and*
- *Near grade crossings.*

The ends of sidings or double-track sections should not be located on or near heavy grades (1% or more) because of the difficulty of starting and stopping heavy trains. Curves should also be avoided at the ends of double-track sections because of the difficulty of installing and maintaining switches located on curves. Finally, grade crossings should not be located near the ends of double-track sections because they would be blocked by a train stopped for a meet or overtake (*1*).

Double-tracking an entire line, while very beneficial from a capacity standpoint, is also very costly.

At the extreme, the entire line can be double-tracked. Adding double track to all of Tri-Rail's line in South Florida allowed it to increase service from one passenger train per direction per hour to three. However, the cost of double-tracking a long rail line can be very high, particularly when bridges or tunnels are required, or when additional right-of-way must be acquired.

Adding and Lengthening Sidings

Sidings are short sections of double track not long enough for trains to pass without one having to stop.

Shorter sections of double track are known as sidings. When trains meet at a siding, one will need to stop and wait for the opposing train to pass (sections of the line that are considered "double track" are long enough for some trains to meet without having to stop). Trains experience two types of delay at sidings, *fixed* and *variable.* Fixed delay includes delay associated with decelerating, stopping, and accelerating, as well as any difference in operating speed between the siding and the main line. Variable delay consists of time that a train must wait for the opposing train once it is in the siding (*11*).

Increasing the number of sidings reduces variable delay, as trains can be directed to a siding closer to the time a meet will occur, but does not change the fixed delay

associated with stopping. The capacity benefit diminishes as each new siding is added because the variable delay is reduced by smaller and smaller increments, but the fixed delay remains (*1*).

Lengthening sidings reduces variable delay, because the distance between the ends of sidings is reduced. However, it adds to fixed delay, because the amount of time required to transit a siding increases as the siding's length increases (*1*).

Providing Higher-Speed Siding Entries and Exits

Increasing the siding entry speed may also require improvements to the siding itself.

Fixed delay is reduced when trains can enter and exit the main line at higher speeds. A siding's entry and exit speed is controlled by the angle of departure of the siding from the main line, which is measured by the switch number (see Exhibit 8-43, page 8-62). The higher the switch number, the faster the entry and exit speeds. Sidings must permit speeds at least as high as the entry and exit speeds, must be signaled, and must be long enough to allow a train to stop from the higher entry speed (*1*).

Train Control System Improvements

Signals can be moved closer together, which shortens block lengths and permits trains to run closer together, within the limits created by the safe braking distance needed for the worst-case train. Changing the signal spacing mainly reduces delay when one train overtakes another, as the overtaken train can depart sooner once the other train has passed. Shortening the lengths of blocks can also create a minor improvement in meet delay, as dispatchers have better information about train positions to help them make decisions about at which siding to have trains meet (*1*).

Infrastructure Improvements

Improving track conditions to improve train speeds may not improve capacity if blocks have to be lengthened to accommodate faster trains.

Track conditions on a railroad being considered for commuter rail service may restrict trains' maximum speed. The Federal Railroad Administration defines various track classes, based on such factors as curvature, superelevation, track condition, number of crossties per unit length, and so forth, and sets maximum allowed passenger and freight train speeds based on those classes. Infrastructure improvements to upgrade the track class will improve train operating speeds; however, capacity may not change, as signal blocks may need to be lengthened to safely accommodate the higher speeds, resulting in little or no net change in time to transit a block. (In cases where no train signaling exists—*dark territory*—a signaling system will need to be developed.) Exhibit 8-48 shows the maximum speeds permitted for different track classes. Lower regulatory speeds may apply, depending on the type of train control system being used.

Exhibit 8-48
U.S. Railroad Track Classes

Track Class	Passenger		Freight	
	mi/h	km/h	mi/h	km/h
Excepted	Not allowed	Not allowed	10	16
1	15	24	10	16
2	30	48	25	40
3	60	96	40	64
4	80	128	60	96
5	90	144	80	128

Source: Code of Federal Regulations, Title 49, Part 213.
Note: Track classes 6 and higher, not shown, are used for high-speed intercity passenger rail.

Other infrastructure issues can create capacity constraints (*1*):

- *Junctions* are often under the control of different dispatchers, requiring a train to be held at a junction, blocking the exit. Providing a siding at the junction can mitigate this problem.
- Trains operate more slowly when entering and exiting *freight yards.* Providing the ability to bunch trains, either through closer signal spacing or additional tracks can mitigate impacts on capacity. Older freight yards may have been designed for shorter trains; the yard entry track needs to be sufficiently long to hold an entire train without blocking the mainline, while yard switches are lined manually.
- Cars may be temporarily stored on the mainline during *switching operations* on industrial tracks. A service track to store these cars can be constructed to mitigate this problem.

Commuter Rail Operating Speeds

Exhibit 8-49 gives average commuter rail operating speeds, including station stops, for different combinations of P/W ratios, station spacings, and dwell times. The exhibit assumes a combination of conventional block signaling and track conditions providing a passenger train speed limit of 79 mi/h (127 km/h), no grades, and no delays due to other trains. Note that in most cases, except for the higher P/W ratios and longer station spacings, a train will not be able to accelerate to the assumed speed limit before it has to slow for the next station. When the characteristics of the line (e.g., grades and station locations) and equipment to be used are known, a train simulator should be used to estimate operating speeds. A dwell time of 30 s would be difficult to achieve on a higher-volume line, but might be appropriate for lower-volume lines and off-peak periods (*12*).

Exhibit 8-49
Average Commuter Rail Operating Speeds

Station Spacing (mi)	Average Operating Speed (mi/h) P/W = 3.0	P/W = 5.8	P/W = 9.1
Average Dwell Time = 30 s			
1.0	16.8	20.3	22.3
2.0	25.8	30.9	35.0
4.0	36.4	44.1	48.6
5.0	40.3	48.7	52.7
Average Dwell Time = 60 s			
1.0	14.8	17.4	18.8
2.0	23.3	27.4	30.6
4.0	33.8	40.4	44.1
5.0	37.8	45.0	48.5

Source: Galloway (*12*).
Notes: P/W = power-to-weight ratio. Values assume 79 mi/h speed limit, no grades, and no delays due to other trains. A metric version of this exhibit appears in Appendix A.

Person Capacity

Except for a few situations in which standing passengers are accepted for short distances into the city center, commuter rail person capacity is based solely on the number of seats provided on each train. A peak-hour factor is used in the rail capacity methodology to develop a design hourly capacity that allows for variations in passenger boarding demand between trains during the peak hour. For individual trains, a person

capacity based on 90% of a seated load is a reasonable value that reserves capacity to accommodate higher-than-average passenger demands on a given trip.

Car seating capacities vary by car type and by rail operator. Generally, single-level coaches or electric multiple-unit cars have seating capacities in the range of 80–90 for a two-by-two seating configuration, and 110–116 for a three-by-two configuration. Bi-level coaches are becoming more prevalent among U.S. commuter rail systems. These come in multiple configurations but generally offer two-by-two seating, with seating capacities for the newest models ranging from 135 to 150 passengers per car.

Maximum train lengths (or consists) are another determining factor in the person-carrying capacity of a train. The maximum train length will be governed by factors unique to each commuter rail system, including:

- Station platform lengths (which can be limited by local conditions such as right-of-way, horizontal and vertical track curvature, and the proximity of turnouts or track switches);
- Yard track lengths;
- The maximum number of cars that can be hauled by the model of locomotive being used for the service; and
- Availability of rail cars to lengthen trains.

AUTOMATED GUIDEWAY TRANSIT CAPACITY

AGT has nuances that must be considered when applying the generalized rail transit capacity methodology.

In general, AGT capacity can be estimated using the generalized rail transit capacity method presented earlier in this section. However, there are some nuances specific to AGT that must be considered that are discussed below.

AGT Technology

AGT provides a very small share of urban, public, fixed-guideway transit—being used for less than 0.1% of passenger trips in the United States—but its use increases when institutional systems are considered, most of which are intra-airport shuttles. Technology ranges widely from standard-gauge advanced light rapid transit (e.g., Vancouver's SkyTrain), to the downtown people-mover in Miami, to small-scale monorails in amusement parks. All AGT systems are proprietary designs. As such, AGT vehicle performance, acceleration, and braking rates vary greatly, as does their balance between speed, vehicle size, and capacity.

Train Control Separation

Train control systems on AGT range from sophisticated moving-block signaling systems to basic manual systems in which only one train may be on a section of line—or the entire line—at a time. Manual or radio dispatching may ensure that a train does not leave a station until the leading train has left the station ahead. One variation uses sectioned power supply. Power is disconnected for a given distance behind an operating train.

These operating variations are not fully accommodated in the generalized method. However, if the basic AGT performance criteria are known, then the method will provide an approximation of the minimum train separation time for a range of AGT train controls—from a moving-block signaling system to a simple fixed-block system. A

surrogate of this can be roughly simulated by setting the train detection uncertainty factor *B* at four times the minimum braking distance. The results are shown in Exhibit 8-50 for trains of typical AGT lengths, using the specific AGT values in Exhibit 8-51, with terms adjusted from typical rail transit values shown in bold.

Exhibit 8-50
AGT Minimum Train Separation Times

Train Length	Minimum Train Separation (s)	
	Fixed Block	Moving Block
160 ft (50 m)	48.7	16.7
80 ft (25 m)	37.6	13.4
40 ft (12.5 m)	20.5	11.2

Source: *TCRP Report 13* (*1*).

Exhibit 8-51
Suggested AGT Separation Calculation Default Values

Default Value			
General Method	AGT	Term	Description
20 ft	20 ft	P_e	positioning error
650 ft	**165 ft**	L	**length of the longest train**
35 ft	**0 ft**	d_{eb}	**distance from front of train to exit block**
75%	75%	f_{br}	braking safety factor — % of maximum braking rate
2.4	**4**	b	**train detection uncertainty constant — fixed block**
1	1	b	train detection uncertainty constant — moving block
3 s	**1 s**	t_{os}	**time for overspeed governor to operate**
0.5 s	0.5 s	t_{jl}	time lost to braking jerk limitation
4.3 ft/s²	**2.0 ft/s²**	a	**service acceleration rate**
4.3 ft/s²	**3.3 ft/s²**	d	**service deceleration rate**
1.5 s	**0.5 s**	t_{br}	**brake system reaction time**
60 mi/h	**50 mi/h**	v_{max}	**maximum line velocity**
165 ft	**80 ft**	S_{mb}	**moving-block safety distance**

Source: *TCRP Report 13* (*1*).
Notes: Bold type indicates AGT default values that differ from other rail transit values. A metric version of this exhibit appears in Appendix A.

The results show that separation times with a simulated single aspect block system are two to three times longer than with the more complex—and expensive—moving-block signaling system. The moving-block results are consistent with another reference specializing in AGT train control, where typical short train AGT separation with moving-block control was cited at 15 s (*16*).

The separation range is wide and highly dependent on the train control system of the proprietary AGT system. The best method of determining the minimum train separation is from the system manufacturer or designer. Using the general methodology to determine train control separation should be a last resort when specific information is not available.

AGT headways.

The selection of a minimum headway for AGT systems should reflect the train control separation, dwell time, and any operating margin that conforms with existing operations or is suggested by the system manufacturer. The typical headway of airport systems is 120 s, with a few operating down to 90 s. Claims have been made for closer headways with some proprietary systems. Headways shorter than 90 s are possible, but may limit dwell times and constrain the operating margin. They should be considered

with caution unless off-line stations are adopted. Off-line stations make closer headways possible and practical—at a price.

Loading Levels

AGT loading levels tend to be atypical of transit overall.

Loading levels of AGT cars tend to be atypical of normal transit operations. At one extreme are airport shuttles with wide cars and no or few seats where loading can reach 3 p/ft length (10 p/m length) under pressure from arriving flights. Loading diversity on airport systems fluctuates related to flight arrival times, rather than 15-min peak periods within a peak hour. After an arriving flight, three trains at 120-s headways can exceed maximum loading levels—to be followed by a number of underutilized trains.

At the other extreme are the narrow, all-seated amusement park monorails with loading as low as 0.6 to 0.9 p/ft length (2 to 3 p/m length). The peak-hour factor (PHF) on the latter type systems attains 1.0 when arrangements—and continual passenger queues—ensure that every seat on every train is occupied—in some cases, through all hours of operation.

The design capacity of non-public transit AGT systems requires consultation with the system supplier. The methodologies and calculations of this manual should only be used as a last resort—and then treated as a guideline.

Off-Line Stations

Off-line stations increase capacity.

Off-line stations maximize system capacity. They are used on several rail transit lines in Japan to achieve some of the highest throughputs for two-track rapid transit lines in the world. In North America, they are the exclusive preserve of the AGT line in Morgantown, West Virginia.

Off-line stations permit a train throughput that is partly independent of station dwell time. The throughput is that of the train control system plus an allowance for switch operation and a reduced operating margin. Morgantown and certain other AGT systems use on-vehicle switching techniques where even this allowance—typically 6 s—can be dispensed with. In theory, trains or single vehicles can operate at or close to the minimum train control separation—which can be as low as every 15 s.

Major stations with high passenger volumes may require multiple platform berths, otherwise partial dwell times must be added to the train separation times to obtain the minimum headway. The design capacity of such specialized systems should be determined through consultation with the system manufacturer or design consultant.

ROPEWAY CAPACITY

Overview

Ropeways in North America are more commonly used by private owners than by public transit agencies.

This section discusses the capacity of transit modes that are hauled by cable (wire rope). Although these modes are not widely used in North America for public transit, they are sometimes considered as modal alternatives in transit feasibility studies, and have been constructed as part of a number of private developments, particularly ski areas. In Europe, funicular railways can be found in a number of hilly urban settings, and both funiculars and aerial tramways are used for access to some remote villages inaccessible by road.

Surface modes include some of the oldest mechanized purely urban transportation systems, discounting extensions of intercity rail networks into city centers. Vehicles are either permanently attached to the rope, or can attach and detach from the rope by means of a grip mechanism. In either case, the motor driving the rope is located in a remote location, not on the vehicle itself, and the vehicle operates on a guideway. As described in Chapter 2, Mode and Service Concepts, surface ropeway modes include *cable cars, inclined planes* (funicular railways), and *cable-hauled automated people-movers*.

For the purposes of this method, two capacity categories are used: (*a*) reversible systems and (*b*) continuously circulating systems. These categories include both surface and aerial ropeway modes as members.

Reversible System Capacity

A reversible system typically provides two vehicles that are always attached to a rope and that move back and forth along the line at the same time. When one vehicle is at one terminal, the other vehicle will be at the opposite terminal. Vehicles are accelerated to line speed by increasing the speed of the haul rope and decelerated by slowing the haul rope. Passenger loading and unloading occurs while the vehicle is stopped. Modes that fall into this category are inclined planes and aerial tramways.

The line capacity of a reversible system depends on the length of the line, the line speed, and dwell times at stations. Reversible systems are usually designed with only two stations. A third station, if used, desirably should be located exactly halfway along the line so that both vehicles can be in the station at the same time. If the station is not located exactly halfway, then each vehicle will make two intermediate stops: one while at the station and one while the other vehicle is at the station.

Manufacturers claim line speeds of up to 33 to 46 ft/s (10 to 14 m/s) for funiculars and up to 39 ft/s (12 m/s) for aerial tramways. The average line speed will be somewhat less, due to acceleration and deceleration needs, and (for aerial tramways) any slowing of the line required as the carrier passes over towers.

Equation 8-16 provides the directional line capacity of a reversible system (*5, 17*).

$$T = \frac{1{,}800 N_v}{(N_s t_d) + \frac{L_l}{v_l}} \qquad \textbf{Equation 8-16}$$

where

T = directional line capacity (trains/h, carriers/h);

1,800 = number of seconds in an hour, divided by two;

N_v = number of vehicles (1 or 2);

N_s = number of stops per direction:
1—two-station system,
2—three-station system, with middle station exactly halfway, and
3—three-station system, with offset middle station;

t_d = average dwell time (s);

L_l = line length (ft, m); and

v_l = average line speed (ft/s, m/s).

Continuously Circulating System Capacity

A continuously circulating system provides multiple carriers, cars, or trains that move around a route that forms a loop. Vehicles can be attached to the rope at all times (*fixed grip)* or can be attached and detached as needed (*detachable grip*).

See Chapter 2 for descriptions and illustrations of the various ropeway modes.

The concept of moving at high speed along the line and detaching from the line at stops and stations is shared by all detachable-grip modes, including detachable-grip aerial lifts, funitels, cable-hauled automated people movers (APMs), and cable cars. At stops or stations, passenger loading takes place while the vehicle is stopped (cable cars and some APMs), or while moving at creep speed (0.8 ft/s or 0.25 m/s). Manufacturers claimed line speeds range up to 20 ft/s (6 m/s) for detachable-grip gondolas, to 23 ft/s (7 m/s) for funitels, and 26 ft/s (8 m/s) for cable-hauled APMs.

Fixed-grip modes do not detach from their haul rope. Fixed-grip ski lifts load and unload passengers at line speed, but for other applications, the rope must be brought to either a full stop or creep speed at stations. To minimize the number of stops that passengers must make between stations, many fixed-grip gondola systems are designed as *pulse* systems, with three or four carriers attached in a series. At the station, all of the carriers in the series can be loaded and unloaded at the same time, thus minimizing the number of intermediate stops and improving overall travel speeds. Fixed-grip gondolas have a maximum claimed line speed of 23 ft/s (7 m/s).

The line capacity of a continuously circulating system depends on the average line speed and the spacing between carriers. For APMs, which can have multiple stations, dwell time is used to develop the minimum safe spacing between trains, following the generalized rail transit capacity method described above. Platform doors are often used both for safety (keeping passengers from falling onto the tracks or between cars of a train), and to control dwells, by keeping late-arriving passengers on the platform from holding the train doors open. For fixed-grip aerial lifts, dwell time is incorporated in the average line speed. Dwell time is not a factor for detachable-grip aerial lifts and funitels, as the carriers circulate through the station at a constant, low speed, without stopping. Equation 8-17 provides the directional line capacity of a continuously circulating system (*5, 17*).

Equation 8-17

$$T = 3{,}600\frac{v_l}{d_c}$$

where

T = line capacity (trains/h, cars/h, carriers/h);

v_l = average line speed (ft/s, m/s); and

d_c = average carrier/train/car spacing on the line (ft/carrier, m/carrier).

Person Capacity

Manufacturers' stated capacities typically do not account for loading diversity.

Manufacturers of ropeway systems tend to state *theoretical* person capacities, based on the maximum number of people that can be carried over the course of an hour, assuming all passenger space within each vehicle is occupied. For some applications that may experience constant queues, such as ski areas, this may be a reasonable assumption. However, for public transit use, as well as any other application where minimizing passenger wait time is desired, a peak-hour factor should be applied. The

PHF accounts for the system's inability to fill every seat in every vehicle, as some capacity is reserved to handle surges in passenger demand.

The person capacity of an aerial ropeway cannot be easily increased, except for gondola systems designed with future expansion in mind.

Changing the person capacity of aerial ropeway systems is difficult, because the infrastructure (e.g., towers, rope size, vertical clearances) is designed around a particular number and size of carriers. Changing the carrier size typically requires major changes to the infrastructure. However, it is possible to design a gondola system for a larger number of carriers than will be used initially. This reduces initial capital costs and allows the capacity to be better matched to demand, as additional carriers can be added later as needed, up to the maximum number for which the system was designed.

Because the number of carriers used on detachable-grip systems can be varied by the operator, the person capacity of these systems can be adjusted over time by adding additional carriers. In this case, consideration should be given to differentiating between capacities that can currently be achieved with a given number of carriers and the maximum capacity that could be achieved.

The sizes of the cabins used by the various modes addressed in this section vary greatly. Once a particular cabin size is selected, it is difficult—if not impossible—to add person capacity by using larger carriers without rebuilding much of the system. Other infrastructure elements (e.g., towers, platforms, clearances) are designed around a particular carrier and may not be able to accommodate a larger carrier. Exhibit 8-52 provides typical ranges of cabin sizes for each mode.

Exhibit 8-52
Typical Cabin Sizes of Ropeway Modes

Mode	Capacity (p/car)	Comments
Surface Modes		
Inclined plane/funicular	20-175	Two-car trains possible
Automated people mover	30-140	Multiple-car trains possible
Aerial Modes		
Aerial tramway	20-180	Double-decked at upper limit
Gondola	4-15	
Funitel	24-30	

Source: Manufacturer data.

6. APPLICATIONS

DESIGNING FOR FUTURE GROWTH

The long-term capacity of a rail system is the design capacity achievable when the system is saturated and provided with a full complement of rolling stock. It is not the capacity that a rail transit line will provide on opening day or reach after a decade. Instead, it is the capacity after decades of growth.

Design for mature capacity.

A difficult question is for what ultimate capacity a rail transit system should be designed. Certain transportation models can predict passenger demand for several decades ahead. However predictions beyond 10 to 15 years are of decreasing accuracy—particularly in areas without an existing rail transit system or good transit usage. The resulting uncertainty makes the modal split component of the model difficult to calibrate. Even a 10- to 15-year projection period can introduce some uncertainty into the results.

It generally is preferable to base an estimate of future required capacity on assumptions about the ultimate future size of the ridership market to be served, even if these assumptions are relatively generalized. When modeling does not provide a reasonable or believable answer, or where information on future ridership potential is simply unavailable, it is possible to fall back on an old rail transit rule of thumb, namely, to design for three times the initial mature capacity. Mature capacity occurs 5 to 10 years after a system opens, when extensions and branches are complete, modal interchanges—bus feeders and park-and-ride—have matured, and some of the rail transit-initiated land use changes, including development and densification around stations, have occurred.

The line capacity determined from this manual can be used to establish the train and station platform lengths and the type of train control that will allow this long-term demand to be met—whether the demand is obtained from a long-range model or by rule-of-thumb. This long-term demand may be 30 to 50 years ahead. If this suggests that 600-ft (180-m) trains and platforms will be required, it does not mean they have to be built initially. Stations can be designed to have platforms expanded in the future. However, underground stations should have the full length cavity excavated—otherwise it can be difficult and expensive to extend platforms while the rail line is operating.

PLANNING-LEVEL ANALYSIS

The planning procedures require two main inputs: (a) train control system and (b) train length.

With the relative uniformity in the performance of electric multiple-unit trains in urban rail transit service, a simple procedure can be applied to estimate a range of peak-hour passenger capacities for grade-separated lines at their maximum load point.

The necessary choices are only two, the type of train control system and the train length. The range is provided by assigning (*a*) a range centered around a typical dwell time plus operating margin and (*b*) a small loading range centered around a comfortable peak hour average space per passenger of 5.4 ft² (0.5 m²). As this is a peak-hour average, no peak-hour factor is required.

This procedure assumes system and vehicle characteristics that are close to the industry norms listed in Exhibit 8-53. It also assumes that there are no speed-restrictive curves or grades over 2% on the approach to the station with the longest dwell time, and that the power supply voltage is regulated within 15% of specifications. Finally, it assumes an adequate supply of rolling stock, and a system design that ensures that junctions (including multiple line merges) and turnbacks will not be the capacity constraint.

Key assumptions are:

- *Flying junctions or no junctions,*
- *No turnback constraints,*
- *The sum of dwell time and operating margin at the critical station is no more than 70 s,*
- *No speed-restrictive curves or grades on the critical station approach,*
- *Adequate supply of rolling stock.*

If any of these assumptions are not met, then the planning procedures should be used only as guidelines and the more detailed procedures in Section 5 should be used to develop a planning-level estimate of capacity.

Exhibit 8-53
Rail Transit Performance Assumptions for Planning Applications

Description	Default
Grade into headway critical station	< ± 2%
Distance from front of train to station exit block	<35 ft (<10 m)
% service braking rate	75%
Time for overspeed governor to operate	3.0 s
Time lost to braking jerk limitation	0.5 s
Service acceleration rate	4.3 ft/s² (1.3 m/s²)
Service deceleration rate	4.3 ft/s² (1.3 m/s²)
Brake system reaction time	1.5 s
Maximum line velocity	60 mi/h (100 km/h)
Dwell time	35-45 s
Operating margin	20-25 s
Line voltage as % of normal	>85%
Moving-block safety distance	165 ft (50 m)
Average peak-hour passenger loading level—light rail	1.5 p/ft length (5 p/m)
Average peak-hour passenger loading level—heavy rail	1.8 p/ft length (6 p/m)
Maximum car length—light rail	95 ft (29 m)
Maximum car length—commuter rail	85 ft (26 m)
Maximum car length—heavy rail	75 ft (23 m)

Source: *TCRP Report 13* (*1*).

Grade-Separated Rail Capacity

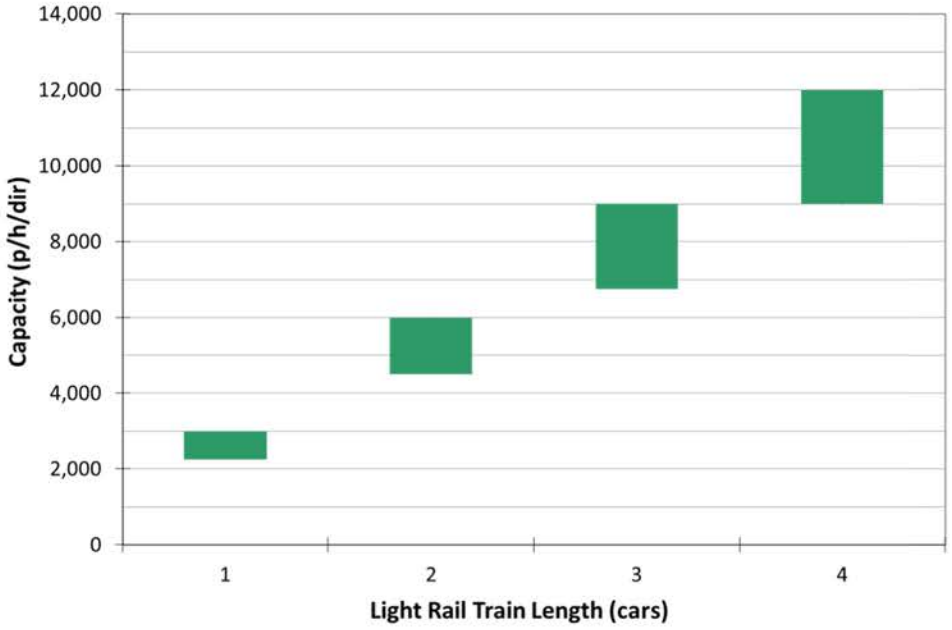
For the purposes of this procedure, grade-separated rail includes all heavy rail, portions of light rail that operate on grade-separated rights-of-way, electric commuter rail lines operating on their own trackage, and AGT systems with characteristics similar to light or heavy rail transit. The capacity of other types of AGT and commuter rail lines cannot be determined with this planning-level method and either the more detailed method presented in Section 5 or simulation (discussed later in this section) should be used.

Systems Designed for Economy

Systems that are designed economically for the minimum *planned* train headway, rather than the minimum *possible* train headway—typically, light rail systems—will design the signal and power system to accommodate this minimum planned headway.

In these cases, line capacity is directly related to the signaling constraint built into the system (assuming no significant single-track sections), and person capacity is then directly related to the line capacity and the train length. Exhibit 8-54 shows the hourly directional person capacity of light rail systems designed for a particular minimum planned headway and a particular maximum train length.

Exhibit 8-54
Capacity of Light Rail Systems Designed for Minimum Planned Headway



Note: Signal system design headway ranges from 3 min (upperbound) to 4 min (lowerbound).

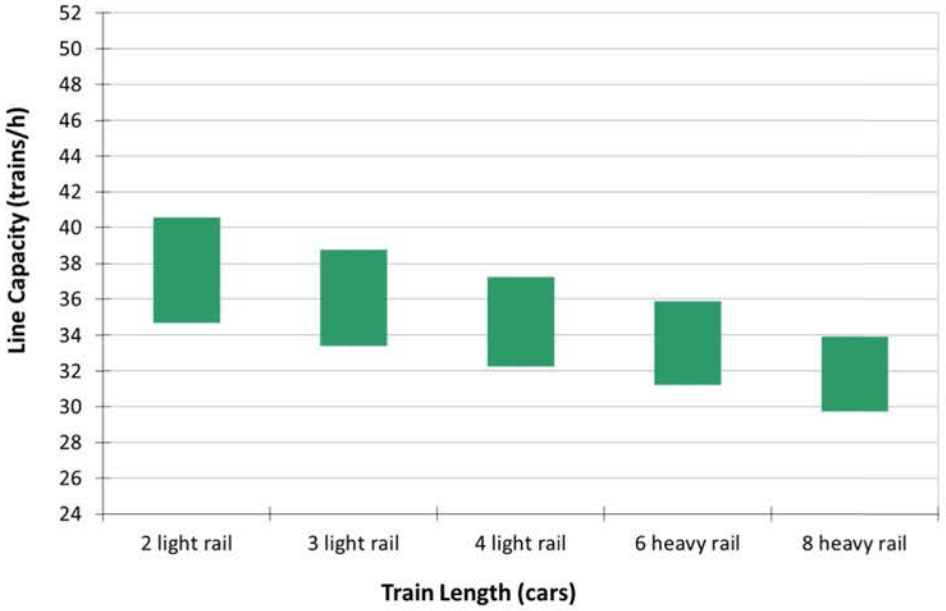
Systems Designed for Maximum Throughput

A three-aspect fixed-block system typically can support no more than 30 trains per hour—and less if a line has flat junctions or a station with extended dwell times.

As described in Section 3, three types of signaling systems are possible: fixed block, cab, and moving block. New systems that are designed for maximum throughput capacity (i.e., operations at minimum practical headway) would not use the more limited and more expensive (due to the number of signal installations required) three-aspect fixed-block signaling system. A fixed-block system may be used for systems designed for less than maximum throughput, in which case Exhibit 8-54 should be used. Consequently, the choice of train control system is limited to cab and moving-block signaling. Exhibit 8-55 through Exhibit 8-58 give line capacity and person capacity for both cab and moving-block signaling systems, based on the assumptions given in Exhibit 8-53.

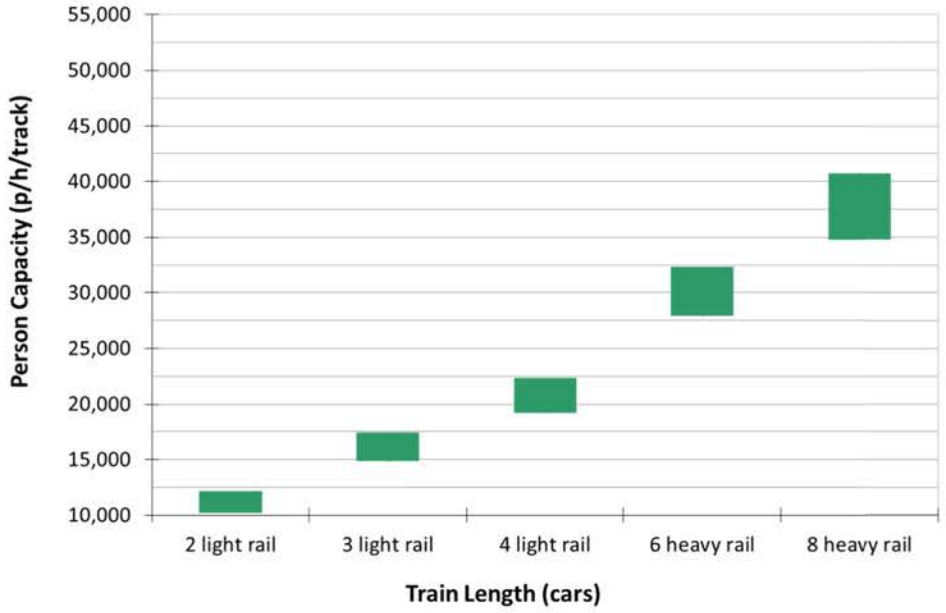
Note that with the exception of San Francisco's Muni Metro, signaled grade-separated light rail lines are rarely provided with the minimum headway capabilities represented by the capacity ranges in Exhibit 8-55 and Exhibit 8-57. Also, operating experience in North America suggests a maximum of 30 trains per hour per track for conventional rapid transit lines. It is apparent from the observed operating experience in New York and Washington that higher dwell times at critical stations prevent the achieving of capacities significantly greater than 30 trains per hour.

Exhibit 8-55
Grade-Separated Line Capacity—Cab Signaling



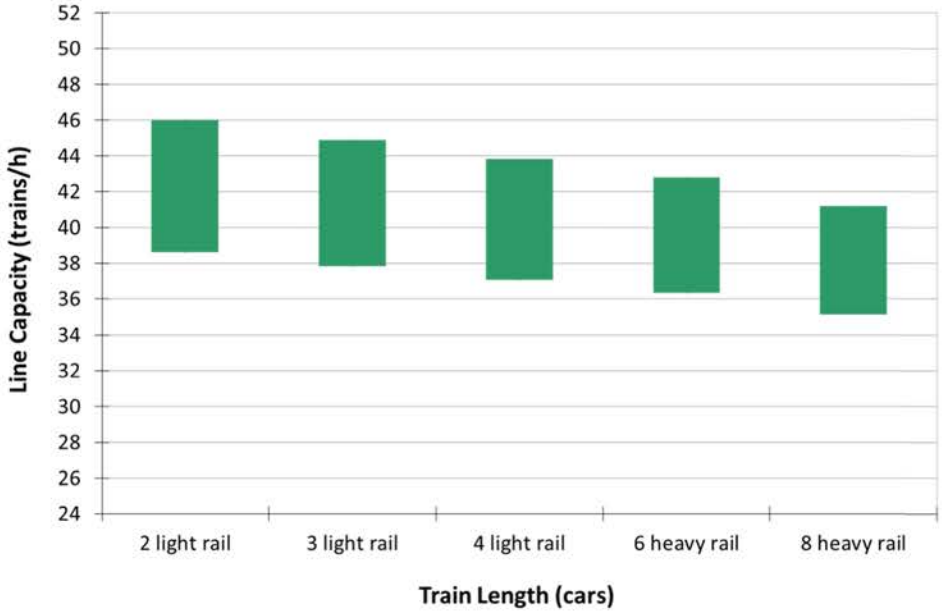
Note: Combination of dwell time and operating margin ranges from 55 s (upperbound) to 70 s (lowerbound).

Exhibit 8-56
Grade-Separated Person Capacity—Cab Signaling



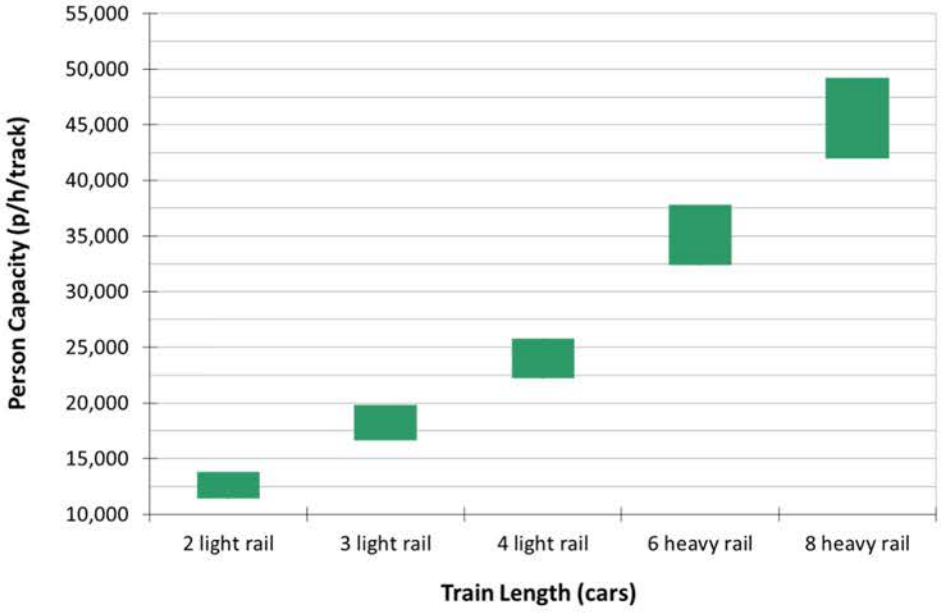
Note: Combination of dwell time and operating margin ranges from 55 s (upperbound) to 70 s (lowerbound).

Exhibit 8-57
Grade-Separated Line Capacity—Moving-Block Signaling



Note: Combination of dwell time and operating margin ranges from 55 s (upperbound) to 70 s (lowerbound).

Exhibit 8-58
Grade-Separated Person Capacity—Moving-Block Signaling



Note: Combination of dwell time and operating margin ranges from 55 s (upperbound) to 70 s (lowerbound).

Non-grade-separated Light Rail Capacity

Light rail can operate in a variety of rights-of-way, each of which can potentially control capacity. The first of these types, grade separated, was addressed above. The remaining types—single track, exclusive lane, and private right-of-way with grade crossings—are covered in this subsection. The lowest capacity of the various right-of-way types along the line will control the overall capacity.

Single Track

Single-track sections with two-way operation will typically be the capacity constraint when they are present. Exhibit 8-59 provides the directional line capacity of single-track sections of various lengths, with and without stations within the single-track section. Exhibit 8-60 provides the directional person capacity. The exhibits are for two-car trains. The line capacity for longer trains will be slightly lower for short single-track sections with no stations (approximately 5% lower for a 650-ft [200-m] long section), but nearly the same for long sections, or when stops are made within the single-track section.

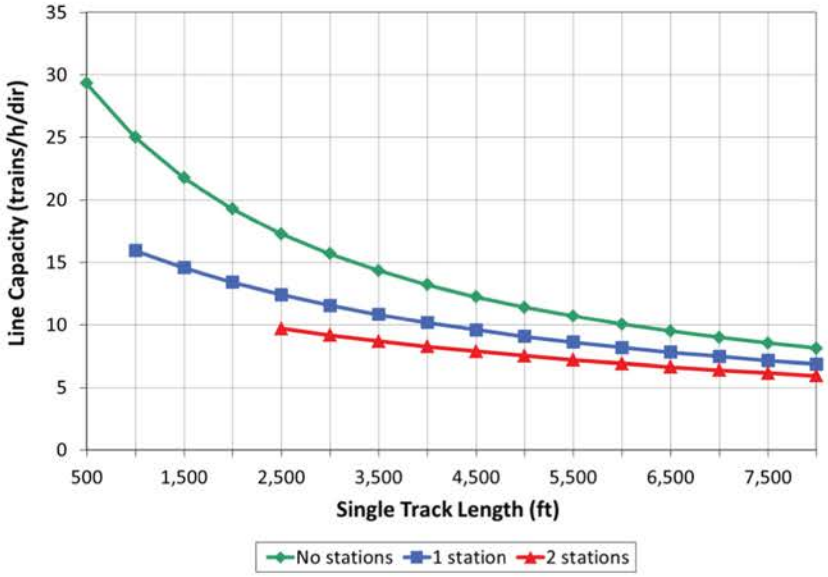


Exhibit 8-59
Single-Track Line Capacity—Two-Car Light Rail Trains

Notes: Assumes 35-mi/h speed limit, 180-ft train length, 20-s dwell time, and 20-s operating margin.
A metric version of this exhibit appears in Appendix A.

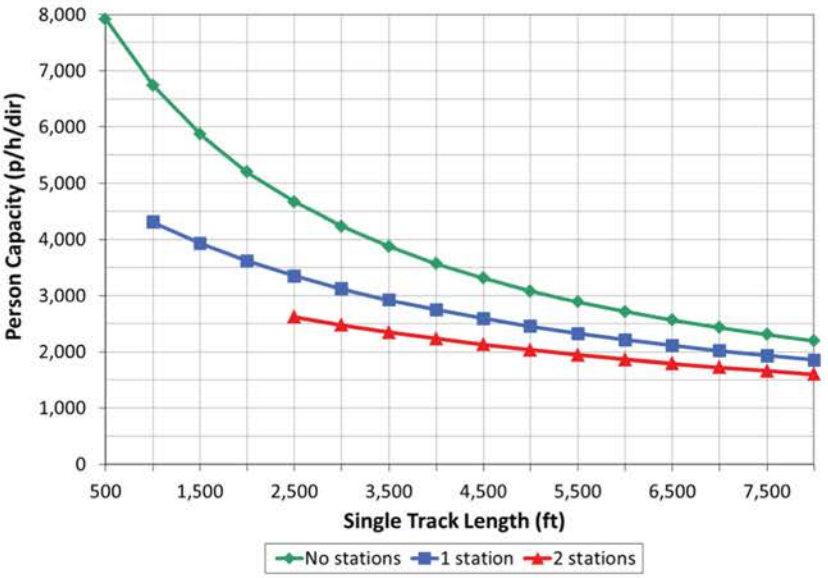


Exhibit 8-60
Single-Track Person Capacity—Two-Car Light Rail Trains

Notes: Assumes 35-mi/h speed limit, 180-ft train length, 20-s dwell time, and 20-s operating margin.
A metric version of this exhibit appears in Appendix A.

Exclusive Lane Operation

The minimum sustainable headway in exclusive lane on-street operation is typically twice the longest traffic signal cycle length. When cycle lengths are long and no signal priority is provided for light rail, exclusive lane operation may constrain capacity. Exhibit 8-61 provides the line capacity for a variety of signal cycle lengths, and Exhibit 8-62 provides the corresponding person capacity. These exhibits are not applicable to streetcar operation where more than one streetcar can occupy a station at a time or where streetcars operate in mixed traffic.

Exhibit 8-61
Light Rail Line Capacity—Exclusive Lane Operation

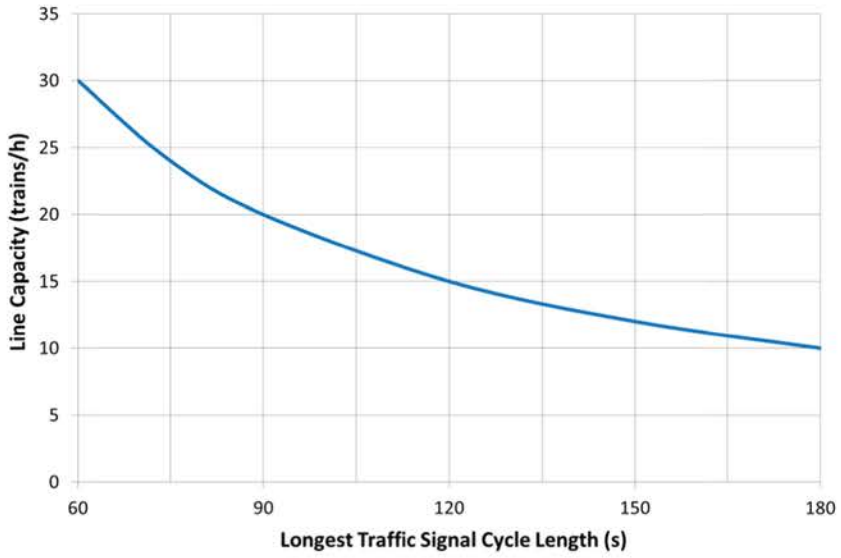
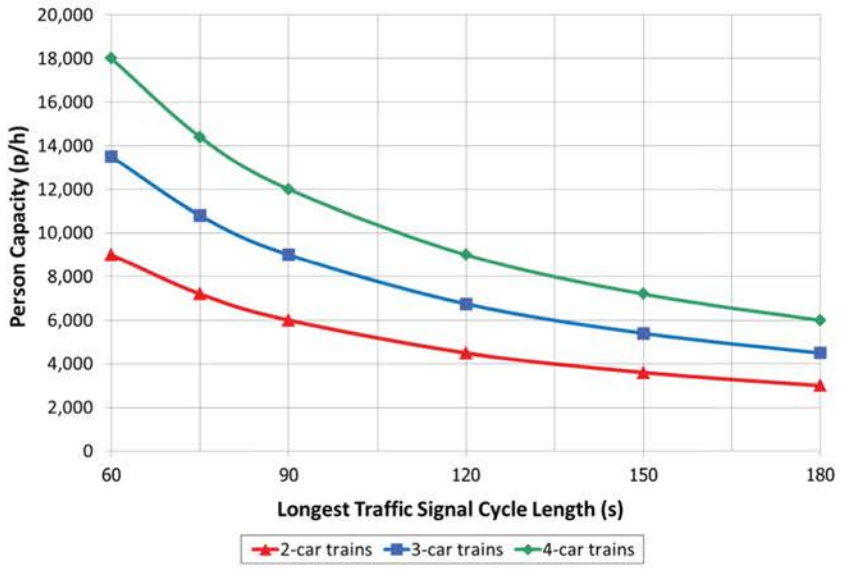


Exhibit 8-62
Light Rail Person Capacity—Exclusive Lane Operation



Exclusive lane, on-street operation is unlikely to be the capacity constraint when traffic signal cycle lengths are relatively short.

Private Right-of-Way with Grade Crossings

This category includes railroad-type operations, with street crossings controlled by gates, and operations within street medians, with street crossings controlled by traffic signals. When trains have full preemption of traffic (e.g., at gated crossings, or when full signal preemption is provided at traffic signals), the grade-separated capacity charts presented earlier may be used. Additional dwell time may be needed when station exits are located near grade crossings and preemption of the crossing is not allowed until passenger movements have ceased and the train is ready to leave the station. When trains do not have full preemption of traffic, use the exclusive lane charts above.

Ropeway Systems

As discussed in Section 5, ropeway systems can be classified into two categories for capacity analysis: (*a*) reversible systems, where one or two vehicles shuttle back and forth along a line, and (*b*) continuously circulating systems, where vehicles or cabins circulate around a loop. Reversible modes include aerial tramways and inclined planes. Circulating modes include gondolas and cable-hauled automated people movers.

Reversible System Capacity

The line capacity of a reversible system is dependent mainly on the length of the line and the speed at which a vehicle (train or cabin) can move from one end of the line to the other. Acceleration and deceleration delays and station dwell time are also major components of line capacity for shorter systems. Exhibit 8-63 provides the person capacity of reversible systems of various lengths and vehicle sizes, assuming two-vehicle operation and line speeds toward the upper end of modern aerial tramways and inclined planes.

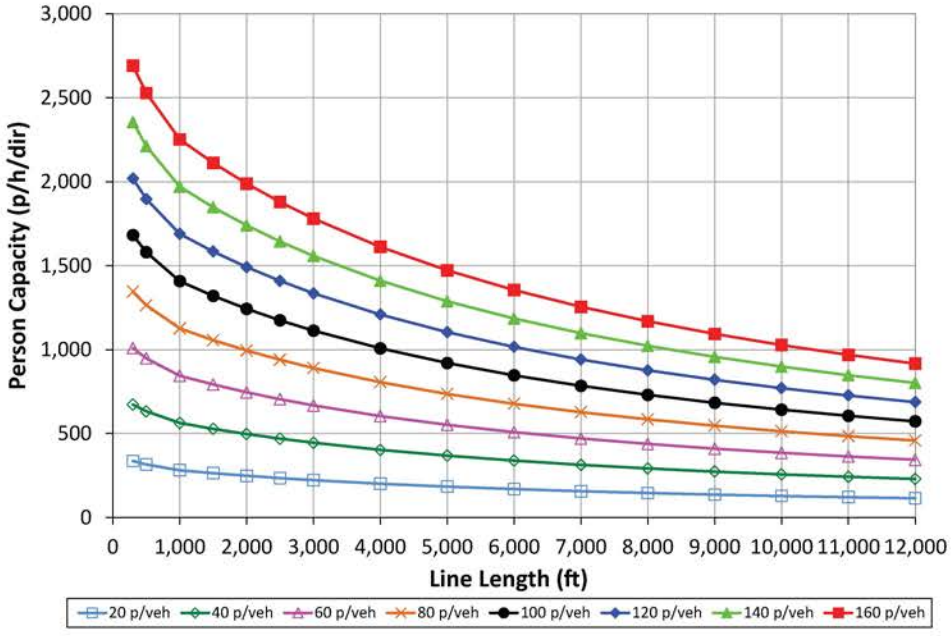


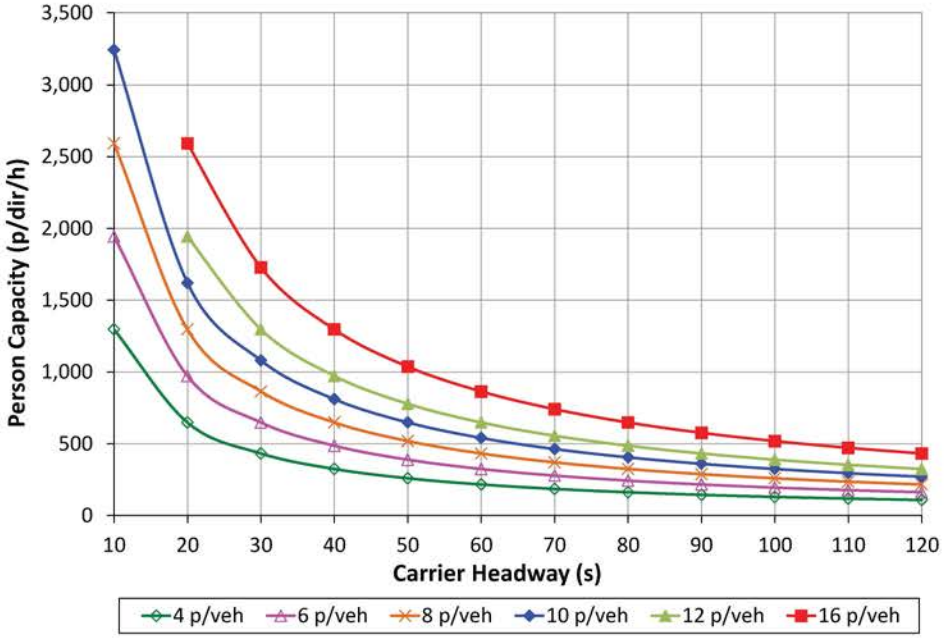
Exhibit 8-63
Reversible Ropeway Person Capacity

Note: Assumes 33-ft/s line speed, 0.66-ft/s^2 acceleration, two-vehicle operation, no intermediate stations, 150-s dwell time, and 0.90 PHF.
A metric version of this exhibit appears in Appendix A.

Continuously Circulating System Capacity

The line capacity of a continuously circulating system is dependent solely on the spacing of carriers or vehicles on the line. Person capacity, therefore, is simply a function of line capacity, vehicle size, and passenger arrival characteristics. Exhibit 8-64 provides the person capacity of detachable-grip gondola systems with different cabin sizes and headways.

Exhibit 8-64
Gondola Person Capacity



Note: Assumes a peak-hour factor (PHF) of 0.90.

TRANSIT OPERATIONS PLANNING

Analytic Needs for Operations Planning

Transit operations planning is performed to fulfill any of several analytic needs:

- Travel demand analysis: service headways and realistic journey times are key inputs to travel demand forecasts;
- Capacity analysis: ensuring that transportation infrastructure capacity is sufficient for the planned level of transit service;
- Analyzing and resolving current operating problems, and identifying and avoiding potential future operating problems;
- Operations and maintenance cost estimating;
- Energy consumption analysis;
- Operational input to air quality and noise/vibration impact assessments;
- Operational input to life safety analysis and transit security assessments;
- Operating crew and other staffing requirements;

- Transit vehicle fleet requirements (and associated capital costs): determining the most appropriate equipment type and the number vehicles required (including spare/out-of-service allowances); and
- Vehicle storage and maintenance facility requirements (and associated capital costs).

Service and Operating Plans

A *service plan* can be prepared for an individual transit line or for an entire network and provides a summary description of the basic characteristics of the service. It also defines the level of service offered to riders and quantifies the essential service parameters, including a description of the route, terminal points and intermediate stations/stops, and service headways by time of day and day of week. Service plans can be illustrated with simple maps and straight-line diagrams and summarized in spreadsheet matrices.

Operating plans provide a somewhat more detailed description of the service provided, including information on service and stopping patterns (including express and skip-stop service and branch line/network operations), service frequency, the type of transit fleet utilized, the length and composition of train consists (the cars, and in the case of railroad systems, locomotives making up a train set), overall fleet requirements, assigned routings over the network and track assignments at stations and terminals, equipment cycles and turns at terminal points (the linkages between an inbound train in one direction and the corresponding outbound train in the other direction), and the timing and routing of non-revenue train movements to and from storage yards and maintenance shops. Transit system operating plans also are an important input to the development of fleet maintenance strategies, including defining the appropriate locations and configurations of depots, shops, and yards.

Operating plans can be prepared and analyzed at two levels of detail, depending upon the type of analysis required and the time and resources available.

1. Sketch-plan models are used for most planning and feasibility studies. These models are spreadsheet-based, easy to develop and use, customizable for the needs of each project, and based on relevant experience observed at the system in question or elsewhere. Sketch plan models are sufficient for developing initial estimates of fleet requirements and operating/ maintenance costs and provide the headway and transit journey time inputs needed to develop ridership estimates. Developing proposed transit schedules in public timetable format can be useful for helping to describe new or enhanced transit services to project stakeholders and the public.
2. Detailed dynamic-simulation models can be developed for transit lines or networks to enable investment-grade analysis of transit system operations used to confirm needs prior to project implementation and to support engineering design and value engineering. Operating plans and simulation models can be used to undertake detailed scheduling and run cutting and to prepare detailed running time estimates for transit services, accounting for station dwell times, vehicle acceleration and deceleration profiles, and, for road-based systems, traffic and intersection delays.

ROLE OF SIMULATION

Definition and Applicability

An operations simulation model realistically depicts train movements over a transit or railroad network, including main lines, junctions, stations, and terminals. Simulations are powerful analytic tools that accurately represent:

- The physical characteristics of the infrastructure of a transit or railroad network,
- The performance characteristics of the trains operating on the network, and
- The signaling/train control system that governs operations of trains within the network.

These models are sophisticated programs designed to realistically depict rail operations in either a planning environment or an online control center. Simulation models can be developed and used at various levels of complexity. These models realistically simulate train movements over a variety of rail networks with different levels of complexity, multiple tracks and/or routes, and variable stopping patterns. They are able to resolve complex multi-train conflicts in realistic ways. Such models have proven to be fully capable of handling complex track configurations and mixes of trains on a network.

Dynamic simulation models are in common use among the owners, operators, and planners of transit and rail systems in the U.S. Users of simulation models include:

- Class I freight railroads,
- Amtrak,
- Commuter railroads, and
- Rail transit agencies.

Operations Simulation Model Types

NCHRP Report 657: Guidebook for Implementing Passenger Rail Service on Shared Passenger and Freight Corridors (*18*) provides a useful overview of the features and role of operations simulation models.

Simple Models

In its simplest form, a simulation model is a computer program that performs a stepwise calculation of the movement of a train over a rail corridor. Using information on speed limits, grades, train acceleration and braking rates, station stop dwell times, etc., the model calculates the speed and distance traveled by the train for each time step (e.g., every 10 s). After the model has stepped along the whole corridor, it produces a tabulation of time and distance traveled, often presented graphically as a time vs. distance string-line chart.

A model that performs this calculation for a single train moving over a rail corridor is usually known as a train performance calculator (TPC), because it calculates travel time without interference from other trains operating on the corridor at the same time. TPCs often have additional features, such as an ability to calculate energy used or fuel consumption. Single-train train performance calculations are used to determine

required rail corridor upgrades and to estimate travel times before the interference effects from other trains and other typical operating delays are taken into account. For initial planning, it is customary to pad the minimum trip time by around 10 percent to estimate a practical trip time. This type of calculation can be used to investigate such questions as the reduction in journey time from increasing top speed from 79 mi/h to 110 mi/h, or from adding or omitting station stops.

Complex Models

The more complex version of a train operations simulator performs a simultaneous calculation of all train movements on the corridor, taking into account signal system characteristics, train priorities, temporary slow orders, and typical dispatcher decisions over where trains should meet or overtake each other. At their most complex, the multi-train simulations closely reproduce how a real rail corridor would be operated, taking into account all the variations in individual train performance and other operating constraints and variations. Results are usually presented as the calculated trip time for each train compared with minimum time with no interference from other trains, slow orders, etc. The difference is reported as a delay. Operation over the corridor can also be represented on a string-line chart (Exhibit 8-65) or as an on-screen animation—a sped-up version of a dispatcher's display (Exhibit 8-66). Details within these graphics are too small to be seen here but are not essential for understanding the general appearance of these types of displays.

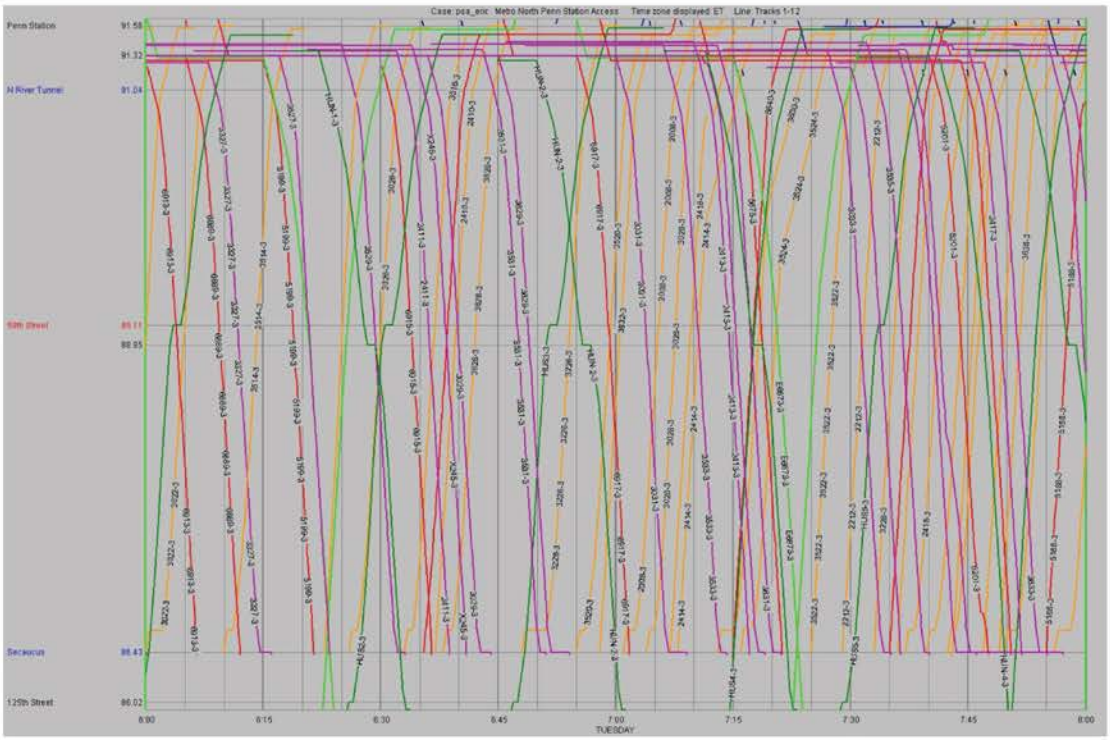
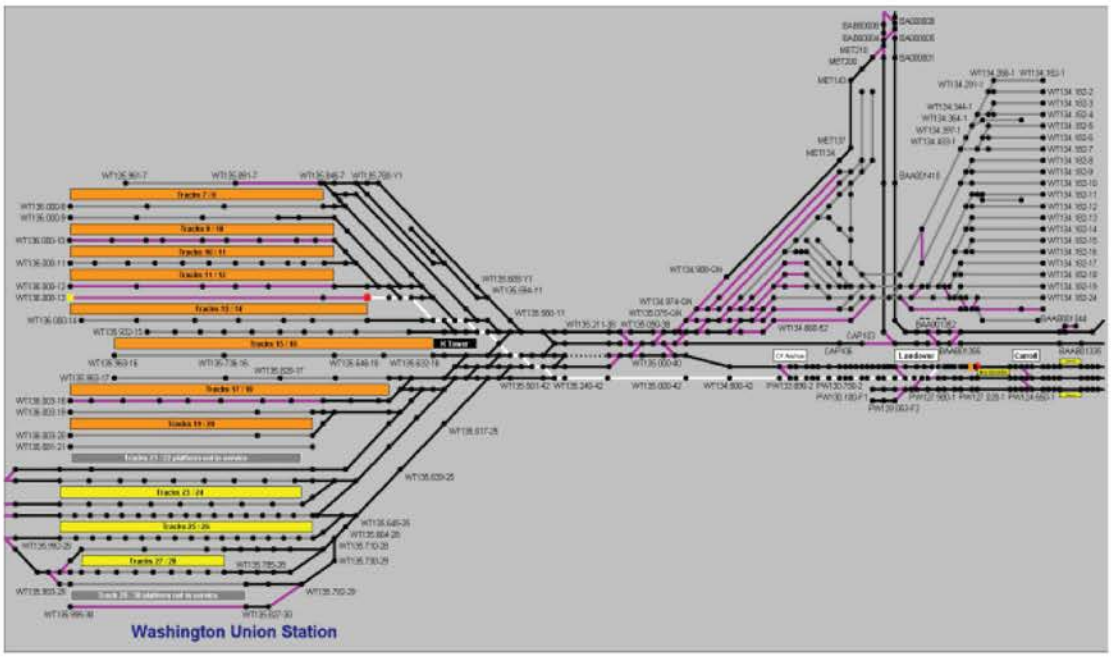


Exhibit 8-65
Example String-Line Chart: Metro North Penn Station Access

Exhibit 8-66
Example Dynamic Dispatch Animation: Washington Union Station



A single run of a corridor operations simulation will only represent operations under one set of input conditions. Railroad operations are subject to a variety of random and planned disruptions to normal operation, including planned and unplanned track maintenance, delays at stations, and delays caused by events elsewhere on the railroad. Freight train operations are not normally conducted with great precision, and even scheduled freight trains are subject to variability. In addition, many through freight trains are unscheduled "extras" that run as needed and may enter the corridor at any time. Multiple model runs are used to address these variables, with results presented as average run times and delay statistics for each train, along with string charts and animations as required.

The primary use of a multi-train simulation model is to investigate needed infrastructure upgrades to an existing rail corridor, to enable it to accommodate additional passenger train trips while still meeting specified service performance requirements (train departure times, trip time, and on-time performance) and complying with any other specified constraints. The analyst will start with improvements identified using a single-train TPC (if available) and will make multiple model runs to test alternative track configurations and other improvements. The objective is to identify a cost-effective package of improvements that will meet the service requirements of all users. Given the trial-and-error process of using simulation models, the complexity of these models, and the potentially large number of alternative corridor configurations to be investigated, an experienced modeling analyst is essential. Modeling is something of an art, and a model cannot represent everything about a route. Interpreting results requires judgment, informed by experience using the model, experience with interpreting the results, and experience observing real-life outcomes.

Simulation Software Features

There are several simulation software packages available for use in railroad and rail transit operations analysis. Simulation software packages are similar in the way that they display simulation results. While timetables and time–distance charts are useful for analysis on simple networks, they often do not show conflict resolutions at a sufficient level of detail. Simulation results can be displayed in these traditional ways, but simulations offer the benefit of providing a train dispatch animation, which, with its multitude of color modes, can bring the solutions to life. With its emphasis of graphical output, the integrity of solutions can be verified and presented without spending a large amount of time examining abstract reports.

Simulation models and other operations planning methods are intended to be objective analytic tools to help develop and test rail operating scenarios and infrastructure solutions. Simulation models have a high degree of buy-in from U.S. Class I freight railroads, Amtrak, and commuter rail operators, as a rational method to plan train schedules and resolve conflicts. They also have been adopted by most rail transit operators. The end-product of these analyses typically entails demonstrating that a recommended service and infrastructure scenario can be operated without creating an unacceptable effect on other traffic.

Two important features typically provided by simulation modeling software are train performance calculations and algorithms for train dispatching and conflict resolution. These are described below.

Train Performance Calculations

The TPC included within a simulation model is a tool used for computing minimum run times for trains operating from one specified point to another over the network without interference from other trains. Experimenting with various stopping patterns, routing configurations, dwell times, and trainset technologies helps identify the most effective scheduling/dispatching solution for a particular train type with specific physical plant characteristics.

This integrated TPC utilizes accurate trainset performance specifications in addition to length, weight, etc. The TPC applies this data in combination with tractive effort curves and dynamic braking curves or brake characteristics to replicate the dynamics of each specific train traveling over the defined physical characteristics of the network.

Dispatching Logic and Conflict Resolution Algorithms

There are two principal types of logic used by dynamic simulation models to resolve conflicts between trains operating over a rail or rail transit network. These can be categorized generally as time based and event based.

Time-based models move trains through a network in real time, advancing all trains in the network in small increments, reacting to the physical characteristics of the track and train equipment, and the indications being given by the signal and train control system. The logic of the signal system is used to resolve conflicts between trains looking to occupy a section of track or a route through an interlocking at the same time. Time-based simulations are useful for modeling most railroad and transit mainline track configurations, as well as terminals where train routings and track assignments are well defined or customized to a particular pattern of operation.

Event-based models do not simply resolve conflicts between pairs of trains, but rather look globally at multi-train conflicts and resolve them as integral elements in the dynamics of the entire network. These models can be equipped with "meet–pass" dispatching logic, which is used to develop the most effective solutions to single-track operations requiring segments with a second main track, passing tracks, or passing sidings. The proven dispatching logic that is integrated with the train control system and TPC identifies conflicts and presents solutions that effectively contribute to improving the performance, reliability, and capacity of the entire rail network. A key aspect of the dispatching logic application is alternate node logic. Alternate node logic is extremely useful for yard and terminal analysis. It is capable of defining the best route and the most appropriate platform assignment for every train based on consist properties and priority, while looking holistically at the network performance.

Event-based models have been proven to be effective in analyzing large, complex networks with high train volumes. This capability is especially important in rail networks where the density and dynamics of passenger trains require a dispatching logic that effectively addresses close-headway operations and intensive interlocking routing issues.

Simulation Model Inputs

A variety of data and assumptions associated with the railroad's physical and operating conditions are necessary to construct a computer simulation model, including:

- Conceptual design drawings for the track alignment and station configurations;
- Specifications for the limits of the simulation study area;
- Assumptions for the fixed-block signal system design;
- Operating speeds including civil speed restrictions;
- Grade and curvature alignment characteristics;
- Characteristics for special trackwork geometry;
- Assumptions on operating rules, special instructions, and policies governing train movements;
- Assumptions on service specifications, timetables, schedules, headways, and station dwell times, including distinctions between peak and off-peak operations for systems heavily used by commuters;
- Trainset performance specifications for the assumed consist configuration, consist composition (number of cars), tractive effort curves, braking effort curves, and all dimension and weight characteristics;
- Assumptions on headways and number of trains per hour to be examined in the simulation;
- Definition of the time period to be analyzed, including warm-up and cool-down periods (e.g., simulating a 40-h weekday period to provide a realistic and valid sample of train movement activity over a continuous 24-h period with the network operating in an equilibrium condition; typically, the weekday 40-h sample will include a morning and an evening peak, each of which can be broken

out into separate reports and track occupancy charts for review and analysis); and

- Detailed train schedule for the time period to be analyzed.

Relevant data representing the dynamics of the proposed operation will need to be collected from key staff in the engineering, mechanical, stations, operations, and service planning departments of the transit operator or railroad. These interfaces may include line operations and control center dispatching staff.

Key characteristics of stations that are considered in simulation models include:

- Location of stations on the network;
- Station platform configuration (identification of tracks with platforms, and location and length of platforms);
- Dwell time for trains for each station; and
- Passenger processing (horizontal and vertical circulation).

Simulation Model Outputs

The modeling software provides numerous outputs that facilitate effective evaluation of performance of different train types, i.e., high speed rail, intercity passenger rail, commuter rail, and freight rail; development of optimal operating patterns and train routing; and assessment of a rail network with different levels of service. The software can assemble operating statistics at a specific "train-by-train" level, for groups of trains, or at a systemwide level. These outputs can be categorized into three major groups: statistical data, static visual representations, and dynamic visual representations.

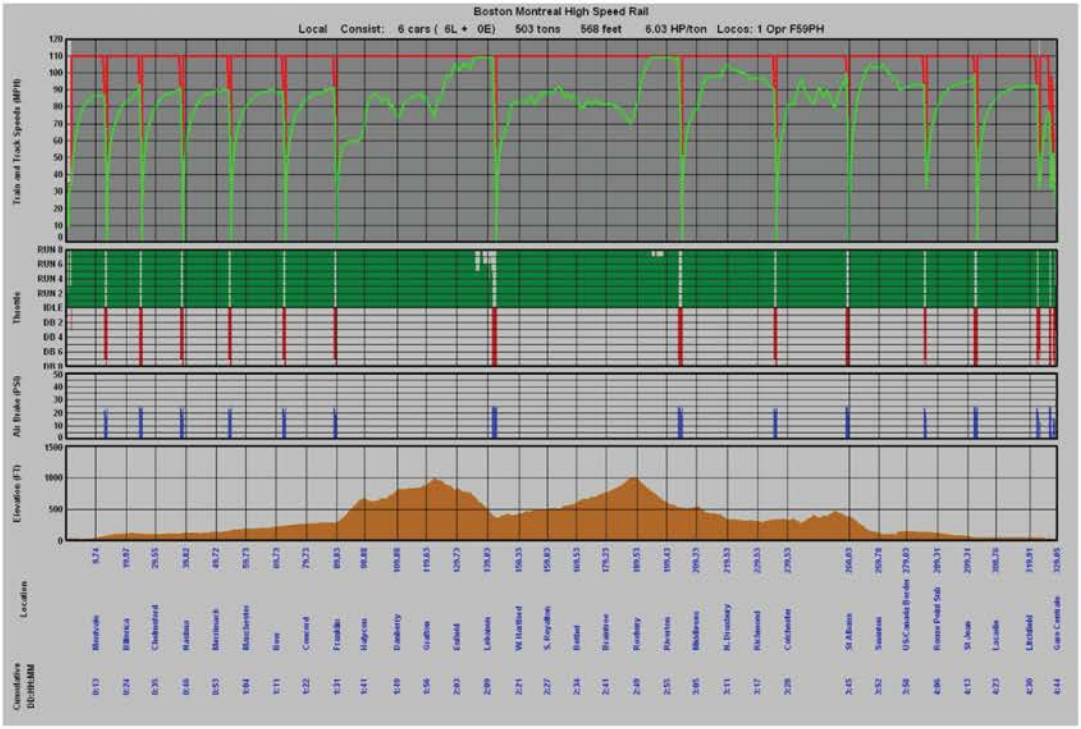
Statistical Outputs

The TPC is used to calculate minimum point-to-point travel times, including station-to-station and end-of-network to end-of-network travel times, based on the performance of a single train traveling along the route without interference from other trains. It also produces throttle and braking positions and the speed of the train at any point along the route. Analysis of the TPC speed profile(s) contributes to straightforward identification of the necessary infrastructure improvement locations when speed-increase opportunities are desired, for example, slow curves. Other types of statistical data include (but are not limited to): ideal and simulated travel times that are used to calculate delays at different levels, detailed train route descriptions, and train and car mileage data. These data typically are represented in data tables and spreadsheets.

Static Visual Representation Outputs

Speed profiles depict maximum speeds and optimal trip times from the train performance calculator (TPC). An example is shown in Exhibit 8-67. As with other screen captures in this section, the exhibit details are not legible as this scale but are not necessary for understanding the general appearance of the visual outputs.

Exhibit 8-67
Example Speed Profile



Time–distance or *string-line* diagrams depict the paths of individual trains over time and space. An example was previously given in Exhibit 8-65. The diagrams use specific color coding for each track to graphically present simulated results for operating speeds, running times, dwell times, practical minimum headways, and line capacity. The model displays the string-line chart(s) after all of the trains have been dispatched in the simulation and any operating conflicts have been identified and resolved by the model. This important analytical tool presents a static snapshot of all the trains and their interactions in the network model. A multitude of color modes makes it easy to observe trains which are stopped for delays and/or slowed due to speed reductions caused by crossing or merging conflicts. The string line graphs also provide the ability to analyze headways and identify "choke" points and capacity limitations.

Track occupancy charts graphically display the trains that occupy specific tracks in stations and yards at specific times throughout the simulation, which is very useful for identifying "slots" at station platforms, evaluating the level of utilization of platform and storage yard tracks over time, and developing equipment cycles by following the established train linkages. In addition to its more typical application for analyzing operations in yards and terminals, this chart can also be used to display the occupancy of any track segment where track utilization and train headway is the focal point of a study's analysis.

In the following track occupancy graphic (Exhibit 8-68), the times displayed for a train are from head-end arrival to rear-end departure. For example, on Track 6, eastbound Train 3516E arrives at 6:40 p.m. and departs as westbound train 3031W at 6:50 p.m. The next train on Track 6, 3520E, arrives eastbound at 7:02 p.m., retains its identity, and departs eastbound at 7:14 p.m. The trains are displayed in their proper time slots, thus providing the ability to observe train movements in either a "turn" (3516E to 3031W) or a "run-through" (3520E to 3520E) dynamic.

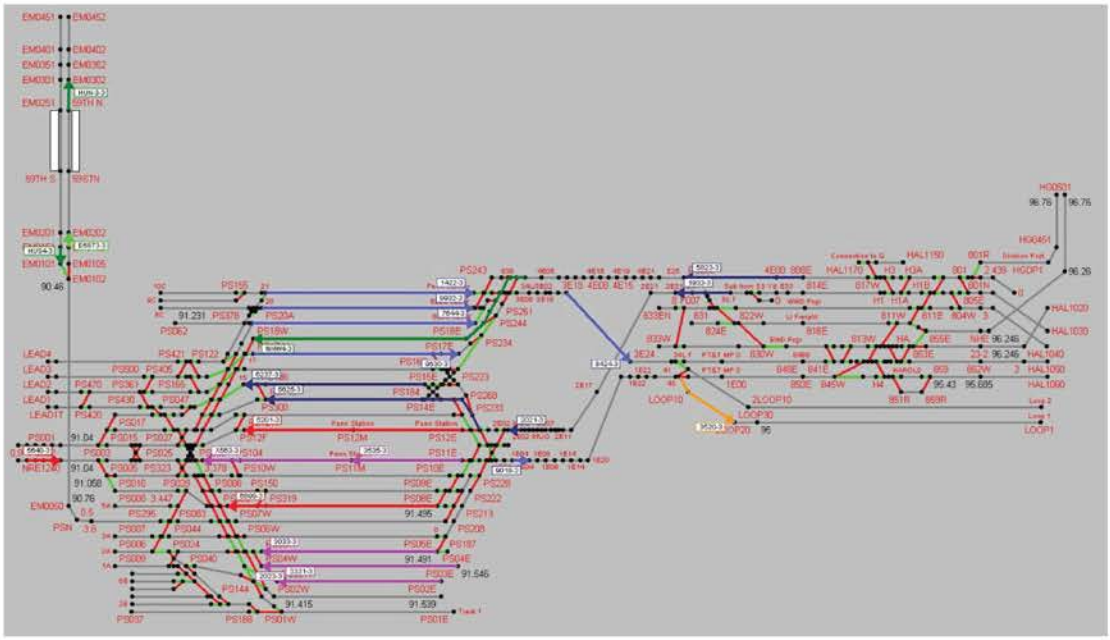


Exhibit 8-68
Example Track Occupancy Chart

Dynamic Visual Representation Outputs

Dynamic dispatch animation presents a "real time" dynamic visual representation of the railroad's operation of the railroad depicted in the simulation. It frequently is the ultimate tool for testing and validating operating plans, clearly showing the entire spectrum of train delays and meet-and-pass conflicts and how they were resolved in the network's train operations. The ability to apply the model's color mode feature provides the ability to observe the performance of an individual train or a group of trains, based on user-selected criteria. In addition, various animation display speeds can also be selected (by the user) and the simulation can be run in reverse or completely stopped at any time. The operational status of trains during animation can be displayed by the user as shown in Exhibit 8-69, where train locations and directions are shown as colored arrows. Output can be a "movie clip" file that can be reviewed by the operations analyst during the analysis process or embedded within and shown as part of a presentation to project sponsors and stakeholders.

Exhibit 8-69
Dynamic Dispatch Animation Example: Penn Station New York



APPLICATION OF SIMULATION

Base Case Model Calibration and Validation

The simulation model will first need to be calibrated and validated to reflect a realistic representation of the scheduled running times for the operations and services being analyzed. The first step in the process is to build a base case computer simulation model that includes all the parameters required by the model for the analysis, including the rail infrastructure characteristics, rolling stock characteristics, and operational service levels for the territory being analyzed. The infrastructure data will include vertical and horizontal attributes, grades and elevations, degree of curvature, speed restrictions, and maximum authorized speeds. The track layout will include all the turnouts and crossovers. Rolling stock parameters and train set performance characteristics will be defined with car dimensions and weights, locomotive tractive effort, and dynamic braking forces. A base case operating plan will be developed to reflect all the train movements to and from the station, including arrival and departure times and detailed equipment data.

The base case simulation model then will be calibrated and validated against existing conditions to verify the accuracy and realistic application of the dataset that will be used as the benchmark for further analyses. The validation phase is not considered complete until the operators of trains on the network being analyzed have reviewed and approved the base case model.

Investment-Grade Analysis

Simulation models are frequently used to support the business case for private investment in rail system infrastructure and are increasingly required to justify public investment in such systems. Simulation case studies are used to analyze the performance, operating reliability and capacity of alternative rail infrastructure

solutions to respond to the assumed or desired frequency or level of service. The model is used to:

- Establish operational feasibility,
- Prove the reliability of the operation, and
- Identify order of magnitude of capital costs for infrastructure and fleet.

Developing Realistic Operating Plans—Balancing Infrastructure Investment with Operational Capacity

The simulation modeling tool eliminates the traditional practice of developing schedules and train movement alternatives based on average run times, an oversimplification that can lead to unachievable operating plans.

Arrival and departure times (as well as other parameters) are modified using the model to improve schedules and craft the most fluid train dispatching scenarios. Furthermore, as traffic density increases, the potential for conflicting train movements increases as well, resulting in exposure to delays. This is precisely where this simulation tool offers unprecedented, effective functionality.

The model simulates train movements resulting in analytical data that identifies the most effective, overall system solution. When an "excessive" number of trains are specified to operate on the network, causing congestion, the model will slow and/or delay trains as needed (either at terminals or enroute) until clear routes become available. This characteristic provides the ability to vary departure times, dwell times, and influence the dynamics of train "turns" to test schedule robustness, effectiveness of train dispatching, and physical plant capacity.

In summary, the model replicates and predicts actual train movements, accurately identifying train dispatching and routing conflicts. Each simulation case analysis delivers precise comparisons of capacity and train delay at specific (and varied) levels of train service within a specified definition of infrastructure and physical characteristics.

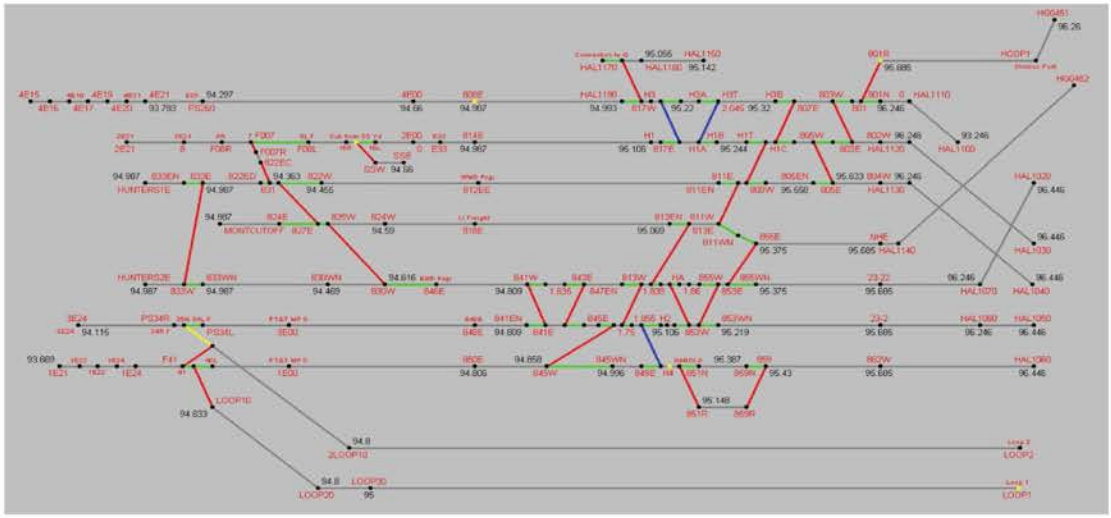
Adding Service

The effects of adding trains to a congested line or network are comprehensively evaluated using the model. The simulation tool measures the delay and performance resulting from service additions both by individual train as well as at the more aggregated levels of train type (i.e., peak vs. off-peak) and overall system network.

Interlockings and Junctions

The model is utilized to evaluate the benefits (and costs) of adding, modifying, or eliminating interlockings, either in mainline road territory or within a complicated terminal or station area, as in Exhibit 8-70. The model simulates the dynamic operating conditions and delays associated with separate or (route) segmented interlockings. The model also can be used to analyze the relative performance of at-grade versus grade-separated junctions and track connections.

Exhibit 8-70
Example Simulated Interlockings



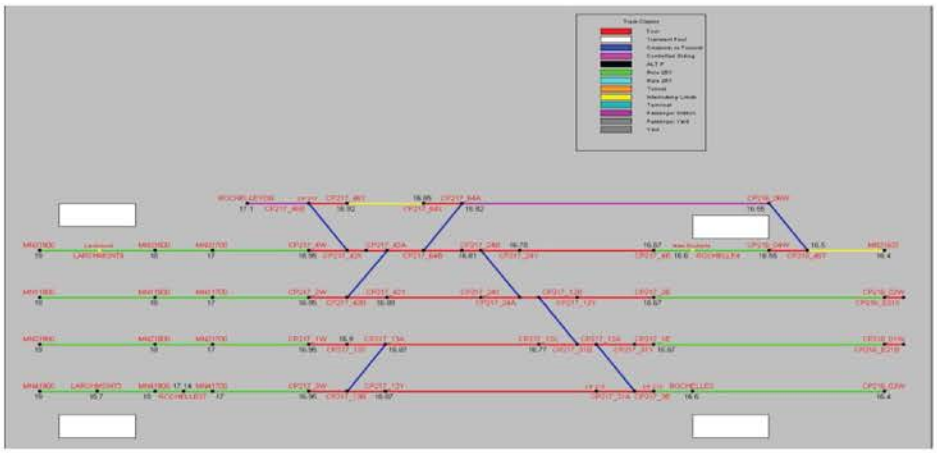
Construction Staging and Maintenance-Of-Way Windows

The model provides the ability to develop realistic construction staging plans and to schedule the most effective maintenance-of-way (MOW) time slots on busy main tracks and terminals. It graphically displays the effects of track impedances and speed restrictions on train movements. The dynamic simulation feature offers the capability to experiment with various staging scenarios and/or MOW windows to determine the best train schedules, physical plant configurations, and timeframes to construct capital improvements or perform maintenance activities.

Establishing or Moving Crossover Locations

The placement of crossovers can have dramatic effects on capacity utilization and train performance in multiple-track territories. The model provides the ability to move crossovers around the rail network and test different assumptions on speeds for diverging train movements, a significant advantage in identifying the locations that are best suited for a given set of train types and schedules. Modeling a variety of crossover configurations also contributes to developing the most effective solutions to congestion issues observed in the simulation. Exhibit 8-71 provides an example of a network graphic with crossovers.

Exhibit 8-71
Example Network Graphic with Crossovers



Single-Track Networks

Significant capital and maintenance cost savings sometimes can be realized in light density railroad and transit operations by operating service over a single main track on all or a portion of a line. These savings, however, come at the expense of capacity and operational flexibility. Simulation modeling can be used to determine the capacity of single-track segments of a railroad or transit line, identify the optimal level and type of service that can be operated over the single track segment, identify the location and length of required intermediate passing sidings, and analyze the benefits and costs of double tracking a single-track line. Examples of single-track systems where simulation modeling proved useful in defining the appropriate track configurations included the Charlotte North Corridor commuter rail line, which is envisioned as a single-track line with intermediate passing sidings, several branch lines of the Long Island Rail Road, which are double tracked over most of their length but have single-track segments near the ends of the lines, and the Baltimore Central Light Rail Line, which was converted from a single-track to double-track system.

Adding, Extending, or Removing Passing Sidings

The utility of passing sidings or long segments of main track in multiple track territory is determined by their size and location. The "ideal" location for a passing siding or additional main track segment for 30-mi/h track can be quite different than for 50-mi/h, 60-mi/h, or 80-mi/h track. The simulation model enables the user to determine whether siding or additional main track segments are of appropriate length and location for the size and speed of the trains being operated, or to identify the best train sizes and operating speeds to match a specific track configuration. Exhibit 8-72 provides an example of a network graphic for a line with passing sidings.

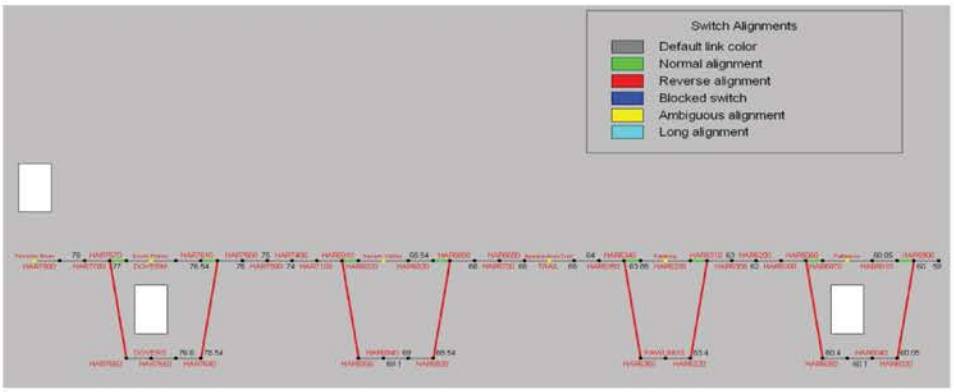


Exhibit 8-72
Example Network Graphic with Passing Sidings

SKETCH-PLANNING TOOLS

Definition and Applicability

Spreadsheet-based or manual methods can be used to generate work products similar to those produced by detailed simulation models. In place of detailed train performance data based on the tractive effort of locomotives or multiple-unit transit or rail cars, simplified train movement assumptions can be captured based on average operating speeds and average train acceleration and deceleration rates. Conflict resolution on mainline track segments and at terminals can be performed manually by

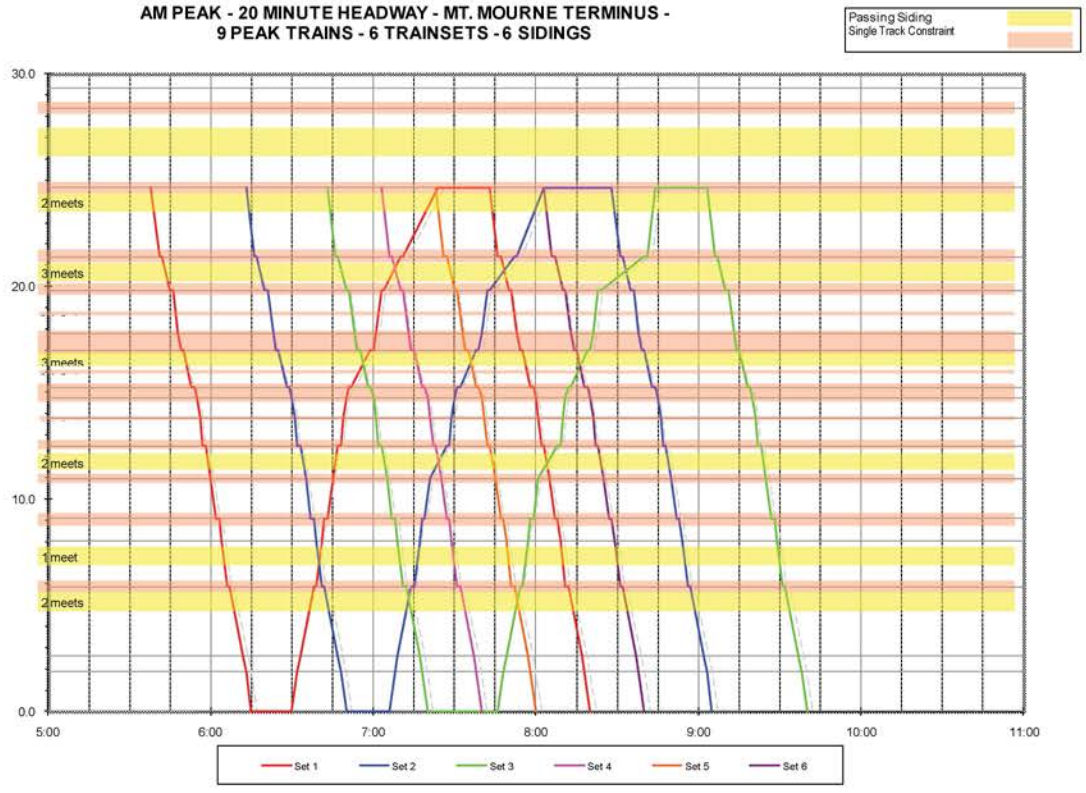
inspecting string-line diagrams and track-occupancy diagrams, and by adjusting train schedules, track assignments and train performance to resolve conflicts.

Sketch plan methods produce many of the same outputs as full simulations, including:

- Spreadsheet TPC,
- String-line diagrams,
- Train schedules,
- Equipment cycles,
- Track-occupancy diagrams, and
- Train loading diagrams.

Exhibit 8-73 through Exhibit 8-76 show examples of the types of outputs possible from sketch-planning tools. As before, the purpose of these exhibits is to illustrate ways that useful information for rail planning can be presented; the exhibit details (which are generally too small to be legible at this scale) are not needed for understanding the basic presentation concept.

Exhibit 8-73
Example Sketch-Plan String-Line Diagram (Charlotte North Corridor Commuter Rail)



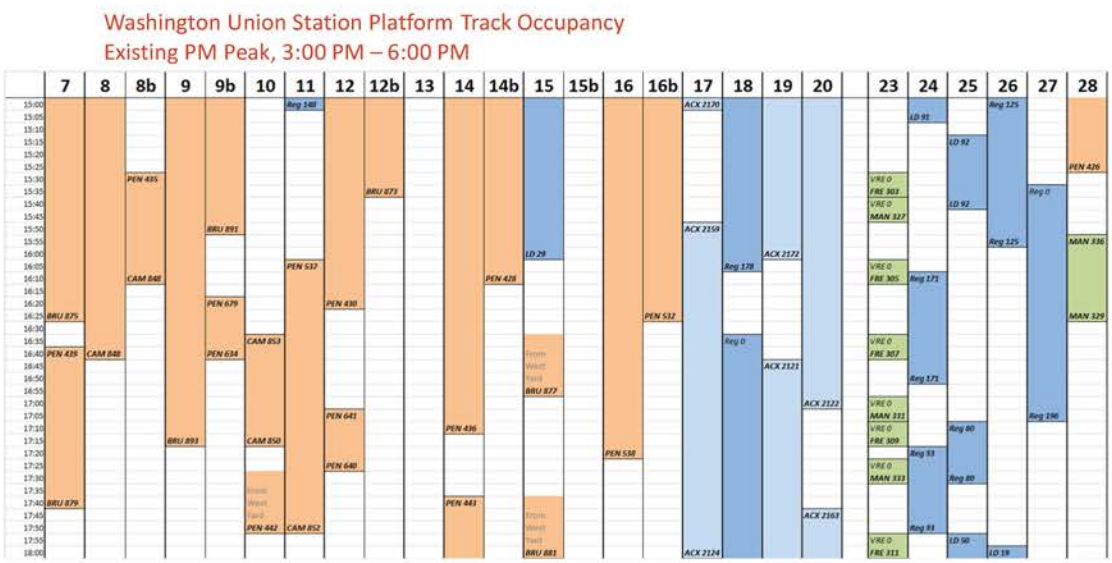


Exhibit 8-74
Example Sketch-Plan Track-Occupancy Diagram (Washington Union Station)

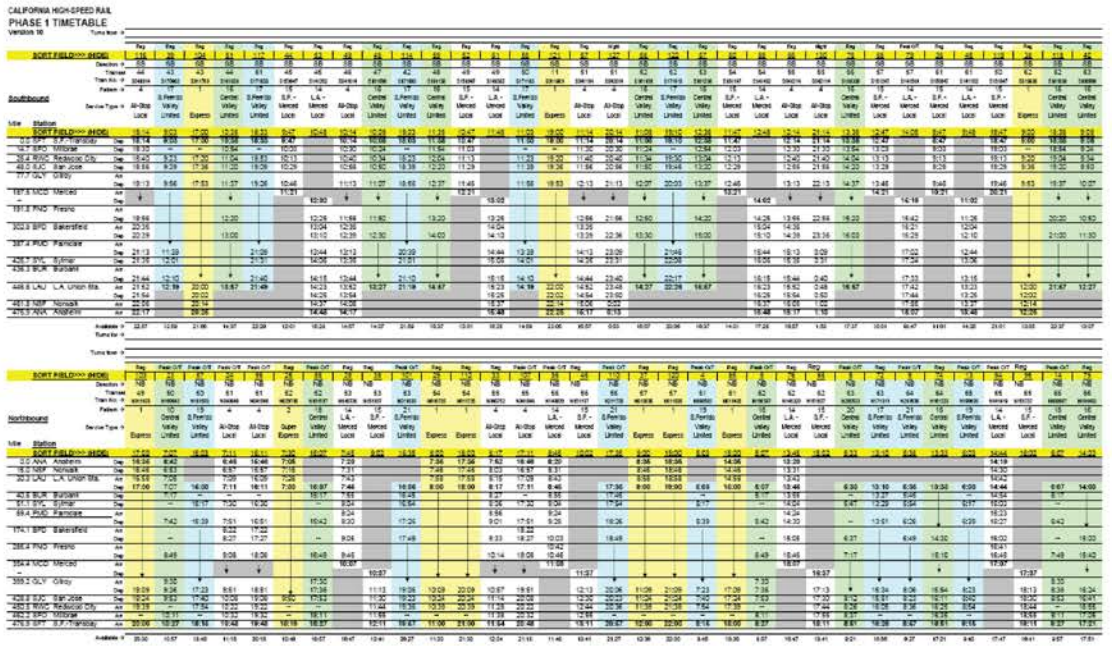
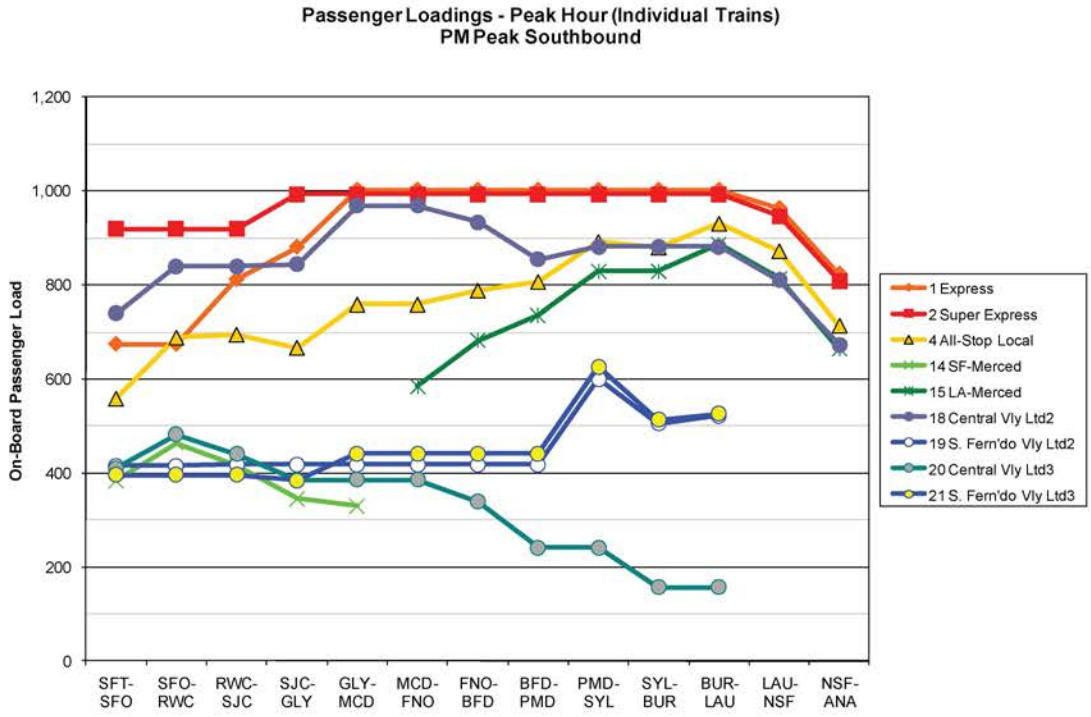


Exhibit 8-75
Example Sketch-Plan Timetable (California High Speed Rail)

Exhibit 8-76
Example Sketch-Plan Train Loading Chart (California High Speed Rail)



BEST PRACTICES FOR THE USE OF SIMULATION MODELS AND SKETCH-PLANNING TOOLS

Sketch-planning tools (including applications of TCQSM methods) are potentially sufficient for the following types of applications:

- Initial planning-level analysis of multiple modes (e.g., BRT vs. rail) or technologies within a corridor or region;
- Single networks or systems (e.g., no junctions); and
- Projects with limited resources and/or rapid turnaround times.

Dynamic-simulation models may be required for:

- Analysis of complex networks, with multiple branch lines and junctions;
- Analysis of major or complex terminals;
- Evaluation of rail or transit services that employ multiple types of stopping patterns (e.g., express, limited stop, and local service);
- Projects with schedule time and resources to support simulation model development; and
- Projects for which investment-grade analysis is required.

It also is possible to combine the use of detailed simulations and sketch-planning tools to productively analyze a wide array of alternative physical rail infrastructure configurations and/or alternative operating plans—without having to develop and run a full-scale simulation for each combination and permutation. The blended approach employs a combination of detailed simulation modeling and spreadsheet-based sketch planning to productively generate corridor and networkwide service plans and detailed

operating plans for a range of alternatives. In this approach, operations planning tools are developed at two levels of detail: system-level sketch planning and detailed simulations of actual infrastructure and operating conditions. These two sets of tools are able to communicate with each other and are deployed in parallel through the various phases of analysis and alternatives screening. This approach gives the analyst the ability to study a wide array of options relatively expeditiously using the sketch-plan tools while developing a high degree of confidence in the precision and accuracy with which selected representative operating plans can be defined using the simulation tools.

Detailed simulation modeling provides the best framework for performing train performance calculations, which are the basis for estimating run times over the rail network for alignment, station and stopping pattern alternatives. The detailed simulation environment also is the best way to understand the stochastic, dynamic effects of real-world operating conditions on system performance, reliability, and practical capacity. TPC data for each potential stopping pattern are then imported into the sketch-plan model and used to generate a hypothetical timetable. Overtaking conflicts are then resolved by reviewing and manipulating string-line diagrams. Once a conflict-free schedule has been developed, additional sketch-plan modules estimate equipment turns, fleet requirements, crew schedules, operational parameters such as train and car miles, and midday and overnight storage requirements.

Standard service plan outputs (for each discrete scenario and variation, generated primarily from the spreadsheet-based sketch-plan models) include:

- Train timetables (usually for a typical weekday);
- String-line diagrams (spreadsheet generated);
- Equipment cycles and revenue/protect equipment/spare fleet requirements;
- Crew schedules and train and engine crew requirements;
- Overnight and midday storage yard requirements;
- Fleet characteristics: type, consist length, top speed, passenger-carrying capacity; and
- Train performance calculations for each train type and stopping pattern.

"Protect equipment" refers to extra trains that are positioned at key locations to provide more rapid recovery from delays.

Once a deterministic service plan solution has been identified using the sketch-plan tools, the train schedule and rail infrastructure characteristics can be input into the simulation model, and the operating plan validated based on results of simulations that introduce stochastic variations into the analysis. This validation step will be undertaken for basic alternatives and at key intervals in the project. Network and service variations that pivot off of these basic alternatives can be analyzed with confidence using the sketch-plan tools with relatively short turnaround times. Standard operating plan outputs (for each discrete scenario, based primarily on detailed simulations), include:

- Operating timetable, including all revenue and non-revenue train movements, and indicating windows for maintenance-of-way and operation of freight traffic; for blended service scenarios, timetables and other simulation outputs will be generated for the transit or passenger line(s) and those elements of the conventional network feeding or otherwise interacting with those lines;
- String-line diagrams;
- Terminal track-occupancy diagrams;

- Operating performance characteristics, by train type and train, for the deterministic base case and any alternative delay or perturbation scenarios analyzed, including extent, location, and causes of delay;
- Equipment cycles and revenue/protect equipment/spare fleet requirements;
- Crew schedules and train and engine crew requirements;
- Overnight and midday storage yard utilization;
- Train performance calculations for each train type and stopping pattern; and
- Rolling stock consists, length, top speed, acceleration/deceleration profiles, and other relevant characteristics.

The output from the ridership forecasts, when these are available, will be used as feedback to the operations planning process to optimize the level of service for the forecast years for which projections are provided. The sketch-plan model contains a module that takes as input station-to-station projections of daily ridership, allocates ridership by time of day and among the rail services available at each time of day, and calculates average load factors for the various trains operating in the schedule. The model can be used to shift ridership among available trains to balance load factors (a coarse approximation of the effects of variable pricing techniques). The frequency and stopping patterns of train services then can be adjusted to match projected ridership and new service plan parameters furnished to the ridership estimation process. One additional service planning and ridership estimation iteration usually is required to provide a reasonably accurate balance between the level of rail service provided and the projected level of patronage. As the alternatives are narrowed through the study process, the number of iterations and the precision with which the ridership and service levels are "equilibrated" will be increased.

7. CALCULATION EXAMPLES

Example	Description
1	High-capacity heavy rail
2	Heavy rail line with junction
3	Heavy rail with long dwell
4	Light rail with single-track section
5	Commuter rail with limited train paths
6	AGT with short trains
7	AGT with off-line stations
8	Aerial ropeway

Exhibit 8-77
List of Calculation Examples

CALCULATION EXAMPLE 1: HIGH-CAPACITY HEAVY RAIL

The Situation

A transit agency is planning to build a heavy rail transit line and wants to determine the minimum train separation possible with a cab signaling system and with a variable safety distance moving-block signaling system.

The Questions

1. What is the minimum train separation (ignoring station dwell time and operating margin effects) with each type of signaling system?
2. What is the non-interference headway with typical dwells and operating margins?
3. What is the resultant line capacity for a new system with higher-quality loading standards?

The Facts

The transit agency is planning to use trains consisting of a maximum of eight 75-ft cars. Trains will operate at a maximum of 60 mi/h (88 ft/s) and will be traveling at 32 mi/h (47 ft/s) when entering stations if the cab signaling system is chosen, and at 34 mi/h (50 ft/s) if a moving-block system is selected. (Note that these station approach speeds are the optimal speeds to achieve minimum train separation. Solving for the optimal approach speed directly is not a simple task and is best done using a computer spreadsheet's solver or goal seek function to automate the iterative process that is required.) The distance from the front of a stopped train to the station exit block is 33 ft. Assume that there are no grades into or out of stations and that no civil speed restrictions limit approach speeds to sub-optimal levels.

Outline of Solution

To answer this question, two equations must be used, one for each signaling system type: Equation 8-1 for cab signaling and Equation 8-3 for moving block. Note that these equations provide allowances for grades and line voltage effects that have been removed as they are not required to answer this question. The values for all variables are summarized in Exhibit 8-78, with default values from Exhibit 8-28 used for input data not specified above.

Exhibit 8-78
Calculation Example 1: Input Data

Value	Term	Description
calculated	t_{cs}	train control separation
600 ft	L_t	length of the longest train
35 ft	d_{eb}	distance from front of stopped train to start of station exit block in meters
47 ft/s (cab) 50 ft/s (moving block)	v_a	station approach speed
88 ft/s	v_{max}	maximum line speed (88 ft/s = 60 mi/h)
75%	f_{br}	braking safety factor—worst-case service braking is f_{br}% of specified normal rate—typically 75%
1.2 (cab) 1 (moving block)	b	separation safety factor—equivalent to number of braking distances (surrogate for blocks) that separate trains
3.0 s	t_{os}	time for overspeed governor to operate on automatic systems—driver sighting and reaction times on manual systems
0.5 s	t_{jl}	time lost to braking jerk limitation
1.5 s	t_{br}	brake system reaction time
4.3 ft/s^2	a	initial service acceleration rate
4.3 ft/s^2	d	service deceleration rate
20.5 ft	P_e	positioning error—moving block only

Computational Steps

Step 1a: Determine the Maximum Load Point Station

Because this example addresses a rail line that does not yet exist, the dwell time selected in Step 1c should reflect conditions at a maximum load point station.

Step 1b: Determine the Control System's Minimum Train Separation

(1) *With Cab Signaling*

The relevant equation is Equation 8-1, modified to remove dwell, operating margin, voltage, and grade elements:

$$t_{cs} = \sqrt{\frac{2(L_t + d_{eb})}{a}} + \frac{L_t}{v_a} + \left(\frac{1}{f_{br}} + b\right)\left(\frac{v_a}{2d}\right) + \frac{at_{os}^2}{2v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$

$$t_{cs} = \sqrt{\frac{2(600 + 35)}{4.3}} + \frac{600}{47} + \left(\frac{1}{0.75} + 1.2\right)\left(\frac{47}{2 \times 4.3}\right) + \frac{(4.3)(3)^2}{2 \times 47}\left(1 - \frac{47}{88}\right) + 3 + 0.5 + 1.5$$

$$t_{cs} = 17.2 + 12.8 + (2.53)(5.47) + (0.412)(0.534) + 3 + 0.5 + 1.5$$

$$t_{cs} = 49.1\ s$$

Compare the approach speed producing the minimum train separation with any speed restrictions on the station approach.

(2) *With Moving-Block Signaling*

The relevant equation is Equation 8-3, modified to remove dwell, operating margin, voltage, and grade:

$$t_{cs} = \frac{L_t + P_e}{v_a} + \left(\frac{100}{f_{br}} + b\right)\left(\frac{v_a}{2d}\right) + \frac{at_{os}^2}{2v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$

$$t_{cs} = \frac{600 + 20.5}{50} + \left(\frac{100}{75} + 1\right)\left(\frac{50}{2 \times 4.3}\right) + \frac{(4.3)(3)^2}{2 \times 50}\left(1 - \frac{50}{88}\right) + 3 + 0.5 + 1.5$$

$$t_{cs} = 12.4 + 13.6 + (0.387)(0.432) + 3 + 0.5 + 1.5$$

$$t_{cs} = 31.2\ s$$

The net result is that the minimum train separation at stations (ignoring the effects of station dwells and an operating margin at this point) would be 49.1 s with a cab signaling system or 31.2 s with a variable safety distance moving-block system and automatic train operation.

Step 1c: Determine the Average Dwell Time at the Critical Station

Step 1c in Section 5 presented four possible methods for determining the controlling dwells. Method 2, *Using Existing Dwell Time Data*, is not applicable to a new system. The simplest option is to use Method 1, which recommends a range of dwell values from 35 to 45 s. If there are no indications of any single, very high-volume stations (where the more complicated dwell calculations should be used) then a median value of 40 s can be selected.

Step 1d: Select an Operating Margin

Section 5 suggests that the more operating margin that can be incorporated in the headway the better, with 20 to 25 s as the best guide. Here, 25 s is selected to provide better reliability.

Step 2: Determine the Minimum Headway Associated with the Right-of-Way Type

Step 2 primarily applies to light rail lines and therefore can be skipped for this heavy analysis.

Step 3: Determine the Limiting Junction Headway

As this will be a new line, it is assumed that it will be designed so that any junctions will not constrain capacity.

Step 4: Check Power Supply Constraints

As this will be a new line, it is assumed that the power system will be designed to accommodate the desired headway.

Step 5: Determine the Controlling Headway

In the absence of other constraints, the controlling headway is the sum of the minimum train separation time (Step 1b), average dwell time at the critical station (Step 1c), and the operating margin (Step 1d). For cab signaling, this headway is 49.1 + 40 + 25 = 114.1 s. For moving-block signaling, this headway is 31.2 + 40 + 25 = 96.2 s.

Step 6: Determine Terminal Layover Time

As this will be a new line, it is assumed that the terminals will be designed so as not to constrain capacity.

Step 7: Determine Train Throughput

Train throughput is 3,600 seconds per hour divided by the controlling headway. For cab signaling, this results in 31 trains per hour (rounded down). For moving-block signaling, this results in 37 trains per hour (rounded down).

Step 8: Determine Person Capacity

In the absence of a specific vehicle, the text accompanying Step 8 in Section 5 indicates that a recommended comfortable heavy rail car loading for a new system is 1.8 passengers per linear foot of train length, inclusive of diversity allowances. At this loading level, each specified train of eight 75-ft-long cars can carry 8 × 1.8 × 75 = 1,080 passengers.

The Results

Multiplying the number of passengers per train by the number of trains per hour provides passengers per peak hour direction per track of 33,480 p/h/dir and 39,960 p/h/dir, respectively. Reflecting the approximations used in this determination, the results should be rounded down to the nearest 1,000—33,000 and 39,000.

CALCULATION EXAMPLE 2: HEAVY RAIL LINE WITH JUNCTION

The Situation

The transit agency from Example 1 has decided to use a variable safety distance moving-block signaling system. The agency would now like to know if it can economize on construction by building a flat junction at a point where two of its lines will diverge. The agency's long-term plan is to run a 2-min headway through the junction, with service split equally between the two branches.

The Question

Can a flat junction on this proposed system support a 2-min headway or must a flying junction be constructed?

The Facts

Many of the variables are the same as those used in the previous example. In addition, the agency plans to build its tracks 16 ft (5 m) apart and use #10 turnouts (switches) with a throw-and-lock time of 6 s at mainline junctions. To make operations through a flat junction reliable, the agency plans to increase the operating margin to 45 s, hence the headway increases from 100 s (36 trains per hour) to 120 s (30 trains per hour).

Computational Steps

Equation 8-10 is used to estimate the capacity of a flat junction. The variables used in the equation are summarized in Exhibit 8-79, with default values from Exhibit 8-28 used for values not specified above.

Exhibit 8-79
Calculation Example 2: Input Data

Value	Term	Description
Calculated	h_j	limiting headway at junction
31.2 s	t_{cs}	line headway, from Calculation Example 1, Step 1b(2)
600 ft	L_t	train length
9.62	f_{sa}	switch angle factor (9.62 for a #10 switch, from Equation 8-10)
16 ft	d_{ts}	track separation
4.3 ft/s^2	a	initial service acceleration rate
4.3 ft/s^2	d	service deceleration rate
88 ft/s	v_{max}	maximum line speed (88 ft/s = 60 mi/h)
6 s	t_{sw}	switch throw and lock time
45 s	t_{om}	operating margin

Substituting the known variables into the equation produces:

$$h_j = t_{cs} + \sqrt{\frac{2(L_t + 2f_{sa}d)}{a}} + \frac{v_{max}}{a+d} + t_{sw} + t_{om}$$

$$h_j = 31.2 + \sqrt{\frac{2(600 + [2 \times 9.62 \times 4.3])}{4.3}} + \frac{88}{4.3 + 4.3} + 6 + 45$$

$$h_j = 31.2 + 17.8 + 10.2 + 6 + 45$$

$$h_j = 110.2 \text{ s}$$

The Results

While the resulting value of h_j would appear to support 2-min headways, it is about 10 s less than the planned headway. Based on this narrow margin, it would be prudent to opt for a flying junction rather than risk service disruptions with a flat junction—even with the operating margin increased to 45 s. This is consistent with the recommendation in Section 5 that junctions should be grade separated at headways below 3 min.

CALCULATION EXAMPLE 3: HEAVY RAIL WITH LONG DWELL

The Situation

A busy heavy rail line operates through a major transfer station with long station dwell times.

The Question

What is the maximum person capacity through this station?

The Facts

- A generous loading standard means more passengers seated.
- The transit agency's loading standard is 1.8 passengers per linear foot of train length during the peak 15 min.
- Service is provided by ten-car trains with each car being 75 ft long.
- The dwell time at this station averages 30 s with a standard deviation of 21 s.

- There is a 1.5% downgrade into the station and a 1.5% upgrade out of the station.
- The line is automated and uses moving-block signaling.
- Train operators are responsible for closing the doors and initiating acceleration; this delay is incorporated into the dwell time.
- Trains are evenly loaded over their length.

Outline of Solution

The solution consists of three key steps: (*a*) determining each train's passenger capacity, (*b*) determining the minimum train separation based on the signaling system and train length, and (*c*) incorporating the station dwell time and an operating margin. To determine the non-interference headway, allowances for dwell time and an operating margin must be added to the minimum train separation time. The results of these steps can then be combined to produce the line capacity based on the parameters given.

Computational Steps

Step 1a: Determine the Maximum Load Point Station

The selected station is the maximum load point station.

Step 1b: Determine the Control System's Minimum Train Separation

This step requires the use of Equation 8-3. The values for all variables are summarized in Exhibit 8-80, with default values from Exhibit 8-28 used for values not specified above.

Exhibit 8-80
Calculation Example 3: Input Data

Value	Term	Description
calculated	t_{cs}	train control separation
750 ft	L_t	length of the longest train
35 ft	d_{eb}	distance from front of stopped train to start of station exit block in meters
50 ft/s	v_a	station approach speed (50 ft/s = 34 mi/h)
88 ft/s	v_{max}	maximum line speed (88 ft/s = 60 mi/h)
75%	f_{br}	braking safety factor—worst-case service braking is f_{br}% of specified normal rate—typically 75%
1	b	separation safety factor—equivalent to number of braking distances (surrogate for blocks) that separate trains
3.0 s	t_{os}	time for overspeed governor to operate on automatic systems—driver sighting and reaction times on manual systems
0.5 s	t_{jl}	time lost to braking jerk limitation
1.5 s	t_{br}	brake system reaction time
4.3 ft/s^2	a	initial service acceleration rate
4.3 ft/s^2	d	service deceleration rate
32 ft/s^2	a_g	acceleration due to gravity
-1.5%	G_i	grade into the station
+1.5%	G_o	grade out of the station
90%	l_v	line voltage as percentage of specification
20.5 ft	P_e	positioning error

Substituting the variables into Equation 8-3 produces:

$$t_{cs} = \frac{L_t + P_e}{v_a} + \left(\frac{1}{f_{br}} + b\right)\left(\frac{v_a}{2(d + a_g G_i)}\right) + \frac{(a + a_g G_o) l_v^2 t_{os}^2}{2 v_a}\left(1 - \frac{v_a}{v_{max}}\right) + t_{os} + t_{jl} + t_{br}$$

$$t_{cs} = \frac{750 + 20.5}{50} + \left(\frac{1}{0.75} + 1\right)\left(\frac{50}{2(4.3 + [32 \times -0.015])}\right)$$
$$+ \frac{(4.3 + [32 \times -0.015])(0.9)^2 (3.0)^2}{2 \times 50}\left(1 - \frac{50}{88}\right) + 3.0 + 0.5 + 1.5$$

$$t_{cs} = 15.4 + (2.33)(6.54) + (0.278)(0.432) + 3.0 + 0.5 + 1.5$$

$$t_{cs} = 35.6 \text{ s}$$

Step 1c: Determine the Average Dwell Time at the Critical Station

From the facts provided, based on field measurements, the average dwell time at this station is 30 s.

Step 1d: Select an Operating Margin

As this is an existing line, the operating margin can be estimated as two times the standard deviation of dwell times—in this case 42 s, based on the facts provided.

Steps 2, 3, 4, and 6

In the absence of other information, it is assumed that junctions, turnbacks, power system, etc. do not constrain line capacity.

Step 5: Determine the Controlling Headway

The controlling headway is the sum of the minimum train separation time (36 s), average dwell time at the critical station (30 s), and the operating margin (42 s), or 108 s.

Step 7: Determine Train Throughput

Train throughput is 3,600 seconds per hour divided by the controlling headway (108 s), resulting in 33 trains per hour (rounded down).

Step 8: Determine Person Capacity

This step is straightforward and is based on the number of cars in each train, the length of each car, and the number of passenger spaces per unit of car length. Because the agency's loading standard is based on peak 15-min conditions, a peak-hour factor must be used. In the absence of other information, a PHF of 0.80 is suggested in Section 5 for heavy rail. The PHF accounts for lower passenger demand during the other 45 min of the peak hour, which results in unused capacity. If the agency policy had been to maintain an average loading of 1.8 p/ft length throughout the peak hour, resulting in more crowded peak 15-min conditions, no PHF would have been needed, as the 1.8 p/ft length value already incorporates peak-hour loading diversity.

When a PHF is and is not needed.

(10 cars/train)(75 ft/car)(1.8 p/ft)(0.80) = 1,080 p/train

Multiplying 1,080 p/train by 33 train/h gives a person capacity of approximately 35,000 passengers during the peak hour in the peak direction through this station (rounded down to the nearest 1,000 to reflect the approximations used).

CALCULATION EXAMPLE 4: LIGHT RAIL WITH SINGLE-TRACK SECTION

The Situation

A light rail line operates with a single-track section.

The Question

What is the maximum possible service frequency?

The Facts

- Service is provided by three-car trains, with each car 85 ft long.
- The single track section is 4,000 ft long with one intermediate station, with an average dwell time of 20 s.
- The section is on a road with a speed limit of 30 mi/h.

Assumptions

- It is assumed that there are no other longer single-track sections on the line, nor any more restrictive limitations imposed elsewhere along the line.

Outline of Solution

The maximum possible service frequency is twice the travel time through the single-track section, plus an allowance for operational irregularities.

Computational Steps

The travel time over the single-track section can be calculated using Equation 8-5. The values for all variables are summarized in Exhibit 8-81, with default values from Exhibit 8-38 used for values not specified above:

Exhibit 8-81
Calculation Example 4: Input Data

Value	Term	Description
calculated	t_{st}	time to cover single-track section
1.1	S_m	speed margin
1	N_{st}	number of stations on the single-track section
44.0 ft/s	$v_{max,st}$	maximum speed in single-track section (44.0 ft/s = 30 mi/h)
0.5 s	t_{jl}	time lost to braking jerk limitation
4.3 ft/s^2	d	deceleration rate
1.5 s	t_{br}	brake system reaction time
4,000 ft	L_{st}	length of single-track section
255 ft	L_t	train length
20 s	t_d	dwell time
6.0 s	t_{sw}	switch throw-and-lock time
20 s	t_{om}	operating margin (middle of range from Exhibit 8-38)

Substituting these results into Equation 8-5 produces:

$$t_{st} = S_m\left[\left(\frac{N_{st}+1}{2}\right)\left(\frac{3v_{max}}{d}+t_{jl}+t_{br}\right)+\frac{L_{st}+L_t}{v_{max,st}}\right]+N_{st}t_d+t_{sw}+t_{om}$$

$$t_{st} = 1.1\left[\left(\frac{1+1}{2}\right)\left(\frac{3\times 44}{4.3}+0.5+1.5\right)+\frac{4{,}000+255}{44}\right]+(1\times 20)+6+20$$

$$t_{st} = 1.1[(1)(30.7+0.5+1.5)+96.7]+20+6+20$$

$$t_{st} = 188\ s$$

The minimum headway that can be operated over the single-track section is twice this time, or 376 s. Normally, this headway would be rounded up to the nearest even hourly headway of 480 s (7½ min), resulting in 8 trains per hour per direction.

A 7½-min headway is often expressed in transit timetables as service every 7 to 8 min.

The Results

The single-track section can support up to 8 trains per hour per direction. However, if there is significant on-street running elsewhere on the line, it is unlikely that service can be maintained with sufficient regularity that trains will not be held up at the entrance to the single-track section, waiting for the opposing train to clear. In this case, it would be prudent to increase the minimum headway to the next even interval, or trains every 10 min.

Comments

Single-track working in emergencies.

In the event of track maintenance or an emergency such as a traffic accident, failed train, or derailment, crossovers are usually provided to permit single-track working around the obstruction. For long-term obstructions—such as a track renewal program—temporary crossovers, called *shoo flys*, can be used. Where a signaling system is used, this operation is only possible if either (*a*) the signaling system is equipped for two-way operation on either track, or (*b*) operations are reverted to a slower manual, line-of-sight operation. Such emergency operation is then limited to a frequency as calculated by Equation 8-5 and line capacity is reduced.

As an example, if normal service on a double-track line is a train every 5 min, but 4,000 ft of single-track operation is needed to pass an obstruction, service will be limited to 7½ minutes. Nominal capacity will be reduced from 12 to 8 trains per hour (i.e., by one-third). This reduction is sufficiently small that it may be accommodated temporarily by accepting higher levels of crowding. Passengers are generally willing to accept this in emergency conditions.

Capacity reduction with single track working.

Longer single-track sections will reduce capacity further. This loss may be made up where operational policies and signaling systems permit platooning trains over the single-track section. Two or three trains can follow each other closely under line-of-sight operating practice at lower speeds. Full capacity may be restored, but additional trains and drivers will be required to compensate for the slower speeds and waiting time while trains accumulate to form a platoon. In addition, passengers will experience long waits between train platoons relative to the normal headway, which will result in more crowded station platforms.

Wrong-side or wrong-way working over line sections with grade crossings on on-street track can be confusing to motorists and pedestrians and can be hazardous. As a result, many light rail operators prohibit such operations except where there are no alternatives, such as in tunnels or subways. Instead, their emergency planning calls for a

bus bridge around any blockage that is expected to take a significant time to clear. All North America light rail operators also have or are affiliated with major bus operations and can expect to obtain buses and drivers for such emergency use on short notice—usually by scavenging buses from nearby high-frequency routes.

CALCULATION EXAMPLE 5: COMMUTER RAIL WITH LIMITED TRAIN PATHS

The Situation

An existing commuter rail agency would like to expand its operations to a new route that is owned by a freight railroad.

The Question

Based on the constraints given below, can the commuter rail agency provide service on the new line with its current single-level car fleet, or must it order new double-level cars for the line?

The Facts

- The freight railroad will only allow six commuter rail trains per hour to use its line.
- Physical constraints mean that station platforms on the new line can be no more than eight cars in length.
- The commuter rail agency currently uses single-level cars that have 120 seats but is considering the purchase of two-level cars with 180 seats, although it would prefer to purchase more single-level cars to maintain a standard fleet.
- The agency has a policy of planning service based on cars being at 90% of seated capacity.
- The agency would like to be able to accommodate a flow of 6,000 passengers per hour in the peak hour.
- Train scheduling can be adjusted to meet the peak 15-min demand, provided no more than six trains are operated per hour.
- Trains are limited by railroad contract, but they can be spaced through the peak hour to best match demand.

Outline of Solution

To determine which car type, if either, can satisfy the agency's capacity needs, the hourly capacity of the line using each car type must be determined. In this example, this procedure is simplified by the agency's ability to schedule trains to meet the peak 15-min demand, avoiding the need to consider the temporal distribution of travel. The capacity that can be provided with each car type should be considered independently.

Computational Steps

The hourly capacity P is determined as follows:

$$P = (\text{passengers per car}) \times (\text{cars per train}) \times (\text{trains per hour}) \times (\text{PHF})$$

Single-level cars

The effective capacity per car is 90% of 120, or 108 passengers. An eight-car train of single-level cars could thus carry 864 passengers. With six trains per hour, the capacity is 5,184 passengers per hour, rounded down to 5,100 to reflect the approximations used.

Two-level cars

The effective capacity per car is 90% of 180, or 162 passengers. An eight-car train of two-level cars could thus carry 1,296 passengers. With six trains per hour, the capacity is 7,776 passengers per hour, rounded down to 7,700 to reflect the approximations used.

The Results

Since eight-car trains of single-level cars are unable to handle the predicted demand of 6,000 passengers per hour, it appears that the agency should plan on ordering two-level cars for use on this route. The calculation above shows that the two-level cars can accommodate the projected demand with some room for ridership growth.

Longer trains that overhang platforms are a poor compromise.

The only alternative to purchasing the two-level cars would be to operate longer trains and assign passengers to cars according to their destination station, since not all cars would be adjacent to a platform at all stations. This would only work if the platforms at major terminal stations could accommodate all the cars of each train. As it complicates train operations and would likely create passenger confusion, the option of purchasing two-level cars is preferable.

CALCULATION EXAMPLE 6: AGT WITH SHORT TRAINS

The Situation

An automated feeder line is planned from a new suburban office development to an existing heavy rail station.

The Question

Based on the use of advanced train control systems, what is the design capacity of this line?

The Facts

The developer wants to incorporate the AGT stations in an elevator lobby on the second floor of each building, which limits station length to 85 ft. AGT trains used in institutional settings normally require most users to stand; the developer would like to provide a comfortable standing environment for the short trip. Most AGT systems are proprietary and the manufacturer would provide capacity capabilities. In this case, the developer does not wish to approach a manufacturer at this stage. However, a review of similar AGT systems suggests that the vehicle would be at least 8 ft wide.

Computational Steps

Exhibit 8-50 shows that an AGT moving-block train control system can provide a minimum train separation of 13.4 s with 80-ft trains. Adding relatively high dwell time

and operating margin values of 40 and 25 s respectively would result in a minimum headway of 78.4 s, which would normally be rounded up to 80 s to provide an integer number of trains per hour. Section 5 states that headways shorter than 90 s are possible but may limit dwell times and constrain the operating margin. They should be considered with caution unless off-line stations are adopted. As the developer has indicated a relatively relaxed loading level, it is realistic to expect dwells to be lower than normal and hence the 80-s headway can be accepted as practical. This equates to 3,600/80 or 45 trains per hour.

The 85-ft platform can hold two 40-ft cars, a common AGT size and comparable to a transit bus. As no specific car design is available at this point, it is reasonable to assume that each car will have a total interior area of at least 288 ft^2 (40-ft length by at least 8-ft width, with each dimension reduced by 8 in. to account for wall thickness). Using a comfortable loading standard of 5.4 ft^2 per passenger gives a total car design passenger capacity of at least 53. Note that an AGT car of this size, on a short-distance line, would normally be rated for 100 passengers, packed closer together.

The resultant design capacity at the preferred loading level is the number of trains per hour, 45, multiplied by the number of passengers per car, 53, and the number of cars per train, 2, or 4,770 passengers per peak-hour direction. As always with such calculations where there are approximations, the number should be rounded down, in this case to 4,700 p/h/dir. Note that this result would need to be multiplied by a peak-hour factor to determine the number of people that could be accommodated without exceeding the preferred loading level at any point during the hour.

Comments

Because the proposed AGT line would connect to a heavy rail station, an 80-s headway might be unnecessary. In operation, a headway corresponding to either the heavy rail headway or half the heavy rail headway (depending on the proportion of AGT ridership expected to come from each direction) might be used, with the goal to serve all passengers on an arriving heavy rail train on the next departing AGT train.

CALCULATION EXAMPLE 7: AGT WITH OFF-LINE STATIONS

The Situation

The developer from Example 6 is expanding the suburban office development to include a major shopping complex and recreation facility with an ice hockey arena.

The Question

How can the AGT line be expanded to handle this load?

The Facts

- Ridership estimates are that the system will handle one-third of the arena's maximum capacity of 24,000 people, plus an estimated demand of 1,200 passengers per hour from the shopping complex.
- Two adjacent stations serve the sports arena, while the shopping center has three stations.

- The developer has contracted with the office building tenants to run trains at least every 6 min until midnight each day, including weekends and holidays.

Computational Steps

To handle 24,000/3 + 1,200 = 9,200 passengers per hour, one solution would be to operate longer trains with higher occupancy and to omit stops in the office buildings with their short stations. The 45-train-per-hour capacity is no longer practical as heavy loads at the two sports arena stations will extend dwells and longer trains will increase the minimum train separation. The capacity is decreased to 40 trains per hour, or 90-s headways. Ten of these trains, one every 6 min, will remain short to serve the office complex. However, during events at the arena, passengers will tolerate a higher loading level. At a maximum schedule load of 3.2 ft^2 per passenger, each car can accommodate at least 90 passengers, or 180 per short train of two cars.

A peak-hour factor is not applied to special event person capacity calculations, as the offered capacity is generally fully utilized and passengers do not expect to be able to board the first train that arrives.

The ten short trains can serve 1,800 passengers. The remaining 30 trains must carry 7,400 passengers per hour. This results in 7,400/30 or 247 passengers per train. Three-car trains holding 90 p/car would be required to meet the demand.

Section 5 stated that off-line stations permit headways that are partly independent of station dwell time with throughput that of the control system minimum train separation, plus an allowance for switch operation, lock and clearance, and a reduced operating margin. Exhibit 8-50 shows that a moving-block signaling system with 80-ft trains has a minimum train separation of 13.4 s. Allowing an operating allowance for merging trains of 45 s and rounding up results in permitted headways as low as 60 s, or 60 trains per hour. In this case, the demand of 9,200 passengers per hour with 180 passengers per train can be met by 52 trains, within the 60-train maximum.

It is not always economical to meet occasional peak demands with rail transit.

Off-line stations would permit trains to operate directly from each arena station to the heavy rail station. However, economics enter the picture. It is unlikely that the developer would be willing to build more expensive off-line stations and purchase addition rolling stock for a sports arena demand that only occurs a few days a year. It is more likely that the system would be designed for maximum office and shopping complex demands. When a sports event takes place, the AGT line would be filled to capacity and the overload would be handled by transit authority buses—of which there is a surplus at the off-peak hours typical of sport event starts and finishes.

CALCULATION EXAMPLE 8: AERIAL ROPEWAY

The Situation

A university hospital is located on a bluff above a river. The university has run out of room to expand on the bluff and is seeking to move some of its operations to a new campus along the riverfront. For the two campuses to function efficiently as a single entity, good transportation links will need to be provided between them. The university is exploring various means to provide these links, including shuttle buses and roadway and parking improvements. Another option under consideration is a direct link between the two campuses using an aerial ropeway, either an aerial tramway or a detachable-grip aerial lift (gondola) system.

The Questions

1. For the aerial tramway, how large will the carriers need to be to handle the projected passenger demand?
2. For the gondola, how many carriers will be needed?

The Facts

Based on the university functions to be located on the riverfront and an estimate of total faculty, staff, and student sizes at build-out, the university estimates that a total of 750 persons will need to be carried in the peak direction during the peak hour. The line would be approximately 2,600 ft long, with no intermediate stations. A decision on a specific manufacturer has not been made; however, as a starting point, assume that the aerial tramway cabin door would be wide enough that three people can walk through at a time and that the gondola carriers would seat eight people each.

Aerial tramway dwell time includes the time to unload and load passengers from the cabin, plus an assumed allowance of 60 s to (*a*) clear exiting passengers from the platform and (*b*) perform safety and communications checks prior to the carrier departing. Maximum acceleration and deceleration is 0.65 ft/s^2.

Gondola carriers take 60 s to traverse each station after detaching from the line. The carriers move at creep speed (0.8 ft/s) through the station to allow passenger loading and unloading.

Outline of Solution

Aerial Tramway

Aerial tramway capacity is based on the number of carriers used (one or two, two is typical), the number of stops per direction (one, in this case), station dwell time (not yet known), line length (given), line speed (a user decision), and the size of the carriers (a user decision). Passenger service time will be based on the time to clear a full cabin, and then load a full cabin. Several combinations of line speeds and cabin sizes may need to be tried in developing a solution.

Gondola

Gondola capacity is based on the spacing between carriers (not yet known) and the average line speed (a user decision). To solve this problem, the minimum number of carriers needed to serve the demand will be calculated by working backward from the required capacity.

Computational Steps

Aerial Tramway

As a starting point, a 60-passenger cabin and the fastest possible line speed (39 ft/s) will be selected. At a maximum acceleration rate of 0.65 ft/s^2, it takes 60 s (39 divided by 0.65) to reach line speed. The average speed during acceleration is half the line speed, or 19.5 ft/s. As a result, the carrier would travel 1,170 ft (60 s multiplied by 19.5 ft/s) during acceleration. The carrier would travel another 1,170 ft during deceleration,

meaning that it would only travel 260 ft at line speed (2,600-ft line length, minus two times 1,170 ft). The total trip time would be about 127 s.

Spending only 10% of the trip length at line speed would be inefficient, so a lower line speed should be tried. At a line speed of 30 ft/s, acceleration and deceleration would take 46 s each and would cover a total distance of 1,380 ft. As a result, the carrier could travel at line speed for 1,220 ft (nearly half the distance) and could cover that distance in 41 s. The total trip time would be about 133 s. The corresponding average line speed would be 2,600 ft divided by 133 s, or 19.5 ft/s.

In the absence of other data, Exhibit 8-13 can be consulted to determine average passenger boarding and alighting times for a high-volume level doorway. From a review of the data provided in the exhibit, 1.8 s per alighting passenger per door channel and 1.9 seconds per boarding passenger per door channel can be chosen as median values. With three door channels, it takes 36 s on average for passengers to exit a full 60-passenger cabin (60 p times 1.8 s/p, divided by 3 door channels), and 38 s to board. The total dwell time, including the 60-s allowance for various checks discussed in the facts of the problem, is 134 s.

All the information needed to calculate line capacity is now known. Entering this information into Equation 8-16 gives:

$$T = \frac{1{,}800 N_v}{(N_s t_d) + \frac{L_l}{v_l}} = \frac{(1{,}800 \text{ s/h})(2 \text{ veh})}{(1)(134 \text{ s}) + \frac{(2{,}600 \text{ ft})}{(19.5 \text{ ft/s})}} = \frac{3{,}600 \text{ veh-s/h}}{267 \text{ s}} = 13 \text{ veh/h}$$

Multiplying 13 carriers per hour by 60 passengers per carrier gives a theoretical directional capacity of 780 passengers per hour, which is more than the required 750 passengers per hour. However, because passengers are not likely to arrive evenly throughout the hour, a peak-hour factor should be applied. Using a PHF of 0.90, the directional design person capacity of the system is about 700 passengers per hour, which is insufficient to avoid pass-ups.

Repeating the above process with an 80-passenger cabin results in a 159-s dwell time, with all other input values remaining the same. The resulting line capacity is 12 carriers per hour, which provides a directional design person capacity of about 865 passengers per hour when a peak-hour factor of 0.90 is applied.

Gondola

Since the only thing known about the gondola system is an assumed carrier size (eight passengers), the number of carriers required will be determined by working backward from the required capacity. Using a PHF of 0.90, a maximum directional capacity of 833 passengers per hour is needed (demand of 750 passengers per hour, divided by 0.90). Dividing this capacity by eight passengers per carrier results in 105 eight-passenger carrier arrivals per hour required at a station. However, because each carrier will make more than one trip each hour, the number of actual carriers required will be smaller.

A carrier traveling at a line speed of 20 ft/s (the maximum for a detachable-grip lift) requires 130 s to travel the length of the line. Therefore, a round trip on the line takes 260 s. In addition, the carriers take 1 min to travel through each station at creep speed, adding another 120 s to the round-trip journey. Consequently, a carrier makes one round trip every 380 s, or 9.47 round trips per hour. The number of carriers that will

provide the required number of hourly station arrivals is 105 arrivals per hour divided by 9.47 arrivals per carrier per hour, or 12 carriers (rounded up).

The Results

Although the aerial tramway carrier travels twice as fast as a gondola at their respective maximum line speeds, it takes much longer to accelerate and decelerate the aerial tramway carrier. As it turned out, the travel times of the two modes were nearly the same over the length of the relatively short route. The headway between aerial tramway carriers is approximately 5 min, while the headway between gondolas is about 32 s.

8. REFERENCES

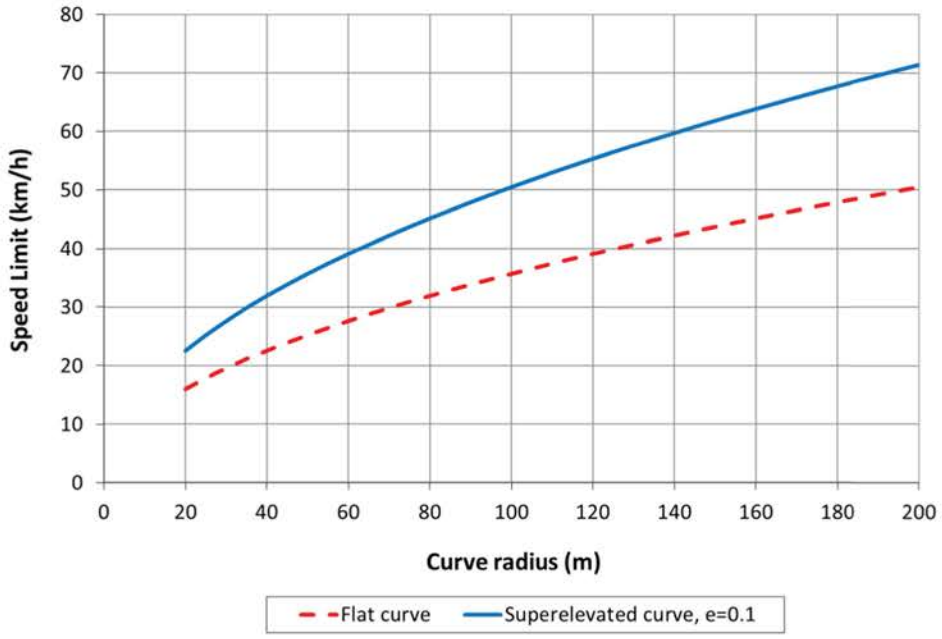
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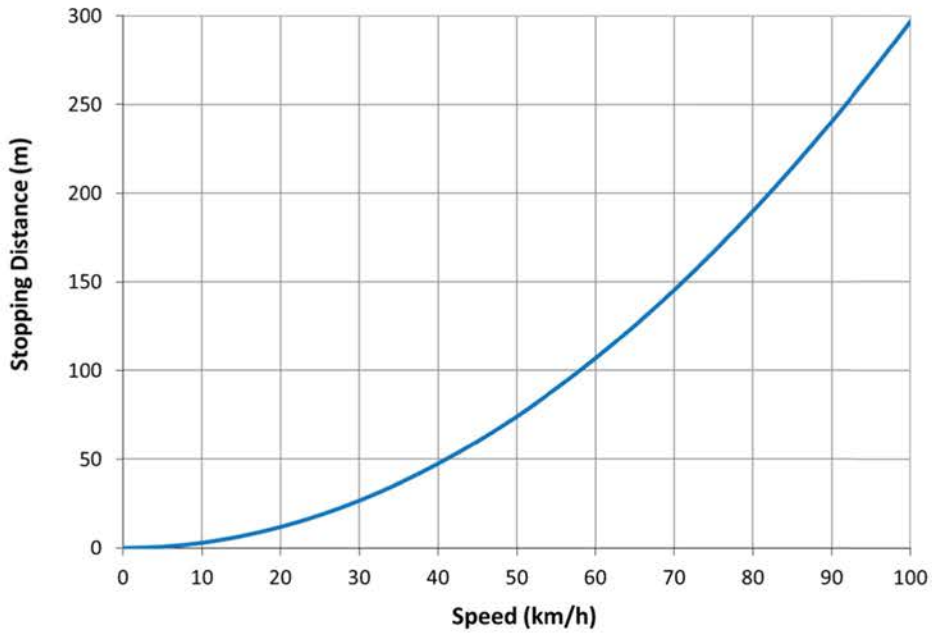
APPENDIX A: EXHIBITS IN METRIC UNITS

Exhibit 8-31m
Maximum Speed Limits on Curves



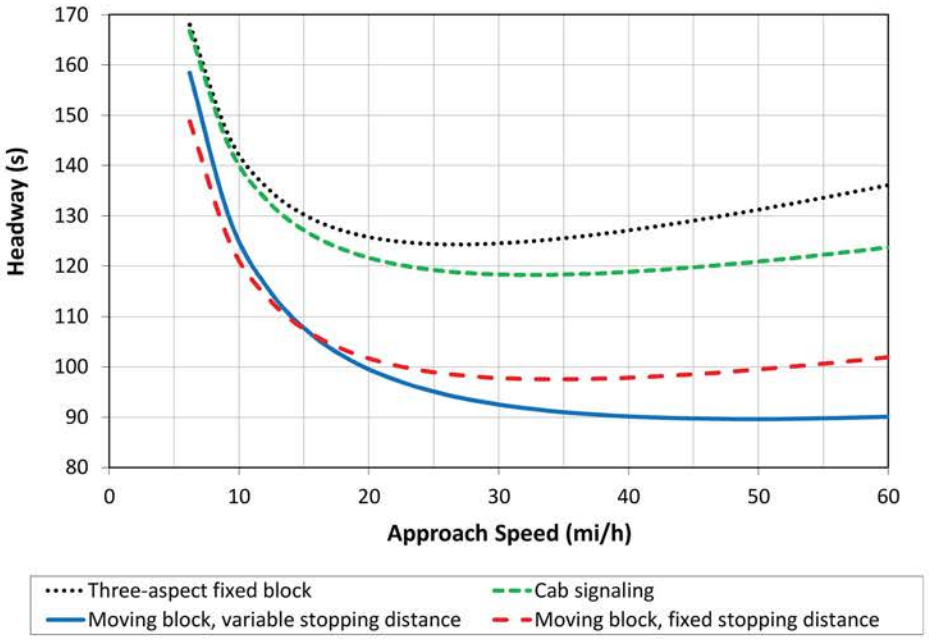
Source: *TCRP Report 13* (*1*).
Note: Transition spirals are not taken into account.

Exhibit 8-33m
Typical Stopping Distance as a Function of Speed



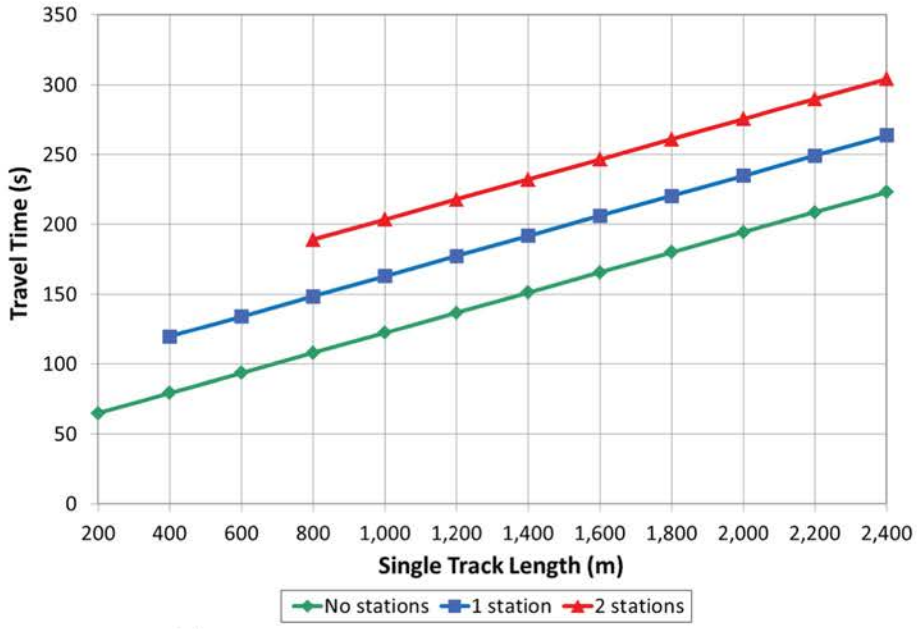
Source: *TCRP Report 13* (*1*).

Exhibit 8-36m
Typical Moving-Block Station Headways Compared with Conventional Fixed-Block Systems



Source: *TCRP Report 13* (*1*).

Exhibit 8-39m
Light Rail Travel Time Over Single-Track Section



Source: *TCRP Report 13* (*1*).
Note: Assumes speed limit of 55 km/h, train length of 55 m, 20-s dwell time, 20-s operating margin, and other data as per Exhibit 8-38. *The recommended closest headway is twice this time.*

Exhibit 8-49m
Average Commuter Rail Operating Speeds

Station Spacing (km)	Average Operating Speed (km/h) P/W = 3.0	P/W = 5.8	P/W = 9.1
Average Dwell Time = 30 s			
1.6	27.0	32.7	35.9
3.2	41.5	49.7	56.4
6.4	58.6	71.0	78.2
8.0	64.9	78.4	84.8
Average Dwell Time = 60 s			
1.6	23.8	28.0	30.3
3.2	37.5	44.1	49.3
6.4	54.4	65.0	71.0
8.0	60.9	72.5	78.1

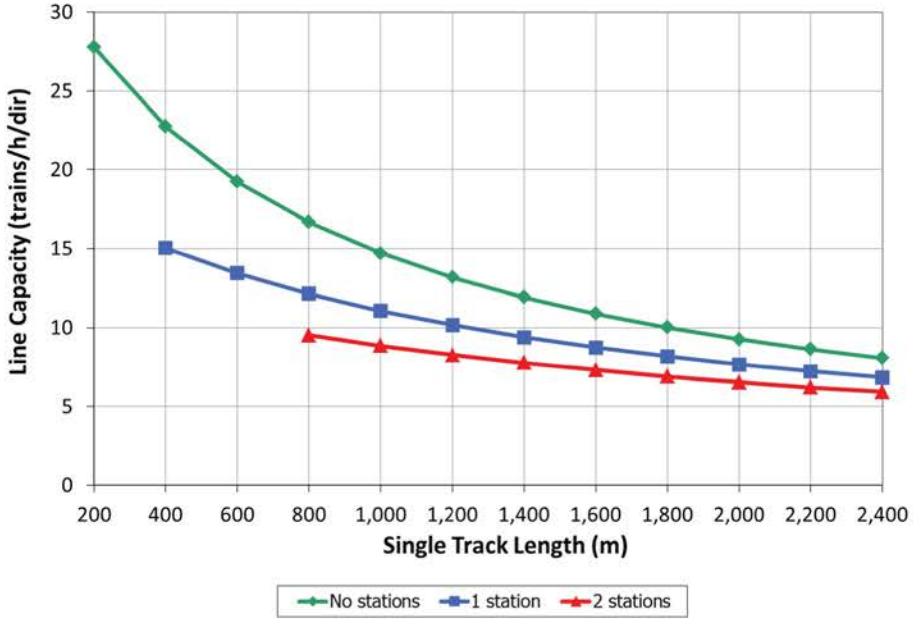
Source: Galloway (*12*).
Note: P/W = power-to-weight ratio. Assumes 127-km/h speed limit, no grades, and no delays due to other trains.

Exhibit 8-51m
Suggested AGT Separation Calculation Default Values

Default Value General Method	Default Value AGT	Term	Description
6.25 m	6.25 m	P_e	positioning error
200 m	**50 m**	L	**length of the longest train**
10 m	**0 m**	d_{eb}	**distance from front of train to exit block**
75%	75%	f_{br}	% service braking rate
2.4	**4**	b	**train detection uncertainty constant — fixed block**
1	1	b	train detection uncertainty constant — moving block
3 s	**1 s**	t_{os}	**time for overspeed governor to operate**
0.5 s	0.5 s	t_{jl}	time lost to braking jerk limitation
1.3 m/s²	**0.6 m/s²**	a	**service acceleration rate**
1.3 m/s²	**1.0 m/s²**	d	**service deceleration rate**
1.5 s	**0.5 s**	t_{br}	**brake system reaction time**
100 km/h	**80 km/h**	v_{max}	**maximum line velocity**
50 m	**25 m**	S_{mb}	**moving-block safety distance**

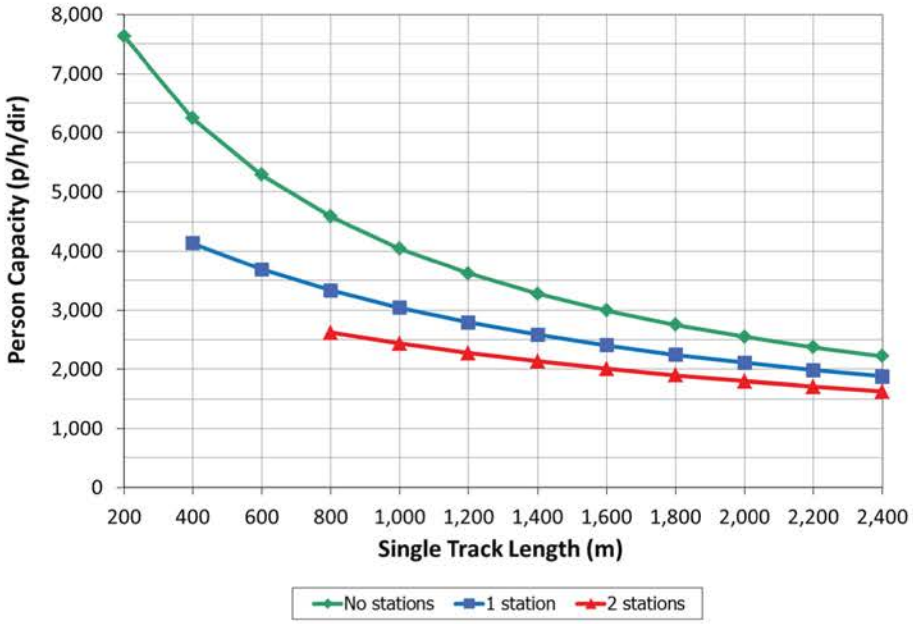
Source: *TCRP Report 13* (*1*).
Note: Bold type indicates AGT default values that differ from other rail transit values.

Exhibit 8-59m
Single-Track Line Capacity—Two-Car Light Rail Trains



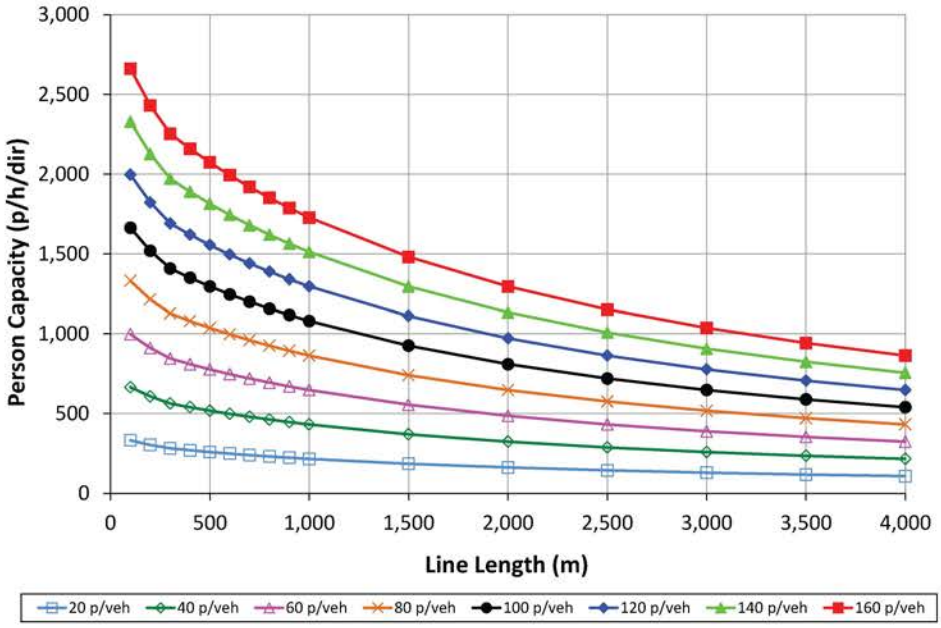
Source: *TCRP Report 13* (*1*).
Note: Assumes 55-km/h speed limit, 55-m train length, 20-s dwell time, and 20-s operating margin.

Exhibit 8-60m
Single-Track Person Capacity—Two-Car Light Rail Trains



Source: *TCRP Report 13* (*1*).
Note: Assumes 55-km/h speed limit, 55-m train length, 20-s dwell time, and 20-s operating margin.

Exhibit 8-63m
Reversible Ropeway
Person Capacity



Note: Assumes 10-m/s line speed, 0.2-m/s^2 acceleration, two-vehicle operation, no intermediate stations, 150-s dwell time, and 0.90 PHF.

CHAPTER 9
FERRY TRANSIT CAPACITY

1. User's Guide
2. Mode and Service Concepts
3. Operations Concepts
4. Quality of Service Concepts
5. Quality of Service Methods
6. Bus Transit Capacity
7. Demand-Responsive Transit
8. Rail Transit Capacity
9. **Ferry Transit Capacity**
10. Station Capacity
11. Glossary and Symbols
12. Index

CONTENTS

1. INTRODUCTION 9-1
How to Use This Chapter 9-1
Other Resources 9-2

2. FERRY SERVICE AND FACILITIES 9-3
Ferry Service 9-3
Ferry Terminals 9-5

3. FERRY SCHEDULING AND SERVICE PLANNING 9-14
Port Dwell Time 9-14
Departure Clearance Time 9-16
Transit Time 9-16
Arrival Time 9-17
Operating Margin 9-17
Pedestrian Movements 9-18
Service Planning 9-18

4. VESSEL CAPACITY 9-21
Berth Capacity 9-22
Dock Capacity 9-27

5. PASSENGER AND AUTO CAPACITY 9-28

6. CALCULATION EXAMPLES 9-30
Calculation Example 1: Vessel Service Time (Passengers) 9-30
Calculation Example 2: Vessel Service Time (Automobiles) 9-32
Calculation Example 3: Berth Capacity 9-33

7. REFERENCES 9-35

LIST OF EXHIBITS

Exhibit 9-1 Examples of Vessels Used for Ferry Transit (2010) 9-3
Exhibit 9-2 Examples of Auto and Passenger Ferry Dock Configurations 9-5
Exhibit 9-3 Illustrative Vehicle Staging Area Diagram 9-7
Exhibit 9-4 Vehicle Staging Area Examples 9-7
Exhibit 9-5 Typical Elements of Passenger Ferry Loading 9-9
Exhibit 9-6 Examples of Ferry Passenger Loading and Unloading 9-12
Exhibit 9-7 Pedestrian Flow Cross-References 9-18
Exhibit 9-8 Example of Multiple-Destination Service 9-19
Exhibit 9-9 Vessel Capacity Measurement Locations 9-21
Exhibit 9-10 Berth Vessel Capacity 9-22
Exhibit 9-11 Embarking and Disembarking Parameters 9-25
Exhibit 9-12 Passenger or Auto Flow through the Ferry Transit System 9-28
Exhibit 9-13 List of Calculation Examples 9-30

1. INTRODUCTION

Ferry service plays a major role in urban transportation systems in many North American cities, such as New York, San Francisco, Seattle, and Vancouver. Ferry transit provides an alternative to cross water bodies that would otherwise necessitate expensive infrastructure that may not be feasible to construct. Ferry transit corridors can also offer direct access to residential and business areas and can potentially reduce the transit travel time that would otherwise be experienced in mixed traffic.

Ferry system capacity is a relatively undeveloped topic.

There is currently little information regarding waterway system- or vessel-related capacity. Ferry operators are stimulating discussion in this area, but it remains a facet of waterway capacity that is relatively undeveloped (*1*). The objective of Chapter 9 is to build a framework for determining the capacity of ferry transit services in North America and provide some essential planning and design tools for the development of new facilities and services.

Due to the high value of waterfront areas in urban areas, project permitting, space constraints, access restrictions, and a host of other considerations make planning and designing ferry service a challenging activity. Further complicating this challenge is the wide variation in environmental conditions, such as tides and currents, that may be encountered. For example, the extremes of tidal fluctuations that must be accommodated in Seattle are 17 ft, while in San Francisco they are about 9 ft, and in New York they are 6 ft. The control of wake wash on shorelines along ferry routes has to be considered and thoroughly studied prior to adopting a route or acquiring vessels. The size and energy in a vessel wake, shoreline geology, location of vulnerable structures, and other marine operations are the main factors that have to be considered.

Organization of Chapter 9.

Chapter 9 of the *Transit Capacity and Quality of Service Manual* addresses the following topics:

- Section 2 addresses ferry service and facilities.
- Section 3 overviews ferry scheduling and service planning.
- Section 4 provides methods for estimating the vessel capacity of ferry berths and docks.
- Section 5 provides a method for estimating the passenger and auto capacity of ferry routes.
- Section 6 shows examples of the calculations involved in applying this chapter's capacity methods.
- Section 7 is a list of references used to develop the material in this chapter.

HOW TO USE THIS CHAPTER

Sections 2 and 3 provide ferry-specific capacity, speed, and service concepts that supplement the more general material found in Chapter 2, Mode and Service Concepts, and Chapter 3, Operations Concepts. This material provides an introduction to ferry operations for those new to the area and complements the broader material on planning ferry service found in *TCRP Report 152: Guidelines for Ferry Transportation Services* (*2*).

Sections 4–6 are focused toward readers who wish to estimate the capacity of ferry service and are more computation-oriented.

OTHER RESOURCES

Other TCQSM material related to ferry transit includes:

- The "What's New" section of Chapter 1, User's Guide, which describes the changes made in this chapter from the 2nd Edition;
- Chapter 2, Mode and Service Concepts, which introduces the ferry mode and the types of vessels used to provide urban ferry transit service in North America;
- Chapter 3, Operations Concepts, which provides a general introduction to transit capacity and speed concepts;
- Chapter 10, Station Capacity, which provides methods that are applicable to sizing passenger circulation elements of ferry terminals, docks, and berths; and
- The manual's CD-ROM, which provides a spreadsheet that implements this chapter's capacity methods, along with a link to an electronic version of *TCRP Report 152*.

2. FERRY SERVICE AND FACILITIES

FERRY SERVICE

Chapter 2, Mode and Service Concepts, introduced the types of ferry services (i.e., urban, rural, and coastal) and vessels used in North America. This chapter focuses on ferry services and vessels that are part of urban transit systems, although many of the chapter's concepts also apply to other types of ferry services.

Ferry Capacity Concepts

Exhibit 9-1 provides examples of some of the types of vessels used in ferry transit service in the U.S. The National Census of Ferry Operators (*3*) provides a comprehensive list of U.S. ferry service providers and vessels.

Exhibit 9-1
Examples of Vessels Used for Ferry Transit (2010)

Operator	Service Type	Number of Vessels	Passenger Capacity	Speed (knots)
New York City DOT	Passenger	8	1,200–6,000	16
New York Waterway	Passenger	10	399	12
		13	149	24
		6	97	24
		2	370	28
Seastreak	Passenger	4	396	36
Golden Gate Transit	Passenger	3	715	21
		3	390–450	34
Vallejo Baylink	Passenger	4	32	300
Oakland–Alameda Ferry	Passenger	2	331–388	26
		2	149–200	NA
Blue & Gold Fleet	Passenger	7	392–787	10–24
Pierce County	Passenger	2	250	11
Washington State Ferries	Auto	27	250–2,500	9–30

Source: National Census of Ferry Operators (*3*).

Unlike other transit modes, where maximum vehicle passenger capacity is ultimately determined by passengers' willingness to crowd aboard transit vehicles, ferry vessels operate under United States Coast Guard (USCG) regulations that limit the number of passengers that can be on board at any one time. This limitation makes it necessary in many instances to have a prepaid holding area where entrance is blocked when the number of passengers in the holding area has reached the vessel's capacity. This restriction can also be accommodated with a first-in first-out (FIFO) queuing corridor.

Multi-destination routes introduce a number of difficult operational problems that may affect capacity.

Multiple-destination routes present an even more complex set of requirements. Consider a route that services three ports, A, B, and C. When a vessel departs Port A, the number of passengers on board must be at or below the vessel's USCG capacity. When passengers are discharged at Port B and new passengers embark, the total passengers on board must still be below the USCG limitation. This condition may require the use of pre-ticketing, counting passengers discharged and loaded at each port, or the use of other methods designed to ensure that the vessel's regulatory capacity is not exceeded.

Ferry Speed Concepts

A vessel's mechanical properties, such as propulsion, will affect the vessel's speed and the resulting travel time over a route. Types of propulsion include fixed pitch propeller or controllable pitch propeller, which are common to monohull vessels; water jet, which is common to catamarans; and cable. Some smaller vessels may also be propelled by outboard motors. Some ferries employ a cycloidal propulsion system. Instead of conventional propellers and rudders, power is obtained from two vertical cycloidal propulsors, one at each end of the boat. This technology allows the ferry to make 360-degree turns or to move sideways with no forward or backward movement.

A vessel's capital and operating costs will ultimately affect the fare and, hence, the passenger demand. Generally, the power required to propel a vessel increases dramatically as its speed increases. It is common for fuel consumption to double as speeds increase from 25 knots (30 mi/h or 50 km/h) to 30 knots. This fuel consumption impacts operating costs—requiring fare revenues from additional passengers or a higher fare, which may also influence demand. The paradox of this fuel consumption curve is that higher speeds make little difference in overall travel time even on routes exceeding 10 mi (16 km). For example, the difference between a 25-knot vessel and a 30-knot vessel on a 7-mi (12-km) route would be about 3 min in travel time (*4*).

A fast ferry is not necessarily essential for a successful ferry transit service; however, a competitive travel time compared to other travel alternatives is essential. Ferry vessels can have slower maximum speeds than alternative modes, but still have faster travel times due to the ferry service having a shorter route or an alternative facility (e.g., a bridge) experiencing congestion that prevents the vehicles using them from achieving their maximum speed (*2*).

The ability for a ferry vessel to travel at its maximum speed may also be constrained by external factors that lead to a speed limit being imposed on marine traffic. These factors include concerns about shore erosion, wave effects on marinas, and possible collisions with endangered species.

Integration with Other Transit Services

Intermodal transfers are usually required at one or both ends of ferry trips.

Because ferries can only take passengers to the water's edge, intermodal transfers are usually required at one and often both ends of the ferry trip. However, when destinations are located close to the ferry terminal, passengers are able to walk to their destinations without having to transfer to another transit mode. Ferries are also capable of transporting bicycles, allowing passengers to bike to their destination.

Options for providing intermodal transfers include park-and-ride lots, feeder bus service, roll-on, roll-off bus service (for auto ferries), and terminals located close to rail service (as in New York and San Francisco). The general design considerations for the landside elements of ferry terminals are similar to those for making transfers between other types of transit service and are covered in Chapter 10, Station Capacity.

Purpose-built ferry terminals, such as those used for Vancouver's SeaBus, can provide quick and convenient connections to other transit modes, as well as facilitate the rapid movement of a large number of passengers on and off vessels. In other cases, ferry systems—for reasons of cost, environment, or desire to quickly implement service—may use existing dock facilities, which may not be located in optimal locations

for making intermodal transfers. Therefore, the tradeoffs involved with siting ferry terminals need to be carefully considered when planning potential ferry service.

FERRY TERMINALS

Overview

Docks and loading facilities form a system that processes vehicle and passenger movement between shore and ferry. The following sections describe the various elements of this system and considerations that influence passenger flow and the vessel turnaround time, which, in turn, influences a particular dock's or berth's vessel capacity.

Ferry Terminal Elements

Docks

Docking configurations depend upon the vessel; offshore water depths; tidal variations; shoreline development restrictions or desires; and required interfaces to other transit systems, roadways, and pedestrian routes.

Freeboard is the vertical distance between the waterline and the vessel deck or the top of a dock.

Auto ferries are typically bow-loaded and hence have dock facilities that accommodate this process, as illustrated in Exhibit 9-2(a). Departing vehicles are stored at landside or overwater vehicle staging areas. Due to tidal variations and differences in vessel freeboard, it is generally necessary to have a transfer span that connects from the fixed pier to the vessel auto deck. Depending on local conditions, these spans may vary in length from a few feet to well over 100 ft (30 m) and, owing to dead and live loads, require a robust mechanism for adjusting the transfer span's end elevation and slope.

Exhibit 9-2
Examples of Auto and Passenger Ferry Dock Configurations



(a) Bow loading (Seattle)



(b) Bow loading (Copenhagen)



(c) Side loading (San Francisco)



(d) Side loading (Sydney, Australia)

Passenger loading for auto ferries can occur via the vehicle transfer span (typically on smaller ferries) or by means of a separate walkway directly to the passenger deck, which is generally about 18 ft (5.5 m) above the vehicle deck. Where a separate facility is provided, passenger loading can occur at the same time as vehicle loading, decreasing the overall time required to exchange passengers and vehicles.

Passenger ferries are often side-loaded, which can be accommodated by parallel or linear berthing facilities. The most typical dock design has parallel berths, such as those found at Sydney's Circular Quay (Exhibit 9-2[d]). Some dock facilities may have a variety of berthing arrangements to facilitate a range of vessel types. Another option is bow-loading, which is the most common arrangement for ferries operating in New York Harbor. Bow-loading (Exhibit 9-2[b])offers significant time benefits, as the vessel does not need to be tied up to the dock and several passenger streams can board simultaneously, but requires that the vessel and dock have the same freeboard as well as special engineering of the docks (*2*).

Again, because of tidal variations, docks are often floating facilities. Floating facilities have the advantage of keeping the relative elevation between the boat and the dock constant in all tidal conditions. However, providing a float large enough to accommodate a passenger holding area may not be feasible, and the inherent dangers of having passengers on a floating structure during vessel docking has resulted in passenger holding areas often being located on fixed piers or on shore. A transfer span is normally still required somewhere between the vessel and the fixed portion of the facility, and a movable gangway is required between the vessel and the landing facility (either fixed or floating).

Vehicle Staging Area

A critical aspect of an auto-ferry facility is its ability to accommodate vehicle loading and unloading. A number of North American auto-ferry operators request that auto-passengers on longer-distance routes make reservations and/or arrive 30 min to 3 h prior to departure. The suggested arrival time is a function of the anticipated demand and may include time for security and hazardous material checks. For services between Canada and the United States, the advance time may also include customs and immigration checks.

The process of vehicle loading and unloading is time consuming and hence requires adequate access facilities and circulation provisions at the terminal. One of the key facilities in this process is the vehicle staging lot. This area allows for the storage of queuing vehicles and a smooth transition between embarking and disembarking vehicle movements. The staging areas can be located over water on a pier or landside. A plan sketch showing potential elements associated with a landside staging area is shown in Exhibit 9-3 and examples are shown in Exhibit 9-4. The various components of staging areas are described below.

Exhibit 9-3
Illustrative Vehicle Staging Area Diagram

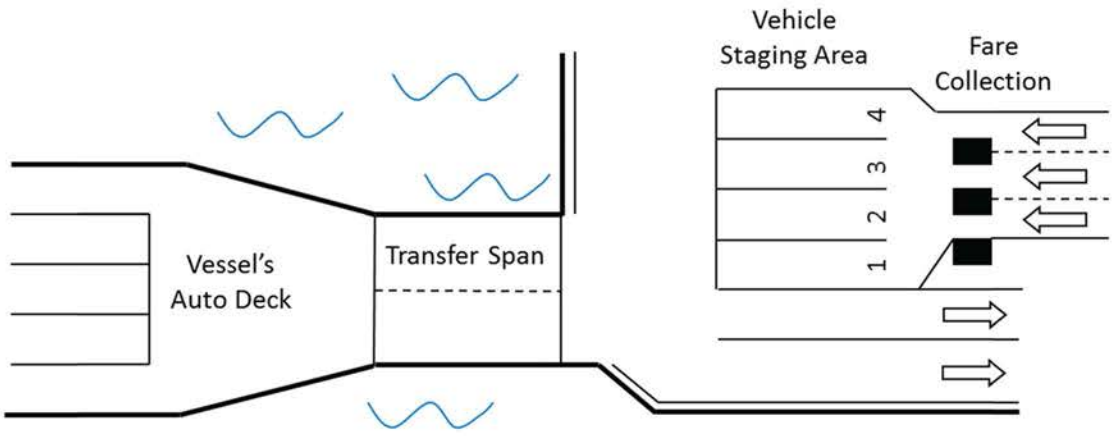


Exhibit 9-4
Vehicle Staging Area Examples



(a) Seattle



(b) Bar Harbor, Maine

The staging lot design for embarking vehicles will depend upon a number of factors. These include the following:

A vessel's capacity to transport vehicles is measured in auto equivalent units (AEUs) that reflect the amount of space used by each vehicle type.

- *Vessel auto-deck capacity:* Because the auto-deck size varies considerably from one vessel to another, the concept of auto equivalent units (AEUs) is commonly used to measure auto-deck capacity. Different vehicle types are weighted based on the space they occupy compared to a standard automobile. For example, the typical factor for a recreational vehicle, single-unit truck, or bus is three, and the factor for a semi-trailer truck is five. It is important to consider the average fully loaded volume, as some vessels may have adjustable platform decks that can be fully or partially utilized on a given sailing. If the average fully loaded sailing holds 10 autos, 5 RVs, 5 buses, and 10 semis, then the capacity is (10 × 1) + (5 × 3) + (5 × 3) + (5 × 5) = 65 AEUs.

Staging areas can be used to organize vehicles by size, weight, and destination prior to loading.

- *Loading process:* In order to keep the vessel balanced while vehicles are loaded, and to make sure that other vehicles do not block vehicles disembarking at intermediate stops, ferry operators carefully manage the order of vehicle loading from the staging area. Vehicle loading will usually take place under the supervision of experienced crewmembers that are directed by an officer or first mate of the vessel. For these same reasons, vehicles that are first to board the ferry are not necessarily the first to disembark. The staging area should be designed to allow the flexibility of vehicle choice or, alternatively, staff should be available to assign vehicle types to a particular queuing bay. In some cases, such as the Lake Michigan Carferry, vehicles are loaded and unloaded by

crewmembers or staff only. Auto ferries between St. Thomas and St. John in the U.S. Virgin Islands require drivers to back their vehicles on board; a flow-through arrangement through the car deck is more efficient and is typical of auto ferries.

The size of the staging area should, at a minimum, be sufficient to accommodate the vessel auto-deck capacity. However, an overload factor should be considered to accommodate excess vehicle demand. Washington State Ferries uses an overload factor between 1.3 and 2.2 depending on scheduled ferry headways, plus an additional two lanes for emergency and high-occupancy vehicles (HOVs). Holding-area size may also be influenced by the local tolerance for vehicle queuing on adjacent streets.

Well-designed vehicular circulation paths, with suitable signing and striping (e.g., lane numbers), are important to ensure the safe and efficient flow of traffic through the staging area. Barriers or traffic cones are often used to close off any temporary excess queue storage, so as to better define the vehicle path.

Vehicle Fare Payment

Vehicle arrival patterns tend to be related to whether a particular sailing usually has excess capacity or not.

Fare payment and ticket collection practices vary depending upon the type of service. At larger ferry terminals, the fare may be collected (or checked, in the case of pre-ticketing) at booths or ticket machines prior to entering the staging area. Smaller terminals may adopt a less formal process where the fare is purchased from staff roaming through the vehicle staging area or from a crewmember aboard the vessel. Persons traveling with their automobiles tend to adjust their behavior depending upon the demand for the service. That is, if a vessel typically has excess capacity, vehicles will arrive just before a vessel's departure. Hence, there will be a short period of high vehicle arrival volumes that may require a number of staff or ticket booths. Alternatively, if a given sailing is frequently over capacity, motorists will arrive early and there is less need to have high-capacity fare collection facilities. Some systems also exclusively use pre-ticketing, eliminating the need for fare payment at the staging area entrance, although validation of the fare is typically still required and other types of checks (e.g., vehicle height and length, number of passengers, identification checks) may also be performed.

Vehicle Disembarking

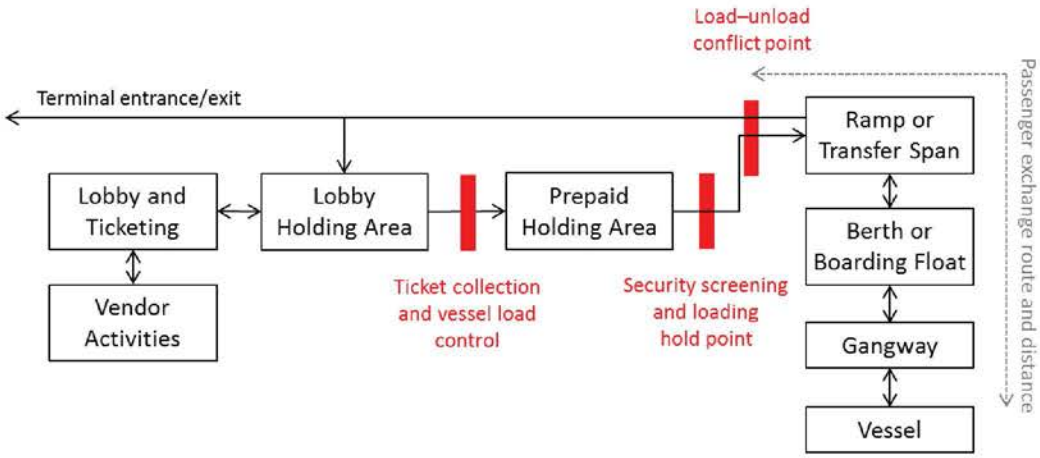
The disembarking process is commonly a direct path from the vessel auto-deck to serve vehicles in a timely manner, although dock and shoreline constraints may require more indirect routings. Some urban ferry terminal designs include special features, such as HOV lanes that feed into the urban street system.

Passenger Lobby Area

Most passenger ferry terminals have a lobby area that receives passengers walking in from the street and transferring from other transportation modes, and which provides services and other necessary functions. The general configuration of a passenger ferry terminal is depicted in Exhibit 9-5. While the arrangement may vary among various systems, the layout shown can be used as a guide for the different functions. Ticketing is often done in the lobby area and, as with other transit modes, automated vending and online sales are becoming more common. In addition to general shelter, ticketing, and circulation needs, there often are vendor areas where

newspapers, coffee, or other small items can be purchased. Space may also be necessary for disembarking passengers to wait for connections to other transportation modes, or for meet-and-greet areas.

Exhibit 9-5
Typical Elements of Passenger Ferry Loading



Passenger Ticket Collection and Vessel Load Control

At the ticket collection and vessel load control point, the ticketed status of all passengers is verified, and an accurate count of the passengers entering the pre-paid holding area is performed. As discussed earlier, vessels are licensed by the USCG for particular capacities that cannot be exceeded. Manual ticket collection and counting and lock-out turnstiles are common methods employed to accomplish this function. It is desirable to perform this function upstream of the prepaid holding area so passengers can flow freely to the vessel when it is time to board.

Prepaid Passenger Holding Area or FIFO Corridor

Passenger holding (waiting) area sizing and LOS is discussed in detail in Chapter 10.

A prepaid passenger holding area may be provided where ticketed passengers are staged prior to boarding the vessel. The passenger holding area should be sized at least as large as the vessel, but the level of service (LOS) provided should be appropriate for passenger arrival patterns. Often the bulk of passengers arrive shortly prior to sailing and a lower LOS may be tolerable for short periods of time.

An alternative to a prepaid passenger holding area is a FIFO queuing corridor. Passengers may wait in line in the order of arrival for the next sailing. Ticket verification and control of passenger loads can be done manually or by turnstile count at the end of the corridor to prevent vessel overloading, but this point may become the critical bottleneck along the loading pathway and as a result slow the boarding and departure process. LOS standards can be used to size this type of facility, but achieving a particular level in practice can be difficult due to the tendency for passengers to crowd as close to the control point as possible.

Passenger Security Screening and Loading Hold Point

A security screening point may be necessary within or at the exit of the holding area. The type and extent of screening will vary by system and by threat level, but Homeland Security regulations in place at the time of writing require that it be done. Planners and ferry terminal designers are advised to work with the service provider and the

Department of Homeland Security to ensure that capacity calculations properly reflect the local procedures.

The loading hold point is also the location where passengers are released from the holding area and allowed to proceed to the vessel. Common practices consist of just a simple gate if passenger loads are controlled at the entry to the prepaid passenger holding area.

Passenger Load–Unload Conflict Point

At some point past the prepaid passenger holding area and prior to boarding the vessel there will be a "load–unload conflict point." This is the point that all disembarking passengers must pass before embarking passengers can proceed to the vessel. To minimize walking and boarding times, it is important to keep this point as close to the vessel as possible, but distances as long as several hundred feet (100 m or more) are still common.

Passenger Transfer Span

As with vehicle loading, there is usually a need to have a transfer span between the fixed or landside portion of the passenger facility and the berth or boarding float. Tidal variations and differences in vessel freeboard have to be considered in the design since vertical differences of up to 20 ft (6 m) or more are possible. The total length of transfer spans may be well over 100 ft (30 m) and require grades that are not ADA compliant. For these reasons, careful planning of facilities and operations is especially critical.

Berth or Boarding Float

The berth is the location where the vessel ties to the terminal facility. While these are sometimes fixed facilities where tidal or lake level fluctuations allow, they are more commonly floating structures. They provide room for crew operations during docking, storage and usage of boarding ramps or gangways, and service areas for the handling of supplies, water service, and sewage discharge. Actual passenger space may be limited only to that necessary for pathways to access the vessel. The design of the float and the passenger areas should focus on the smooth flow of passengers and on providing safe barriers between passenger areas and other uses.

Gangway or Boarding Ramp

Gangways come in a variety of types, from large, wide, hydraulically operated systems for large vessels to small and portable hand-carried ramps for smaller vessels. Regardless of the type, it is always difficult to design to prevent trip points, pinch points, and transitions between surfaces. Both the vessel and the board float may be moving relative to each other and may pitch and yaw. As a result this point is often the bottleneck in the entire loading and unloading process.

Vessel Entry and Interior Circulation

As passengers enter or exit the vessel, the interior layout and relationship of stairways (or ladders) and seating areas to the entrance can influence the time it takes to board passengers. Passageways within the vessel should provide for wayfinding, seating decisions, and queuing at the top and bottom of stairways.

Ferry Terminals as a System

Well-designed ferry terminals provide fast ferry turnarounds. Saving time on a ferry route through good terminal design is considerably cheaper than increasing speed on the route, because of the power consumption and cost issues associated with higher-speed vessels that were noted earlier. Faster turnarounds allow a vessel to make more trips over the course of the day, which results in a better quality of service and greater capacity. Therefore, ferry terminals should be designed to minimize, to the extent possible, the distances between passenger and vehicle service elements. In addition, the capacity and service time of each individual ferry terminal element should be evaluated to ensure that no one element becomes a bottleneck (i.e., provides substantially less capacity or longer service time than other elements in the system).

Terminal siting is also important for minimizing ferry operations costs and maximizing the daily capacity and service frequency provided by an individual vessel. Terminals are often located to minimize the crossing distance (for example, at the ends of points of land), although shoreline land use, harbor depths, environmental constraints, and activity center locations also play roles in determining terminal locations.

Ferry Terminal Examples

Ferry terminal loading area designs vary considerably. Some examples are provided below and are illustrated in Exhibit 9-6:

- *Brisbane (Australia) CityCat:* Loading occurs from a floating platform (some covered, some not) approximately 110 ft^2 (10 m^2) in area. Passengers first disembark from a single 3-ft (1-m) wide manual gangway. When all passengers have disembarked, passengers may then embark. Fares are collected by a combination of an onboard cashier (for those paying cash), and an onboard ticket-validating machine (for those holding multiple-ride tickets and passes).
- *Sydney (Australia) Ferries:* Passenger loading at Circular Quay occurs from a large covered floating platform, which blends seamlessly from the terminal. Passengers pay their fares prior to entering the platform area. The facility design allows passengers to disembark using the upper-deck gangway, while other passengers simultaneously embark on the lower-deck gangway. The disembarking movement is connected to a fenced walkway that leads directly into the terminal.
- *NY Waterway (New York):* Bow loading is used at terminals, which provides several benefits: vessels dock more quickly, passenger movement occurs more quickly as the gangway allows several passenger streams to move simultaneously, and a separate ramp is not required (thus reducing capital costs) as the dock and vessel have the same freeboard (*2*).
- *SeaBus (Vancouver)*: Gangways are located on both the port and starboard sides of the vessel. Passengers are unloaded from one side and loaded on the opposite side. This configuration allows the 400-passenger vessels to be loaded and unloaded within 90 s.

With bow loading, ferries bump against the dock and a gangway is dropped down onto the deck. This saves time in comparison to a ferry maneuvering in, tying up, and a gangway deploying.



(a) San Francisco (Ferry Building)



(b) San Francisco (China Basin)



(c) Vancouver



(d) Vancouver



(e) Brisbane, Australia



(f) New Orleans

Exhibit 9-6
Examples of Ferry Passenger Loading and Unloading

Passengers visible against the far wall in picture (c) have just disembarked the vessel from its opposite side.

Other Terminal Design Considerations

Elevation differences may exist at several points in the system:

- *Height difference between the fixed-landside approach and the water:* The fixed-landside approach to a passenger boarding facility is typically high enough above average water level to prevent submergence in all but the most extreme conditions. The height of the stable approach can range from several feet to over 20 ft (1 m to over 6 m), and is based on historical data.
- *Water level changes:* All waterfront facilities experience changes in the height of the water relative to the fixed approach. Coastal facilities undergo tidal cycles, with normal ranges from little more than 1 ft (0.3 m) to over 20 ft (6 m). Non-tidal (inland) facilities experience water level changes less frequently, as the result of rain, snowmelt, dam releases, and so forth, which tend to occur in predictable patterns. However, the changes can sometimes be more severe, with

ranges in excess of 20 ft (6 m). Extreme weather conditions can add considerably to the range at all facilities.

- *Height difference between passenger loading platform and the vessel:* When the loading platform is a fixed-elevation facility such as a bulkhead or pier, the freeboard difference between the platform and the vessel is an access barrier. Because the heights of platforms and vessel decks vary greatly, there will be widely varied and unique height differences for dock–vessel combinations. This height difference may also vary for a particular dock–vessel pair, depending on loading and weather conditions (*5*).

Safety features to accommodate these conditions should include:

- *Guardrails:* Guardrails are critical to ensuring passenger safety because of the inherent dangers of accidentally leaving the path of travel at a marine facility.
- *Edge treatments and detectable warnings:* Tactile edge treatments and detectable warnings for the sight-impaired are important in ensuring passenger safety.
- *Changes in slopes, heights, materials, and so forth:* The path of travel from land to vessel is likely to have frequent changes, particularly slopes. Changes in the height of the loading platform relative to the shore or the vessel, due to tides or fluctuations in river level, will need to be accounted for. Attention to the slope of the ramp should be made for passengers with disabilities but boarding assistance may still be required. In some jurisdictions, ADA requirements applicable to other modes are enforced, with 1:12 ramp slopes and other features.
- *Non-slip surfaces:* Most areas at a marine facility will periodically get wet or damp from water spray. The wide use and application of non-slip surfaces are important for passenger safety.
- *Assistance:* Crew assistance for all passengers in the marine environment is standard practice due to the constantly changing conditions. This positive tradition in the industry will help meet the growing need for access for persons with disabilities.

3. FERRY SCHEDULING AND SERVICE PLANNING

The discussion of ferry scheduling and service planning is most easily illustrated by considering all of the steps involved in a one-way ferry trip. The following sections provide details for each schedule element, starting with the arrival of the ferry at the first port. Steps are given with primary attention to passenger ferry service; combined passenger and vehicle ferries may require additional consideration. Some of these elements are further discussed in the berth capacity section, as they influence both the vessel schedule and the time a vessel occupies a berth. Note that while the steps are provided in a logical order, many of the steps may occur simultaneously depending upon the service type, ferry design, and other local conditions.

PORT DWELL TIME

The overall dwell time of a ferry at a port consists of passenger exchange and vessel clean-up, resupply, and security considerations. The embarking and disembarking volume at the busiest entrance to each vessel is used to measure the passenger or vehicle demand, as this volume will control the total time needed to serve all passengers. Unless a vessel and its berth are designed to accommodate multiple gangways, this demand will be the same as the total passenger or vehicle demand. For larger passenger vessels, passenger embarking and disembarking may occur simultaneously if permitted by safety and security regulations. In this case, the greater of the embarking or disembarking volume at the busiest entrance should be used to determine the loading time. The following sections expand upon the factors that may influence scheduling time.

The passenger or auto volume at a vessel's busiest entrance will control the service time.

Passenger Disembarking

Internal vessel circulation: as mentioned in previous sections, the floor plan or internal design of a ferry may influence disembarkation time, or even prove to be the rate-limiting step for disembarkation time.

Vessel exit and gangway time: the time required to exit the ferry and pass over the gangway.

Walk time to load–unload conflict point: the time required for all disembarking passengers to walk to the point where passengers are waiting to board. Once all disembarking passengers have cleared the conflict point, they no longer influence ferry scheduling, and passengers can begin to board the ferry (assuming the necessary cleaning and security checks have taken place).

Vessel Clean-up and Security Clearance

These schedule elements are typically performed in parallel with passenger exchange, so their effect on vessel scheduling may be minimal. Nevertheless, the elements must be considered, especially if the passenger exchange time is less than that required for vessel servicing.

Vessel clean-up: crew members may have to clean passenger areas and remove waste from the vessel.

Resupply: time is required to re-stock the vessel with supplies, which may include food or onboard vending, fuel, and other items necessary for each journey.

Sewage and water: sewage and other waste products may need to be removed from the ferry and water supplies refilled.

Empty vessel sweep: it is typical to perform a sweep of the vessel to ensure that all passengers have disembarked. This is important for fare collection as well as from a security standpoint. The vessel sweep may begin as soon as passengers have cleared an area, but must be completed before any embarking passengers board.

Passenger Embarking

Ticket sales: ticket sales may influence the schedule time on routes where tickets are sold as passengers board. This is not the typical case for higher-capacity systems due to the significant reduction in boarding efficiency.

Fare or ticket collection: fare payment and ticket collection procedures vary considerably in the ferry transit industry. At lower-volume terminals, passenger and auto fares are often collected at the gangway or on board. Services that make multiple stops may also wish to collect fares on board to minimize or eliminate the need for staff at each dock. Depending on cash handling and the potential need to issue receipts, the time to serve each embarking passenger may be considerable. During peak tourist times on an Australian ferry, for example, fare payment has been observed to delay a vessel's departure at busy stops, as the line of passengers waiting to pay a cash fare to the onboard cashier can extend back onto the loading platform. A longer-distance ferry operator in the San Francisco Bay Area previously employed a modified proof-of-payment system where passenger fares were inspected 15 min after departure, giving passengers time to purchase their fare on board, while eliminating fare collection queues while boarding. At larger terminals, fare payment and collection occurs in the terminal building, prior to the entrance to a fare-paid waiting area. Payment can be made to cashiers or through the use of ticket/token machines and fare gates. Automobile fare payment or validation will typically occur at booths prior to entering the staging area. In either of these cases, fare payment does not affect the embarking or disembarking time.

Fare payment does not affect passenger service time when fares are collected at the entrance to a fare-paid passenger waiting area.

Security screening: security screening is required by Department of Homeland Security regulations, and the level of screening may vary as threat levels change. Screening is unique to each operation and ranges from simple observations of passengers to x-ray of individual parcels or canine screening for explosives.

FIFO exit from pre-paid holding area or load–unload conflict point: as discussed previously, the type of holding area influences the boarding process. When the holding area is controlled to prevent overcrowding, a FIFO system is not necessary. However, in cases where there is no holding area, or the holding area is of insufficient size, a process for maintaining the relationship between passenger arrival time at the terminal and ability to board the ferry must be maintained. This process may impact the schedule if it places restrictions on the speed of the boarding process.

Walk time to vessel: the time required for all passengers to travel to the vessel entrance or gangway.

Vessel entrance or gangway: the stability and pedestrian friendliness of the loading facilities affect the passenger disembarking and embarking time. This also includes the

time to traverse the loading area facilities, which is a function of the length and width of the access walkway/roadway, and the boarding ramp or gangway.

Internal vessel circulation: similar to disembarking, the internal vessel design or floor plan may restrict the flow of passengers onto the ferry, which may affect the schedule in extreme cases.

DEPARTURE CLEARANCE TIME

The following steps determine how quickly a ferry can depart and commence travel to the next port:

Gangway removal: the gangway technology will affect the time it takes to place and remove the gangway. There are a number of technologies in use:

- Hand winch or manually placed,
- Electric,
- Hydraulic, and
- Bow loading.

Mooring disengagement: mooring procedures vary considerably. Examples include:

- *Blue & Gold Fleet (San Francisco):* A three-step process involving fixing the spun line, bell line, and stern line. The mooring time is approximately 1 min in calm conditions; longer at other times.
- *Golden Gate Ferries (San Francisco):* The stern line is fixed and the vessel is left running to maintain tension. The 2-ton gangways rest upon the vessel to keep the vessel in place. This process takes approximately 30 s to complete.
- *Staten Island Ferry (New York):* The vessel is docked with a rack system that guides the vessel. The lower-level gangway is attached with mooring hooks and the upper- and lower-level gangways are then placed on the vessel.

Maneuvering time: depending on the ferry type and operation, it may be necessary to maneuver the ferry to prepare for transit to the next port. Vehicle ferries with a single entrance are a common example of when maneuvering time may be required

Harbor traffic: depending upon the service location, it may be necessary to take the level of harbor traffic into account when performing ferry scheduling. Harbor traffic may result from major port facilities, small pleasure craft, or even windsurfers, which can cause delays to ferries, particularly on weekends. These conditions may result in congestion or a high-risk environment, forcing vessels to reduce travel speeds. Some locations may enforce restrictions on a direction of travel, meaning that vessels traveling in that direction must yield to vessels traveling in the other direction.

TRANSIT TIME

The *transit time* is the time required for the vessel to travel from one port to the next. The transit time is based on the distance between the two ports and the average speed of travel of the vessel. It may not be appropriate to assume a constant vessel speed, since time is required to accelerate up to and decelerate from the cruising speed. Furthermore, other speed restrictions and no-wake zones along the route may impact travel speeds. The travel time should be calculated using typical conditions for the

route, including typical sea, wind, and weather conditions as well as currents and the effects of other waterborne vessel traffic.

ARRIVAL TIME

Similar to departure time, these steps occur in the reverse order when approaching the port:

Harbor traffic: high levels of harbor traffic may impact the time it takes for the ferry to arrive at the dock; such impacts require additional schedule time to ensure on-time arrivals.

Maneuvering time: the time required to maneuver the ferry in the appropriate position for docking.

Mooring time: the time required to moor the vessel; see discussion under departure clearance time.

Gangway positioning: the time required to position the gangway between the vessel and the dock.

OPERATING MARGIN

While the above elements account for the required schedule time for service from one port to another, it is typical to incorporate additional time (an *operating margin*) to accommodate uncertain or extreme conditions.

Schedule reliability: one of the primary reasons to include operating margin in a schedule is to provide schedule reliability. The level of reliability required may vary depending on the ferry service. For example, it is common for commuter-type ferry service to have a higher expectation of schedule reliability than recreational ferry services.

Wind, weather, and seas: as mentioned above, the transit time takes into account normal or typical wind, weather, and sea conditions. However, it is advisable to consider the variability of these environmental factors and incorporate additional time to account for the likelihood of less-than-favorable conditions.

Fog: depending on the location of the ferry service, it may be necessary to consider the possible presence of fog, which can dramatically slow vessel speeds, depending on the severity of the fog.

Tides and currents: additional time may need to be incorporated into the schedule when there are significant sea level changes due to tides, or when currents and other disturbances may influence travel times.

Unusual marine traffic: additional accommodation may be required for unusually high marine traffic levels.

Mechanical: mechanical issues may impact ferry service in a variety of ways. For example, a problem with a mechanically moved gangway may result in a schedule delay. The ferry service operator must take these potential issues into account and determine the appropriate additional schedule time needed to accommodate some unforeseen mechanical issues. However, it is not expected that extreme mechanical issues or failures should be accommodated within the schedule due to the relatively low expected occurrence of such issues.

PEDESTRIAN MOVEMENTS

The previous section provided a brief overview of the elements that may affect scheduling of ferry service. A number of these elements involve pedestrian flow concepts which are further developed in Chapter 10, Station Capacity. Exhibit 9-7 provides a list of cross references pertaining to pedestrian flow.

Exhibit 9-7
Pedestrian Flow Cross-References

Item Description	Reference	Page No.
Illustration of walkway LOS	Exhibit 10-4	10-14
Illustration of queuing (waiting) area LOS	Exhibit 10-5	10-14
Relationship between walking speed and pedestrian space	Exhibit 10-10	10-21
Relationship between pedestrian flow rate and pedestrian space	Exhibit 10-11	10-22
Doorway capacity	Exhibit 10-26	10-40
Fare control passenger headways and capacity	Exhibit 10-27	10-42
Relationship between walkway width and pedestrian flow rate	Equations 10-2, 10-3	10-43, 10-44
Pedestrian LOS on walkways	Exhibit 10-28	10-44
Queuing (waiting) area LOS	Exhibit 10-32	10-55
Platform (waiting area) sizing procedure	Not applicable	10-56, 10-57

SERVICE PLANNING

The above elements aid in determining the one-way travel time from one port to another. Once the overall schedule time from one port to another has been determined for all segments of a planned ferry service, a ferry service plan may be developed. Since the character of ferry routes may vary considerably between operating agencies and locations, it is impractical to define an all-encompassing methodology for ferry service planning. Nevertheless, ferry services may be classified as point-to-point or multiple-destination types of services:

Point-to-point ferry services operate only between two ports. In this type of service, all passengers disembark at the end of the journey.

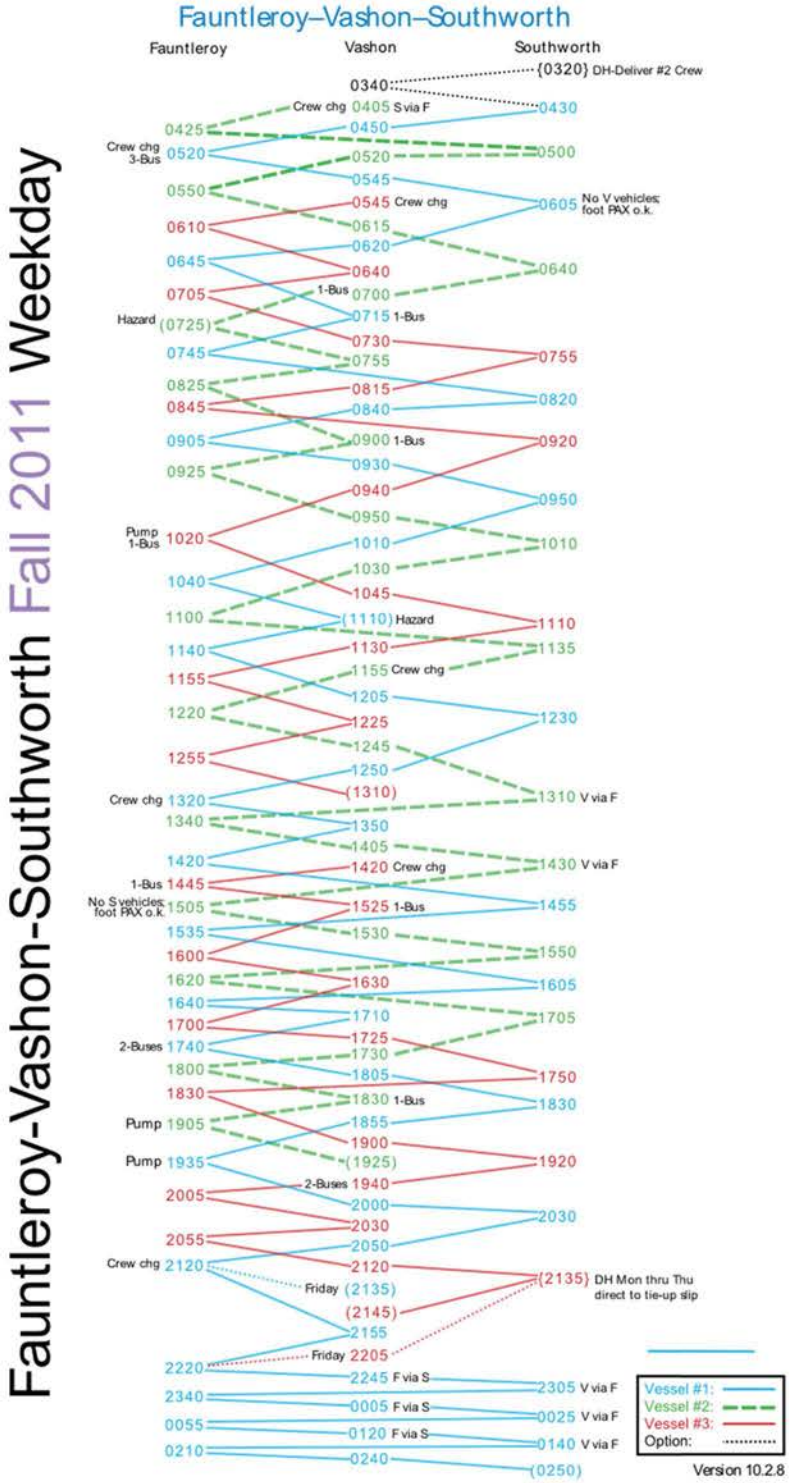
Multiple-destination ferry services operate between more than two ports and do not require all passengers to disembark at each stop. As previously mentioned, this type of service requires careful planning to allocate passenger space to various destinations to ensure that all segments can be served while not exceeding the USCG vessel passenger limit.

There are many trade-offs when determining ferry fleet sizes and schedules. The operation of a number of small ferries with frequent headways may accommodate the same passenger demand as larger ferries with less frequent headways. The trade-off between ferry size and schedule headway is also influenced by dock capacity, operating costs, and passenger expectations.

These trade-offs are complicated in multiple-destination routes. In some instances it may be desirable to have *asymmetric service* in multiple-destination routes, meaning that not all ferries follow the same pattern throughout the day or by direction. These services can be built by determining the number of trips needed between each pair of destinations and assigning such blocks of service to different ferry vessels in the most economic manner possible. Such services allow for maximum flexibility in serving passenger demand while attempting to minimize the operating cost. Exhibit 9-8 shows an example of a complex multiple-destination service across Puget Sound between Southworth, Vashon Island, and Fauntleroy. One disadvantage of asymmetric service for

ferry transit service is that it does not allow for "memory" or "clockface" schedules, in which a ferry departs for a destination at regular, repetitive times (e.g., at 20 and 50 min after the hour).

Exhibit 9-8
Example of Multiple-Destination Service



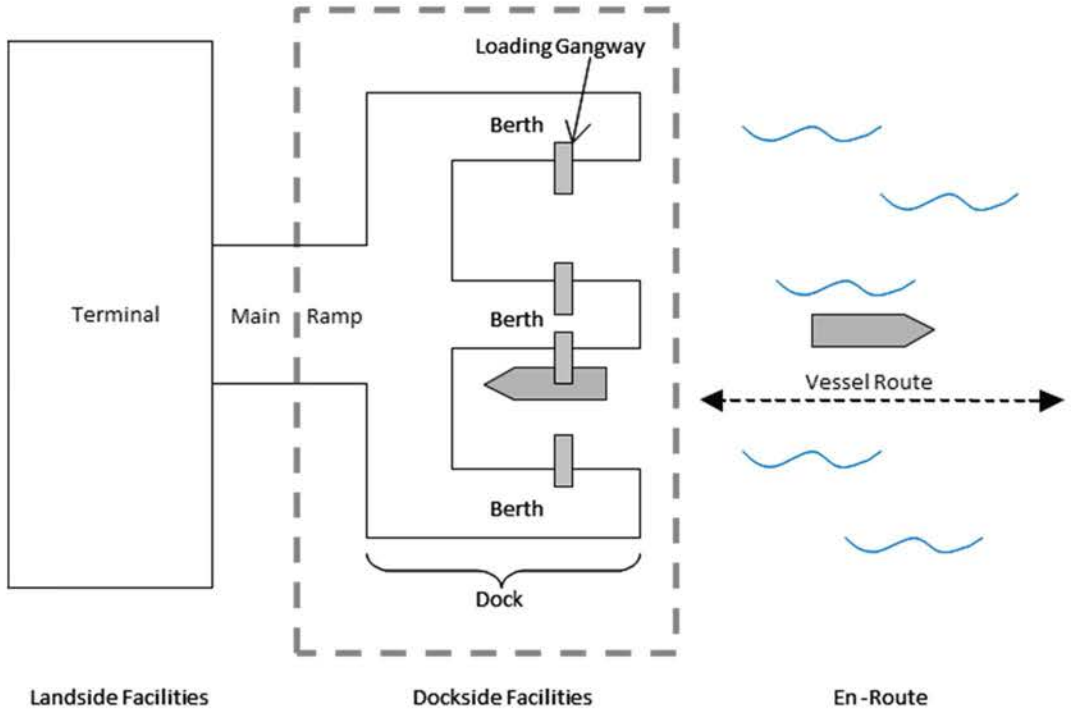
Source: Washington State Ferries.

When multiple ferry routes serve a common destination, interlining routes is another option for minimizing the number of vessels required. For example, if one route has a 35-min sailing time (70-min round trip including required layover time and operating margin) and it is desired to operate the route hourly, while another route serving the same destination has a 20-min sailing time (40-min round trip), vessels could be scheduled to alternate between the two routes. The combined cycle time for the two routes would be 110 min, which could be operated by two vessels alternating between routes instead of three dedicated to specific routes (two to the longer route and one to the shorter route).

4. VESSEL CAPACITY

Vessel capacity can be calculated for two key locations: berth and dock facility. A route's vessel capacity will be constrained by the lowest-capacity dock facility along the route. These locations are depicted in Exhibit 9-9.

Exhibit 9-9
Vessel Capacity Measurement Locations



The berth encompasses the passenger loading platform, the gangway connecting the platform to the vessel, and any walkway facilities connecting the platform to a waiting area or the shore. The dock facility is composed of one or more berths.

Within a given hour, a ferry berth may accommodate multiple vessels. Given that each vessel uses a portion of the hour to serve passengers and/or autos and clear the berth, only a limited number of vessels can access the berth in the hour. The vessel capacity of a ferry berth is defined as the maximum number of vessels per hour that can use the berth at a given level of passenger demand.

Ferry operators can determine how the current or planned vessel demand compares to the vessel capacity of the loading facilities, as illustrated in Exhibit 9-10. When a facility operates close to its capacity, any operating irregularities will cause delays to vessels, as they will arrive at the berth only to find it occupied by another vessel. In addition, when a facility operates close to its capacity, any growth in demand will increase each vessel's service time, and thus reduce the time within the hour available to other vessels. In this case, measures may be implemented to decrease the vessel loading and clearance time or, ultimately, to construct an additional berth.

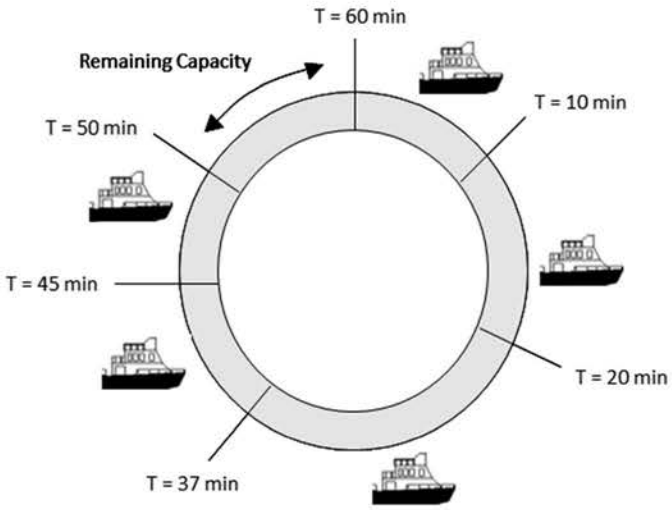


Exhibit 9-10
Berth Vessel Capacity

In situations where vessel capacity is not anticipated to be an issue, quantifying the loading time enables planners and ferry operators to estimate a new route's travel time and to isolate any design issues related to the loading facilities.

Quantifying loading time is important even when vessel capacity is not an issue.

The vessel capacity of the dock facility is a function of the capacity of the individual berths. The following sections present an overview of the primary factors that determine vessel capacity at each of these locations.

BERTH CAPACITY

The vessel capacity of the berth is dependent upon three key components: passenger disembarking time, passenger embarking time, and clearance time. The clearance time is the average time from when one vessel is ready to leave the berth to when another vessel is able to use the berth. A portion of the clearance time is made up of the minimum time for one vessel to maneuver out of and clear the berth area and the next vessel to maneuver into the berth. Clearance time also includes the time required to deploy and remove the gangway(s) and any arrival or departure delays caused by harbor traffic. In total, clearance time represents the average time when the berth is unavailable for passenger movement.

Disembarking and embarking time is a function of a number of factors, including the passenger or auto demand, the fare collection method, and the design of the gangways and walkways between the vessel and the passenger load–unload conflict point. The vessel and loading design may enable a portion of the embarking and disembarking times to be overlapped.

Ferry terminals can also operate like transit centers, where passengers arrive and transfer to another vessel to complete their journey. In these cases, the time a given vessel occupies a berth depends more on the time required for passengers to transfer between vessels and the time required to stagger scheduled vessel arrivals and departures to avoid harbor congestion, than on the disembarking, embarking, and clearance times. This form of operation requires many more berths than a situation in which timed transfers are not provided or where little or no transfer demand exists (i.e., passengers exit the terminal building after arriving and continue to their destination via another travel mode).

Disembarking/Embarking Time Factors

Berth Vessel Capacity

The maximum number of vessels per hour that a berth can accommodate based on a given passenger demand is given by the following expression:

Equation 9-1

$$V_b = \frac{3{,}600}{t_v}$$

where

V_b = vessel capacity of the berth (vessels/h),

3,600 = the number of seconds in one hour, and

t_v = design vessel service time (s/vessel), discussed below.

The design vessel service time is approximated by the passenger or automobile disembarking and embarking times (whichever is higher), the vessel clearance time, and an operating margin, as shown in Equation 9-2. The operating margin addresses the reliability needs discussed previously, ensuring that the estimated vessel capacity can be reliably achieved, rather than being a maximum capacity achievable only under ideal conditions. Little guidance is available for determining this margin other than that it should be based upon observed variations in berth times for existing similar services (similar to the process used in other TCQSM chapters for determining an operating margin for bus and rail transit), or determined by other operating experience. If capacity is not expected to be an issue, and it is only desired to know the average time a vessel will occupy the berth (e.g., for use in estimating average travel time), an operating margin does not need to be calculated.

Equation 9-2

$$t_v = t_{ed} + t_c + t_{om}$$

where

t_v = design vessel service time (s/vessel),

t_{ed} = total embarking and disembarking time (s/vessel),

t_c = clearance time (s/vessel), and

t_{om} = operating margin (s/vessel).

No default values are currently available for ferry capacity parameters; field data collection is suggested.

Discussions with various ferry operators suggest that commuter embarking and disembarking has very little variation, while tourist services experience significant variation around the mean. There are currently no ferry-related data that would allow a default standard deviation or coefficient of variation to be given; however, one could determine this parameter from a series of field observations. Similarly, no data are currently available to provide a default clearance time; however, one could be determined from observations of current operations or from discussions with vessel captains.

Determining the disembarking and embarking times requires field measurements, or estimates of the number of embarking and disembarking passengers or automobiles. The previous discussion on ferry scheduling can provide guidance on how to estimate these times when field data are unavailable, based on passenger demand, terminal and vessel design elements, and fare collection procedures. In general, each step for the scheduling process should be estimated, with many of the steps drawing from the

pedestrian flow procedures for stations presented in Chapter 10, Station Capacity. For activities that overlap, care must be taken to use the time from the slowest combination of activities, since this will control the maximum embarking or disembarking rate. Information from terminal design may also be relevant when considering passenger flow within the vessel itself. Finally, queues will likely form where there are delays. The queue-discharge time must also be incorporated into the boarding or disembarking time. The following section provides an example layout for a sequential disembarking and embarking process.

Many aspects of embarking and disembarking depend on concepts from Chapter 10, Station Capacity.

Sequential Passenger Disembarking and Embarking

This section applies to situations in which passengers disembark from the vessel and have cleared all walkways before passengers are allowed to embark. The service time elements in this process are as follows:

1. Passenger time to disembark the vessel over one or more gangways. This time is related to the number of gangways, the gangway width, and the passenger demand.
2. Disembarking passenger time to traverse the walkway to the dock exit. This time is related to the walkway width and the rate at which passengers exit the gangway(s).
3. If disembarking passengers arrive at the dock exit at a faster rate than the exit can process them, there will be additional delay at the exit. This could be an issue if the exit is narrower than the walkway leading to it, or if a doorway or exit gate is involved.
4. Once disembarking passengers have cleared the area, embarking passengers are allowed from the waiting area onto the walkway leading to the vessel. Entrance to the walkway could be controlled by a door, sliding gate, or other mechanism, any of which will have an associated time to serve all of the passengers in the waiting area. If fares are collected at the waiting area exit, this time should be included in the service time.
5. Embarking passenger time to traverse the walkway to the vessel. This time is related to the walkway width and the rate at which passengers exit the waiting area.
6. Time to board the vessel over its gangway(s). If passengers arrive at the gangway(s) at a faster rate than they can be processed, there will be additional delay at the gangway. If fares are collected at the gangway, this time should be included in the service time.

The passenger embarking and disembarking time can be illustrated by the following expression:

$$t_{ed} = 60\left(\frac{P_d}{C_d} + \frac{L_w}{v_d} + \frac{P_e}{C_e} + \frac{L_w}{v_e}\right)$$

Equation 9-3

where

t_{ed} = embarking and disembarking time (s/vessel);

60 = number of seconds in 1 min;

C_d = disembarking capacity at the constraining point, typically the minimum of the gangway capacity C_g or the walkway exit capacity C_x (p/min);

C_e = embarking capacity at the constraining point, typically the minimum of the waiting area exit capacity C_w, the gangway capacity C_g, or the fare collection capacity C_f (p/min);

P_d = disembarking passenger volume (p);

P_e = embarking passenger volume (p);

L_w = walkway length (ft, m);

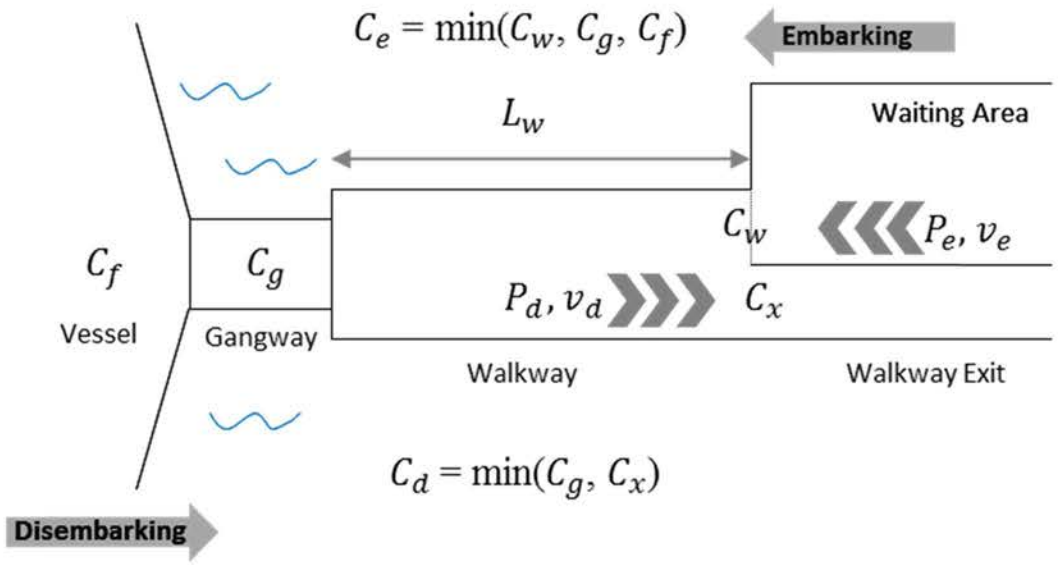
For relatively uncongested situations (i.e., walkway LOS C or better) with no steep grades, 250 ft/min (75 m/min) is a reasonable default passenger speed.

v_d = disembarking passenger speed on walkway, from Exhibit 10-10 (U.S. customary units), Exhibit 10-10m (metric units), or defaulted (ft/min, m/min); and

v_e = embarking passenger speed on walkway from Exhibit 10-10, Exhibit 10-10m, or defaulted (ft/min, m/min).

The parameters used to determine embarking and disembarking time are illustrated in Exhibit 9-11.

Exhibit 9-11
Embarking and Disembarking Parameters



Note: The gangway is considered as a point and hence the time to traverse its length is not included.

Passenger speeds on the walkway can be determined using Exhibit 10-10 and Exhibit 10-11 in Chapter 10, Station Capacity, starting with a known capacity of the gangway or waiting area exit that constrains how quickly passengers can enter the walkway. For example, if the walkway is 6 ft (1.8 m) wide and the gangway can process 60 p/min, the pedestrian flow per unit width entering the walkway from the gangway is 10 p/min/ft width (33 p/min/m width). Using the right (uncongested) side of the unidirectional commuter curve in Exhibit 10-11 gives a pedestrian space of approximately 26 ft² (2.5 m²) per passenger at this pedestrian flow per unit width. Applying this result to Exhibit 10-10 gives an average pedestrian walking speed of 250

Wider ramps, gangways, and doors speed boarding and alighting (more passengers can move side by side) and thereby reduce vessels' terminal time.

ft/min (75 m/min). These calculations assume walkways that are level or have grades of 5% or less; passengers will travel more slowly on steeper walkways.

The disembarking capacity C_d is the point along the disembarking process with the lowest capacity. This will typically be the gangway capacity or the walkway exit capacity, but passenger movement could also be constrained internal to the vessel or, due to fare collection activities, upon exiting. Similarly, the embarking capacity C_e is typically constrained by the exit from the passenger waiting area, the gangway capacity, or the fare collection time boarding the vessel or at the waiting room exit (if applicable).

Gangways can be treated as a free-entry fare gate, and their capacities can be determined from Exhibit 10-27 in Chapter 10, Station Capacity. The capacities of other potential constraining points, such as doors or gates, can also be determined from this exhibit.

When local data on fare collection times are not available, fare collection service times can be approximated using the values for buses given in Exhibit 6-4 in Chapter 6, Bus Transit Capacity.

Simultaneous Passenger Embarking and Disembarking

In the event that passenger embarking and disembarking occurs at the same time, inputs to Equation 9-3 should only include the greater of the embarking or disembarking service time. This value is not necessarily dependent upon the magnitude of the embarking or disembarking volume. Although the disembarking volume may be greater than the embarking volume, the service time for embarking passengers may be larger if passengers pay fares when boarding.

Sequential Automobile Disembarking and Embarking

When automobiles and other vehicles are carried, the time required to load and unload these vehicles will usually control the embarking and disembarking time. This service time is constrained by the time to serve individual vehicles at the gangway, the number of gangway channels available, and the distance between the gangway and the front of the vehicle staging area, as shown in Equation 9-4:

$$t_{ed} = \frac{h_v(A_d + A_e)}{N_{ca}} + \frac{2L_r}{v_v} \qquad \textbf{Equation 9-4}$$

where

t_{ed} = embarking and disembarking time (s/vessel),
h_v = average vehicle headway (s/auto),
A_d = number of disembarking autos (auto equivalent units),
A_e = number of embarking autos (auto equivalent units),
N_{ca} = number of channels for automobiles,
L_r = distance between gangway and front of vehicle staging area (ft, m), and
v_v = vehicle entering/exiting speed (ft/s, m/s).

There are currently no default values for headway or vehicle speed; however, these can be determined from field observations.

DOCK CAPACITY

The vessel capacity of the dock represents the total number of vessels that can be served at the dock facility per hour. The dock facility capacity is the sum of the vessel capacities of the individual berths making up the dock, as shown in Equation 9-5:

Equation 9-5

$$V = \sum_{i=1}^{N_b} V_{bi}$$

where

V = dock vessel capacity (vessels/h),

V_{bi} = vessel capacity of berth i (vessels/h), and

N_b = number of berths at the dock.

5. PASSENGER AND AUTO CAPACITY

The passenger capacity can be calculated at a number of locations along the passenger's path of travel. These locations are illustrated in Exhibit 9-12 and are broken into three key components: landside, dockside, and en-route.

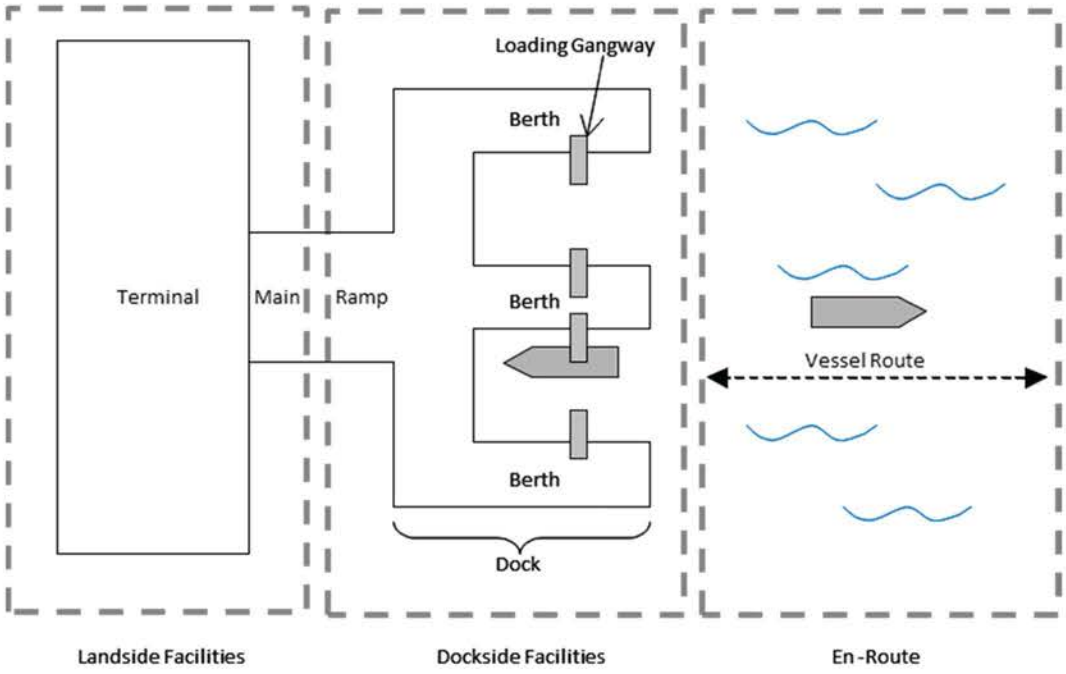


Exhibit 9-12
Passenger or Auto Flow through the Ferry Transit System

Landside: Methods for determining the capacity of various passenger circulation elements of a ferry terminal are provided in Chapter 10, Station Capacity. In some cases, landside access issues may present a serious constraint on ferry capacity. When this occurs, the Chapter 10 methods should be used to determine whether the terminal constrains passenger flow and, consequently, ferry capacity.

Dockside: The passenger or auto capacity of a single berth or the dock as a whole (multiple berths) can be determined using this chapter's methods. The results can be compared against current or planned demand for the service and to the vessel capacities of the dock and its component berths.

The maximum number of embarking and disembarking passengers (autos) that can be served at the berth will depend upon the number of vessels serving that berth during the hour. The greater the number of vessels, the greater the total clearance time and, hence, the less time available in the hour to load and unload passengers or vehicles. If the embarking and disembarking time for all vessels at the berth exceeds the available time within the hour, then it can be concluded that the passenger (auto) demand exceeds the berth's passenger (auto) capacity.

The maximum number of embarking and disembarking passengers (autos) that can be served at the berth will also depend upon the distribution of embarking and disembarking passengers (autos) at a berth for each vessel. When all passengers (autos) disembark all vessels that arrive at the berth, the embarking demand per vessel cannot

exceed the vessel's passenger (auto) capacity. When vessels make multiple stops, a portion of the passengers aboard will not disembark. The difference between the vessel's passenger capacity and the number of passengers remaining aboard at a stop represents the embarking passenger capacity for each vessel.

En-route: The en-route capacity of a ferry system is much less complicated. As mentioned previously, the vessel's passenger capacity is set by the vessel's USCG license. Some vessels may have three or four different licenses, whereby the passenger limit will depend upon the size and composition of the crew. Ferry operators may need to match the crew size and passenger license to projected passenger demand. For autos, the concept of AEUs described earlier in this chapter is used to measure the vessel's vehicle capacity on the vessel. This is a method that weights different vehicle categories (e.g., autos, autos with trailers, single-unit trucks) based on the space they occupy relative to an automobile.

Equation 9-6

$$P = V_c f(PHF)$$

where

P = person (auto) capacity on the route's maximum load segment (p/h, autos/h),

V_c = vessel's passenger (auto) capacity (p/vessel, autos/vessel),

f = vessel frequency (vessels/h), and

PHF = peak-hour factor, the ratio of the hourly demand to four times the highest 15-min demand.

The PHF is used to reduce a maximum (theoretical) capacity to a design capacity that can accommodate variations in demand from one sailing to the next without requiring passengers to wait for the next vessel. With a few exceptions (such as Vancouver's SeaBus and many ferry services to New York City), most North American passenger ferry operations are operated at headways of 30 min or longer. In the absence of local information, a PHF of 0.90 to 0.95 is recommended for these longer-headway services as an allowance for variations in demand. Smaller PHFs (e.g., 0.75–0.85, similar to bus and rail PHFs) may be appropriate for shorter-headway ferry services. Ferries that require advance reservations can be planned using a PHF of 1.00, as all available space will be utilized whenever possible, and there is no passenger expectation of space being guaranteed on the next departing ferry.

6. CALCULATION EXAMPLES

Example	Description
1	Vessel service time (passengers)
2	Vessel service time (automobiles)
3	Berth capacity

Exhibit 9-13
List of Calculation Examples

CALCULATION EXAMPLE 1: VESSEL SERVICE TIME (PASSENGERS)

The Situation

A short passenger ferry route is planned that connects three locations along and across a river in an urban area. For scheduling purposes, it is desired to know how long vessels will stop at each location.

The Question

What are appropriate vessel service times to plan for at the three stops, during the afternoon peak period?

The Facts

- The route will use a ferry with a 50-person capacity.
- Ticket machines located on the shore will be used to issue tickets; a crewmember will collect the tickets at the gangway.
- The ferry has one doorway and hence there is sequential passenger disembarking and embarking.
- The average number of embarking and disembarking passengers per stop during the afternoon peak period is forecast as follows:

	Stop #		
	1	2	3
Disembarking passengers	10	20	20
Embarking passengers	30	10	10

- The docks have a gangway width of 40 in. (1 m). Sloped walkways lead from each dock onto the shore. The walkways have dimensions of 6.5 x 50 ft (2 × 15 m) and each walkway ends in a pair of free-swinging gates opening outward into an uncovered waiting area. Embarking passengers are not allowed onto the walkway until the disembarking passengers have exited.

Comments and Assumptions

- Based on observations of a ferry service with similar mooring operations and gangway equipment to that proposed, the clearance time is estimated to be 90 s (45 s upon arrival and 45 s upon departure).
- Because berth capacity is not being calculated, an operating margin to account for non-typical conditions does not need to be estimated.

- From Exhibit 10-27, average capacities for manual ticket collection are 30 p/min (i.e., 2 s/p). Both the gangway and the walkway exit gates can be treated as free-admission gates, which have a capacity range of 40–60 p/min/channel. The lower value (40 p/min/gate) will be assumed for the walkway exit gates, as these require physically pushing or pulling the gates to open them, or to keep them open, while the higher value (60 p/min/channel) will be assumed for the gangway, as passengers can pass through it freely. A 40-in (1-m) wide gangway is the equivalent of one channel.
- All input parameters are known. The vessel service time is the sum of embarking, disembarking, and clearance times. As passenger movement along the walkway occurs in one direction at a time, embarking and disembarking times will need to be calculated separately for each stop to determine their contribution to vessel service times.

Solution

Step 1: Calculate the Disembarking Capacity

The disembarking capacity C_d is calculated using the methods given in Chapter 10, based on the minimum of the gangway or exit capacity. Gangway capacity is based on the capacity of a single gangway channel C_g (60 p/min) and the number of gangway channels available N_{cg} (1), resulting in a gangway capacity of 60 p/min. Fare collection capacity is based on the number of fare-collection channels N_f and the fare collection service time per passenger t_f. Exit capacity is based on the number of exit channels provided N_{ce} (2) and the capacity of a single exit channel C_x (40 p/min), resulting in a capacity of 80 p/min. The gangway capacity is the most restrictive, so the disembarking capacity is 60 p/min.

$$C_d = \min\begin{Bmatrix} C_g N_{cg} \\ C_x N_{ce} \end{Bmatrix} = \min\begin{Bmatrix} (60)(1) \\ (40)(2) \end{Bmatrix} = 60 \text{ p/min}$$

Step 2: Calculate the Embarking Capacity

Embarking capacity C_e is calculated similarly to disembarking capacity. However, as fares are collected when boarding, this process must also be considered in this step. Fare collection is performed by a single crewmember who can check one passenger in 2 s, or 30 p/min. This is less than the gangway and entrance capacities, so it is used as the embarking capacity.

$$C_e = \min\begin{Bmatrix} C_g N_{cg} \\ 60 N_f / t_f \\ C_x N_{ce} \end{Bmatrix} = \min\begin{Bmatrix} (60)(1) \\ (60)(1/2.0) \\ (40)(2) \end{Bmatrix} = 30 \text{ p/min}$$

Step 3: Calculate the Total Embarking and Disembarking Time

Equation 9-3 is used to calculate the total embarking and disembarking time t_{ed}. The calculation is illustrated for the first stop:

$$t_{ed} = 60\left(\frac{P_d}{C_d} + \frac{L_w}{v_d} + \frac{P_e}{C_e} + \frac{L_w}{v_e}\right)$$

$$t_{ed} = 60\left(\frac{10}{60} + \frac{15}{75} + \frac{30}{30} + \frac{15}{75}\right)$$

$$t_{ed} = 94 \text{ s}$$

Step 4: Calculate the Vessel Service Time

Finally, using Equation 9-2, the average vessel service time t_v is the sum of the calculated embarking and disembarking time t_{ed} and the clearance time t_c given in the problem statement. (The operating margin shown in Equation 9-2 does not need to be included, as only the vessel service time is of interest in this example.) For the first stop, the calculation is as follows:

$$t_v = t_{ed} + t_c$$
$$t_v = 94 + 90$$
$$t_v = 184 \text{ s}$$

The Results

Steps 3 and 4 are repeated for stops 2 and 3, resulting in the following estimated vessel service times. These times are for planning purposes and are shown below for each stop:

Stop #	1	2	3
Vessel service time (s)	184	154	154

Changing the proposed fare collection system to avoid fare collection at the gangway would improve the vessel service time by an average of 30 s/stop. Improvements in the gangway or mooring technology could also be considered to improve service times, as the planned 90 s forms a significant portion of the total time.

CALCULATION EXAMPLE 2: VESSEL SERVICE TIME (AUTOMOBILES)

The Situation

A new auto ferry route is planned to connect two locations on opposite sides of a bay. It is desired to know how long a typical ferry on this route will occupy the berth when auto demand equals or exceeds the ferry's capacity.

The Question

What is the average vessel service time when the ferry is fully loaded entering and leaving the dock?

The Facts

- The route will use a ferry with a capacity of 100 autos.
- The fare will be collected in the auto staging area prior to embarking.
- The ferry will have sequential auto disembarking and embarking.
- The gangway can accommodate two lanes of vehicles and is located 150 ft from the front of the vehicle staging area.

Comments and Assumptions

- The clearance time, based an investigation of similar mooring and gangway technology, is estimated to be 3 min (1.5 min upon arrival and 1.5 min upon departure).
- Because berth capacity is not being calculated, an operating margin does not need to be estimated.
- Assume that the vehicle headway is 3.0 s/auto.
- Assume that the approximate auto entry speed is 10 mi/h (14.7 ft/s).
- The vessel service time is the sum of embarking, disembarking, and clearance times.

Solution

Step 1: Calculate the Total Embarking and Disembarking Time

As this is an auto ferry, Equation 9-4 is used to calculate the total embarking and disembarking time t_{ed}:

$$t_{ed} = \frac{h_v(A_d + A_e)}{N_{ca}} + \frac{2L_r}{v_v}$$

$$t_{ed} = \frac{3(100 + 100)}{2} + \frac{(2)(150)}{14.7}$$

$$t_{ed} = 320 \text{ s}$$

Step 2: Calculate the Vessel Service Time

The vessel service time t_v is the sum of the embarking and disembarking time t_{ed} and the clearance time t_c given in the problem statement:

$$t_v = t_{ed} + t_c$$

$$t_v = 320 + 180$$

$$t_v = 500 \text{ s (8 min, 20 s)}$$

The Results

When a ferry is fully loaded entering and leaving the dock, its average service time will be 500 s.

CALCULATION EXAMPLE 3: BERTH CAPACITY

The Situation

A passenger ferry berth currently serves six ferries during the evening peak hour. The transit agency wishes to add another ferry during the peak hour.

The Question

Are additional berths required?

The Facts

- The observed average passenger embarking and disembarking time t_{ed} at the berth is 3 min; however, this time can vary somewhat from one ferry to the next.
- The observed average clearance time is a total of 4 min (2 min upon arrival and 2 min upon departure).

Comments and Assumptions

- Because berth capacity is being calculated, the design vessel service time should include an operating margin to account for longer-than-normal embarking, disembarking, and clearance times (for example, due to high passenger demands or harbor traffic).
- In the absence of other guidance, the operating margin will be based on the additional time required to limit the failure rate (the percentage of ferry arrivals in which an arriving ferry has to stop and wait for another ferry to depart the berth). In this case, the operating margin is assumed to be an additional 1.5 min, meaning that the next arriving ferry will not be delayed as long as the actual vessel service time does not exceed the average time by more than 1.5 min.

Steps

Step 1: Calculate the Vessel Service Time

The average passenger embarking and disembarking time t_{ed} and the average clearance time t_c were given. The vessel service time is then given by Equation 9-2:

$$t_v = t_{ed} + t_c + t_{om}$$
$$t_v = 180 + 240 + 90$$
$$t_v = 510 \text{ s } (8 \text{ min}, 30 \text{ s})$$

Step 2: Calculate the Berth Capacity

Equation 9-1 is used to calculate the berth capacity. Fractional values of vessels per hour are rounded down to the next lower integer value in determining the number of vessels that can be completely served during the course of an hour.

$$V_b = \frac{3{,}600}{t_v}$$
$$V_b = \frac{3{,}600}{510}$$
$$V_b = 7 \text{ vessels/h}$$

The Results

The existing berth is capable of serving the proposed new service in addition to the six existing ferry services.

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CHAPTER 10
STATION CAPACITY

1. User's Guide
2. Mode and Service Concepts
3. Operations Concepts
4. Quality of Service Concepts
5. Quality of Service Methods
6. Bus Transit Capacity
7. Demand-Responsive Transit
8. Rail Transit Capacity
9. Ferry Transit Capacity
10. **Station Capacity**
11. Glossary and Symbols
12. Index

CONTENTS

1. INTRODUCTION 10-1
Chapter Overview 10-1
How to Use This Chapter 10-1
Other Resources 10-2
Station Design Capacity 10-2
Access for Persons with Disabilities 10-2
Emergency Evacuation 10-3
Security 10-4

2. STATION TYPES AND CONFIGURATIONS 10-5
Overview 10-5
Bus Stops 10-5
Transit Centers 10-6
Busway and BRT Stations 10-7
Light Rail and Streetcar Stations 10-8
Heavy Rail and AGT Stations 10-8
Commuter Rail Stations 10-9
Ferry Docks and Terminals 10-10
Intermodal Terminals 10-10
Passenger Amenities in Stations 10-10

3. PASSENGER CIRCULATION 10-13
Introduction 10-13
Pedestrian Level of Service 10-13
Station Access 10-15
Horizontal Circulation 10-20
Vertical Circulation 10-24
Platforms and Waiting Areas 10-29

4. VEHICLE CIRCULATION AND STORAGE 10-31
Transit Vehicles 10-31
Private Vehicles 10-34

5. STATION ELEMENTS AND THEIR CAPACITIES 10-38
Introduction 10-38
Station Access 10-39
Horizontal Circulation 10-43
Vertical Circulation 10-48
Platforms and Waiting Areas 10-55
Interactions Between Station Elements 10-58
Alternative Performance Measures for Sizing Station Circulation Elements 10-58

6. APPLICATIONS 10-62
Alternative Mode and Alignment Comparisons 10-62
Alternative Station Location and Features Comparisons 10-63
Remodeling an Existing Station 10-63
Addressing a Specific Capacity Issue in an Existing Station 10-64
Comprehensive Analysis of Passenger Circulation 10-64
Pedestrian Microsimulation 10-67

7. CALCULATION EXAMPLES 10-73
Calculation Example 1: Suburban Transit Center Design 10-73
Calculation Example 2: Stairway Sizing 10-76
Calculation Example 3: Platform Sizing 10-79
Calculation Example 4: Escalator Queuing Area 10-81
Calculation Example 5: Multiple Pedestrian Activities in a Facility 10-83
Calculation Example 6: Complex Multilevel Station 10-85
Calculation Example 7: Application of Pedestrian Microsimulation Software 10-88

8. REFERENCES 10-91

APPENDIX A: EXHIBITS IN METRIC UNITS 10-94

LIST OF EXHIBITS

Exhibit 10-1 Example Transit Station Security Elements 10-4
Exhibit 10-2 Examples of Passenger Amenities at Transit Stations 10-11
Exhibit 10-3 Passenger Amenities Illustrated 10-12
Exhibit 10-4 Illustration of Walkway Levels of Service 10-14
Exhibit 10-5 Illustration of Queuing Area Level of Service 10-14
Exhibit 10-6 Signage and Communication System Examples 10-16
Exhibit 10-7 Doorway Example (New York) 10-17
Exhibit 10-8 Fare Machine Examples 10-18
Exhibit 10-9 Faregate Examples 10-19
Exhibit 10-10 Pedestrian Speed on Walkways 10-21
Exhibit 10-11 Pedestrian Flow on Walkways by Unit Width and Space 10-22
Exhibit 10-12 Examples of Multiple Pedestrian Activities Within a Transit Station 10-23
Exhibit 10-13 Moving Walkway Examples (New York) 10-23
Exhibit 10-14 Stairway Examples 10-24
Exhibit 10-15 Pedestrian Ascent Speed on Stairs 10-25
Exhibit 10-16 Pedestrian Flow Volumes on Stairs 10-26
Exhibit 10-17 Escalator Configuration Examples 10-27
Exhibit 10-18 Elevator Application Examples 10-28
Exhibit 10-19 Transit Station Platform Configurations 10-29
Exhibit 10-20 Bus Berth Designs and Examples 10-33
Exhibit 10-21 Park-and-Ride Lot Examples 10-34
Exhibit 10-22 Kiss-and-Ride Examples 10-36
Exhibit 10-23 Bicycle Parking Examples 10-37
Exhibit 10-24 Summary of Secure Bike Storage Options 10-37
Exhibit 10-25 Doorway LOS 10-39
Exhibit 10-26 Observed Average Doorway Headway and Capacity 10-40
Exhibit 10-27 Observed Average Faregate Headways and Capacities 10-42
Exhibit 10-28 Walkway LOS 10-44
Exhibit 10-29 Stairway LOS 10-48
Exhibit 10-30 Stair Lane Width and Capacity 10-50
Exhibit 10-31 Nominal Escalator Capacity Values 10-52
Exhibit 10-32 Levels of Service for Queuing Areas 10-55
Exhibit 10-33 Transit Platform Areas 10-56
Exhibit 10-34 Sample Pedestrian Flow Diagram Through a Transit Terminal 10-65
Exhibit 10-35 Elements of Passenger Circulation in a Transit Station 10-65
Exhibit 10-36 List of Calculation Examples 10-73

Exhibit 10-37 Calculation Example 1: Bus Routes Planned to Use Proposed Transit Center....10-73
Exhibit 10-38 Calculation Example 1: Maximum Design Year Berth Needs....10-75
Exhibit 10-39 Calculation Example 4: Time Clearance Diagram....10-82
Exhibit 10-40 Calculation Example 5: Cross Passageway Layout....10-83
Exhibit 10-41 Calculation Example 5: Circulation and Queuing Spaces....10-84
Exhibit 10-42 Calculation Example 6: Station Layout....10-86
Exhibit 10-10m Pedestrian Speed on Walkways....10-94
Exhibit 10-11m Pedestrian Flow on Walkways by Unit Width and Space....10-94
Exhibit 10-15m Pedestrian Ascent Speed on Stairs....10-95
Exhibit 10-16m Pedestrian Flow Volumes on Stairs....10-95

1. INTRODUCTION

CHAPTER OVERVIEW

Transit stops, stations, and terminals (generically referred to as *stations* in this chapter) are the locations where passengers board, alight from, and transfer between transit vehicles. They range in size and complexity from simple streetside bus stops to large intermodal terminals, such as New York's Grand Central Terminal.

Chapter 10 of the *Transit Capacity and Quality of Service Manual* (TCQSM) discusses the features and elements of transit stations and provides methods for estimating their design requirements.

Organization of Chapter 10.

- The remainder of Section 1 introduces concepts applied throughout Chapter 10.
- Section 2 describes the various station types and typical configurations.
- Section 3 presents fundamentals of passenger circulation and introduces the concept of pedestrian level of service.
- Section 4 discusses issues related to vehicular circulation as it relates to station design and performance.
- Section 5 explores the various station elements and describes methods for analyzing their capacities.
- Section 6 presents applications of analytical methods to station elements.
- Section 7 provides examples of calculations for station capacity and sizing.
- Section 8 is a list of references used to develop the material in the chapter.
- Appendix A provides substitute exhibits in metric units for Chapter 10 exhibits that use U.S. customary units only.

HOW TO USE THIS CHAPTER

Sections 1 and 2 provide general concepts and background information about transit stations that will be useful to transit agency and consultant staff who are new to planning, designing, and operating these facilities.

Section 4 provides background information about transit, automobile, and bicycle circulation and parking facilities at a station that is relevant for non-technical audiences, as well as guidance on designing these facilities that is directed more toward facility planners and designers.

Section 6 describes potential applications of this chapter's material to planning and designing transit stops and stations, along with the role of simulation. The earlier subsections in this section are relevant for a broader audience, while the sections on comprehensive analysis and pedestrian microsimulation are directed toward facility planners and designers.

Section 3 provides pedestrian circulation and level of service concepts that analysts will ideally be familiar with prior to applying the computational methods in Section 5. Section 7 provides example calculations based on the Section 5 methods. These sections are directed to readers who will be directly involved in sizing station elements.

OTHER RESOURCES

Other TCQSM material related to station capacity includes:

- The "What's New" section of Chapter 1, User's Guide, which describes the changes made in this chapter from the 2nd Edition;
- The "Passenger Load" section of Chapter 5, Quality of Service Methods, which presents information on the amount of space taken up by passengers holding or carrying various items;
- Chapter 9, Ferry Transit Capacity, which refers readers to this chapter for information on sizing ferry terminal elements; and
- The manual's CD-ROM, which provides links to the electronic versions of the TCRP reports referenced in this chapter.

STATION DESIGN CAPACITY

Design capacity is determined by passenger demand volumes under typical peak-period conditions, additional demand that builds during service disruptions and special events, and emergency evacuation situations. Either peak-period demand or emergency evacuation needs may drive the design of a specific station element, and both types of conditions should be evaluated during station planning and design. Specific requirements for addressing emergency evacuation contained in the National Fire Protection Association (NFPA) standard for fixed-guideway transit and passenger rail stations (NFPA 130, *1*) are reviewed in this chapter.

Either peak-period or emergency evacuation needs may drive the design (required capacity) of a specific station element.

Research has shown that a breakdown in pedestrian flow occurs with dense crowding of pedestrians, resulting in restricted and uncomfortable movement (*2*). For this reason, many of this chapter's methods for sizing station elements for peak-period conditions are based on maintaining a desirable pedestrian level of service (LOS), rather than designing for maximum pedestrian capacity and a less desirable service level.

In larger stations and terminals, the various pedestrian spaces interact with one another such that pedestrian circulation may better be evaluated from a systems perspective. Simulation models can assess route choice and the complex interaction of pedestrians to predict emergent crowd dynamics, including the impact of queue spillback on upstream facilities. These models can be used to size internal spaces within a station, and their application is discussed in this part of the TCQSM. For stations with frequent transit service, the time required to clear a station platform before the arrival the next train or bus may be a critical consideration. Even where services do not run on a close headway, platform clearance time is a useful measure of passenger convenience.

ACCESS FOR PERSONS WITH DISABILITIES

The needs of persons with disabilities should be considered throughout the process of planning and designing transit station facilities. Both physical and cognitive disabilities should be considered and provisions for addressing these are referenced throughout the chapter. The Americans with Disabilities Act (ADA) requires all new transit stations in the United States to be accessible to persons with disabilities. It also requires that key stations in existing systems be made accessible and that major remodeling of any station incorporate accessible features. The act includes provisions

Station design must also consider the needs of persons with disabilities.

both for persons with mobility impairments, who may use wheelchairs, and for persons with other sensory or cognitive impairments, including visual and hearing limitations.

http://www.access-board.gov/ada-aba/ada-standards-dot.cfm

Specific regulations for transit stations, including accessible route provision, architectural features, and accessible communications elements and features are contained in the *ADA Standards for Transportation Facilities* (*3*). These issues should be addressed at each stage of the transit station planning and design process. For example, opportunities may be found to incorporate ramps into the design that serve passengers with disabilities and also benefit movement by other passengers. Elements addressing the needs of persons with disabilities can be worked into a facility's overall design.

EMERGENCY EVACUATION

NFPA 130 establishes standards for the evacuation of fixed guideway transit and passenger rail stations.

Provisions for evacuation during an emergency are an important consideration in the design of transit stations and terminals. Design and performance standards for emergency evacuation are presented in NFPA 130.

The key provisions of NFPA 130 (2010 edition) related to station capacity are summarized as follows (*1*):

- Sufficient exit capacity shall be provided to evacuate platform occupants (including those on trains) from platforms in 4.0 min or less.
- Sufficient exit capacity shall be provided to permit evacuation from the most remote point on a platform to a point of safety in 6.0 min or less.
- A second means of egress with at least 44-in. (1.12-m) clear width and remote from the major egress route shall be provided from each platform.
- The maximum distance to an exit from any point on a platform shall be not more than 325 ft (100 m).
- Escalators shall not provide more than half of the exit capacity from any level (except in specific circumstances), and one escalator at each level, resulting in the most adverse exiting condition, shall be assumed to be out of service and unavailable for egress.

NFPA 130 specifies facility element capacities and pedestrian speeds to be used in evacuation analysis.

The current edition of NFPA 130 contains more detailed information on the evacuation standards and calculation procedures. In particular, the standard specifies design capacities and pedestrian travel speeds that should be used for evacuation analysis. These capacities and speeds are often different than those presented in this chapter for designing daily passenger circulation.

Evacuation analysis should be performed in conjunction with analysis and planning for daily circulation patterns. While in some cases the overall requirements for evacuation exceed the requirements for daily circulation, the two circulation patterns are dramatically different and each may result in different requirements at particular points in a station. While evacuation requirements must be satisfied, this represents a rare circumstance, with daily circulation defining the passengers' normal experience; hence, evacuation should not be the only consideration in station design.

The requirements of daily passenger circulation and emergency evacuation should be considered in tandem both in overall station planning and in the design of individual station systems, such as vertical circulation or mezzanines, and in the design of individual elements. One example of overall station planning in which both requirements need to be addressed is the issue of center versus side platforms. In more

complex or higher-capacity stations, the number of platforms may also need to be addressed from both daily use and emergency perspectives. The number and configuration of platforms directly affects potential platform access, particularly when vertical circulation is required to access and egress platforms.

When multilevel stations are considered, the typical peak-period circulation pattern may differ greatly from an emergency situation. For example, the daily flow pattern in a particular rail transit station may emphasize intra-station transfers and large numbers of passengers passing through on trains without boarding or alighting. During an emergency, the same station would experience much higher exiting volumes than normal, including the normal exiting volumes, those passengers who normally remain on trains passing through the station, and those passengers who transfer at the station but normally do not exit there.

Circulation elements that are normally used for entering a station can largely be used for exiting during an emergency condition. Thus, stairs normally used by entering passengers can be used by those exiting, and inbound-moving escalators can be turned off or switched to the outbound direction. Some consideration should also be given to the need for emergency crews to enter a station as it is being evacuated.

SECURITY

Public security in transit stations has important consequences for transit ridership. Both actual security, as measured by reported and unreported incidents, and perceived security are important for passengers. If passengers feel that a stop or station is unsafe, they will try to avoid it, even if the actual level of crime is low. Law enforcement personnel, video cameras, and emergency call boxes (see Exhibit 10-1) can play an active role in station security. However, factors such as visibility, lighting, and the presence of other people also play key roles. Visibility applies both within an enclosed station and from a street or other nearby land uses into a station.



(a) Law enforcement presence (Tacoma)



(b) Video surveillance (New York)

Exhibit 10-1
Example Transit Station Security Elements

A number of world cities have experienced acts of terrorism on transit properties, including within stations. *TCRP Synthesis 80: Transit Security Update* (*4*) provides summaries of strategies that transit agencies use effectively to reduce crime, improve passengers' perceptions of security, and address terrorist threats. The *TCRP Report 86: Public Transportation Security* series (*5*) also provides information on various aspects of transit security developed in the wake of the September 11, 2001 terrorist attacks. Finally, the FTA's Safety and Security website (*6*) provides another useful resource.

2. STATION TYPES AND CONFIGURATIONS

OVERVIEW

Various types of transit stops, stations, and terminals provide service tailored to the specific needs of a transit system or a particular locale. These facilities often have common features and elements, but they may display unique characteristics. The basic types of transit stops, stations, and terminals are presented in this chapter, along with examples of typical passenger amenities that are provided.

BUS STOPS

Most bus stops are located along streets and consist of a waiting area integrated with the public sidewalk, signage to mark the bus stop, and, in some cases (depending on passenger volume, available space, and available power), small-scale passenger amenities such as a bench, small shelter, bicycle parking, printed schedule and route information, or real-time bus-arrival displays. Lighting, either from adjacent street lighting or built into a shelter, is desirable to enhance nighttime security.

Bus stops can also be located on- or off-street in conjunction with transit centers, rail transit stations, or intermodal terminals; these are discussed in the "Transit Centers" section that follows.

From a capacity standpoint, the key element is sizing the waiting area appropriately so that passengers waiting for buses neither unduly restrict pedestrian movement on the adjacent sidewalk, nor hinder passengers alighting from arriving buses. The methods given in Section 5 for passenger waiting areas can be used to determine the space needed to accommodate the anticipated peak-passenger demand, while the method for sidewalks can be used to determine the space needed to accommodate sidewalk pedestrian flow (with consideration of maintaining a minimum clear width for wheelchair movement).

In some cases, bus stops may be located on boarding islands within the street or within a transit center. In these cases, it is particularly important to provide sufficient waiting area so that passengers do not spill over into the adjacent roadway.

Stops that comply with the ADA will provide (*3*):

- A firm, stable surface;
- A clear length of 96 in. (2440 mm), measured perpendicular to the curb or roadway edge, and a clear width of 60 in. (1525 mm), measured parallel to the roadway, to the extent that the construction specifications are within a public entity's control; and
- An accessible connection to a street, sidewalk, or pedestrian path.

The ADA also specifies standards for bus stop slope, sign legibility, and (if provided) clear space within bus shelters (*3*).

TCRP Report 19: Guidelines for the Location and Design of Bus Stops (*7*) provides guidance on designing bus stops to accommodate transit vehicles; many larger transit agencies have developed their own standards specific to their bus fleet and local conditions. TCQSM Chapter 6, Bus Transit Capacity, describes the advantages and

disadvantages of near-side, far-side, and mid-block on-street bus stops on pages 6-11 and 6-12. Bus stops can be placed on the near side of an intersection, on the far side, or mid-block. In all cases, good access to the sidewalk and crosswalk network is essential.

TRANSIT CENTERS

The term *transit center* is normally applied to facilities where multiple bus routes converge, offering transfer opportunities between routes and, frequently, layover area for bus routes that terminate at the center. The term can also apply to intermodal stations that may combine transfers between local buses with opportunities to transfer to rail and other modes. Both types of facilities are normally located wholly or partially off-street. Good wayfinding information is essential for passengers to find their way to their transfer connection, and should also consider the needs of persons with disabilities. Amenities beyond those that might be found at an on-street bus stop can include a larger or more elaborate shelter, climate-controlled waiting areas, ticket sales, concessions, transit system and neighborhood maps, secure bicycle parking, taxi stands, restrooms, and a passenger pick-up/drop-off ("kiss-and-ride") area. Transit centers associated with intermodal stations in suburban areas might also provide a park-and-ride facility. Additional security features could include video surveillance or on-site security staffing or policing. Bus operations elements frequently include the provision of a driver break room and restrooms, along with parking spaces for field supervisors.

As with on-street bus stops, the key passenger capacity elements involve providing sufficient waiting area at individual stops and sufficient circulation area to allow passengers to quickly move between stops or the transit center entrances and exits. Depending on the surrounding land uses and the bus arrival pattern at the center (e.g., timed transfers), waiting or transferring may be significantly more dominant. The methods given in Section 5 of this chapter can be used to size waiting and circulation areas.

Bus capacity—in the form of providing sufficient bus bays for loading and unloading passengers and providing layover berths for buses that end their route at the transit center—is also an important consideration for transit centers. The methods given in Section 4 of this chapter can be used to estimate the number of required bus berths; that section also discusses kiss-and-ride, park-and-ride, and bicycle access.

Some other aspects of transit center design are outside the scope of the TCQSM but should also be considered in the planning and design process. These include:

- Location of pedestrian crossings of vehicular roadways and means of directing pedestrians toward those crossings, which promotes both passenger safety and smoother transit vehicle operations.
- Bus turning radii, to ensure smooth transit vehicle operations.
- Locations of bus access points to the transit center relative to the adjacent street system, relative to pedestrian and auto (e.g., park-and-ride, kiss-and-ride) access points, and relative to the directions in which buses arrive and depart, to minimize traffic conflicts and bus delay.

Some larger transit agencies, such as in British Columbia, Canada (*8, 9*) and Copenhagen, Denmark (*10*), have developed architectural and engineering design guidance for transit centers. ADA requirements in the U.S. for bus stops and public

facilities (*3*), and corresponding local standards or best practice elsewhere, should also be incorporated into a transit center's design.

BUSWAY AND BRT STATIONS

Busway and bus rapid transit (BRT) stations are located along roadways or lanes dedicated for buses and are frequently larger and more elaborate than typical bus stops, but are often shorter than light rail stations. Like the busways they serve, these stations may be either off-street or on-street. The length of a busway or BRT station is generally 40 to 100 ft (12 to 30 m) but some extend to 400 ft (120 m) to serve multiple routes and services. Amenities may be limited, consisting of just a paved area and sign, or more elaborate, with shelters, seating, ticket machines, real-time bus arrival information, radiant heating, security features, and other amenities.

Busway stations may also require vertical circulation elements to avoid the need to have passengers cross a busway at-grade; these elements are also needed when the station itself is located above or below grade. Busway stations toward the outer end of a route may also provide park-and-ride lots. Busway stations in some South American cities (such as Bogotá, Curitiba, and Quito) are enclosed with fare collection at the station and high-level bus boarding.

Busway and BRT stations usually consist of side platforms boarded from the right side of the bus, but some center platform stations are used with boarding from the left side of the bus (this requires buses designed with doors on both sides, as are used in Cleveland and Eugene). Center platforms can also be used when a busway operates in a contraflow (i.e., left-side running) configuration, allowing the use of standard buses with right-side doors. Busway stations may have a single lane in each direction where all buses stop at each station, or a passing lane can be provided at stations to increase operational capacity and allow for multiple services that skip some stations.

Coordination between the design of BRT stations, vehicles, and guideways allows providing features that have the potential to increase both passenger convenience and the speed of boarding and alighting, reducing dwell times. Such features include level boarding, precision docking of buses, and wider doors on both buses and stations, where applicable.

As with other types of bus stops, the methods given in this chapter's Section 5 can be used to size a station's waiting and circulation areas. When off-board fare payment is used, Section 5 also can be used to evaluate the space required for passengers queued at ticket machines and the number of machines themselves. Section 5 also provides guidance on locating and sizing a station's vertical circulation elements.

Bus capacity—in the form of providing sufficient bus bays for loading and unloading passengers and (potentially) providing passing lanes for buses not stopping at the station—must also be considered in the station design. The methods given in Chapter 6 can be used to determine the number of bus bays required to achieve a desired operational reliability.

Design guidance on other aspects of busway and BRT stations can be found in several TCRP and FTA publications (*11–13*) and an APTA recommended practice (*14*). A European research project (*15*) has also developed best practices for integrating BRT stations into their surroundings.

LIGHT RAIL AND STREETCAR STATIONS

Light rail stations are typically 180 to 400 ft (55 to 120 m) long. Various platform configurations are possible, including center, side, or split on opposite sides of an intersection. Stations may be on-street, off-street, along a railroad right-of-way, on a transit mall, or as part of a transit center. High and low platforms have both been used, although the trend in recent years has been the increasing use of an intermediate height for platforms that is approximately 14 in. (0.35 m) above the top of the rail to match the floor height of low-floor light rail vehicles. Light rail stations usually include canopies over part of the platform, limited seating, and ticket vending machines. Other amenities could include climate-controlled waiting areas, concessions, transit system and neighborhood maps, secure bicycle parking, taxi stands, electronic information displays, restrooms, security features, kiss-and-ride, and park-and-ride. Fare collection on light rail systems is typically by the proof-of-payment system, so stations typically do not have fare gates or barriers.

Light rail stations located above or below grade, in freeway medians, and in locations where it is not desired to have passengers cross the tracks will also require vertical circulation elements and fences between tracks. ADA requirements pertaining to rail stations include the need to minimize the vertical and horizontal gap between platform and vehicle (except at stations where vehicles are intended to be boarded from the street or sidewalk). Other ADA requirements address platform slope, provision of detectable warnings at the platform edge, signage, public address systems, clocks, and track crossings (*3*).

The methods given in Section 5 can be used to size a light rail station's waiting areas, circulation paths, ticket machines, and vertical circulation elements. Some U.S. transit agencies that operate light rail have developed design standards for stations and a European research project (*15*) has developed best practices for integrating light rail stations into their surroundings.

Except where they are shared with light rail, modern streetcar stations or stops are typically shorter, narrower, and less elaborate than LRT stations, matching the streetcars' size and length. Streetcar lines are more likely to use adjacent sidewalks for boarding. Although any of the amenities associated with light rail can be applied to streetcar stops, the number or size of elements may be reduced.

HEAVY RAIL AND AGT STATIONS

Stations in heavy rail (rapid transit, metro) and automated guideway transit (AGT) systems are usually more elaborate than light rail or commuter rail stations. Due to the presence of third-rail power in most of these systems, and to discourage passengers from entering or crossing the trackway, these stations require high-level platforms. Some systems also use platform screen doors to control access to the trackway and/or maintain climate control on the platforms. Stations are most often located underground or elevated, and frequently have intermediate mezzanine levels between the street and platform levels. Both center and side platform configurations are used, and some stations have more than two tracks. Special configurations allow cross-platform transfers or reflect location-specific conditions. Heavy rail stations are generally 600 to 800 ft (180 to 240 m) long. AGT stations are often shorter, given the smaller trains used on these systems.

Most heavy rail stations have fare control arrays and enclosed paid zones, although some European systems use proof-of-payment systems. Depending on the fare payment system, fare-collection machines may be located both inside (e.g., addfare) and outside (e.g., fare purchase) the fare-paid area. Stations where a parking fee is charged may also have a parking fee payment machine inside the fare-paid area (to ensure people who park use the transit service). Many U.S. heavy rail stations provide a staffed station agent booth to monitor station activity and to answer passenger questions. Other station amenities can include security features, concessions, transit system and neighborhood maps, secure or staffed bicycle parking, electronic information displays, taxi stands, restrooms, kiss-and-ride, and (in suburban areas) park-and-ride. Underground stations may provide multiple exits. Good wayfinding information is needed to direct passengers—particularly those unfamiliar with the station—to the exit closest to their destination.

The methods given in Section 5 can be used to size the full range of station elements found in these types of stations, while Section 4 addresses kiss-and-ride, park-and-ride, and bicycle access. One difference to note is that when seating space on arriving trains is limited, passengers may choose to queue near the locations where the train doors will be, to maximize their chance of getting a seat. As a result, platform space will be used differently than when passengers expect to be able to get a seat or have no expectation of getting a seat. Section 6 describes the application of simulation to station planning and design, which is often necessary for high-volume, multiple-exit stations where there are many interacting passenger flows and activities.

COMMUTER RAIL STATIONS

Commuter rail stations range from suburban locations with one or two platforms, limited service, and relatively small passenger volumes to major urban terminals with many tracks and platforms offering a variety of local and express services to various destinations. Stations may use either center or side platforms, or a combination of both. Higher-volume systems tend to use high platforms, while lower-volume systems tend to use low or intermediate-height platforms. In some cases, passenger and freight trains share the same tracks. Horizontal clearance requirements for freight cars may be greater than those for passenger equipment and thus can impact platform height, platform offsets from the track, and the placement of platform features such as wheelchair ramps. Platforms can range from 300 to more than 1,000 ft (90 to over 300 m) long.

Passenger flow on commuter rail platforms can be more complex when multiple routes and services share the same platform and waiting areas. Where that is the case, not all passengers waiting on platforms will board a train when it arrives, leaving residual passenger volumes on platforms. Commuter rail cars typically have fewer doors than heavy rail cars and may fully load or unload at a single major terminal, increasing their boarding, alighting, and dwell times at those stations.

U.S. commuter rail systems often rely on park-and-ride as their primary access mode. Fares are typically purchased from machines or a ticket sales booth. Other station amenities can include a climate-controlled waiting area, concessions, secure bicycle parking, taxi stands, restrooms, kiss-and-ride, real-time train arrival information, and security features. Some commuter rail systems allow bicycles on board trains. As with

other types of rail stations, Section 4 addresses sizing station access features, while Section 5 addresses sizing passenger circulation and waiting area elements.

FERRY DOCKS AND TERMINALS

Ferry docks and terminals can vary from simple waterside facilities with limited shelters and relatively small passenger flow volumes to major terminals with multiple ferries receiving and discharging large numbers of passengers and vehicles. Since waterside locations are particularly exposed to the weather, protection from the climate can be an important factor in providing a good quality of travel. The effect of tides, changing river levels, and waves must be adequately addressed and pose unique challenges for passenger access, especially where extreme height changes are experienced, potentially requiring long or steep ramps to reach vessels.

As discussed in Chapter 9, Ferry Transit Capacity, a relatively structured system is required to process passengers from shore to vessel. This system encompasses fare collection, security checks, and passenger counting (to ensure that the number of passengers on board does not exceed the vessel's regulatory capacity), and to restrict access to potentially hazardous areas. This chapter's Section 5 can be used to size ferry terminal passenger circulation elements. *TCRP Report 152: Guidelines for Ferry Transportation Services* (*16*) provides additional guidance about ferry terminal elements.

INTERMODAL TERMINALS

The term *intermodal terminals* refers to a variety of stations and terminals that provide key transfers between transit modes. Combinations may include local bus, bus rapid transit, intercity bus, light rail, heavy rail, commuter rail, intercity passenger rail, ferry, or AGT. Such facilities may have a variety of other services and connections, including parking, drop-off, ticket vending, and information booths. Intermodal terminals are increasingly regarded as ideal locations for land use intensification and may be integrated with retail shopping, services, and entertainment. Because these facilities typically have many entrances and exits and potentially multiple levels, good wayfinding information is needed to direct passengers from entrances to their transit vehicle and vice versa. Because of the heavy passenger volumes using these facilities and the interactions between various terminal elements, simulation is typically used to model passenger movements through an intermodal terminal. Section 6 describes the role of simulation in terminal planning and design.

PASSENGER AMENITIES IN STATIONS

Passenger amenities are provided at a bus stop or transit station to enhance comfort, convenience, and security for transit patrons. Amenities include such items as shelters, benches, vending machines, trash receptacles, lighting, phone booths, art, and landscaping. Improvements to station amenities can reduce the perceived inconvenience of transferring and waiting time. Although the effect that a specific amenity may have on transit ridership is likely to be small, the cumulative impact of providing an overall good level of amenity may be significant.

Amenities at most bus stops or transit stations are placed in response to a human need or a need to address a local condition. Some advantages and disadvantages of

various passenger amenities are summarized in Exhibit 10-2. Examples of passenger amenities at transit stops and stations are illustrated in Exhibit 10-3.

Exhibit 10-2
Examples of Passenger Amenities at Transit Stations

Amenity	Advantages	Disadvantages
Shelters	• Provide comfort for waiting passengers • Provides protection from climate (sun, glare, wind, rain, snow) • Help identify the stop/station	• Requires maintenance, trash collection • Can be vandalized Visual impact on surroundings
Benches	• Provide comfort for waiting passengers • Help identify the stop/station • Lower cost compared to a shelter	• Require maintenance • Can be vandalized
Lean bars	• Provide some comfort for waiting passengers • Lower cost, less space, and less maintenance compared to benches	• Not as comfortable as benches • Require maintenance
Lighting	• Increases visibility • Increases passengers' perception of security • Discourages "after hours" use of facilities by indigents	• Requires power • Requires maintenance • Can be costly
Maps	• Provide information on how to use the transit system • Provide information on how to get to destinations in the vicinity	• Require periodic updating
Real-time arrival information	• Assures passengers that their bus/train is coming • Reduces perceived waiting time • Improves perception of service reliability	• Requires power and communications connections • Requires maintenance • Can be costly
Radiant heating	• Provides comfort for waiting passengers in cold climates	• Requires power • Requires maintenance • Can be costly and a potential liability
Vending machines and newsstands	• Provide services (e.g., food, drink, news) for waiting passengers • May produce revenue for transit system	• Increase maintenance through trash accumulation and spilled food/drink • May have poor visual appearance • Can be vandalized
Trash receptacles	• Provide place to discard trash • Keep the stop/station and its surroundings clean	• May be costly to maintain • May be used by customers of nearby land uses • May have a bad odor • May create security issues
Telephones	• Convenient for transit patrons • Provides access to transit information and emergency services	• May encourage loitering • May encourage illegal activities • Widespread usage of mobile phones may reduce their need
Art	• Creates a more aesthetically pleasing station environment	• May be perceived as wasteful by transit critics

Source: Derived from Texas Transportation Institute (*7*), updated for the TCQSM 3rd Edition.



(a) Shelter & bench (Denver)



(b) Telephones (Denver)



(c) Vending machines (Brisbane, Australia)



(d) Lighting (Cleveland)



(e) Trash receptacle (Albuquerque)



(f) Art (Los Angeles)

Exhibit 10-3
Passenger Amenities Illustrated

The space needed for passenger waiting at transit stops and stations should account for space taken by shelters, benches, information signs, and other amenities. Amenities at bus stops and transit stations should be placed so that they do not interfere with the landing area for a lift or ramp for people with disabilities and so that their spacing or placement does not constrict movement by wheelchair users.

Placement of passenger amenities at bus stops and in stations impacts space required for circulation and waiting areas.

When shelters are provided at light rail and busway stations, they typically do not cover the entire station platform. The extent of coverage depends on local climate, impacts on surrounding properties, circulation, and passenger waiting patterns. If most passengers wait for trains or buses on one platform and alight on the other platform, then canopies may be provided only on the side of the station where passengers wait, or there may be fewer or smaller canopies on the alighting side of the station.

3. PASSENGER CIRCULATION

INTRODUCTION

This section introduces the concept of pedestrian level of service (LOS) and it describes the basic elements that might be found in a transit station, working from the outside of the station inward to the transit platform. Computational methods for sizing station elements are presented in Section 5.

PEDESTRIAN LEVEL OF SERVICE

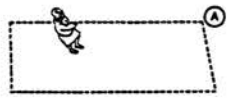
Pedestrian levels of service provide a useful means of evaluating the capacity and comfort of an active pedestrian space. Pedestrian LOS thresholds related to walking are based on the freedom to select desired walking speeds and the ability to bypass slower-moving pedestrians. Other considerations related to pedestrian flow include the ability to cross a pedestrian traffic stream, to walk in the reverse direction of a major pedestrian flow, and to maneuver without conflicts with other pedestrians or changes in walking speed.

Levels of service for pedestrian circulation areas are based on available standing space, perceived comfort and safety, and the ability to maneuver from one location to another. LOS letters range from A to F, with A representing an unimpeded condition and F representing an undesirable condition in which pedestrian movement is severely constrained. Pedestrian capacity—the maximum number of pedestrians that can pass a point in a given period of time—is represented by the threshold between LOS E and F. However, station design for typical conditions is usually based on maintaining a desirable (more comfortable) pedestrian LOS, rather than designing for maximum pedestrian capacity.

The thresholds between each LOS letter correspond to a particular average space available to each pedestrian. The pedestrian space corresponding to a desired LOS can therefore be used in planning and designing features such as platform size, number and width of stairs, corridor width, and so forth, by sizing these elements to provide the desired LOS at a particular pedestrian flow.

Exhibit 10-4 illustrates the space available to walking pedestrians at various levels of service. At the highest levels of service, pedestrians can move relatively freely at or near their desired speed, and following their desired path. At lower levels of service, pedestrians' freedom of movement becomes more and more constrained. The situation is similar in queuing areas, illustrated in Exhibit 10-5. At the highest levels of service, standing pedestrians have relatively high levels of personal space, while others can circulate between the standing pedestrians. As LOS gets worse, standing pedestrians become packed together and circulation becomes difficult or impossible.

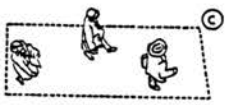
Planning or designing a pedestrian space for typical operating conditions seeks to balance pedestrian comfort (LOS) against other practical needs, such as construction and maintenance costs. The choice of a design LOS should also consider how long pedestrians will experience the condition: for example, persons will tolerate being packed together on an elevator longer than they will waiting on a station platform.



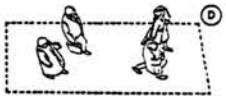
LEVEL OF SERVICE A
Walking speeds freely selected; conflicts with other pedestrians unlikely.



LEVEL OF SERVICE B
Walking speeds freely selected; pedestrians respond to presence of others.



LEVEL OF SERVICE C
Walking speeds freely selected; passing is possible in unidirectional streams; minor conflicts for reverse or cross movement.



LEVEL OF SERVICE D
Freedom to select walking speed and pass others is restricted; high probability of conflicts for reverse or cross movements.



LEVEL OF SERVICE E
Walking speeds and passing ability are restricted for all pedestrians; forward movement is possible only by shuffling; reverse or cross movements are possible only with extreme difficulty; volumes approach limit of walking capacity.



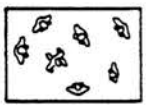
LEVEL OF SERVICE F
Walking speeds are severely restricted; frequent, unavoidable contact with others; reverse or cross movements are virtually impossible; flow is sporadic and unstable.

Source: HCM 2000 (*17*).

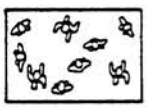
Exhibit 10-4
Illustration of Walkway Levels of Service



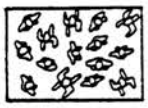
LEVEL OF SERVICE A
Standing and free circulation through the queuing area possible without disturbing others within the queue.



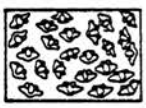
LEVEL OF SERVICE B
Standing and partially restricted circulation to avoid disturbing others within the queue is possible.



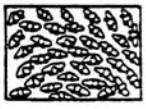
LEVEL OF SERVICE C
Standing and restricted circulation through the queuing area by disturbing others is possible; this density is within the range of personal comfort.



LEVEL OF SERVICE D
Standing without touching is impossible; circulation is severely restricted within the queue and forward movement is only possible as a group; long-term waiting at this density is discomforting.



LEVEL OF SERVICE E
Standing in physical contact with others is unavoidable; circulation within the queue is not possible; queuing at this density can only be sustained for a short period without serious discomfort.



LEVEL OF SERVICE F
Virtually all persons within the queue are standing in direct physical contact with others; this density is extremely discomforting; no movement is possible within the queue; the potential for pushing and panic exists.

Source: HCM2000 (*17*).

Exhibit 10-5
Illustration of Queuing Area Level of Service

Pedestrian performance is often reported in terms of the average LOS of a space over time (typically over the busiest 15-min period of activity). Where the nature of pedestrian movement is heavily pulsed (for example, in areas adjacent to train alighting activity), reporting based on longer time periods may obscure pedestrian circulation problems. The average LOS experienced by individual passengers may be reported instead of (or in addition to) a time average LOS, although conversely, this metric may exaggerate pedestrian circulation concerns. It is, therefore, appropriate in many cases to review pedestrian LOS in the context of other useful reporting metrics such as volume-to-capacity ratio, passenger journey time, platform clearance times, or average queuing delay time. These metrics are described in more detail later in this chapter.

STATION ACCESS

Information Provision

The impact of information provision on station capacity is felt at locations where pedestrians have to stop to orient themselves or to read needed information (e.g., the track assigned to a particular train). These stopped pedestrians create an impediment to the flow of other pedestrians, thereby reducing the capacity of a walkway or other station circulation element.

Clarity of Station Layout

In more complex transit stations and terminals, passengers' ease in finding their way around the station becomes important. While signage is an indispensable element in wayfinding, station layout and design can do much to make a station more understandable and easier to navigate. For example

- Clear, unobstructed sight lines can provide visual connections to other levels and between points inside and outside the station;
- Alternate symbols, finishes, colors, and shapes can distinguish between alternate routes or services; these should be used consistently systemwide;
- Center platforms allow passengers who have missed their intended stop to easily reverse direction and do not require passengers to identify the correct platform before reaching it, reducing confusion;
- Tactile signage and audible information offers direction and information to persons with visual impairments;
- Cross-platform transfers for dominant passenger movements reduce passenger demand on vertical circulation elements, shortens passenger walking distances, and makes connections easier to find; and
- The same design elements that contribute to wayfinding can also contribute to real and perceived safety within the station and passenger comfort.

Signage and Information Displays

Station signage, illustrated in Exhibit 10-6, provides information to passengers both waiting in the station and arriving on transit vehicles. Static and electronic signs can direct passengers to loading areas or platforms for various transit services, to station exists and nearby destinations, and to emergency evacuation routes. System maps,

schedules, fare information, and neighborhood maps provide information for passengers. While most stations or stops will include at least minimal signage, more complex stations require more extensive wayfinding systems. Signage and information is particularly important to the occasional transit passenger, but reinforces the transit experience and options for all passengers.

Signage, along with other station elements and finishes, provides an opportunity at "branding" of a particular transit service or system. Consistent elements and styles become recognizable symbols of the service recognized by the public and can impart a modern and comfortable image for the station and the service.

Signage should be accessible to persons with disabilities, including Braille and audible information, and should be placed so that it is accessible to wheelchair users.



(a) Posted system and area information



(b) Real-time schedule information



(c) Wayfinding information



(d) Audible schedule information



(e) Emergency call box



(f) Elevator availability information

Exhibit 10-6
Signage and Communication System Examples

Photo locations:
(a) San Diego
(b) Minneapolis
(c) New York
(d) Minneapolis
(e) Boston
(f) San Francisco

Public Address Systems

Public address systems may be provided in stations both for public information and for security. A public address system can be activated by on-site personnel or it can be connected to a remote central control facility. It may be combined with passenger call boxes allowing passengers to call for information or emergency assistance. Video monitors allow staff to monitor conditions and events in the station and to record them for law enforcement purposes. The presence of video cameras and call boxes also acts as a deterrent to some crimes. The ADA requires that where public address systems are used, "the same or equivalent information shall be provided in a visual format" (*3*).

Doorways

Doorways (Exhibit 10-7) limit the capacity of a walkway by imposing restricted lateral spacing. Because of this restriction on capacity, doorways will impact the overall capacity of a pedestrian walkway within a transit station, and therefore will require additional design considerations. Doorways are required to comply with the ADA Accessibility Guidelines. Revolving doors or gates are not considered part of an accessible route.

Exhibit 10-7
Doorway Example
(New York)



The effect of doorways on pedestrian flow will depend on the headway (time) between pedestrians. When a pedestrian reaches a doorway, there must be sufficient time-headway separation to allow that pedestrian to pass through the doorway before the next pedestrian arrives. If time-headways between successive pedestrians are too close, a pedestrian queue will develop. The capacity of a doorway is therefore determined by the minimum time required by each pedestrian to pass through the entrance.

At exterior entrances, the provision of canopies extending beyond doorways can provide a useful space for pedestrians to get out of rain or snow and put down umbrellas before entering or after exiting. However, if incorrectly sized, these can attract people to stand in such a way that they block passage in and out of the entrance.

Fare Purchase

Higher-capacity transit services typically require passengers to purchase their fare before boarding a transit vehicle. Fare purchase is one of the least-standardized elements of transit service, as it depends on the particular characteristics of the transit system's fare structure and the equipment used to purchase tickets (Exhibit 10-8). There are frequently several steps involved in the process and may include:

- Selecting a ticket type (e.g., child, adult, senior);
- Selecting a fare type, destination, or amount (e.g., one-way, round-trip, all-day, two zones, airport station, $2.50);
- Selecting the number of tickets desired;
- Selecting a payment method (cash, card);
- Making the payment; and
- Receiving the ticket(s) and possibly a receipt or change.

The number of steps involved, the clarity of the sequence of the steps, the ease of determining the required fare, and the familiarity of the user with the transit system and the fare-purchasing process all play a role in determining how long it takes to process a transaction. As one example, WMATA has used 2.5 p/min as an average fare purchasing rate for its machines in station planning studies (*18*). Ticket machines that incorporate video displays should be designed and located so that the display is legible under a variety of conditions (Exhibit 10-8c). Ticket vending machines must be made accessible for persons with disabilities, including Braille writing, audible information, and other design features.



(a) Portland



(b) Baltimore



(c) Blocking glare in Seattle

Exhibit 10-8
Fare Machine Examples

At busier heavy rail stations, several ticket machines are typically provided to handle peak-passenger demand for tickets. At light rail and bus rapid transit stations, at least one ticket machine is provided on each platform, but some redundancy is desirable in case one machine is out of service. Staffed ticket booths are used at older heavy rail stations and at many commuter rail stations. Where distance-based fares are used,

addfare machines are usually placed inside the fare-paid area so that passengers with insufficient value left on their ticket can pay the balance of the fare.

Fare Control

Faregates limit the capacity of a circulation route by imposing restricted lateral spacing and by requiring pedestrians to perform an activity that consumes additional time. Faregates are typically applied at heavy rail stations to control fare payment. They are applied to a lesser extent at commuter rail, light rail, and bus rapid transit stations, due to the proof-of-payment system associated with most of these systems. Faregates are required to comply with the ADA Accessibility Guidelines, although turnstiles and some types of gates are not considered part of an accessible route.

Exhibit 10-9 illustrates the placement and operation of faregate configurations in a transit terminal. There are three different types of faregates applied in stations:

- Free admission (a barrier only),
- Mechanical coin- or token-operated, and
- Automated (using contactless smart cards or magnetic farecards).

Automated faregates using magnetic stripe farecards came into wide use starting in the 1970s, while contactless smart card systems were pioneered in Hong Kong in 1997 grew in usage throughout the 2000s. Both technologies can accommodate a variety of fare types (e.g., distance-based fares, peak and off-peak fares) and can generate useful passenger flow data. Free-admission gates (e.g., turnstiles or swinging gates) are used when no fare is collected, but passenger counts are desired. Some agencies—particularly ferry systems—use staff to check and collect tickets, but this form of fare collection is little used for rail transit applications in North America and Western Europe, except during special event situations, such as at sports stadia. Systems using automated faregates generally also have a channel available next to the station agent's booth to accommodate checking users with non-standard tickets (e.g., visitor passes with scratch-off dates).

Exhibit 10-9
Faregate Examples



(a) New York



(b) San Francisco

The effect of faregates on pedestrian flow will depend on the headway between pedestrians. When a pedestrian reaches a faregate, there must be sufficient time separation to allow that pedestrian to pass through the faregate before the next pedestrian arrives. If the times between successive pedestrians are too close, a pedestrian queue will develop. The capacity of a faregate is therefore determined by the minimum time required by each pedestrian to pass through.

Despite increasing concern for security, screening is not currently undertaken in most transit stations. However, planners of new stations or those in particularly sensitive locations may wish to make provision for screening either in the future or on an as-needed basis.

HORIZONTAL CIRCULATION

Walkways

The capacity of a walkway is controlled by the following factors:

- Pedestrian walking speed;
- Pedestrian preferred density;
- Pedestrian characteristics; usage of baggage, strollers, or bicycles; and presence of wheelchair users; and
- Effective width of the walkway at its narrowest point.

Speed

Normal walking speeds of pedestrians vary over a wide range, depending on many factors. Walking speeds have been found to decline with age. Studies have also shown that male walking speeds are typically faster than female walking speeds. Other factors influencing a pedestrian's walking speed include the following:

- Time of day;
- Weather and temperature;
- Pedestrian traffic composition, including wheelchair users;
- Trip purpose; and
- Reaction to surrounding environment.

Free-flow walking speeds have been shown to range from 145 ft/min (45 m/min) to 470 ft/min (145 m/min). On this basis, speeds below 145 ft/min (45 m/min) would constitute restricted, shuffling locomotion, and speeds greater than 470 ft/min (145 m/min) would be considered as running. A pedestrian walking speed typically used for design is 250 ft/min (75 m/min), which is approximately 3.0 mi/h or 4.5 km/h.

Walking speeds of elderly persons may be less. *TCRP Report 112/NCHRP Report 562* recommends a minimum walking speed of 3.5 ft/s (210 ft/min or 65 m/min) for timing crosswalk signals (*18*). This speed may have applications elsewhere when planning for the elderly in transit facilities.

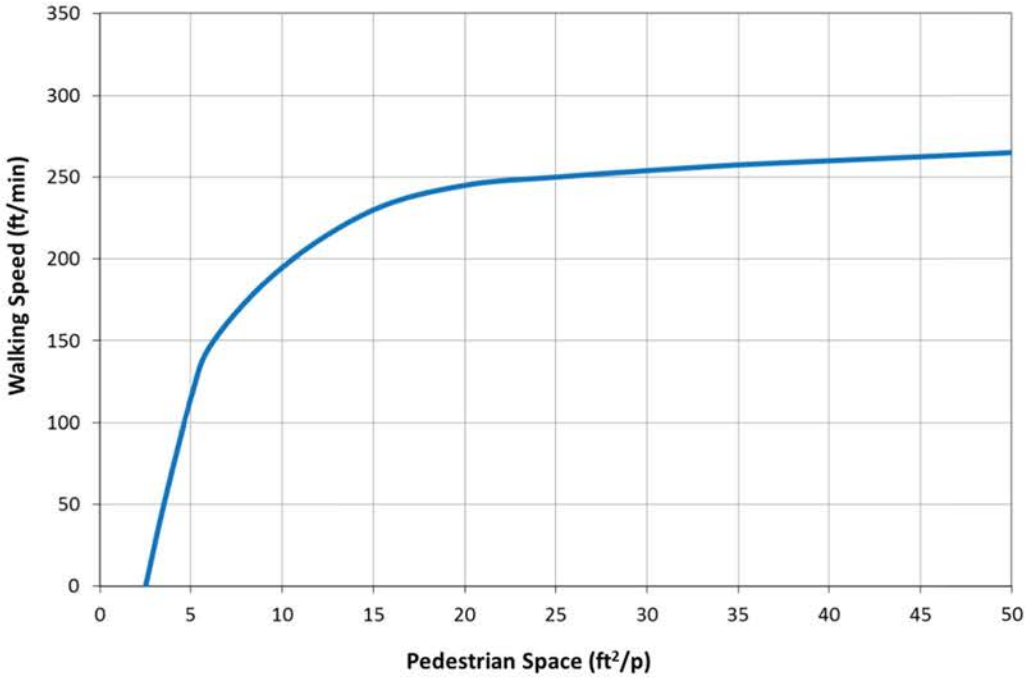
Density

Perhaps the most significant factor influencing pedestrian walking speed is density. Normal walking requires sufficient space for unrestricted pacing, sensory recognition, and reaction to potential obstacles. Increasing density reduces the available space for walking and it increases conflicts between pedestrians and therefore reduces walking speeds. This is an even greater concern for people who use mobility aids such as crutches, canes, and wheelchairs.

Density is the most significant factor influencing pedestrian walking speed.

Exhibit 10-10 shows the relationship between walking speeds and average pedestrian space (the inverse of density). Observing this exhibit, pedestrian speeds are free-flow up to an average pedestrian space of 25 ft² (2.3 m²) per person. For average spaces below this value, walking speeds begin to decline rapidly. Walking speeds approach zero, becoming a slow shuffle, at an average pedestrian space of approximately 5 ft² (0.5 m²) per person.

Exhibit 10-10
Pedestrian Speed on Walkways



Source: Fruin (*2*).

Note: A metric version of this exhibit appears in Appendix A.

Effective Walkway Width

The full walkway width will not be used by pedestrians.

The final factor affecting a walkway's capacity is the effective width available. Studies have shown that pedestrians keep as much as an 18-in. (0.5-m) buffer between themselves and adjacent walls, street curbs, platform edges, and other obstructions, such as trash receptacles, sign posts, and so forth. In practice, the width of the unused buffer depends on the character of the wall or obstruction, the overall width of the available walkway, and on the level of pedestrian congestion. In general, 18 in. (0.5 m) should be deducted next to platform edges and 12 in. (0.3 m) should be deducted next to walls and other obstructions more than 3 ft (1 m) tall. Obstructions 3 ft (1 m) tall or less may have a smaller buffer of 6 to 12 in. (0.2 to 0.3 m).

Exhibit 10-11 shows the relationship between pedestrian flow per unit of effective walkway width and average pedestrian space. Curves are shown for one-directional, bi-directional, and multi-directional (cross-flow) pedestrian traffic. As this exhibit shows, there is a relatively small range in variation between the three curves. This finding suggests that reverse and cross-flow traffic do not significantly reduce pedestrian flow rates, however there may be specific instances where this is not the case, for example, constrained or narrow walkway areas, cross passages where sightlines prevent

converging pedestrians from viewing one another, and areas where wayfinding decision making (or other activities that distract pedestrians) may occur.

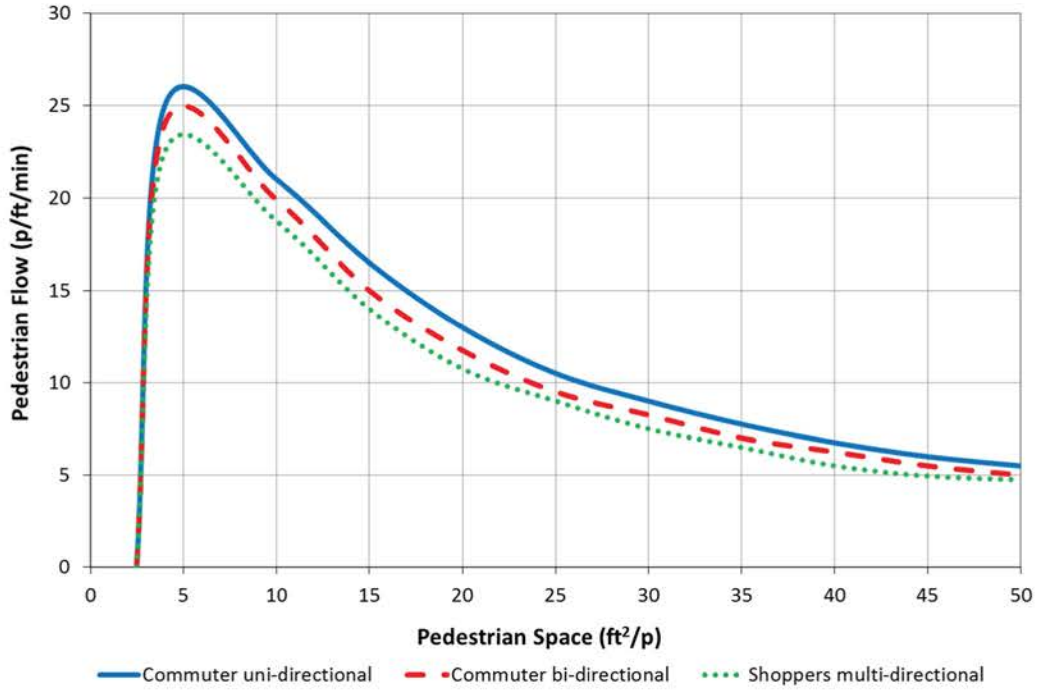


Exhibit 10-11
Pedestrian Flow on Walkways by Unit Width and Space

Source: Fruin (*2*).

Note: A metric version of this exhibit appears in Appendix A.

As shown in Exhibit 10-11, the maximum average peak-flow rates (26.2, 24.7, and 23.3 p/ft/min, or 86.0, 81.0, and 76.4 p/m/min, for one-directional, bi-directional, and multi-directional flow, respectively) occur at an average occupancy of 5 ft² (0.5 m²) per person. While this represents the maximum possible throughput, it represents a condition of extreme congestion, does not reflect the needs of mobility impaired persons, and creates a potentially unsafe condition. Therefore, it should not be used as a basis for design. The LOS concept of designing to a desired level of pedestrian comfort is recommended instead.

Multi-activity Passenger Circulation Areas

Some areas of transit stations include a variety of pedestrian activities within the same general space. People may be walking through, standing in line to buy tickets, waiting to meet someone, and shopping within the same space. Portions of these spaces may also be of little use to pedestrians, such as a corner beyond the major flow of pedestrians or concentrations of other activities.

Exhibit 10-12
Examples of Multiple Pedestrian Activities Within a Transit Station



(a) Grand Central Terminal (New York)



(b) Victoria Station (London)

Time–space analysis is used to study complex passenger circulation patterns involving multiple activities.

In such cases, either the pedestrian time–space analysis method is applied or pedestrian flows are simulated using pedestrian microsimulation software (*20*). Time–space analysis incorporates the space per person thresholds embodied in the LOS approach and factors them by the time spent engaging in a specific activity within a given space.

Moving Walkways

Moving walkways (Exhibit 10-13) are very common in larger airports, but have been applied less frequently in transit station contexts. Moving walkways are normally installed where large numbers of pedestrians traverse medium and longer distances, from approximately 100 to 1,000 ft (30 to 300 m), such as when connecting two relatively distant platforms at a transfer station. Individual moving walkways can be constructed in varying lengths, but they are rarely more than 400 ft (120 m) in length, with longer distances being covered by a series of moving walkways with a circulation space between each successive walkway.

Exhibit 10-13
Moving Walkway Examples (New York)





Moving walkways normally operate at a speed of 100 ft/min (30 m/min) but some operate at up to 160 ft/min (50 m/min). Thus, most moving walkways operate at less than walking speed. Moving walkways that accelerate pedestrians to a faster speed have been developed but have had limited success due to user difficulty in maintaining balance on entering and exiting and service reliability. A pair of moving walkways that accelerate in the middle of the run are operating at Toronto Pearson International Airport.

Design Factors

When planning moving walkways, the following factors should be considered:

- The pedestrian volumes moving in each direction. For longer multi-unit moving walkway systems, the volumes may differ in various segments as pedestrians access intermediate destinations.
- Adequate space, measured in corridor width, for moving walkways and a parallel walkway (*a*) to carry those who cannot or do not wish to use the moving walkway and (*b*) to serve as an alternate route when a walkway is undergoing maintenance.
- The ongoing cost of operating and maintaining the moving walkway.

VERTICAL CIRCULATION

Stairways

In stations where the platform area is grade separated from the rest of the station and the adjacent outside area, stairways traditionally have been applied as the primary vertical pedestrian movement system. Exhibit 10-14 shows typical treatments.



(a) Los Angeles



(b) Portland

Exhibit 10-14
Stairway Examples

The capacity of a stairway is largely affected by the stairway width. Unlike walking on a level surface, people tend to walk in lines or lanes when traversing stairs. The stairway width determines both the number of distinct lines of people who can traverse the stair and the side-to-side spacing between people. This spacing, in turn, affects pedestrians' ability to pass slower-moving pedestrians and the level of interference between adjacent lines of people. The consequence is that meaningful increases in capacity are not directly proportional to the width, but occur in increments of about 30 in. (0.75 m).

A stairway's capacity is largely affected by its width.

Unlike on walkways, a minor pedestrian flow in the opposing direction on a stairway can result in a capacity reduction disproportionate to the magnitude of the reverse flow. As a result, a small reverse flow should generally be assumed to occupy one pedestrian lane or 30 in. (0.75 m) of the stair's width. For a stair 60 in. (1.5 m) wide, a small reverse flow could consume half its capacity.

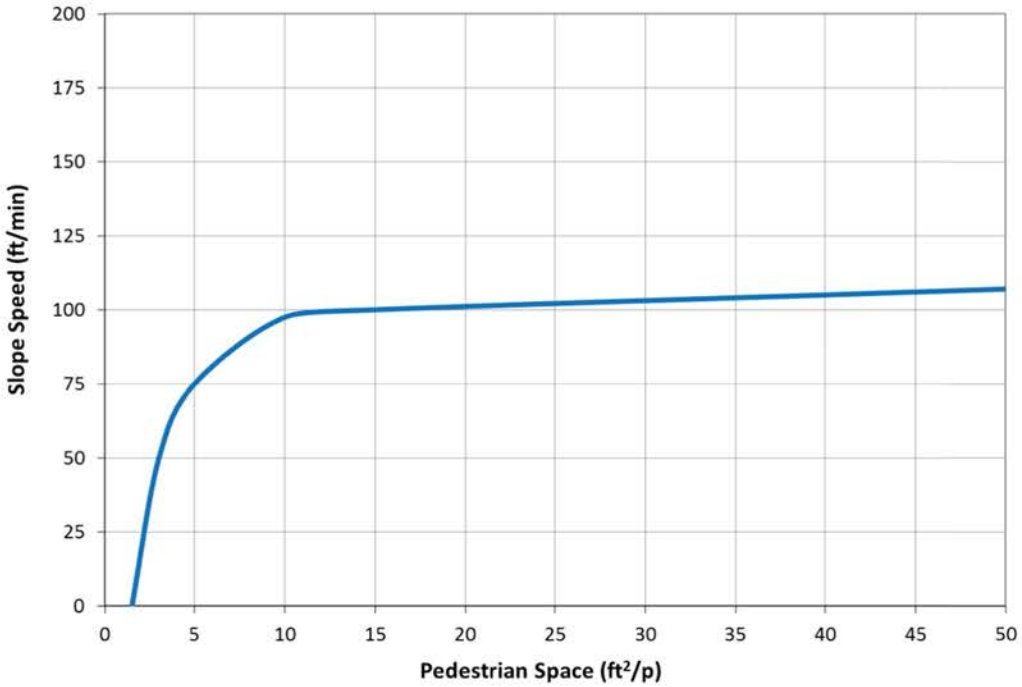
Critical passenger flows on stairways occur in the ascending direction.

Because pedestrians are required to exert a higher amount of energy to ascend stairs as compared with descending stairs, lower flow rates typically occur in the ascending direction. For this reason, when stairs serve both directions simultaneously or when the same stair will be used primarily in the up direction during some time periods and primarily in the down direction during other time periods, the lower ascending flow rate should be used for analysis and design.

Ascending speeds on stairs have been shown to range from 41 ft/min (12 m/min) to 68 ft/min (21 m/min), measured in the vertical dimension (as opposed to measuring along the incline). Descending speeds on stairs have been shown to range from 56 ft/min (17 m/min) to 101 ft/min (31 m/min), measured in the vertical dimension. Ascending speeds are also slower on stairs with greater rises because pedestrians slow as they become more tired toward the top. For general planning and design purposes, average speeds of 50 ft/min (15 m/min) in the up direction and 60 ft/min (18 m/min) in the down direction, measured in the vertical dimension, are considered reasonable. The angle of a stair's incline affects pedestrian comfort, safety, and speeds. While less-steep stairs decrease pedestrian speed measured on the vertical dimension, they increase speeds measured along the horizontal and diagonal dimensions and improve passenger comfort and safety. The vertical dimension is the overall height or rise of a stair; the horizontal dimension is the length or run of the stair; and the diagonal dimension is the length of the stair measured along the incline.

Exhibit 10-15 illustrates the relationship between ascending speeds and pedestrian space. This exhibit reveals that normal ascending speeds on stairs are approached at an average pedestrian space of approximately 10 ft^2/p (0.9 m^2/p). Above approximately 20 ft^2/p (1.9 m^2/p), faster walking pedestrians are able to approach their natural unconstrained stair climbing speed and pass slower-moving people.

Exhibit 10-15
Pedestrian Ascent Speed on Stairs



Source: Fruin (*2*).

Note: A metric version of this exhibit appears in Appendix A.

Exhibit 10-16 illustrates the relationship between flow rate on stairs in the ascending direction and pedestrians' space. As observed in this exhibit, the maximum ascending flow rate occurs at a pedestrian space of approximately 3 ft²/p (0.3 m²/p). For this lower pedestrian space, ascending speeds are at the lower limit of the normal range. In this situation, forward progress is determined by the slowest moving pedestrian. Although the maximum flow rate represents the capacity of the stairway, it should not be used as a design objective (except perhaps for emergency situations). At capacity, ascending speeds are restricted and there is a high probability of intermittent stoppages and queuing.

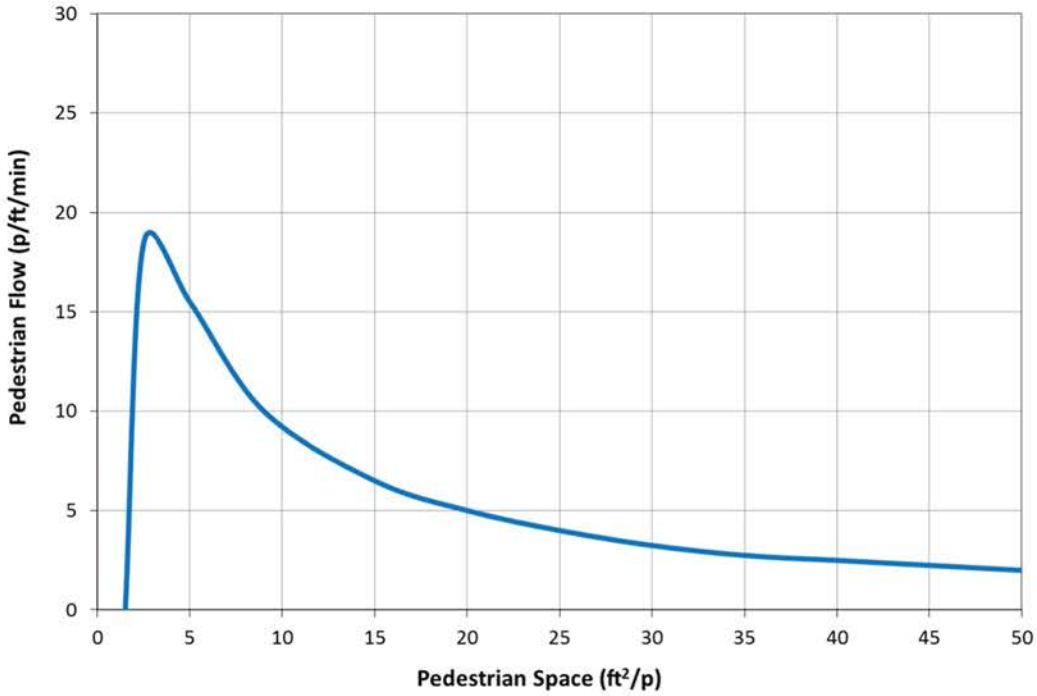


Exhibit 10-16
Pedestrian Flow Volumes on Stairs

Source: Fruin (*2*).

Note: A metric version of this exhibit appears in Appendix A.

Passenger queuing can occur at the destination end of stairways, if people are forced to converge on too constricted a space. This can be a serious design deficiency in certain terminal facilities, with potential liability exposure. Because this can cause a backup on the stairs, it is even more critical than ensuring that adequate space is provided at entry points.

Escalators

Design Factors

Escalators (Exhibit 10-17) have been installed in many transit stations where there are grade separations between the platforms, other areas of the station, or the outside areas. Typically, escalators are used to supplement stairways and, in many cases, the two facilities are located adjacent to one another. When possible, co-location of stairs, escalators, and one end of an elevator is important for pedestrians with visual

impairments or service animals, as these pedestrians do not use escalators, and guide dogs are trained to avoid escalators.

Exhibit 10-17
Escalator Configuration Examples



(a) Denver



(b) Los Angeles

The capacity of an escalator is dependent upon the entry width and operating speed. In the United States and most other countries, the normal angle of incline of escalators is 30 degrees, and the stair width is either 24 or 40 in. (0.6 or 1.1 m) at the tread. Operating speed is typically 90 ft/min (27.4 m/min), but a higher speed of 120 ft/min (36.6 m/min) is occasionally used when allowed by code and insurance underwriters. These operating speeds are within the average range of stair-climbing speeds.

Studies have shown that increasing the speed of an escalator from 90 to 120 ft/min (27.4 to 36.6 m/min) can increase the capacity by as much as 12%, as people enter the escalator more rapidly. Another interesting finding is that the practice of walking on a moving escalator does not significantly increase escalator capacity, although it does increase a person's overall travel speed. An escalator's capacity is established at its entrance and a moving pedestrian must occupy two steps at a time, thereby reducing the standing capacity of the escalator (*2*).

The size of the queuing area provided at the exiting end of an escalator is an important consideration.

As with stairways, both ends of an escalator require some queuing area if passenger demand exceeds the capacity of the facility. A clear area at the end of an escalator is especially important, as passengers are unable to queue on a moving escalator and will be pushed into the area at the end. The area at the end of an escalator should be wider than the escalator itself to allow people to quickly pass anyone who has stopped at the end of the escalator, and this area should be free of any queues, such as for another escalator, fare gate, ticket machine, vending machine, or automated teller machine. This clear area should generally be at least 20 ft (6 m) in length.

Ramps, Lifts, and Elevators

Ramps, lifts, or elevators are required in new or modified grade-separated facilities to meet ADA requirements.

Ramps, lifts, or elevators are required in all new transit or modified transit stations in the United States to meet ADA requirements when level changes are required to access or move within a station. These requirements are defined in the ADA Accessibility Guidelines (*3*).

Ramps

Ramps may be provided primarily to serve people with disabilities, but are also useful to passengers with baby carriages, wheeled luggage, or heavy packages. Some persons with disabilities who can negotiate stairs will prefer a ramp and will use one if it is available and convenient. Ramps may also be designed for general passenger use in place of stairs or steps. While ramps generally should not have a slope greater than 1:12

(8.3%), an even more gradual slope (1:20 to 1:16, or 5% to 6.25%) is preferred wherever feasible. The ADA requires level landings at the ends of each ramp, and at the end of each ramp run. In addition, the ADA limits the lengths of individual ramp runs, and the maximum rise of each run.

Used as an alternative to elevators or lifts, ramps have the advantage that they require little maintenance, have no operating cost, and are available to a broader spectrum of passengers who may choose them.

Lifts

Open lifts are sometimes used in stations to move passengers using mobility aids between levels a few feet apart, in locations where a ramp is not feasible.

Elevators

Elevators may be provided at one end of a platform or in the center. Separate elevators may be needed between the street and the concourse (mezzanine), and between the concourse and the platforms. Side platform stations generally require at least two elevators, whereas a center platform station may only require one. In the case of especially deep stations, as in New York City (e.g., 168th, 181st, and 191st Streets), Washington, DC (Forest Glen), and Portland (Washington Park), elevators are the sole means of passenger access to and from stations, not including emergency stairs.

Ongoing elevator maintenance is important for keeping stations consistently ADA accessible.

Good, ongoing elevator maintenance is important for maintaining accessibility for mobility-impaired passengers at transit stations. As a cost-saving measure, most transit stations provide only one elevator per platform, or from the concourse level to the street. However, when any of these elevators is out of service, the station is effectively inaccessible to mobility-impaired passengers. Although these passengers can be served during these times by directing them to alternate stations and providing them with paratransit bus service to their destination, it is much less convenient for these passengers and serves to reduce the accessibility and convenience of the transit system as a whole to passengers with disabilities.

Exhibit 10-18 shows typical elevator applications in a transit station. Traffic flow on elevators differs from other vertical pedestrian movers. As opposed to escalators and stairs, which provide constant service, elevators provide on-demand service. Because of its characteristics, determining the capacity of an elevator is similar to determining the capacity of a transit vehicle.



(a) Station access (Portland)



(b) Station circulation (Los Angeles)

Exhibit 10-18
Elevator Application Examples

PLATFORMS AND WAITING AREAS

Bus Stop and Station Platforms

Transit platforms function as waiting and queuing areas for passengers waiting for a transit vehicle to arrive, and as circulation areas for both departing and arriving passengers. The effective platform area required is based on maintaining a minimum LOS for queuing and circulation. It is important to note that transit platforms have critical passenger holding capacities, which, if exceeded, could result in passengers being pushed onto tracks or roadways.

It is important to consider the characteristics of passengers and provide for passengers who may require additional space. Exhibit 10-19 illustrates typical side and center platform configurations at stations. Passengers do not spread out evenly on platforms, however, so that a platform that has enough space overall may experience congestion in specific areas, especially shortly after a transit vehicle arrives. These patterns are best analyzed through the use of pedestrian microsimulation software. The placement and direction of stairs, escalators, and other means of accessing platforms can have a significant effect on the distribution of passengers on a platform and can also enhance or impede exit from the platform. Thus platform loading is a key design consideration when planning these elements.

Exhibit 10-19
Transit Station Platform Configurations



(a) Center platform (Philadelphia)



(b) Side platform (Boston)

ADA considerations for station platforms.

The ADA affects the design of various platform elements, including platform edge treatments. For example, stairs with an open sloping underside must be protected so that people with a visibility impairment will encounter a barrier before potentially striking their head against the sloped bottom of the stairway. ADA does not directly affect the overall area or width required for a platform, but an accessible route at least 36 in. (915 mm) wide must be maintained along the platform. When the accessible route is next to the platform edge, the 24-in. (610-mm) platform edge treatment area is not included, so the total clear width along a platform edge must be 60 in. (1,525 mm).

Shelters, Waiting Rooms, and Seating

Shelters provide protection from rain, wind, and sun.

Shelters are typically used with bus stops or transit stations that are largely unenclosed to provide protection from rain, wind, and sun. In some cases they may also be heated. The design of shelters is influenced both by local climate and the desired level of amenity. For example, in colder, windier climates, shelters may be more enclosed with walls whereas in milder climates they may have only partial walls to act as a wind break. In a bus rapid transit system, station shelters may incorporate the

additional function of providing a fare-controlled area and may encompass a raised platform to provide high-level boarding.

Shelters often have a modular design for cost effectiveness, branding consistency, and to provide flexibility for installing multiple modules at busier stations or single modules at stations with lighter traffic. Transparent sides on shelters improve both real and perceived security, although one or more sides of a shelter may be used for advertising to pay part or all of the cost of the shelters. Another consideration is electrical supply to shelters and integral lighting and information systems.

Waiting rooms are typically associated with larger bus terminals or rail stations and tend to provide a greater degree of climate control than shelters. While shelters may have a very limited number of seats or benches, waiting rooms tend to provide more. Waiting rooms may also contain ticket windows, ticket machines, telephones, and vending machines, and may provide a climate-controlled area for passengers who use those facilities.

Seating may be provided anywhere in a station. Providing seating in different areas, such as on a platform and in a waiting room, offers passengers the opportunity to select seating most convenient to them. Seating is particularly useful for the elderly and when transit service is less frequent, resulting in increased passenger waiting times in a station. When designing seating and determining the desired number of seats, it should be recognized that closely spaced seats may not be used due to discomfort at close interpersonal spacing or partial occupancy by a person sitting in the next seat, even though additional people may wish to sit. Seat perches and lean bars may provide some useful additional comfort for waiting passengers in locations where providing full-size seating is not possible.

4. VEHICLE CIRCULATION AND STORAGE

TRANSIT VEHICLES

Off-Street Bus Stops

Off-street bus stops are typically provided as part of an all-bus transit center or in conjunction with a rail station. For small transit stations, the number of berths (loading areas) is small, with a fairly simple access and layout configuration. For larger terminals, numerous berths and more sophisticated designs are applied.

Determining the Required Number of Bus Berths

The number of bus berths provided at a bus station depends on a variety of factors, including the size and layout of the site; the number of routes passing through the station and their headways; and the number of routes terminating at the station, their headways, their scheduled layover/recovery time, and the type of buses and services (e.g., urban, regional, intercity).

One method for determining the *maximum* required bus berths is as follows (*21*):

- Routes running through the station require two berths to pick up and drop off passengers (one for each direction of the route).
- Routes terminating at the station require one berth to pick up passengers and, potentially, additional layover berths, if it is likely that one or more following buses on a route would arrive prior to the end of a given bus's recovery time.
- The number of berths needed for a route is determined by the route's recovery time at station divided by the route headway, multiplied by a factor of 1.2 to account for early-arriving buses, rounded up. For example, a route with 5-minute headways and a 10-minute recovery at the station would require (10 / 5 × 1.2) = 2.4 berths, rounded up to 3 berths. If the calculation indicates that only one berth is required, layover needs can be met in the berth used for passenger pick-up and no separate layover berth is required.
- When layover berths are required, an additional berth shared by all terminating routes should be provided in a convenient location (from the passenger point-of-view) for dropping off passengers. More than one berth might be needed, depending on bus volumes and arrival patterns.
- Boarding berths should also be located at convenient locations for passengers; layover berths can be situated in more remote portions of the site.
- Headways and recovery time may vary over the day, so the combination that produces the greatest required number of berths should be used in determining the maximum number of berths needed. Consideration should also be given to sizing the station to accommodate future growth (i.e., anticipated route headways in the long term).

This arrangement provides one berth for each route or route direction, which provides a simple-to-understand configuration for passengers, and also works best for accommodating timed transfers. It also provides sufficient layover berths to serve all of the buses that would likely be on the site at the same time. When available space or

construction costs are significant constraints, the number of berths can be reduced by investigating the potential to share berths:

- Routes that would not use the station at the same time (because they operate at different times of day or pass through the station at different times during the hour) could share berths.
- Layover berths needed only to accommodate early buses could potentially be shared, but with an increased risk of the number of buses on site exceeding the number of layover berths provided, if both buses sharing a layover berth arrived early.
- If timed transfers are not used, stops could also operate like larger on-street stops, with multiple loading areas per stop and arriving buses pulling forward to the first available berth.

Berths that are shared between routes must be long enough to serve the longest bus operated on any of the routes sharing the berth. The number of routes sharing a single berth should be kept to a minimum where possible to minimize passenger confusion.

"Intelligent" bus stations have been developed in some European cities (*10*). Buses are assigned a specific berth as they approach within a few minutes of the station and electronic signage at the station informs passengers at which berth their bus will arrive. This arrangement is similar to a hub airport, where a particular gate may serve flights to many different destinations over the course of a day. Although this system does not reduce the total number of berths that are needed for peak conditions, it does offer the potential to provide a higher level of amenities at the most convenient (and therefore most heavily used) berths; a central passenger waiting area is also typically provided.

Bus terminals should be sized to provide ample space for passenger circulation, queuing, and amenities. However, terminals that are larger or more spread out than necessary to serve their functions can increase passenger transfer times and operating costs, and may be less secure.

Bus Berth Designs

Exhibit 10-20 illustrates various berth designs. Four types of bus berths are typically applied: linear, sawtooth, drive-through, and pull-in/back-out. Many larger bus-operating transit agencies have developed design guidance for bus berths specific to their bus fleets. Preferably, desired operating patterns should dictate the type of bus berths used, rather than the berths placing constraints on the operation. A bus terminal may have more than one type of berth to best serve different operating patterns and characteristics.

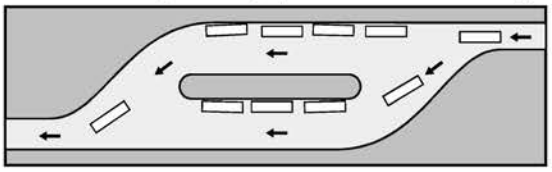
Linear berths can operate in series and have capacity characteristics similar to on-street bus stops. Their main advantage is that they require the least curb space—as long as buses do not need to move in and out of berths independently of each other. If independent bus movement is required, linear berths can actually require more curb space than other types (e.g., sawtooth), as buffer space is needed between each bus stopping position to allow buses to enter and exit each berth.

Sawtooth berths are a popular design, as they permit independent movement into and out of the berth, while retaining the ability to design bus stops around either a central island platform or along the perimeter of the bus roadway. Both of these types of stations designs minimize the need for pedestrian crossings of the bus roadway.

Shallow sawtooth berths laid end to end are increasingly used in transit terminal design.

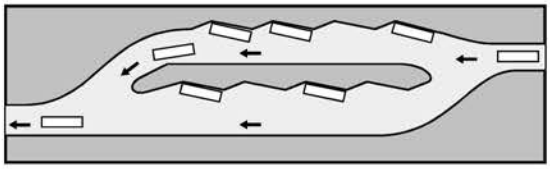
Exhibit 10-20
Bus Berth Designs and Examples

(a) Linear
Linear berths are less efficient than other berth types and are typically used when buses will occupy the berth for a short time (for example, at an on-street bus stop).



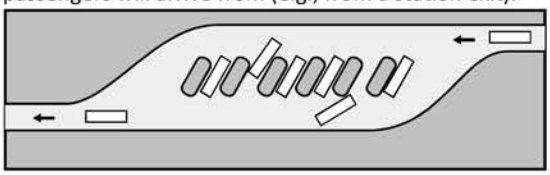


(b) Sawtooth
Sawtooth berths allow independent movements by buses into and out of berths and are commonly used at bus transfer centers.





(c) Drive-Through
Drive-through berths allow bus stops to be located in a compact area, and also can allow all buses to wait with their front destination sign facing the direction passengers will arrive from (e.g., from a station exit).





(d) Pull-In/Back-Out
Pull-in/back-out berths require buses to back out, but allow a number of berths in a compact area. They are typically used when buses will occupy the berth for a long time (for example, at an intercity bus terminal).

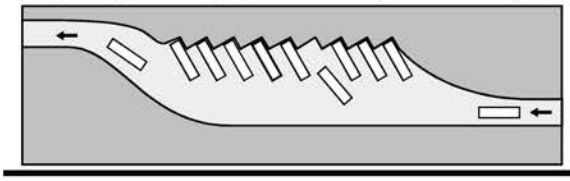




Photo locations:
(a) Newport, RI;
(b) Olympia, WA;
(c) Vail, CO; and
(d) Newark Airport, NJ.

Drive-through berths provide a series of boarding islands placed at a 45° or 90° angle to the flow of bus traffic through the station. They provide a compact bus berth layout, but require passengers to cross the bus roadway to access the islands, which increases potential conflicts between buses and pedestrians.

Pull-in/back-out berths are rarely used in bus transit stations, except in very constrained sites, due to the hazards of backing a bus out with very limited driver visibility (back-up cameras help mitigate this hazard to some degree). They are

sometimes used in intercity bus terminals, where buses occupy berths for long periods of time, and staff may be available to guide bus drivers out of the berths.

The National Transportation Safety Board recommends that transit facility designs incorporating sawtooth berths, or other types of berths that may direct errant buses towards pedestrian-occupied areas, should include provisions for positive separation (such as bollards) between the roadway and pedestrian areas sufficient to stop a bus operating under normal parking area speed conditions from progressing into the pedestrian area (*22*).

On-Street Bus Stops

On-street bus stops can be designed using the procedures in Chapter 6, Bus Transit Capacity. Given a known volume of buses to be served, dwell time and clearance time characteristics, and a design level of reliability (i.e., probability that a bus can enter a loading area immediately upon arriving at the stop), the number of berths required to serve the demand can be calculated.

PRIVATE VEHICLES

Park-and-Ride Facilities

Park-and-ride facilities are sized based on estimated demand.

At selected transit stations, park-and-ride facilities for autos are provided (Exhibit 10-21). Generally, park-and-ride facilities are located along the outer portions of a rail line or busway, in the outer portions of central cities, and in the suburbs in metropolitan areas. At many locations, park-and-rides are integrated with bus transfer facilities. Their size can vary from as few as 10 to 20 spaces at minor stations to more than 1,000 spaces at major stations. Most park-and-ride facilities are surface lots, with pedestrian connections to the transit station. Due to their added cost, parking structures are used where land is at a premium and a substantial number of parking spaces are required. Some of these facilities contain several thousand spaces and have direct access to freeways.



(a) Cleveland



(b) Houston

Exhibit 10-21
Park-and-Ride Lot Examples

Surface parking lots around transit stations occupy potentially valuable space that could be used for transit-oriented development. Instead, parking for commuters can be integrated with transit-oriented development. One option is to utilize parking structures in place of surface parking to free additional land for mixed-use development. Parking garages can also contain street-level commercial space to better integrate them with surrounding development. Parking, whether structured or surface,

can also be moved 100 to 300 ft (30 to 90 m) from the station if the area between is developed in a pedestrian-friendly manner. In a mixed-use development, the same parking spaces used by commuters during the daytime can also serve residents, shoppers, and diners during the evening and weekend.

The required number of park-and-ride spaces at a transit station typically involves identifying the demand for such parking, and then relating the space demand to the ability to physically provide such a facility within cost constraints. Parking spaces in park-and-ride facilities typically have a low turnover during the day, as most persons parking at transit stations are commuters who are gone most of the day. In larger urban areas, the regional transportation model will have a mode split component which will help identify park-and-ride demand at transit station locations. This information is particularly applicable for new rail line or busway development. Where the regional model does not have the level of sophistication to provide such demand estimates, then park-and-ride demand estimation through user surveys and an assessment of the ridership sheds for different station areas would be appropriate.

The following are illustrative ranges of the number of parking spaces provided per daily boarding passenger at U.S. public transit stations (*23*):

- Commuter rail: 0.4 to 0.6
- Heavy rail: 0.4 to 0.6 typical, range 0.1 to 1.1
- Light rail: 0.2 to 0.3 typical, range 0.1 to 1.2

The wide range of parking spaces per boarding passenger at light rail and heavy rail stations reflects variations in the mix of walking, bicycling, feeder bus, and kiss-and-ride trips at specific stations, along with variations in development densities around each station and planned long-term passenger volumes at a station (*23*).

TCRP Report 153: Guidelines for Providing Access to Public Transportation Stations (*23*) overviews planning, operating, and conceptually designing park-and-ride lots. It also compares the costs of surface and structured parking for various land costs.

Kiss-and-Ride Facilities

Kiss-and-ride facility capacity is governed by space required for passenger pick-ups.

Kiss-and-rides are dedicated areas at transit stations where transit patrons can be dropped off and picked up by another person in a private vehicle (Exhibit 10-22). Short-term parking is based on the need to serve vehicles waiting to pick up transit riders, as the drop-off requires no parking maneuver (although curb space is needed to handle the drop-off). Parking times for vehicles waiting to pick up passengers averages 7–8 min per vehicle (*23*). As with park-and-ride facilities, the sizing of kiss-and-ride facilities is reflective of the demand and physical constraints of the site.



(a) Denver



(b) Boston



(c) Toronto

Exhibit 10-22
Kiss-and-Ride Examples

Bicycle Access and Parking

Bicycle access can constitute a significant share of the boarding passengers at transit stations: for example, it provided more than 6% of the access mode share at five BART rail stations in 2008 (with a high of 11% at Ashby Station). Many of the factors that encourage bicycling as a transit access mode—for example, bicycle facility quality in the station catchment area, topography, weather, traffic volumes and speeds, and the local bicycling culture—are outside the control of transit agencies; however, the provision of high-quality secure bicycle storage facilities at stations does influence the use of bicycles as an access mode (*23*).

Bicycle storage may be provided at transit stations where demand exists and space allows. Bicycle racks provide a simple, relatively low-cost approach and can hold a large number of bicycles in a relatively small space, but the bicycles are subject to potential damage and theft. Enclosed bicycle lockers and cages provide added protection from theft and from weather, but are more costly and require more space. The demand for bicycle spaces will vary greatly by station and may be best assessed by observation and test provision of facilities. Exhibit 10-23 illustrates different types of bicycle parking options, while Exhibit 10-24 presents their pros and cons.

When bicycles are allowed on board transit vehicles, and elevation changes are required to travel between transit vehicles and station entrances, elevators and ramps are options for facilitating bicycle movement. Stair channels that allow bicyclists to roll their bicycle up and down stairs may also be an option, but their design also needs to accommodate ADA requirements for stairways. At the time of writing, no U.S. standard existed for stair channel design. The Chicago Transit Authority and the Bay Area Rapid Transit District were among the transit agencies that had installed channels at selected stations (*24*).

Exhibit 10-23
Bicycle Parking Examples



(a) Bicycle racks (Clearwater, FL)



(b) Bicycle lockers (San Jose)



(c) Storage cage (Fredericia, Denmark)



(d) Bike-share station (Minneapolis)

Exhibit 10-24
Summary of Secure Bike Storage Options

	Bike Stations	Bike Lockers: Subscription	Bike Lockers: Shared System	Self-Service Bike Cages
Description	Provides valet attended parking. Other services (e.g., lockers, changing rooms, showers, bicycle repair) optional.	Metal or plastic crates for storing bicycles. Self-serve.	Metal or plastic crates for storing bicycles. Self-serve.	Bicycle racks behind a locked door. Free-standing cages, or fenced-in room.
Method of access	Electronic key, must purchase membership.	Subscribers assigned a specific locker.	Electronic key accesses network of lockers on first-come, first-served basis.	Electronic or other entry through door for subscribers.
Typical fees	Monthly or annual subscription.	Deposit and monthly or annual fee.	Fees charged by use (several cents per hour).	Monthly or annual subscription.
Benefits	High level of service and security.	Users guaranteed a spot. More secure than racks.	Higher utilization than subscription lockers. Users pay only for what they use. More secure than racks.	Lower operating costs than attended parking. More secure than open racks. High potential utilization.
Cons	High capital and operating costs. Additional agency-owned infrastructure.	Potential for patrons to store items other than bicycles. Subscription waitlists common. Low utilization.	Potential for patrons to store items other than bicycles. Electronic payment system increases operating costs.	Additional agency-owned infrastructure. Lower security and service compared to attended parking.

Source: *TCRP Report 153* (*23*).

5. STATION ELEMENTS AND THEIR CAPACITIES

INTRODUCTION

This section provides computational methods for sizing the basic elements that might be found in a transit station, working from the outside of the station inward to the transit platform, following the same pattern used in Section 3.

Terms used in this chapter for evaluating pedestrian circulation are defined as follows:

- *Pedestrian capacity*: the maximum number of people who can occupy or pass through a pedestrian facility or element, expressed as persons per unit of area per minute or as persons per unit of width per minute. Both a maximum "absolute" capacity reflecting the greatest possible number of persons who can pass through and a "design" capacity representing the maximum *desirable* number of pedestrians are applied in appropriate ways. Higher "theoretical" capacities are sometimes identified (e.g., for escalators and moving walkways), but are not based on practical experience and are not generally applicable in analysis or design.
- *Pedestrian speed*: average pedestrian walking speed, generally expressed in units of feet or meters per minute or per second. In pedestrian simulation modeling, a range of pedestrian speeds may be used in place of an average speed, better representing the variability in pedestrian activity.
- *Pedestrian flow rate*: number of pedestrians passing a point per unit of time, expressed as persons per minute or other time period; "point" refers to a line across the width of a walkway, stairway, or doorway, or through a pedestrian element such as an escalator or fare control gate.
- *Pedestrian flow per unit width*: average flow of pedestrians per unit of effective walkway width, expressed as persons per inch, foot, or meter of width per minute.
- *Pedestrian density*: average number of persons per unit of area within a walkway or queuing area, expressed as persons per square foot or meter.
- *Pedestrian space per person*: average area available to each pedestrian in a walkway or queuing area, expressed in terms of square feet or square meters per person; this is the inverse of density. The space normally required by people varies according to the activity they are engaged in and increases with walking speed. It is important to consider the type and characteristics of the pedestrians. For example, the area required by a person using a wheelchair or transporting luggage or packages is greater than for a person standing without items.
- *Pedestrian time-space*: the space normally required by pedestrians for various activities (walking across a space, queuing, buying a ticket, shopping, etc.) multiplied by the time spent doing the activity within a specific area.
- *Effective width or area*: the portion of a walkway's or stairway's width or the area of a space that is normally used by pedestrians. Areas occupied by physical obstructions and buffer areas adjacent to open platform edges, walls, and obstructions are excluded from effective width or area.

STATION ACCESS

Doorways

Doorway Level of Service

The LOS criterion selected to evaluate doorways (Exhibit 10-25) should be the same as that used for evaluating walkways. The objective is to maintain a desirable average pedestrian flow rate (or walking speed) throughout the walkway system. Consideration should be made of pedestrian characteristics, including provisions for passengers with luggage, bicycles, strollers, wheelchairs, or other mobility aids.

Exhibit 10-25
Doorway LOS

LOS	Pedestrian Space (ft^2/p)	Expected Flows and Speeds: Avg. Speed, *S* (ft/min)	Expected Flows and Speeds: Flow per Unit Width, *v* (p/ft/min)	*v/c*
A	≥ 35	260	0–7	0.0–0.3
B	25–35	250	7–10	0.3–0.4
C	15–25	240	10–15	0.4–0.6
D	10–15	225	15–20	0.6–0.8
E	5–10	150	20–25	0.8–1.0
F	< 5	< 150	*Variable*	*Variable*

LOS	Pedestrian Space (m^2/p)	Expected Flows and Speeds: Avg. Speed, *S* (m/min)	Expected Flows and Speeds: Flow per Unit Width, *v* (p/m/min)	*v/c*
A	≥ 3.3	79	0–23	0.0–0.3
B	2.3–3.3	76	23–33	0.3–0.4
C	1.4–2.3	73	33–49	0.4–0.6
D	0.9–1.4	69	49–66	0.6–0.8
E	0.5–0.9	46	66–82	0.8–1.0
F	< 0.5	< 46	*Variable*	*Variable*

Source: Fruin (*2*).
Note: *v/c* = volume-to-capacity ratio.

Doorway Capacity

The capacity of a doorway will be based solely on the width of the doorway if it is normally open, but will be reduced if the door is normally closed so that pedestrians have to open it. The capacity of a normally closed door is thus further affected by the difficulty of opening the door, although this effect is reduced if a steady flow of pedestrians keeps the door open for extended periods.

Exhibit 10-26 summarizes observed average headways for different types of doorways. Although it is recommended that headways be recorded at doorways similar in design and operation to the one under investigation, the values in Exhibit 10-26 may be used if field data are not available, with the lower value representing closer to a minimum headway.

Type of Entrance	Observed Average Headway (s)	Equivalent Pedestrian Volume (p/min)
Free swinging	1.0-1.5	40-60
Revolving, per direction	1.7-2.4	25-35

Source: Fruin (*2*).

Note: Values assume each doorway serves one pedestrian lane.

Exhibit 10-26
Observed Average Doorway Headway and Capacity

Determining the Required Number of Doorways

The following is a list of steps recommended for determining the required number of doorways:

1. Based on the desired LOS, choose the maximum pedestrian flow rate from Exhibit 10-25.
2. Choose an analysis period appropriate to the location of 15 min or less.
3. Estimate the pedestrian demand during the analysis period.
4. Compute the design pedestrian flow (persons per minute) by dividing the demand by the number of minutes.
5. Compute the required width of the doorway (in feet or meters) by dividing the design pedestrian flow by the maximum pedestrian flow rate.
6. Compute the number of doorways required by dividing the required entrance width by the width of one doorway (always round up).
7. Determine whether the design pedestrian flow exceeds the entrance capacity by following the procedures below.

Determining Entrance Capacity

As discussed above, the capacity of a doorway is based on the width of the doorway and the number of people who can pass through per minute. The following steps may be used to compute the capacity for a given number of entrances:

1. Determine the number of pedestrians who can pass through in 1 minute. Since doorways may display different characteristics, this should be done through field observations at the doorway or one of similar configuration. If field observations are not possible, the lower volume value from Exhibit 10-26 may be used.
2. Compute total entrance capacity (persons per minute) by multiplying the equivalent pedestrian volume by the number of doorways.
3. Adjustments should be made as appropriate to reflect special pedestrian characteristics.
4. Compute hourly pedestrian capacity by multiplying the total entrance capacity by 60.

Emergency Evacuation Capacity

For emergency evacuation purposes, the 2010 edition of NFPA 130 (*1*) requires a minimum doorway or gate width of 36 in. (910 mm). The evacuation capacity of single-leaf doors or gates is 60 p/min. The evacuation capacity of bi-parting doors and gates is based on width: 2.08 p/in./min or 0.0809 p/mm/min. Except where the fare collection

equipment provides unobstructed egress during an emergency, gates must provide at least half of the exit capacity.

Fare Purchase

Ticket Vending Machine Service Times

Because of the range of ticket vending machines (TVMs) in use, and because fare policies are unique to each agency, it is difficult to provide standard service times for TVMs. It is recommended that service times be recorded at machines similar in design to the type under investigation. Fare payment technology continues to evolve and innovations such as automatic recharging of smart card balances and fare payment via mobile telephone will make it less necessary for riders to use TVMs in the future.

Determining the Required Number of Ticket Vending Machines

TCRP Report 80: A Toolkit for Self-Service Barrier-Free Fare Collection (*25*) identifies two potential methods for determining the number of TVMs required at a station:

1. Install sufficient TVMs so that peak-period queues do not exceed "tolerable" levels, except during periods of unusually high demand.
2. Install sufficient TVMs to meet off-peak demand, and supplement them with on-site fare sales during peak times.

Even when only one machine is needed to serve peak demand, a second machine may be needed as an alternate if one machine is out of service; otherwise, the agency will need to develop a policy for accommodating passengers not able to pay their fares when the single machine is out of service.

A simple process for determining the required number of TVMs at a station or entrance is given by Equation 10-1 (*25*):

Equation 10-1

$$N_{TVM} = \frac{P_{arr} p_t}{\left(\frac{3{,}600}{t_t}\right)}$$

where

N_{TVM} = number of required TVMs (round up),
P_{arr} = design number of arriving passengers at a station or entrance (p/h),
p_t = proportion of arriving passengers purchasing a ticket,
3,600 = number of seconds in an hour (s/h), and
t_t = average transaction time (s/p).

The number of TVMs calculated by Equation 10-1 provides sufficient capacity to meet demand over the course of an hour, but it does not prevent queuing from occurring within the hour, due to variations in passenger arrival patterns and individual transaction times. Therefore, an additional queuing analysis may be desirable to determine the probability that an arriving passenger would experience a waiting time exceeding a desired maximum value.

Ticket Validators

Where a proof-of-payment fare system is utilized, ticket validators may be used to validate or cancel a ticket with a time stamp to indicate that the ticket has been used and is valid for travel during a specific time period. Ticket validators are placed both for convenience and clarity to travelers and in a position that is consistent with local policy on where tickets must be validated (i.e., the extent of fare-paid areas). When validation is required before boarding a vehicle, validators are placed on station platforms or boarding areas. Validators may also be placed on vehicles if validation is allowed just after boarding, but this also introduces the possibility that some passengers may validate only when they see an inspector approaching on the vehicle. The number and placement of validators should be sufficient to serve boarding passengers without unduly diverting passengers from their routes to the transit vehicle or to cause unnecessary clustering to reach a validator.

Fare Control

Faregate Capacity

Different fare media and reader systems are in use including tickets that are transported through a reader and both contact and contactless cards. Different processing speeds may be found within each of these categories depending on the mechanical characteristics of the gate and the technologies applied in each system. Generally, however, a well-functioning contactless system tends to be faster than those requiring contact, and contact systems are generally faster than systems that transport tickets. Determining actual processing speeds of a particular fare gate system requires measurement under real-world conditions.

For reference, Exhibit 10-27 summarizes observed average headways for different types of faregates. However, it is recommended that, where possible, headways be observed at faregates that are of a similar design and operation to those under investigation. Observations should be made when a faregate is operating at maximum capacity, as evidenced by a queue at the entry to the gate.

Exhibit 10-27
Observed Average Faregate Headways and Capacities

Type of Entrance	Observed Average Headway (s)	Equivalent Pedestrian Volume (p/min)
Free admission (barrier only)	1.0–1.5	40–60
Ticket collection by staff	1.7–2.4	25–35
Single-slot coin- or token-operated	1.2–2.4	25–50
Double-slot coin-operated	2.5–4.0	15–25
BART (transported magstripe ticket, low bi-leaf gate)	2.3–2.9	21–26
London (transported magstripe ticket, high bi-leaf gate)	2.4	25
New York (swiped magstripe ticket, turnstile)	2.6–2.9	21–23
London (smart card, high bi-leaf gate)	2.4	25
Exit gate, 3.0 ft (0.9 m) wide	0.8	75
Exit gate, 4.0 ft (1.2 m) wide	0.6	100
Exit gate, 5.0 ft (1.5 m) wide	0.5	125

Sources: Fruin (*2*), TCQSM 2nd Edition (*26*), Weinstein (*27*), Weinstein et al. (*28*).

Magstripe and smart card readers can theoretically process substantially more passengers per minute than the values suggested by Exhibit 10-27. For example, in a controlled test of the New York subway's faregates using clean card readers and trained staff, between 38 and 53 p/min could be processed, depending on the protocol used for using the faregate (e.g., looking at the faregate's display or not). Reasons that the higher flow rates could not be achieved in actual operation include: (*a*) passengers hesitating briefly to avoid hitting a locked turnstile, (*b*) passengers hesitating to make sure the faregate was ready to accept their ticket, (*c*) misswiping a farecard, (*d*) dirty card reader contacts, and (*e*) passengers carrying items, such as newspapers or small bags (*28*).

Determining the Required Number of Faregates

The procedure to determine the required number of faregates is based on determining the capacity of individual faregates in either direction (entering and existing) and providing enough capacity to handle peak-period conditions and allow for some growth. Special provisions may be made for periodic high volumes such as after a major public event. Consideration should be given to pedestrian characteristics, including provisions for passengers with luggage, bicycles, strollers, wheelchairs, or other mobility aids. The possibility of one or more gates being unavailable due to malfunction or maintenance should be considered. The following steps are recommended for determining the required number of faregates:

1. Choose an analysis period appropriate to the location of 15 minutes or less.
2. Estimate the pedestrian demand during the analysis period.
3. Compute the design pedestrian flow (passengers per minute) by dividing the demand by the number of minutes.
4. Compute the number of gates, turnstiles, or combination required by dividing the passenger flow by the capacity of individual units, or subtracting the capacity of units if more than one type is to be used (always round up or add one extra unit for each direction of flow). One gate should always be provided for reverse flow, even if the reverse flow is relatively minor.

Emergency Evacuation Capacity

For emergency evacuation purposes, the 2010 edition of NFPA 130 (*1*) sets a capacity of 25 p/min for turnstiles and 50 p/min for gate-type barriers. Electronically operated faregates are required to open to allow unimpeded egress during evacuations. NFPA 130 also sets minimum and maximum dimensions for gate-type faregates.

HORIZONTAL CIRCULATION

Walkways

Principles of Pedestrian Flow

As was illustrated in Section 3, pedestrian speed, flow, and density are interrelated. The relationship between density, speed, and flow for pedestrians is described by the following formula:

Equation 10-2

$$v = S \times D$$

where

v = pedestrian flow per unit width (p/ft/min, p/m/min),

S = pedestrian speed (ft/min, m/min), and

D = pedestrian density (p/ft², p/m²).

The flow variable used in this expression is expressed as a flow per unit of width. An alternative and more useful expression can be developed using the reciprocal of density, or *space*, as follows:

$$v = S/M$$

Equation 10-3

where

v = pedestrian flow per unit width (p/ft/min, p/m/min),

S = pedestrian speed (ft/min, m/min), and

M = pedestrian space (ft²/p, m²/p), adjusted as appropriate for pedestrian characteristics.

Levels of Service for Walkways

Exhibit 10-28 lists the thresholds for pedestrian LOS on walkways in transit facilities. These levels of service are based on average pedestrian space and average flow rate. Average speed and volume-to-capacity ratio are shown as supplementary criteria. Maximum capacity is taken to be 25 p/ft/min (82 p/m/min), corresponding to LOS E.

Note that the LOS thresholds shown here differ from those shown in the HCM 2010 (*29*). Thresholds shown in the HCM 2010 are intended primarily for sidewalks and street corners, while those shown here are typically used for transit facilities, whether on-street or off.

LOS thresholds for walkways are not the same as the HCM's thresholds for sidewalks.

Exhibit 10-28
Walkway LOS

LOS	Pedestrian Space (ft²/p)	Expected Flows and Speeds: Avg. Speed, *S* (ft/min)	Expected Flows and Speeds: Flow per Unit Width, *v* (p/ft/min)	*v/c*
A	≥ 35	260	0–7	0.0–0.3
B	25–35	250	7–10	0.3–0.4
C	15–25	240	10–15	0.4–0.6
D	10–15	225	15–20	0.6–0.8
E	5–10	150	20–25	0.8–1.0
F	< 5	< 150	*Variable*	*Variable*

LOS	Pedestrian Space (m²/p)	Expected Flows and Speeds: Avg. Speed, *S* (m/min)	Expected Flows and Speeds: Flow per Unit Width, *v* (p/m/min)	*v/c*
A	≥ 3.3	79	0–23	0.0–0.3
B	2.3–3.3	76	23–33	0.3–0.4
C	1.4–2.3	73	33–49	0.4–0.6
D	0.9–1.4	69	49–66	0.6–0.8
E	0.5–0.9	46	66–82	0.8–1.0
F	< 0.5	< 46	*Variable*	*Variable*

Source: Fruin (*2*).
Note: *v/c* = volume-to-capacity ratio.

Pedestrian Demand

When estimating the pedestrian demand for a particular facility, it is important to consider short peak periods and surges within the peak. For general design purposes, a 15-min peak period is usually recommended. However, because micropeaks (temporary higher volumes) are likely to occur, consequences of these surges within the peak should be considered. Due to the incidence of intensive peaks just after a transit vehicle arrives and discharges passengers, analysis of a shorter time period may be appropriate for walkway segments close to a transit platform. Where headways are very close, the time between trains or buses may define the period of analysis on these segments. Micropeaking may result in increased crowding for a given time period, but the short duration may justify the temporary increase in congestion and short duration queuing.

Determining Required Walkway Width

The procedures to determine the required walkway width for a transit terminal corridor are based on maintaining a desirable pedestrian LOS. Exhibit 10-28 lists the pedestrian LOS thresholds for walkways. These levels of service are based on average pedestrian spaces and average flow rates. It is generally desirable for peak-period pedestrian flows at most transit facilities to operate at LOS C or above. The following steps are recommended for determining the required walkway width:

1. Chose an appropriate analysis period in minutes; this may be the headway or another period but not generally more than 15 min.
2. Based on the desired LOS, choose the maximum pedestrian flow rate (p/ft/min or p/m/min) from Exhibit 10-28.
3. Estimate the pedestrian demand for the walkway during the desired analysis period.
4. Compute the design pedestrian flow (p/min) by dividing the demand by the number of minutes.
5. Compute the required effective width of walkway (in feet or meters) by dividing the design pedestrian flow by the maximum pedestrian flow rate.
6. Compute the total width of walkway (in feet or meters) by adding 2 to 3 ft (0.6 to 1.0 m), with a 12- to 18-in. (0.3- to 0.5-m) buffer on each side to the effective width of walkway.

Determining Maximum Walkway Capacity

The maximum capacity of a walkway is taken to be 25 p/ft/min (82 p/m/min), corresponding to LOS E. Therefore, for a given walkway width, the following steps may be used to compute the maximum capacity:

1. Compute the effective width of walkway (ft or m) by subtracting 3 ft (1 m) or other appropriate buffer zones from the total walkway width.
2. Compute the design pedestrian flow (p/min) by multiplying the effective width of walkway by 25 p/ft/min (82 p/m/min).
3. Compute the pedestrian capacity (p/h) by multiplying the design pedestrian flow by 60.

As noted previously, station elements should not be designed for maximum capacity under normal operating conditions, as doing so results in uncomfortably dense

concentrations of pedestrians and constrains the ability of station elements to accommodate growth in passenger volumes.

Designing for Emergency Evacuation

For emergency evacuation design purposes, the NFPA 130 capacity and pedestrian travel speed values for platform, corridor, and ramps of 4% slope or less should be used in place of the values presented above. In the 2010 edition, these values were a pedestrian flow rate of 2.08 p/in./min (0.0819 p/mm/min), and a travel speed of 200 ft/min (61 m/min) (*1*). The larger walkway width resulting from the two calculations—design LOS or emergency evacuation—should be selected.

Multi-activity Passenger Circulation Areas

The time-space required for a particular activity is represented by the equation:

$$TS_{req} = \sum P_i \times S_i \times T_i$$ **Equation 10-4**

where

TS_{req} = time-space required (ft²-s, m²-s),

P_i = number of people involved in activity *i* (p),

S_i = space required for activity *i* (ft²/p, m²/p), and

T_i = time required for activity *i* (s).

The total time space requirements of all of the activities are then compared with the time-space available, represented by the formula:

$$TS_{avail} = S_{avail} \times T_{avail}$$ **Equation 10-5**

where

TS_{avail} = time-space available (ft²-s, m²-s),

S_{avail} = space available within the area analyzed (ft², m²), and

T_{avail} = time available as defined for the analysis period (s).

The approach to applying time-space analysis varies depending on the situation being analyzed and the specific issues or options to be addressed. A typical application might involve the following steps:

Steps for applying a time-space analysis.

1. Establish pedestrian origins and destinations within and at the edges of the space analyzed.
2. Assign pedestrian routes through the pedestrian network for each origin-destination pair.
3. Sum the volumes of persons passing through each analysis zone.
4. Identify the walking time within each zone for pedestrians. This may vary depending on their route through each zone.
5. Determine the percentage of people passing through each zone who stop and dwell in that zone for various specific purposes, such as waiting for a train, buying tickets, shopping, etc.
6. Determine the time spent dwelling in each zone for each purpose.

7. Calculate the time-space demand by multiplying the number of persons and the number dwelling by the time for walking through and the dwell time for various activities and by the space used by a person engaged in each activity.
8. Calculate the time-space available by multiplying the usable floor area by the duration of the analysis period.
9. Calculate the demand-supply ratio by dividing time-space demand by time-space available.
10. Apply an LOS based on ranges of demand-supply ratios.

Computer microsimulation programs for pedestrian circulation have developed to a point where they are useful for analysis of both simple and more complex pedestrian environments, and they are replacing spreadsheet-based time-space analysis in many situations. The application of pedestrian microsimulation software is discussed in Section 6.

Moving Walkways

Moving Walkway Capacity

The capacity of a moving walkway is primarily dependent on its width at its entrance, as this determines the number of people who can enter the walkway. The speed of the walkway only affects the capacity to the extent that it affects the spacing of people as they enter. Walking on a moving walkway increases pedestrian travel speed and reduces travel time, but does not affect capacity because it does not affect the rate of entry to the moving walkway. Likewise, systems that accelerate pedestrians to higher speeds do not significantly increase the capacity compared with a standard moving walkway of the same width because the capacity at the entrance is the same as a standard speed unit and governs the capacity.

Manufacturers of moving walkways sometimes state theoretical capacities based on square feet of walkway per minute. These theoretical capacities are generally much higher than practical capacities and should not be used in passenger flow analysis. Studies have shown that the practical capacity of a double-width moving walkway is comparable with the capacity of a double-width escalator of equal width, or approximately 90 p/min or 5,400 p/h.

Evaluation Procedure

In typical application, no more than one moving walkway is provided per direction, with any additional capacity requirements accommodated by an adjacent walkway. The procedures to determine the required queuing area at each end of the walkway are similar to the procedure for escalators, discussed later in this section.

Emergency Evacuation Capacity

The NFPA 130 standard (*1*) does not address moving walkways. It is prudent to calculate emergency evacuation flow under the assumption that power is off. Note that a moving walkway under repair, like an escalator under repair, would not be available for walking.

VERTICAL CIRCULATION

Stairways

Levels of Service for Stairways

The required width of a stairway is based on maintaining a desirable pedestrian LOS. Stairway levels of service are based on average pedestrian space and average flow rate. Exhibit 10-29 summarizes the LOS thresholds for stairways. The threshold between LOS E and F (17 p/ft/min or 56 p/m/min) represents the capacity of a stairway. Note that these thresholds differ from those given in the HCM 2000 (*17*); the thresholds given in Exhibit 10-29 are ones typically used for transit facilities.

Stairway LOS thresholds for transit facilities are different from those given in the HCM.

Exhibit 10-29
Stairway LOS

LOS	Avg. Ped. Space (ft^2/p)	Avg. Ped. Space (m^2/p)	Flow per Unit Width (p/ft/min)	Flow per Unit Width (p/m/min)	Description
A	≥ 20	≥ 1.9	≤ 5	≤ 16	Sufficient area to freely select speed and to pass slower-moving pedestrians. Reverse flows cause limited conflicts.
B	15-20	1.4-1.9	5-7	16-23	Sufficient area to freely select speed with some difficulty in passing slower-moving pedestrians. Reverse flows cause minor conflicts.
C	10-15	0.9-1.4	7-10	23-33	Speeds slightly restricted due to inability to pass slower-moving pedestrians. Reverse flows cause some conflicts.
D	7-10	0.7-0.9	10-13	33-43	Speeds restricted due to inability to pass slower-moving pedestrians. Reverse flows cause significant conflicts.
E	4-7	0.4-0.7	13-17	43-56	Speeds of all pedestrians reduced. Intermittent stoppages likely to occur. Reverse flows cause serious conflicts.
F	≤ 4	≤ 0.4	*Variable*	*Variable*	Complete breakdown in pedestrian flow with many stoppages. Forward progress dependent on slowest moving pedestrians.

Source: Fruin (*2*).

Evaluation Procedures

The LOS thresholds for stairways (Exhibit 10-29) are based on average flow rates. The threshold between LOS E and F (17 p/ft/min or 56 p/m/min) represents the maximum capacity of a stairway.

Critical passenger flows on stairways occur in the ascending direction.

When designing stairways, the following factors should be considered (*2*):

- Where possible, the number and width of stairs should be planned to minimize the duration of queues or avoid queuing altogether;
- Clear areas large enough to allow for queuing pedestrians should be provided at the approaches to all stairways;
- Riser heights should be kept below 7 in. (0.18 m) to increase safety, passenger comfort, and traffic efficiency; and
- When a stairway is placed directly within a corridor of the same width, the stairway will have a lower pedestrian capacity than the corridor and will be the controlling factor in the design of the walkway section.

When minor, reverse-flow traffic volumes frequently occur on a stair, the effective width of the stair for the major-direction design flow should be reduced by a minimum of one traffic lane, or 30 in. (0.75 m).

The following steps are necessary to calculate the width of stairway, stairway capacity, and queuing area required for a given peak pedestrian volume.

Determining Required Stairway Width by the LOS Method

This procedure to determine the required stairway width is based on maintaining a desirable pedestrian LOS. For normal use, it is desirable for pedestrian flows to operate at or above LOS C or D. However, in most modern terminals, escalators would be provided to accommodate pedestrians. Stairs, therefore, are typically provided as a supplement to the escalators to be used when the escalators are over capacity or out of service due to a mechanical failure, maintenance outage, or power failure. Under these circumstances, maximum stair capacity, or LOS E (17 p/ft/min or 56 p/m/min) may be assumed. Pedestrian characteristics at a stair location should be incorporated into the analysis.

The following steps are recommended for determining the required stairway width using the LOS method:

1. Based on the desired LOS, choose the maximum pedestrian flow rate from Exhibit 10-29.
2. Select an analysis period appropriate to the location.
3. Estimate the directional pedestrian demand for the stairway for the analysis period.
4. Compute the design pedestrian flow (persons/minute) by dividing the demand by the number of minutes.
5. Compute the required width of stairway (in feet or meters) by dividing the design pedestrian flow by the maximum pedestrian flow rate.
6. Increase the stairway width by a minimum of one traffic lane (30 in., or 0.75 m) when minor, reverse-flow pedestrian volumes occur frequently.

Determining Required Stairway Width by the Pedestrian Lanes Method

Studies and observations indicate that pedestrians tend to form "lanes" when walking on stairs. The LOS approach to analyzing stairs described above results in a linear relationship between stair capacity and stair width and assumes that increasing or decreasing the width results in a proportional increase or decrease in capacity, even when the change in width is small. Analyzing stair capacity based on lanes suggests instead that stair capacity is not linear but is more stepped, such that adding a few inches (cm) has little effect on capacity, but that increases in capacity occur mainly when the width of a pedestrian lane is added.

When measuring lanes, the width taken by handrails must be considered. Two approaches are possible, based either on the clear width between handrails or based on the full width of the stairway. For the purposes of this method, it is recommended that the width of the stair be assumed to be the lesser of the width of the stair tread or the width between the handrails plus 3 in. (7.5 cm) on each side to account for some shoulder and elbow room over the handrails.

Observations and survey data (*30*) indicate that where circumstances dictate, people may move in lanes as narrow as 21 in. (53 cm) wide, but at such narrow widths, there is considerable friction and side-to-side contact. Generally free flow occurs in

lanes of 28 to 30 in. (71 to 76 cm) in width (including handrail width). A marked increase in capacity is observed when stair lane width increases from 26 in. (66 cm) to 28 in. (71 cm). Some additional peak capacity was observed with lanes between 31 and 33 in. (79 to 84 cm) in width.

Items carried by passengers also play a role in the effective width of pedestrian lanes. One or a few individuals carrying items are unlikely to significantly affect the capacity or effective width of a lane, unless they are significantly hindered by a large item, which would cause a temporary impediment to flow. However, if the population using a particular stair is prone to carrying items such as briefcases, shopping bags, or luggage, the effective width of pedestrian lanes will increase and the capacity of stairs minimally capable of carrying two lanes of people would decline. This likely explains the additional capacity observed on stairs with lanes between 31 and 33 in. (79 to 84 cm) in width.

Exhibit 10-30 summarizes the capacity of stair lanes by width. As personal spacing and items carried vary by location, it is recommended that users conduct counts in their locale for similar types of activities to establish appropriate lane widths and capacities for their application.

Exhibit 10-30
Stair Lane Width and Capacity

Lane Width		Approximate Capacity	
in.	cm	(p/min/lane)	Comments
21–27	53–70	30	Notable friction, not recommended for daily use
28–30	71–78	38	Recommended for general use
31–33	79–85	42	Provides extra space and slightly greater capacity
≥34	≥86	Little or no additional capacity	May be beneficial where pedestrians carry items

Determining the Number of Lanes for a Specific Stair Width

For an existing stair, observations during peak-volume periods will indicate the number of lanes that pedestrians naturally form on the stair. For planning a new stair, it should be assumed that people will create lanes approximately 28 to 30 in. (71 to 76 cm) wide. Lanes less than this width will generally only occur when the space between handrails is insufficient for two 28-in. (71-cm) lanes. For example, a stair that is 72 in. (183 cm) wide will generally operate as two generous lanes, not as three lanes averaging 24 in. (61 cm) in width. When a stair width could create three lanes of approximately 27 in., the development of two or three lanes may vary over time and may be affected by the steepness and rise of the stair, since people in the middle of a stair do not have access to a handrail.

Determining Maximum Stairway Capacity

As discussed above, the maximum capacity of a stairway is taken to be 17 p/ft/min (56 p/m/min), or LOS E. Therefore, for a given stairway width, the following steps may be used to compute the capacity:

1. Compute the design pedestrian flow (p/min) by multiplying the width of stairway by 17 p/ft/min (56 p/m/min).
2. Adjust for friction due to bi-directional flows by deducting 0 to 20%, depending on the pattern of flows. Little or no deduction should be applied when all flow is in one direction or when flows are fairly balanced. Up to a 20% deduction may be appropriate for conditions with a relatively small reverse direction flow.

3. Compute the pedestrian capacity (p/h) by multiplying the design pedestrian flow by 60.

Determining Required Size of the Stair Queuing Area

- Compute the stairway capacity using the above procedure.
- Compute the maximum demand by determining the maximum number of pedestrians arriving at the approach of the stairway at one time.
- Determine the number of arriving pedestrians exceeding capacity by subtracting the capacity from the demand.
- Compute the required queuing area by multiplying the number of pedestrians exceeding capacity by 5 ft^2 (0.5 m^2) per pedestrian.

Effect of Stair Rise on Capacity and Flow Rates

Studies have shown that as stair rise increases, pedestrians tire and slow down, reducing the flow rate on taller stairs. The rates and calculations presented above are generally applicable for stairs of up to about 15 ft (4.6 m) of vertical rise, though some difference may appear even within that range. When stairs of greater rise are under consideration, studies may be performed to determine the effect of greater heights on a specific population. It should also be noted that a route that passes through sequential stairs in relatively close succession will experience some of the effect of the overall rise, even though individual stairs may be shorter.

Designing for Emergency Evacuation

For emergency evacuation design purposes, the NFPA 130 capacity and pedestrian travel speed values for stairs, stopped escalators, and ramps over 4% slope should be used in place of the values presented above. In the 2010 edition, these values were the following for both the up and down directions: a pedestrian flow rate of 1.41 persons per inch per minute (0.0555 p/mm/min), and a vertical component of travel speed of 48 ft/min (15.0 m/min) (*1*). Exit stairs should be a minimum 44 in. (1.12 m) wide. The larger walkway width resulting from the two calculations—design LOS or emergency evacuation—should be selected.

Escalators

Escalator Capacity

Escalator manufacturers rate the maximum theoretical capacity of their units based on 100% step utilization. Observations indicate, however, that 100% utilization is never obtained. In general, passengers use alternate steps, leaving one step between them and the person in front of them (*2*). Because 100% utilization is typically not attainable, nominal design capacity values have been developed (see Exhibit 10-31). These values represent a step utilization of one person every other step on a 24-in. (0.6-m) wide escalator and one person per step (or two people every second step) on a 40-in. (1.0-m) wide escalator. Note that the capacity of medium-width escalators with 32-inch (0.8 m) steps have been observed to have peak occupancy close to the capacity of a double width escalator because people tend to stagger themselves on alternate steps on these escalators.

Exhibit 10-31
Nominal Escalator Capacity Values

Type	Width at Tread (in.)	Width at Tread (m)	Incline Speed (ft/min)	Incline Speed (m/min)	Nominal Capacity (p/h)	Nominal Capacity (p/min)
Single width	24	0.6	90	27.4	2,040	34
			120	36.6	2,700	45
Double width	40	1.0	90	27.4	4,320	72
			100	30.5	5,100	85
			120	36.6	5,400	90

Sources: Fruin (*2*), unpublished New York City Transit data.

Determining the Required Number of Escalators

The procedures to determine the required number of escalators are based on the width and speed of the escalator being considered. The following is a list of steps suggested for determining the required number of escalators:

1. Determine an analysis period appropriate to the location of 15 min or less.
2. Estimate the directional pedestrian demand for the escalator for the analysis period.
3. Compute the design pedestrian flow (pedestrians per minute) by dividing the demand by the number of minutes.
4. Based on the width and speed of the escalator, choose the nominal capacity (pedestrians per minute) from Exhibit 10-31.
5. Compute the required number of escalators by dividing the design pedestrian flow by the nominal capacity of one escalator, rounding up.

Determining Required Size of the Queuing Area

The possibility that escalators can generate large queues, even at pedestrian demands below nominal capacity, should be considered. Queues may generate when demand exceeds capacity or when pedestrian arrival is intermittent or persons are carrying baggage or luggage. For these situations, an adequate queuing area should be placed at the approach of an escalator based on an average pedestrian space of 5 ft^2 (0.5 m^2) per person. (Where alternative stationary stairs are conveniently available, the maximum wait time for an escalator may be reduced somewhat, but unless specific data are available, it should be assumed that most people will wait for an escalator.) Sufficient space should also be provided at the discharge end of an escalator to avoid conflicts with other traffic streams. The following are steps for computing the required size of a queuing area at the approach to an escalator:

1. Determine the capacity of the escalator from Exhibit 10-31.
2. Compute the maximum demand by determining the maximum number of pedestrians arriving at the approach of the escalator at one time.
3. Determine the number of arriving pedestrians exceeding capacity by subtracting the capacity from the demand.
4. Compute the required queue area by multiplying the number of pedestrians exceeding capacity by 5 ft^2 (0.5 m^2) per pedestrian.

Designing for Emergency Evacuation

For emergency evacuation design purposes, the NFPA 130 standard allows both stopped and running escalators, equipped to operate in both directions, to be

considered as emergency exits. The 2010 NFPA 130 values for stopped escalator capacity and pedestrian travel speed may be found in the preceding section on stairways. A double-width escalator is generally assumed to have a usable with of 44 in. (1120 mm) for NFPA 130 analysis. Escalators shall not account for more than one-half of the exit capacity, and one escalator shall be considered to be out of service at each level (*1*).

Elevators

Elevator Level of Service

The LOS of an elevator system is typically based both on wait time and on the level of crowding. The tolerance level for an acceptable waiting time for elevator service at a transit terminal is around 30 s but also depends on the vertical distance traveled and alternate means. Average pedestrian space will be less important, unless inadequate capacity causes excessive crowding or causes people to miss an elevator, increasing their travel time and raising frustration. It is important to consider the maneuverability of wheelchairs in an elevator. This is particularly important in crowded situations or where the person using a wheelchair needs to turn to access the control panel or to exit.

Elevator Waiting Time

In evaluating wait time for an elevator, both the maximum and average wait times can be measured. The maximum wait time with a single elevator is the cycle time for the elevator to depart, make one or more intermediate stops, and return to its starting point ready to return in the initial direction. This represents the time spent by a person who arrived just as the elevator doors were closing but was unable to board. The average waiting time will generally be half of the cycle time. The effect on waiting times of multiple elevators depends on the coordination of their operation. If electronic controls space elevator departures, waiting times will be reduced by a factor of the number of elevators. In practice, the reduction is usually somewhat less, particularly if passengers hold elevator doors.

Elevator Capacity

The capacity of an elevator system depends on the following four factors:

- Entering and exiting patterns of users;
- User characteristics, including luggage, strollers, bicycles, and wheelchairs;
- Elevator travel time; and
- Practical capacity of the elevator cab.

Boarding and alighting times will depend on the door width and whether passengers are carrying baggage or luggage. The number of passengers boarding may also affect boarding rates. Studies that have investigated boarding rates for transit vehicles have found that boarding rates increase as the number of passengers increase due to "peer pressure." To determine average boarding and alighting times for a particular elevator system, it is recommended that field data be collected.

Elevator travel time will be based on the operating characteristics of the elevator, including the following:

- Distance traveled (height of shaft),
- Elevator speed,
- Elevator acceleration and deceleration rates, and
- Elevator door opening and closing times.

The above factors will remain constant for a particular elevator system. The practical capacity of an elevator in a transit station will be based on the following:

- Presence of heavy winter clothing, and
- Presence of baggage or luggage.

The presence of heavy clothing, bags, or luggage increases the required area per person and, therefore, reduces standing capacity. Although the crush capacity of an elevator is approximately 1.8 ft^2 (0.17 m^2) per person, most people require 3.0 ft^2 (0.28 m^2) or more to feel comfortable in an elevator and this is a suitable design standard. As mentioned above, riders of elevators are more willing to accept less personal space due to the short time period associated with the elevator ride. Provision for baggage is particularly important at stations serving airports or intercity bus or rail terminals and at other stations along lines serving those facilities.

Designing for Emergency Evacuation

The 2010 edition of NFPA 130 (*1*) allows the use of elevators for evacuation when certain design requirements are met to promote their continued operation during adverse conditions. Elevators may not constitute more than 50 percent of the required egress capacity, at least one elevator must be assumed to be out of service, and one elevator must be reserved for fire department use. In addition, a holding area must be provided that meets requirements put forth in NFPA 130.

Ramps

Ramp Level of Service

LOS thresholds have not been established for ramps, but they would be comparable with those for walkways.

Evaluation Procedures

In many applications, ramps are considered auxiliary to the main circulation routes in a station, provided to serve only a small portion of a station's total users. In these cases, their capacity will not be critical to the analysis of passenger flow and they need not be evaluated in terms of LOS. Where ramps are used in place of stairs as a primary pedestrian circulation element, they can be treated much like level walkways. Grades of up to 6% have been found to have negligible effect on pedestrians, while a slope of 10% has reduced speeds by about 12%.

Designing for Emergency Evacuation

The 2010 NFPA 130 standard (*1*) specifies ramp capacities and pedestrian travel speeds for use in emergency evacuation design that are the same as those for walkways.

PLATFORMS AND WAITING AREAS

Levels of Service for Bus Stops and Station Platforms

Levels of service for passenger queuing and waiting areas, such as station platforms, are shown in Exhibit 10-32. The thresholds were developed based on average pedestrian space, personal comfort, and degrees of internal mobility. LOS is presented in terms of average area per person and average interpersonal space (distance between people).

The LOS required for waiting within a facility is a function of the amount of time spent waiting, the number of people waiting, the waiting pattern (in a queue versus looser standing),and a desired level of comfort. Typically, the longer the wait or the looser the waiting pattern, the greater the space per person required. A person's tolerance of a level of crowding will vary with time. People will accept being tightly packed on an elevator for one minute, but not in a waiting area for 15 minutes (*17*).

A person's acceptance of close interpersonal spacing will also depend on the characteristics of the population, the weather conditions, and the type of facility. For example, commuters may be willing to accept higher levels or longer periods of crowding than intercity and recreational travelers (*17*).

Exhibit 10-32
Levels of Service for Queuing Areas

LOS	Average Pedestrian Area (ft^2/p)	Average Pedestrian Area (m^2/p)	Average Inter-Person Spacing (ft)	Average Inter-Person Spacing (m)
A	≥ 13	≥ 1.2	≥ 4.0	≥ 1.2
B	10–13	0.9–1.2	3.5–4.0	1.1–1.2
C	7–10	0.7–0.9	3.0–3.5	0.9–1.1
D	3–7	0.3–0.7	2.0–3.0	0.6–0.9
E	2–3	0.2–0.3	<2.0	<0.6
F	< 2	< 0.2	*Variable*	*Variable*

Source: *Fruin (2).*

The typical design LOS used for bus stops and station platforms is LOS C to D or better. Passenger congestion in the LOS E range is experienced only on the most crowded elevators or transit vehicles. LOS D represents crowding with some internal circulation possible; however, this LOS is not recommended for long-term waiting periods. The presence of passengers who use wheelchairs, strollers, or bicycles, or carry luggage or packages should be assessed and suitable provision made in station space.

Platform Usage

The shape and configuration of a station platform is dictated by many systemwide factors. Platform length is typically based on transit vehicle length and the number of transit vehicles using the platform at any one time. Platform width is dependent upon structural considerations, passenger queuing space, circulation requirements, and entry/exit locations.

Transit platforms can be divided into the following areas (*20*):

- Walking areas;
- Waiting areas;

- Waiting area buffers (adjacent to the platform edge and to waiting areas), with the platform edge denoted by a 18-in. (0.5-m) detectable warning strip;
- Dead areas between bus loading areas or train doors;
- Space taken up by seats, pillars, and other obstructions; and
- Queue storage.

Exhibit 10-33 illustrates the use of these areas for a transit platform serving buses.

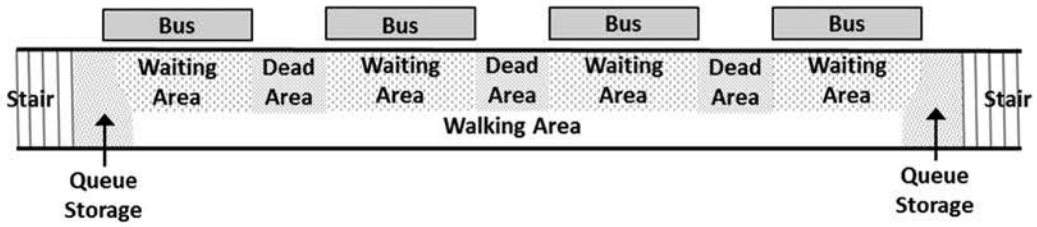


Exhibit 10-33
Transit Platform Areas

Source: Benz (*20*).

There are several different platform components which impact capacity and size requirements.

Walking and waiting do not occur evenly over the platform area. Some areas are used primarily for walking (e.g., near entry/exit locations and along the back edge of the platform) while other areas are used primarily for waiting (e.g., loading areas). Areas that are generally not used by passengers are termed *dead areas.* These areas are typically present between buses at a bus terminal or in front of or behind a train at a rail station. Dead areas should be taken into consideration when choosing the size and configuration of a platform. Where a platform serves multiple routes, special consideration should be made of passengers who will continue to wait on the platform until their train or bus arrives.

Platform Sizing

Evaluation Procedure

The procedures to determine the size of a transit platform are based on maintaining a desirable pedestrian LOS in the waiting and circulation areas, while providing needed buffer space and reserving space for physical objects, such as staircases or seating. The following is a list of steps recommended for determining the desired platform size:

1. Based on the desired LOS, choose the corresponding average pedestrian space from Exhibit 10-32;
2. Adjust as appropriate for passenger characteristics (e.g., wheelchair usage, luggage, bicycles);
3. Estimate the maximum passenger demand for the platform at a given time;
4. Calculate the required waiting space by multiplying the average space per person by the maximum passenger demand;
5. Calculate the additional walkway width needed to serve arriving passengers by using the appropriate procedures for walkways described previously;
6. Calculate the queue storage space required for exit points (at stairs, escalators, and elevators) as described previously;

7. Consider the additional platform space that will be unused, including dead areas and physical obstructions;
8. Add a buffer zone to the width of the platform (18 in., or 0.5 m, on each side having direct access to a roadway or trackway) ;
9. Calculate the total platform area by summing the required waiting space, walkway width, queue storage at exit points, dead areas, and buffer zone width; and
10. Apply a safety or growth factor if appropriate.

The result of this calculation will be a minimum platform area required to meet demand. Actual platform area and dimensions may be determined by other factors, such as minimum clearances and architectural considerations, especially in low- to medium-volume stations. Calculation Example 3 later in this chapter demonstrates the application of this process.

Designing for Emergency Evacuation

NFPA 130 does not directly affect overall platform area unless obstacles, such as a stairway or open platform edge, require additional platform width to provide egress capacity past the obstacle (*1*). The standard specifies that egress routes must be at least 44 in. (1.12 m) wide. When such a route passes between an open platform edge, an additional 18 in. (450 mm) must be provided. When a route passes a sidewall or obstacle such as a stairway, an additional width of 12 in. (300 mm) must be provided. With both an open platform edge and a sidewall, a total width of 74 in. (1.87 m) would be required.

Shelters and Waiting Rooms

Level of Service

No specific LOS has been suggested for shelters, waiting rooms, or seating. The space provided within shelters or waiting rooms can be assessed using the LOS thresholds for queuing spaces, as presented in Exhibit 10-32. These thresholds are based on average pedestrian space, personal comfort, and degrees of mobility within the space. However, local circumstances must be taken into consideration when determining what the projected or desirable occupancy is, since such spaces are rarely used by all passengers and may only be used to the maximum extent on limited days of the year, depending on local climates. For example, shelters may be used on a daily basis for 6 months of the year in a colder northern climate but may be used only a few days a month in warmer, dryer climates. As a result, it may be more desirable to handle full stop or station loads in the more adverse climate, but provide more limited capacity relative to station passenger volumes where the shelter is used less often.

Evaluation Procedures

The LOS for persons standing in a shelter or waiting room may be assessed using the LOS criteria for queuing spaces, as presented in Exhibit 10-32. In larger waiting rooms where circulation is to be maintained or other activities such as ticket selling are occurring, the time-space analysis approach described in Equation 10-4 and Equation 10-5 can be applied or a pedestrian simulation software applied. A simpler analysis

could be conducted using a space per pedestrian that is between the walking criteria shown in Exhibit 10-28 and the queuing criteria presented in Exhibit 10-32.

The desirable number of seats is a question of the maximum number of people who would choose to sit, the average waiting time, and such design issues as the space available for seating and the cost of installing and maintaining seats. One approach to assessing the desired number of seats in an existing station is to temporarily locate more than the anticipated number of seats in a station, using movable stacking chairs, and count the number of people who choose to sit in them during peak periods. The temporary seats can then be replaced with permanently mounted seats and benches.

INTERACTIONS BETWEEN STATION ELEMENTS

To maximize flow through the various components of the pedestrian system, minimum "protected run-off" areas are often defined on either side of critical components. Critical components are typically considered to be doors and faregates, and on the approach to (and egress from) stairs, elevators, and escalators. Typically in the region of 15 ft (5 m), these run-off areas are intended to ensure that obstacles (including conflicting pedestrian movements) do not interfere with smooth pedestrian flow at these critical points within the pedestrian system. In the case of escalators, it is particularly important that egress paths are not blocked, for safety reasons.

ALTERNATIVE PERFORMANCE MEASURES FOR SIZING STATION CIRCULATION ELEMENTS

Passenger space and density has traditionally been a common measure used to size station circulation elements, particularly in combination with pedestrian LOS based on area per passenger. However, other performance measures can also be used for design. Three of these—volume-to-capacity (*v/c*) ratios, clearance time, and queue length/duration—are described in this section. Any of these methods may be used along with pedestrian LOS, pedestrian time-space, or microsimulation to address specific project concerns. The choice of method(s) will depend on the specific issues or concerns, available input data, and available schedule and budget for analysis. Multiple methods may be used together on the same or different areas of a station, or they may be used in sequence during project development, moving from simpler, less-demanding methods to more elaborate procedures.

Station capacity analysis entails various *methods* to calculate multiple performance *measures* or *metrics*. For some relatively simpler measures, a method using a computer spreadsheet can be applied. These simpler or aggregate measures can also be obtained from computer microsimulation. However, as discussed in the section on microsimulation, additional more-complex measures based on the *individual* experience of large numbers of people can be reported.

Volume-to-Capacity Ratio Analysis

All elements in a pedestrian network can be analyzed based on a comparison of pedestrian volume and capacity, expressed as a ratio of volume divided by capacity, or *v/c*. Some elements, including escalators, faregates, and ticketing machines are better analyzed in this way than in terms of LOS, in part because it may be considered acceptable for them to operate near capacity, at least for brief periods of time. Stairs and passageways can also be analyzed in this way instead of by the LOS method, when a

more refined numerical measure is desired. A *v/c* ratio less than one indicates that an element is operating at less than capacity, a *v/c* of 1.0 represents an element operating at capacity, and a *v/c* ratio greater than 1.0 indicates that an element is operating over capacity (or forecast to exceed capacity).

A key consideration in *v/c* analysis is defining the capacity of an element. Capacity may be defined in two fundamental ways: *maximum* capacity or *design* capacity. Maximum capacity represents the maximum number of people who can be processed by an element during a fixed time frame. This maximum number should be based on real-world behavior as measured by field counts, not a hypothetical capacity as sometimes expressed by equipment manufacturers. Estimating maximum capacity requires a situation in which a queue has developed at the entrance to an element and can be measured only as long as the queue exists. Where such a condition does not occur naturally, some manipulation, such as closing alternate routes, might be necessary to observe maximum capacity.

In contrast, design capacity represents a desirable maximum volume reflecting a busy, but comfortable condition and would normally be a somewhat lower volume than maximum capacity. The selection of a design capacity is usually arbitrary, but could be based on a user preference survey. It may also reflect the desire to plan for redundancy in the event of equipment failure or routine maintenance. Particularly in the case of faregates, it should be noted that maximum capacity, and perhaps design capacity, is influenced not only by the physical characteristics of the gate, but also by the characteristics of the fare system. Thus, identical faregates on different systems may have different capacities, and the capacity of existing faregates can change with a change in the fare system.

Platform Clearance Time Analysis

Platform exit capacity is a key consideration in heavily used stations.

Pulsed Nature of Pedestrian Flows from Platforms

The pedestrian LOS approach to analyzing flow normally considers a fixed time period and analyzes density based on average volumes over that period. However, pedestrian flows can be highly variable, particularly in a transit system where flows on certain elements occur in pulses immediately after the arrival of a transit vehicle. In these situations, passengers tend to move through some circulation elements based on the processing rate of the element rather than spread out over a period of time. For example, the calculation for sizing a stair serving a station platform can focus on the time required to clear the volume generated by each arriving train. The result for all exits from a platform is platform clearance time. Design objectives for platform clearance time can then be set for a variety of circumstances, including clearance of a platform or mezzanine, for both normal and emergency purposes.

General Approach to Platform Clearance Time Analysis

A key capacity analysis for larger transit stations is the platform exit capacity needed to accommodate passenger demands during the peak period. This capacity ensures that each station platform is clear before the next train arrives. The general solution is as follows:

$$\frac{\text{Passengers/train}}{\text{Capacity (passengers/minute)}} \leq \text{Train headway (minutes)}$$ **Equation 10-6**

or

$$\text{Capacity (passengers/minute)} \geq \frac{\text{Passengers/train}}{\text{Train headway (minutes)}}$$ **Equation 10-7**

Because people may not use, or be able to use, all available exits, some safety factor is needed. This could be as much as 20 to 30%. Where simultaneous arrivals or departures occur on both sides of a center platform on a regular basis, the passenger volume of both trains or buses should be considered.

Analysis by this method normally focuses on the one direction of flow affected by surges associated with transit arrivals. However, counter-flow must also be considered where appropriate (unless a circulation element only receives flow in the peak direction either due to controls on flow or transit operating circumstances). Where counter-flow occurs, it is usually assumed that at least one pedestrian lane is fully occupied by counter-flow, even if the volume is significantly less than the capacity of the lane.

Steps for Platform Clearance Analysis

The steps for a platform clearance analysis are as follows:

1. Determine the passenger volume departing the platform. This may represent a crush loaded train, a forecast disembarking volume, or a forecast peak load for emergency evacuation. Where two or more trains may be present, volumes should be combined.
2. Determine the distribution of passengers to various exit routes, including stairs, escalators, passages, and other routes to exit platforms.
3. For each stair, determine the number of lanes available for exiting and its total capacity per minute. If counter-flows to the platform will occur at the same time that people are leaving the platform after a train arrival, determine the number of lanes needed to serve counter-flow.
4. For each platform exit, divide the volume assigned to that element by its total capacity per minute. The result is the provisional clearance time for each element (in minutes). The maximum clearance time among all the exit routes is the platform clearance time.
5. Review the clearance time for all platform exits. Where passengers have multiple choices and clearance time from some elements is significantly less than other elements, consider reassignment to better balance clearance time. Note, however, that clearance time is rarely identical on all elements leading from a platform, due to unbalanced transit vehicle loadings, passenger preference for certain destinations outside the station, and other factors.
6. Recalculate the clearance time for each element and the platform as a whole based on the reassigned distribution from Step 5.

Excessive platform clearance time or excessive time on specific elements may suggest the need for additional exit capacity, which is added by introducing additional stair lanes (or other egress elements). At a maximum, platform clearance time should be less than the headway between train or bus arrivals. However, clearing platforms in less than the headway is not always adequate from the standpoint of passenger comfort and convenience and a shorter clearance time may be needed.

Queue Analysis

Queues occur in the transit environment in two ways: deliberate or incidental. Deliberate queues occur where people are waiting for a specific function, such as purchasing tickets or lining up at a vendor within the transit facility. The formation and direction of these queues may be controlled or influenced by stanchions, floor markings, or other elements, or they may be uncontrolled and variable. Incidental queues occur when a surge of passengers exceeds the capacity of available circulation elements, such as stairs, escalators, or fare gates. These queues tend to be more amorphous, with people joining from multiple directions and filling in available space.

Typical measures of queues include:

- The maximum area or extent of the queue (measured as the linear distance from the element causing the queuing);
- The delay or maximum amount of time spent in a queue per person (or per group of people), from the moment of entry to exiting the queue; and
- The duration of the queue, from the time it forms until it dissipates and returns to a free-flow condition where pedestrians walk at close to their desired speeds.

In the case of "deliberate" queues at service points (such as ticket vending machines or counters), it is important to understand the passenger arrival pattern at the service point, and the distribution of transaction times at that service point, in order to adequately assess potential queue propagation and spatial requirements.

6. APPLICATIONS

This section presents examples of some the real-world situations that this chapter's methods can be applied to. This chapter also discusses the use of pedestrian microsimulation as part of a station analysis. Detailed examples of some of this chapter's quantitative analysis methods are presented in Section 8, Calculation Examples.

ALTERNATIVE MODE AND ALIGNMENT COMPARISONS

The provision of stop, station, and terminal facilities is an important consideration at the systems planning level of selecting transit modes and alignments. While the details of final station locations and design need not be determined at this stage in project development, an understanding of the physical requirements for station facilities, their effect on the service provided to travelers, and their costs are integral to evaluating alternative modes and alignments.

The steps that might be applied in such an analysis are:

1. Identify the goals and objectives for the transportation improvements and revise these as needed.
2. Identify the modes to be considered, the general area to be served, and the initial alignments for each mode.
3. Determine typical and minimum requirements for stations for each mode, including such factors as length, width, allowable curvature, access for persons with disabilities, and passenger amenities. Develop one or more typical station layouts, such as for an at-grade, elevated, or underground station, or an on-street and off-street station, depending on the range of settings likely to occur in the study. This chapter provides information on the various station elements.
4. Determine desired station locations for each combination of mode and alignment based on relationship to destinations, operational considerations, and physical constraints. Adjust as required to address station requirements.
5. Determine which station locations can be served by a station of typical size and configuration, and locations where different station characteristics are required due to passenger volumes, physical constraints, or unique opportunities. Apply either a typical station configuration or a customized conceptual layout to each proposed station location.

With travel demand forecasts for each station, the methods of assessing the capacity of station elements presented in this chapter may be used to determine where a typical layout will suffice and where larger capacities may be required (or minimal features may suffice).

With conceptual station locations and layouts associated with each mode and alignment alternative, conceptual cost estimates can be developed and the environmental, community, and transportation impacts of the stations can be assessed along with the other elements of the project.

ALTERNATIVE STATION LOCATION AND FEATURES COMPARISONS

Once a mode, basic alignment, and conceptual station locations have been identified for a new transit facility or service, the development of station plans is advanced to a greater level of detail along with other elements of the project. The emphasis on station design is increasingly focused on meeting the projected demand and unique constraints and opportunities at each station location.

Similar to the steps in the previous application, the steps that might be applied to prepare station plans during project development are:

1. Keeping in mind the overall goals and objectives for the project, consider objectives for each station. These may consider the function of each station (entry/exit vs. transfers), character of the area served (walk-in/park-and-ride, residential/employment/mixed use), and community or stakeholder input.
2. If a typical station layout is to be applied for consistency and cost effectiveness, determine whether that layout will adequately serve the passenger volumes expected at each station using the capacity measures described in this chapter.
3. Where necessary or desirable, adjust the typical design or apply a unique design. In developing unique station designs, consider the effect of alternate features and layouts on passenger experience based on descriptions provided in this chapter and determine the required size and number of various station elements based on the capacity measures described in this chapter. Apply the requirements of NFPA 130 and the ADA to the design to provide for safe and accessible facilities.
4. At each stage of project development, determine whether spreadsheet-based capacity analyses will suffice or if pedestrian microsimulation software should be applied to part or all of a station plan. The decision will revolve around the complexity of the issues and the design, the questions to be answered by the analysis, the data available for analyses, and the cost of the alternative approaches to analysis.
5. Adjust station locations as needed to satisfy design requirements or respond to other factors.

REMODELING AN EXISTING STATION

With age or changing conditions, existing transit stops or stations may become obsolete or deficient. New development next to a station might call for a new station entrance or result in a change to the pattern of use of the station. The issue or opportunity will be to reexamine the station in a comprehensive manner and address issues of capacity, design, and features.

The steps that might be applied to the development of plans for remodeling an existing station are:

1. Assess the current condition, layout, and function of the existing station. Collect detailed data on existing passenger flows. Project future changes to passenger demands.
2. Develop one or more alternative concepts for addressing existing and projected future demands and for improving the passenger experience.

3. Apply the requirements of NFPA 130 and the ADA to the design to provide for safe and accessible facilities and to verify the design's compliance with these standards.
4. Determine whether spreadsheet-based capacity analyses will suffice or if pedestrian microsimulation software should be applied to part or all of a station plan. The decision will revolve around the complexity of the issues and the design, the questions to be answered by the analysis, the data available for analyses, and the cost of the alternative approaches to analysis.

ADDRESSING A SPECIFIC CAPACITY ISSUE IN AN EXISTING STATION

Daily experience may indicate a localized capacity issue within a station while most areas of the station functions adequately. For example, a particular stair, escalator, or corridor may experience excessive delays and congestion under certain frequent conditions (such as just after arrival of trains or buses). The steps that might be applied to evaluating a capacity issue within an existing station are:

1. Assess the nature of the existing issue. Measure the capacity of elements in the area of concern using methods described in this section and record peak-flow volumes. Collect detailed data on existing passenger flows and project future volumes or allow for a margin of growth.
2. Develop one or more alternative concepts for addressing the existing circulation issue and allowing for projected growth. Note that improvements to address capacity issues may involve changes to the elements where issues are observed, or they may be applied in a different area as long as it would provide relief to the areas of concern. For example, relieving a stair or escalator that experiences congestion could be addressed by widening the stair or adding an adjacent escalator, or it might be addressed by adding vertical circulation in another area of the station where it would divert patrons from the area of concern.
3. Check for compliance with the requirements of NFPA 130 and the ADA. Note that localized improvements may or may not require full compliance for the station, but in any case should not make the condition worse or less-compliant with those standards.
4. Determine whether spreadsheet-based capacity analyses will suffice or if pedestrian microsimulation software should be applied to a portion of the station adequate to assess the effects of the improvements on passenger flow. Note that analysis of smaller areas may be well suited to a simulation model as the data and model building required are commensurately smaller as well.

COMPREHENSIVE ANALYSIS OF PASSENGER CIRCULATION

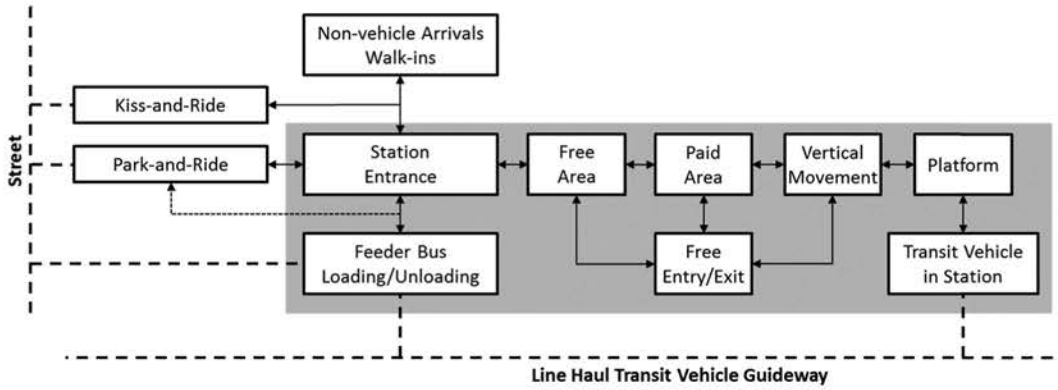
Comprehensive analysis of passenger flow in a station applied using a systems approach.

The more complex a station and its functions, the more complex its planning and design will be. A systematic approach can be taken with more complex stations. Multiple levels in a station present particular challenges, but also opportunities. The capacity of a station and its elements to carry passenger volumes are important. However, other aspects should be considered as well, including the clarity of station layout and wayfinding, access for persons with disabilities, and integrating the station with the surrounding community.

Pedestrian System Requirements

An initial step in evaluating a transit station design is to outline the pedestrian system requirements. Determining passenger circulation and queuing requirements begins with a detailed understanding of the pedestrian flow process through a station in the form of a flowchart. Exhibit 10-34 presents a sample flow diagram, although the elements and their order depend on the particular station. Properly done, the system diagram serves as a checklist and a reminder of the interrelationship of the various functional elements of the station. Exhibit 10-35 shows possible elements and components to be considered in a system diagram for the evaluation of pedestrian flows at a transit station.

Exhibit 10-34
Sample Pedestrian Flow Diagram Through a Transit Terminal



Source: Demetsky et al. (*31*).

Exhibit 10-35
Elements of Passenger Circulation in a Transit Station

Element	Components
Train Arrival	On- or off-schedule; train length; number and locations of doors
Passengers	Number boarding and alighting; boarding and alighting rates, passenger characteristics; mobility device use, baggage or packages carried, bicycles and strollers, etc.
Platform	Length, width, and effective area; locations of columns and obstructions; system coherence: stair and escalator orientation, lines of sight, signs, maps, and other visual information
Pedestrians	Walking distance and time; numbers arriving and waiting; effective area per pedestrian; levels of service
Stairs	Location; width; riser height and tread; traffic volume and direction; queue size; possibility of escalator breakdown
Escalators	Location; width; direction and speed; traffic volume and queue size; maintainability
Elevators	Location; size and speed; traffic volume and queue size; maintainability; alternate provisions for disabled passengers when elevator is non-functioning

After the system elements have been described schematically, they should be described quantitatively. Often this can be done following the same basic format and sequence as the system description. Pedestrian volumes can be scaled to size and

plotted graphically to illustrate volume and direction. Pedestrian walking times, distances, and waiting and service times can also be entered into this diagram.

The characteristics of users at a particular station should be assessed and considered in planning and design. Passenger characteristics include such factors as trip purpose, regular use (commuters) versus new or infrequent users, persons with disabilities, age stratification, and so forth. Trip purpose will relate to whether passengers carry luggage, packages, recreational equipment, or other items.

Comprehensive Passenger Circulation Analysis

The proximity of various station components to each other and the number of transit passengers those components must process impact station capacity. To allow a comprehensive assessment of the interaction of different station components on capacity, a broader evaluation of the pedestrian network should be conducted for larger, more complex stations. Simulation models can assist in the evaluation of alternate transit station designs as to their ability to effectively process transit passengers within defined parameters.

Manual Method/Input to Simulation Models

In the absence of a transit station simulation model, a basic assessment of the interactions of different station components on capacity can be assessed by establishing and evaluating a link–node network (*32*). These network data also serve as typical inputs into computer simulation models. The methodology includes the steps described below.

Step 1: Define the System as a Link–Node Network

Paths passengers take through a terminal (origin–destination pairs) are transformed into a network of links and nodes. Each link, representing a horizontal and/or vertical circulation element, is described by four factors: (*a*) type—walkway, ramp, stairway, escalator, or elevator; (*b*) movements allowed—one-way or two-way (shared or not shared); (*c*) length—in feet or meters; and (*d*) minimum width—in feet or meters. Nodes are queuing points and/or decision points. They are typically fare collection devices, doors, platform entrances or exits, vertical circulation elements, and junctions of paths.

Step 2: Determine Pedestrian Volumes for the Identified Analysis Period

For each pedestrian origin–destination pair within a station, a pedestrian volume is assigned for the identified analysis period (typically the peak hour or the peak 5 to 15 min within the peak hour). Origin–destination pairs distinguish between inbound and outbound passengers. Adjustments may be made as appropriate for passenger characteristics.

Step 3: Determine Path Choice

The particular path or alternate paths that a passenger can or must traverse between a particular origin and destination pair (for both inbound and outbound passengers) are identified.

Step 4: Load Inbound Passengers onto the Network

Inbound passenger volumes for the analysis period are assigned to applicable links and nodes.

Step 5: Load Outbound Passengers onto the Network

Outbound passenger volumes for the analysis period are assigned to applicable links and nodes.

Step 6: Determine Walk Times and Crowding on Links

To calculate the walk times and crowding measures on a link, the flow on that link should be adjusted to reflect peak-within-the-peak-hour conditions (typically 5 to 15 min).

Effective widths of links and nodes are the actual minimum widths or doorway widths. When a wall is located on one side of a corridor, 1.0 to 1.5 ft (0.3 to 0.5 m) is typically subtracted. A buffer of 6 in. to 1 ft (0.15 to 0.3 m) is typically subtracted on each side of obstructions within corridors, such as trashcans and low railings. A buffer of 6 in. (0.15 m) is typically subtracted for walls in stairwells because transit users on the outside often use handrails.

The adjusted flow is divided by the effective width to determine the number of pedestrians per foot or meter width per minute. For a given LOS, the average space mean speed can be identified from Exhibit 10-28 for walkways, Exhibit 10-29 for stairways, and Exhibit 10-31 for escalators.

Step 7: Determine Queuing Times and Crowding at Nodes

Passenger queues at critical nodes can be estimated either by observation or analytical means. Queuing patterns vary depending on specific conditions at each location, particularly the arrival pattern of people at the constrained point. For example, queuing may occur at platform stairs immediately after a train or bus arrives, but the duration may vary considerably.

Step 8: Determine Wait Times for Transit Vehicles

Wait times for transit vehicles are a key input to determining required queuing areas on platforms. A typical assumption used, when service is frequent (10 minute headways or less), is that average wait time is half the bus or train headway.

Step 9: Add Travel Time Components and Assess Overall LOS

Overall travel times for different origin–destination pairs can be totaled and averaged to identify an average passenger processing time through a particular transit station.

PEDESTRIAN MICROSIMULATION

Pedestrian simulation modeling made significant advances in the first decade of the 21st century, evolving from aggregate (network) models and initial programs where individuals occupied and moved between individual cells in a grid, to agent-based dynamic models representing individuals and allowing a full range of movement, speed, and interpersonal spacing. Similarly, the evolution of pedestrian "knowledge" and

replication of a range of pedestrian characteristics in any population has evolved, from simpler hydraulic models (in which pedestrian movement is governed solely by external forces) to agent-based models that capture individual human behavior as well as movement. In the latter type of model, "agents" represent individual people, to the extent that the programming provides them with individual characteristics and allows them to replicate the complexities of navigation by real-world pedestrians.

Models that use a grid or cell system are of two types. In most such programs, each cell is occupied by a single individual. In a smaller number of programs, much smaller cells are used so that a person is represented as occupying a group of cells. The one-cell-per-person configuration places significant limits on the movement and spacing of individuals in the model. First, the cell size must be set to represent typical (average) interpersonal spacing, so that two people occupying adjacent cells are spaced appropriately. However, preferred minimum spacing differs among people and actual spacing varies as circumstances dictate. Second, movement can only be in increments equal to the size of the cells and can only occur in one of eight directions, and therefore lacks the ability to model more subtle changes in direction.

Models that simulate the movement of pedestrians within a continuous space allow for much more flexible and accurate spacing between pedestrians and complete freedom of movement in terms of both speed and direction. Increasingly, commercial pedestrian modeling software programs have adopted a structure based on continuous space and movement characteristics associated with agents representing individuals.

The question of when it is advantageous to use simulation instead of traditional static analysis tools depends on the complexity of the area and the issues to be addressed, the available data and computer-aided design (CAD) plans, the cost of available software, and the time and budget available for the effort. In general, larger, higher-volume facilities with complex pedestrian flows will often justify simulation, whereas simpler, more-localized issues can be most efficiently addressed by traditional means. Areas where crowd safety is a concern or large investments are planned are also likely to call for simulation analysis. At the same time, setting up a simulation for a small area with simple volume data may be achievable quickly at reasonable cost.

Inputs to Simulation Models

As simulation models have become increasingly sophisticated, the inputs to them become more complex. While some basic inputs are required of any model, it is possible to tailor the level of detail and the required inputs to match the needs of a specific project or analysis. Typical inputs to a simulation model may include:

- A plan of the area to be analyzed, usually entered in one of the common CAD file formats. CAD files developed for other purposes normally require editing to make them readable by the software. Some cleaning is also desirable to remove details that do not contribute to viewing the simulation, to reduce file size, and to increase the speed of simulation.
- Pedestrian volume data are entered as an origin–destination matrix or other format suitable to the data available and the method of analysis. Input data may be broken down into time increments or left in aggregate form to be distributed over time by the simulation.

- Various timing schedules may be required to indicate such events as the arrival and departure of transit vehicles, pedestrian crossing signals, announcements or calls to board, elevator movements, and other periodic or timed events.
- Population profiles indicating movement characteristics such as walking speeds, preferred interpersonal spacing, and other factors may be selected from standard profiles provided by the software, or may be created based on survey data. In addition to representing cultural and regional differences, profiles can represent the different movement patterns of commuters, shoppers, attendees of different types of events, persons with various disabilities, or other groups.

Pedestrian routing within a model may be entered and adjusted manually in any microsimulation program, but most programs also have varying abilities to apply dynamic routing, either by manually creating controls that are then activated by conditions in the model, or performed more automatically by the software. This is an area of ongoing model development. The analyst should be aware of the capabilities and limitations of software to replicate real world routing and apply adjustments as needed to replicate observed or expected routing behavior as closely as possible.

Automated data collection methods (e.g., Bluetooth-based methods) are likely to become more commonplace in the future, offering the potential to make the data collection component of large-scale pedestrian movement studies much easier, more detailed, and more accurate. Such technology is already successfully used for highway surveys and has been trialed successfully in a transit context in London. Although the technology required more development at the time of writing for widespread use in the pedestrian survey context, early results were considered promising.

Outputs and Analyses Available with Pedestrian Microsimulation

In addition to better representing the complexity of pedestrian movement, pedestrian microsimulation offers outputs and facilitates measures of pedestrian flow and comfort not previously possible. Any of the basic measures discussed elsewhere in this chapter can also be derived from pedestrian simulation software. However, the software is able to aggregate the experiences of many agents instead of simply reporting averages, resulting in additional more advanced measures. Some of the basic measures that can be reported by pedestrian simulation software include:

- *Average density*—the size of a user-defined area divided by the number of individuals within it at any instant in time. It can be averaged and graphed across a time period. Note that an average density will include the entire area selected whether or not it is occupied.
- *Agent density*—the density perceived by individuals within the model. Unlike average density, agent density includes the spacing between each individual in the model with other individuals around that person, and only represents occupied space.
- *Flow volume* across a cordon line.
- *Travel time* from one cordon line to another.
- *Time to clear a zone* (such as a transit platform) defined by the analyst.
- *Instantaneous walking speed* passing a cordon line or for all people within a zone.

- *Number of people* within a zone.
- *Space utilization*—the amount of time during an analysis period that specific areas are occupied.

In addition, analyses that track an agent can develop a variety of measures specific to that agent over time (e.g., walking speed, personal density).

Simulation also facilitates more complex measures that consider more than one factor. The terms applied here are indicative of the intent, but both software programmers and analysts can define their own measures. Some possible measures include:

- *Convenience/Inconvenience*—the difference between preferred walking distance and actual walking distance due to diversions from the shortest path.
- *Fulfillment/Frustration*—the difference between a person's desired walking speed and actual walking speed, due either to congestion or waiting time.
- *Comfort/Discomfort*—the difference between a person's preference for personal space and the actual space density immediately around that person (as opposed to the average density for a group of people or all people in the model).
- *Satisfaction/Dissatisfaction*—a holistic measure of each person's experience compared to his or her respective preferences; dissatisfaction, for example, encompasses the elements of inconvenience, frustration, and discomfort.

Finally, simulations can generate global (whole model) measures that are best suited to overall comparison of alternative concepts or designs, including:

- *Weighted journey time*: a cumulative measure in which time spent in various activities (e.g., walking, climbing or descending stairs, waiting) is weighted based on factors representing personal perceptions of time spent in those activities. Weights can be adjusted by the analyst and different weighs can be applied for different classifications of people in the model, such as commuters and shoppers. It is expressed in units of time (hours or minutes).
- *Generalized cost:* a cumulative measure of the time spent in various activities, expressed in terms of money (based on values of time). In addition to weighting by activity type, weights can also be set for different classifications of people in the model.

Pedestrian simulations offer multiple means of summarizing and presenting data. The best choices for presentation will depend on the type of data and the issues addressed by the specific analysis. Available outputs include:

- Tables presenting quantitative measures over time, as instantaneous or cumulative values.
- Graphs in various formats presenting data representing instantaneous or cumulative values over time.
- Maps representing any measure spatially as instantaneous, mean, maximum, or minimum values. Color scales can be set to represent any increment of values. A common type of map represents mean densities on a color scale set to match LOS A through F.

- Video clips showing movements of people, changes in mapped data over time, or both. Movements of people can be represented either on a two-dimensional plan (usually as dots) or represented as realistic-looking three-dimensional individuals. Video can be recorded at a real-time rate or at an accelerated speed.

Maps commonly produced by pedestrian simulations include:

- *Cumulative High Density Map*: this map shows how long various areas of a site experience densities greater than a specified limit. The range of colors represents time. This map is best used for identifying "hot spots" within a site—areas where high levels of density are sustained. It asks the questions "is this design creating persistently uncomfortable crowd densities?" and "should the design be altered to alleviate these problems?"
- *Cumulative Max/Mean/Min Density Map*: this map displays the maximum, mean, or minimum levels of density registered in an area from the beginning of playback to the current moment. It is generally used in combination with value ranges corresponding to levels of service. It is best used for measuring the performance of an area against predetermined standards.
- *Evacuation Map*: this map represents the amount of time required to evacuate areas to defined points of safety. It is normally used in an emergency evacuation assessment, such as the time to clear a platform or station under emergency conditions. It can also be used for platform capacity assessments, to show how quickly platforms clear following the arrival of a train.
- *Space Utilization Map*: this map reveals how much space within a site is being used. It records the location of each agent over the duration of the simulation. Generally brighter colors represent greater space utilization. Areas of the simulation that are not used at all remain unshaded. The color range represents the amount of time a unit of space has been occupied within the simulation. These maps are useful in identifying areas where amenities such as benches or retail shops might be located.

Standards of Performance and Interpretation of Results with Simulations

As microsimulation has both introduced myriad ways to analyze pedestrian circulation, and also shed new light on traditional methods, it suggests a need for new standards for what constitutes preferred or acceptable pedestrian flow in various circumstances. Since simulations offer so many ways to summarize and present data, a key principle in applying these capabilities is to use only those outputs that relate to the issues or questions at hand, rather than "showing off" the capabilities of the software.

Design guidelines for transit systems or specific projects often indicate that a specific pedestrian LOS is to be maintained, generally LOS C or better for urban transit systems and, in some cases, LOS B for intercity rail passenger areas. Standards are often vague as to the duration of the period over which the LOS standard is to be achieved, although an average over the peak 15 min is most common or assumed by analysts. For area analyses, the configuration and size of analysis zones can significantly affect the average density and LOS, but is impractical to define in standards.

While pedestrian microsimulation software can be set to measure LOS, the software naturally provides a more fine-grained look at pedestrian flow and congestion because it can represent continuous or even momentary densities and because it presents densities throughout a space rather than applying analysis zones. This means that new or more-detailed standards for what constitutes preferred or acceptable pedestrian flow conditions are needed.

7. CALCULATION EXAMPLES

Exhibit 10-36
List of Calculation Examples

Example	Description
1	Suburban transit center design
2	Stairway sizing
3	Platform sizing
4	Escalator queuing area
5	Multiple pedestrian activities in a facility
6	Complex multilevel station
7	Application of pedestrian microsimulation software

CALCULATION EXAMPLE 1: SUBURBAN TRANSIT CENTER DESIGN

Based on a BRT planning study in the Vancouver, Canada region.

The Situation

A transit agency plans to construct a transit center in conjunction with a new freeway-based bus rapid transit route. The existing local routes in the area will be modified to feed passengers to the transit center. A large park-and-ride lot will also be provided at the station.

The Question

What is the design year (20-year future) berth requirement for the transit center?

The Facts

- The bus routes anticipated to use the center are listed in Exhibit 10-37, along with their projected headways in the design year.
- Bus routes terminating at the center will have approximately 50% of their layover time at the transit center if the other end of the route is also a transit center and approximately 75% otherwise.

Exhibit 10-37
Calculation Example 1: Bus Routes Planned to Use Proposed Transit Center

Route	Description	Transit Center Use	Peak Headway (min)	Total Route Recovery Time (min)	% Recovery at Transit Center	Recovery at Transit Center (min)
B	Freeway BRT all stop	Through	15	NA	NA	NA
B1	Freeway BRT all stop	Terminating	15	15	50%	8
BX	Freeway BRT express	Terminating	15	12	50%	6
F1	North/south frequent	Through	15	NA	NA	NA
F2	East/west frequent	Terminating	10	18	50%	9
L1	Local route	Terminating	20	12	75%	9
L2	Local route	Terminating	20	10	75%	8
L3	Local route	Terminating	20	14	75%	10
L4	Local route	Terminating	20	15	75%	11
L5	Local route	Terminating	20	24	75%	18

Note: NA = not applicable.

- Each direction of a route should be provided with its own boarding berth, except perhaps for variations of the same route.

- Much of the BRT ridership is anticipated to be park-and-ride based.
- Three versions of BRT service will be provided: (*a*) an all-stop route that starts in the center of a town bypassed by the freeway, (*b*) an all-stop route that begins at the transit center, and (*c*) an express route that runs non-stop the length of the freeway BRT facility.
- The local routes will have timed transfers with each other.
- One shared berth for dropping off arriving passengers on routes terminating at the transit center will also be provided for the more-frequent routes that cannot layover in a boarding berth.

Computational Steps

The process for off-street bus stops described in Section 4, Vehicle Circulation, and Storage, will be used to determine berth requirements.

Through Routes

Routes running through the transit center—B and F1—will require two boarding berths (one for each direction of the route). Therefore, a total of four boarding berths will be required for these routes.

Terminating Routes

The remaining routes terminate at the transit center. The number of required berths is based on the route's recovery time at the transit center, divided by the route headway, multiplied by a factor of 1.2 as an allowance for early-arriving buses, and rounded up. The first berth will normally be a boarding berth, with the remaining needs accommodated by layover berths.

As an example, Route F2 is planned to have a 9-min recovery time and a 10-min headway in the design year. The required number of berths is (9 / 10 × 1.2) = 1.1, which rounds up to 2. If the route ran perfectly to schedule, each bus would depart one minute before the next bus showed up (and therefore only one berth would be needed), but this level of reliability would not occur in actual operation. Therefore, two berths—one boarding and one layover—are needed to accommodate the likelihood of having two buses from the route in the transit center at the same time.

As a second example, Route L2 is planned to have an 8-min recovery time and a 20-min headway in the design year. The required number of berths for this route is (8 / 20 × 1.2) = 0.5, which rounds up to 1. Because only one berth is needed (i.e., it is very unlikely that more than one bus from the route will be in the transit center at the same time), this route's layover needs can take place in the boarding berth.

Exhibit 10-38 shows the resulting berth needs for all of the routes.

Exhibit 10-38
Calculation Example 1: Maximum Design Year Berth Needs

Route	Route Type	Peak Headway (min)	Recovery at Transit Center (min)	Berth Requirement	Berth Allocation: Boarding Berths	Berth Allocation: Layover Berths
B	Through	15	NA	0	2	0
B1	Terminating	15	8	0.6 → 1	0*	1
BX	Terminating	15	6	0.5 → 1	1	0
F1	Through	15	NA	0	2	0
F2	Terminating	10	9	1.1 → 2	1	1
L1	Terminating	20	9	0.6 → 1	1	0
L2	Terminating	20	8	0.5 → 1	1	0
L3	Terminating	20	10	0.6 → 1	1	0
L4	Terminating	20	11	0.7 → 1	1	0
L5	Terminating	20	18	1.1 → 2	1	1
			Maximum Berth Requirement		**11**	**3**

Notes: *This route would share the inbound Route B boarding berth.
NA = not applicable.

Because Route B1 operates the same as Route B inbound from the transit center (making all stops along the freeway BRT facility), it can use the same boarding berth as Route B. Since this berth cannot be used for layover (as the through-routed Route B also uses it), Route B1's berth requirement will be satisfied by providing a layover berth. All of the local routes except for L5 can layover in their boarding berth.

The Results

The resulting maximum berth needs are 11 boarding berths, 3 layover berths, and 1 passenger drop-off area for routes terminating at the transit center and not laying over in their boarding berth. If the site is constrained, the number of berths could potentially be reduced or reallocated as follows:

- Route BX could share the same inbound boarding berth as Routes B and B1. This would risk passenger confusion, as passengers might board a non-stop BX bus instead of the all-stop B or B1 bus they were intending to board (or less seriously, vice versa). In addition, the total number of berths required would not be reduced, as Route BX would still need a layover berth because the shared boarding berth would not be available for layover purposes. However, there might be more flexibility in where a layover berth could be placed within the site, compared to a boarding berth.
- Route F2's and L5's layover berths are only needed to accommodate early-arriving buses, because their recovery times are less than their headways. Therefore, the two routes could potentially share a layover berth that would only be used briefly until the preceding bus departed on schedule, freeing up the boarding berth for the early arriving bus's regularly scheduled layover. The risk is that buses from both routes would arrive early and there would not be enough berths to accommodate both buses.

CALCULATION EXAMPLE 2: STAIRWAY SIZING

The Situation

A new rail station will be constructed below grade. This three-level station (platform, mezzanine, and surface) will serve a new transit center and an adjacent urban university campus. The initial concept is to connect the single center platform to the mezzanine at two locations: at one end of the platform and halfway down the platform. A pair of double-width (40-in.) escalators with a stairway in between would be located at each platform access point. One elevator between each level would also be provided.

The Question

Based on the estimated demand under typical peak 15-min conditions and evacuation conditions, how wide should the stairways be?

The Facts

All values reflect design conditions 25 years in the future, rather than conditions when the station first opens.

- For the design year, four-car trains are expected to run at 7 to 8 min headways (i.e., 8 trains/h/direction).
- The a.m. peak hour exiting demand is estimated to be 3,200 passengers per hour. The corresponding a.m. peak-hour entering demand is estimated to be 500 p/h. The estimated p.m. peak-hour demands are 2,900 p/h entering and 500 p/h exiting.
- During the peak 15 min of the a.m. peak hour, the average inbound train entering the station will have 700 passengers on board, while the average outbound train will have 300 passengers on board. During the peak 15 min of the p.m. peak hour, the average inbound train entering the station will have 200 passengers on board, and the average outbound train will have 500 passengers on board.
- The maximum schedule load of a car is 200 passengers.
- The average peak-hour factor currently observed on the system is 0.714.
- The system operates on a proof-of-payment basis; thus, no fare gates are required.
- Sporting events are held at off-campus sites and do not impact peak-demand conditions at this station.

Computational Steps

Outline of Solution

LOS C is a reasonable design level for a station under typical daily conditions. The NFPA 130 evacuation standard (*1*) is conservative in its assumptions of the number of people that will need to be evacuated. The number of people that should be designed for includes:

- The loads of one train on each track during the peak 15 min, assuming each train is running one headway late (i.e., is carrying twice its normal load, but no more than a full [maximum schedule] load); and
- Passengers waiting on the platform to board trains during the peak 15 min, assuming their trains are running one headway late.

Conditions during both peak hours will be checked to see which controls different elements of the design. Next, the stairways will be sized to accommodate the design conditions during the peak 15 min. The resulting width will then be compared with the width required to evacuate the platform within 4 min. The larger width will control design.

Determining the Design Volume

Peak-hour volumes should be converted to peak 15-min volumes by multiplying by the peak-hour factor, as given in Chapter 2:

$$P_{15} = \frac{P_h}{4(PHF)}$$

For example, the peak 15-min exiting volume during the a.m. peak hour is:

$$P_{15} = \frac{3{,}200}{4(0.714)} = 1{,}120 \text{ p}$$

The corresponding peak 15-min entering volume is 175 passengers during the a.m. peak hour. During the p.m. peak 15-min period, 1,015 passengers will be entering and 175 passengers will be exiting.

The number of people that may need to be evacuated is based on the train loads and passengers waiting to board. During the a.m. peak hour, this number is calculated from the following:

- *Inbound train*: an average train carries 700 people during the peak 15 min. A train operating one headway late would have a demand of twice this number, or 1,400 people, but only 800 of those people (the maximum schedule load of a four-car train) would actually have been able to board the train.
- *Outbound train*: an average train carries 300 people during the peak 15 min. A train operating one headway late would have a demand of twice this number, or 600 people, which is less than the train's capacity.
- *Waiting on platform*: At an average headway of 7.5 min between trains in a given direction, up to half of the entering volume during the peak 15 min typically would be present if the trains arrived on schedule. However, the design should assume that the trains are one headway late and, therefore, twice the typical number of waiting passengers should be used. This results in (175)(0.5)(2), or 175 people.

The total number of people to be evacuated during the a.m. peak hour is the sum of these three components, or 1,575 people. During the p.m. peak hour, the corresponding numbers are 400 inbound, 800 outbound, and 1,015 platform, for a total of 2,215 people.

The greatest exiting or entering volumes under typical daily conditions occur during the a.m. peak hour. The greatest number of people that may need to be evacuated occurs during the p.m. peak hour.

Sizing the Stairways

Exhibit 10-29 gives stairway pedestrian flows of 7 to 10 p/ft/min for a design LOS C. Because the users are commuters, the high end of the range can be used, resulting in the following stairway width:

$$\text{Stairway width} = \frac{1{,}120\,\text{p}}{15\,\text{min} \times 10\,\text{p/ft/m}} = 7.5\,\text{ft}\,(90\,\text{in.})$$

As the exiting volume is split between two stairways, each stairway would only need to be about 45 in. wide to serve exiting flows. An additional 30 in. should be provided for a lane to accommodate the small number of entering passengers, resulting in a total width of 75 in. for each stair.

Because escalators are being provided to supplement the stairs, the stairs would only be totally used in the event of unscheduled maintenance, power failures, or similar situations. Maximum stair capacity, or LOS E could be used:

$$\text{Stairway width} = \frac{1{,}120\,\text{p}}{15\,\text{min} \times 17\,\text{p/ft/m}} = 4.4\,\text{ft}\,(53\,\text{in.})$$

Dividing the result by two (because there are two stairways), and adding 30 in. to accommodate the small reverse flow, results in a total width of 57 in., which could be rounded up to the nearest foot (60 in.). Either width is greater than the NFPA minimum for an exit stair (44 in.).

Under emergency evacuation conditions, 2,215 people would need to be evacuated from the platform within 4 min. One of the four escalators should be assumed to be out of service. A stopped escalator can serve 1.41 p/in/min in the up direction, according to the NFPA 130 standard (1); thus a 40-in. escalator can serve (40 in.)(1.41 p/in./min), or 56 p/min. In 4 min, three escalators could serve (4 min)(3 escalators)(56 p/min/escalator), or 672 people, leaving 1,543 people to be served by stairs. The total stairway width required to serve these people in 4 min is:

$$\text{Stairway width} = \frac{1{,}543\,\text{p}}{4\,\text{min} \times 1.41\,\text{ped/in./min}} = 274\,\text{in.}\,(22\,\text{ft}\,10\,\text{in.})$$

The Results

The two stairways would need to be approximately 11.5 ft wide each. Evacuation needs, in this case, control the stairway size. Since these widths are much larger than needed for normal station operation, consideration might be given to supplementing the stairs with additional emergency stairways at the platform ends, allowing the regular stairs to be reduced in size, which would also result in a smaller overall platform width.

Although not addressed in this example, the evacuation capacity of the routes from the station's mezzanine level to the surface would also need to be evaluated. Further, the maximum time required for a passenger to reach a point of safety (generally either

the surface or a point beyond fire doors) would need to be evaluated. The NFPA 130 standard provides example calculations for these situations.

CALCULATION EXAMPLE 3: PLATFORM SIZING

The Situation

The same rail station that was subject of example 2 is used here. Based on the results of the previous example, it has been decided that the stairs between the escalators will be designed to provide LOS C conditions under normal station operations. Each stair will be 7.5 ft wide. Emergency stairs at the ends of the platform will provide the remaining required emergency evacuation capacity.

The Questions

Based on the estimated demand under typical peak 15-min conditions, how wide should the platform be? What would be the capacity of the platform to handle delayed train conditions?

The Facts

- The same conditions set forth in example 2 apply here.

Computational Steps

Outline of Solution

LOS C is a reasonable design level for a station under typical daily conditions. Design volumes for normal and emergency conditions were developed in Example 2. This example will demonstrate how these design volumes are used to determine a minimum platform size.

Sizing the Platform

Since arrivals exceed departures at the station in the morning and departures exceed arrivals in the evening, the peak platform condition in the station will be in the p.m. peak period when passengers are queuing on the platform to wait for trains. Therefore, the platform analysis will focus on that period. The steps given in the portion of Section 5 on sizing platforms will be followed:

1. *Choose a design pedestrian space.* To achieve LOS C, at least 7 ft^2/p is required for queuing space (from Exhibit 10-32) and at least 15 ft^2/p is required for walking space (from Exhibit 10-28).
2. *Adjust as appropriate for passenger characteristics.* No special characteristics (e.g., passengers with luggage) were identified; therefore, no adjustment is made in this case.
3. *Estimate the maximum passenger queuing demand for the platform.* Under typical conditions, with trains running on schedule, up to 507 passengers would be on the platform when trains arrived. (A total of 1,015 people enter the station during the peak p.m. 15 min, two trains arrive in each direction during the 15 min, and thus one-half of 1,015 people could be present.)

4. *Calculate the required waiting space.* Multiplying 507 passengers by 7 ft²/p results in a required area of 3,549 ft² under typical conditions. At the end of this process, non-typical conditions will be checked to make sure overcrowding will not occur.
5. *Calculate the additional walking space required.* Circulation area is required for arriving passengers to walk to the platform exits. This passenger demand is highly peaked, corresponding to individual train arrivals. During the p.m. peak 15 min, approximately 175 passengers will arrive on four trains. Approximately 70% of these passengers (500/700) will arrive on the two outbound trains, or about (175)(0.7)/2 = 61 passengers per outbound train. At an LOS C flow of 15 ft²/p, and assuming that three-quarters of the passengers from each train would be on the platform simultaneously results in total walking area of (61)(0.75)(15), or 686 ft².
6. *Calculate the queue storage space required for exit points.* From Exhibit 10-31, the capacity of a double-width escalator is 68 p/min at a typical incline speed of 90 ft/min. As two up escalators will be provided, the capacity provided (136 p/min) is much greater than the maximum p.m. peak demand (58 p/train); thus no queue should develop. See Example 4 for an example of how to calculate queue storage space.
7. *Consider the additional platform space that will be unused.* A typical rail transit car has multiple doors along its length, minimizing dead areas. However, an underground station with a center platform will have other unused platform space, including elevator shafts, stairs and escalators, benches, and potentially advertising or information displays, trash cans, or pillars. In this case, a total of 550 ft² will be assumed to be used by the central stairs and escalators, the elevator shaft, and assorted benches and displays, based on an initial design concept for the station.
8. *Calculate the required buffer zone.* A buffer 1.5 ft wide is required on each side of the platform. Since the platform needs to be 300 ft long to accommodate a four-car train, and buffers are required on both sides of a center platform, this results in a total of 900 ft².
9. *Calculate the total platform area.* Adding up the results of steps 4 through 8, and rounding, results in a 5,685 ft² platform area for LOS C conditions.

Based on the initial design concept, the platform would need to be at least 28.5 feet wide to accommodate the central stairs (7.5 ft, from above) and escalators (5 ft each), a 4-ft walkway on either side, and a 1.5-ft buffer zone adjacent to each track. This would result in a total platform area of 8,550 ft², which is much more than is required. (The tracks would typically be parallel through the station, to avoid creating gaps between the cars and the platform at the car doors.) The width could be reduced by placing the platform exit and entry escalators and/or the stairs in separate locations along the platform length.

The platform size can also be evaluated for non-typical situations. For example, if there was a disruption in service, how long would it take for the platform to become overcrowded? Based on the initial design concept, a total of (8,550 – 900 – 550 – 686), or 6,414 ft² of space is available for queuing passengers, while leaving circulation space available for arriving passengers. A typical minimum design value for passenger waiting

areas is 5 ft²/p, which allows passengers to wait without touching one another. At this level of crowding, 1,282 people could be accommodated on the platform. This is about 20% higher than the peak 15-minute entering demand. At a minimally tolerable crowding level of 3 ft²/p, about 2,138 people could be accommodated, representing about 73% of the p.m. peak-hour entering demand. However, most passengers would find this amount of crowding to be uncomfortable, and it is close to the design evacuation load of 2,215 people calculated in the previous example problem (note that this design load evacuation load includes 1,400 passengers requiring evacuation from trains). The transit agency should plan to limit platform access under either circumstance to limit the amount of crowding.

The Results

The initial design concept appears to produce a wider platform than required to accommodate either typical or non-typical conditions. Alternative designs could involve spreading out the exit points to narrow the platform; this would also have the benefit of shortening the distance to the nearest platform exit.

CALCULATION EXAMPLE 4: ESCALATOR QUEUING AREA

Derived from a problem in Fruin (2).

The Situation

A subway platform on an urban heavy rail line will be modified to install an up direction escalator at the center of a subway platform.

The Question

What is the pedestrian queuing and delay for the proposed installation?

The Facts

- Field counts of passengers discharged by the subway trains show that maximum traffic occurs during a short micro-peak, when two trains arrive within 2 min of each other, carrying 225 and 275 passengers, respectively.
- The remaining trains in the peak period are on 4-min headways.
- The platform is 900 ft (275 m) long, and 15 ft (4.6 m) wide.
- Field observations of other subway stations in this city with similar passenger volumes reveal a maximum escalator capacity of 100 p/min (for the assumed 120 ft/min [36.6 m/min], 40-in. [1-m]-wide escalators in this example), as opposed to the nominal capacity of 90 p/min given in Exhibit 10-31.

Computational Steps

Constructing the Time Clearance Diagram

- A graph is constructed (Exhibit 10-39) with time, in minutes, as the horizontal axis, and pedestrians as the vertical axis.
- The escalator capacity of 100 p/min is then drawn (dashed sloped line).
- The arrival rate at the escalator is a function of the train discharge time and walking time required to reach the escalator. If it is assumed that pedestrians

are discharged uniformly along the length of the platform and the escalator is located in the center of the platform, arrival time can be approximately represented on the clearance diagram by determining the time required to walk half the platform length. A commuter walking speed of 91.4 m/min (300 ft/min) is used in this example.

$$\text{Total arrival time} = \frac{1/2 \text{ platform length}}{\text{average walking speed}} = \frac{450 \text{ ft}}{300 \text{ ft/min}} = 1.5 \text{ min}$$

The two train arrivals, with 225 and 275 passengers, are plotted as solid lines on the diagram.

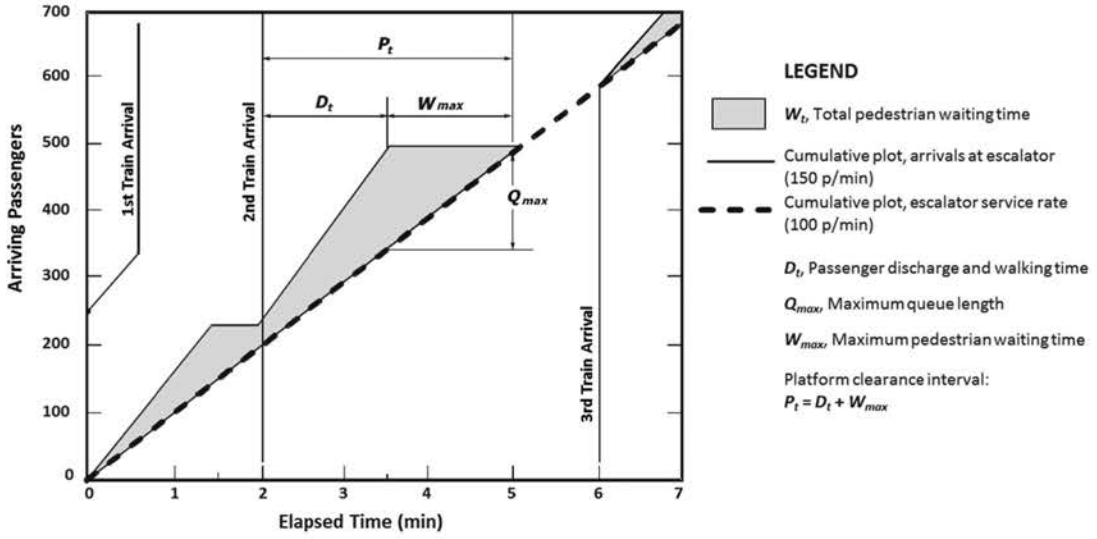


Exhibit 10-39
Calculation Example 4: Time Clearance Diagram

Determining the Maximum Queue Size and Maximum Wait

Assuming that all the passengers will use the escalator and not the stairs, the clearance diagram illustrates a number of significant facts. The shaded area between the pedestrian arrival rate (solid line), and the escalator service rate (dashed line), represents *total waiting time*.

Dividing the waiting time area by the number of arriving passengers gives *average passenger waiting time*. The maximum vertical intercept between these two lines represents *maximum passenger queue length*. The maximum horizontal intercept represents the *clearance interval* of the platform.

The clearance diagram shows that a maximum queue size of 75 persons would be generated by the first train arrival, if all persons seek escalator service. It also shows that 25 persons will still be waiting for the escalator service when the next train arrives.

The maximum waiting time for escalator service after the first train arrival is 1 min. The average passenger waiting time is 15 s. After the second train arrival, the maximum waiting and maximum queue size builds up to 1.5 min and 150 passengers, respectively. If it is assumed that passengers will divert to the stairs if the maximum escalator wait exceeds 1 min, a 1-min-wide horizontal intercept on the graph shows that maximum queue size will not likely get larger than 50 persons. This is about the limit observed for

low-rise escalators of this type, where alternative stationary stairs are conveniently available.

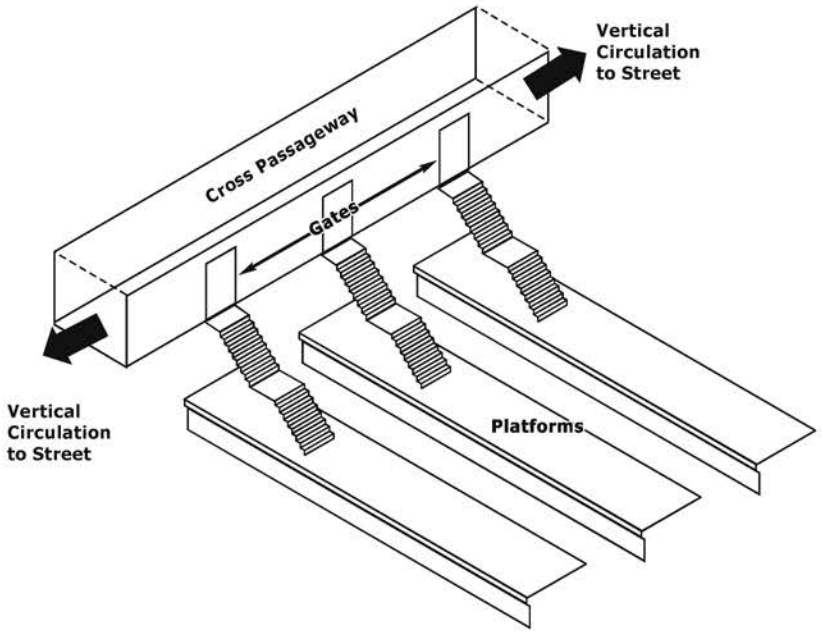
CALCULATION EXAMPLE 5: MULTIPLE PEDESTRIAN ACTIVITIES IN A FACILITY

Derived from an example in Benz (33).

The Situation

A new cross passageway (Exhibit 10-40) will provide access to and from the ends of platforms at a busy commuter rail terminal that currently has access at one end only. The passageway is essentially a wide corridor that will run perpendicular to and above the platforms, with stairs connecting the passageway to each platform. The cross passageway is connected to the surface at several points.

Exhibit 10-40
Calculation Example 5: Cross Passageway Layout



The Question

Can the corridor meet the space requirements of both queuing passengers and circulating passengers within a portion of the cross passageway adjacent to a departure gate?

The Facts

- Surveys at the station show that passengers departing on trains typically start to gather in front of a gate about 23 min before the train's scheduled departure time and assemble at the following rates:

Time Before Departure (min):	20	15	10	5	1
Departing Passengers (% gathered):	9	26	53	86	100

- The maximum accumulation of passengers outside the gate to the train platform occurs just before the opening of the gate—typically 10 min before train departure when 53% of the passengers leaving on the train are present. The

accumulation of waiting passengers, if large enough, can easily affect the cross passageway width available to handle longitudinal flow.

- As shown in Exhibit 10-41, the cross passage way is 140 ft long with an effective width of 25 ft (i.e., the width actually available for passenger activities: the wall-to-wall dimension minus the width occupied by obstructions and columns and the boundary or "cushion" maintained by pedestrians along walls). During the 1 min before the opening of the departure gate, 194 people will be waiting in the cross passageway. The flow rate of people walking along the corridor during this time is 167 p/min.

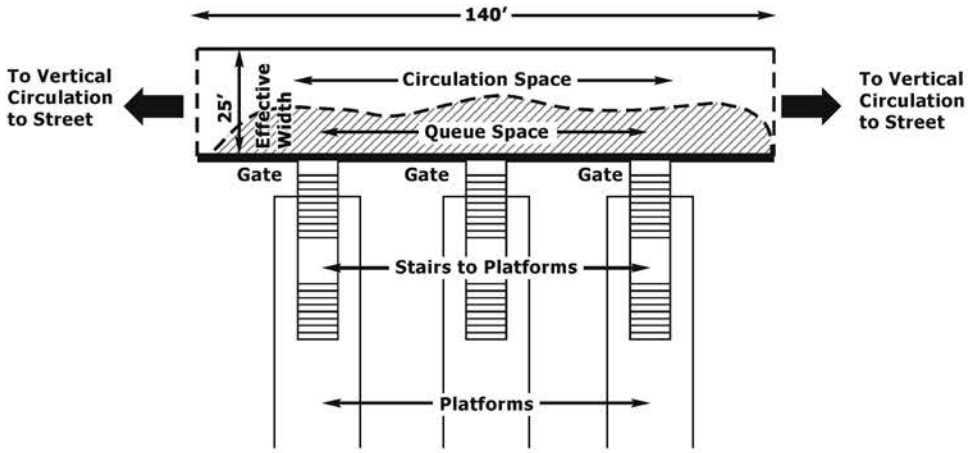


Exhibit 10-41
Calculation Example 5: Circulation and Queuing Spaces

Computational Steps

Outline of Solution

The problem is to examine whether the corridor can meet the space requirements of both queuing passengers and circulating passengers within a portion of the cross passageway adjacent to a departure gate. The analysis period is the 1 min before the opening of the gate when the maximum accumulation of waiting passengers will occur.

Determining the Size of the Queuing Space

With a design criterion of LOS B, the average pedestrian queuing area is 10 ft²/ped (see Exhibit 10-32). This criterion reflects the unordered (random) nature of the queue in this space, the need for some circulation and movement within the queue, and the comfort level expected by commuter rail passengers who may be waiting for some time before the gate opens. The 194 people waiting will require:

$$194 \text{ p} \times 10 \text{ ft}^2/\text{p} = 1{,}940 \text{ ft}^2$$

The shape of the queue has to be estimated in order to determine the portion of the 25-ft-wide cross passageway that the queue will occupy. For this example, the waiting passengers, occupying 1,940 ft², are assumed to be evenly distributed along the 140-ft linear dimension of the space. Therefore, the queue is expected to require the following width at its widest point:

$$\frac{1{,}940\ \text{ft}^2}{140\ \text{ft}} = 13.9\ \text{ft}$$

This leaves 11.1 ft available for the flow of the 167 circulating passengers who would walk through the cross passageway during the 1-min peak queue period. The unit width flow rate available is:

$$\frac{167\ \text{p/min}}{11.1\ \text{ft}} = 15.0\ \text{p/ft/min}$$

The Results

From Exhibit 10-28, this identified pedestrian flow rate equates to LOS C to D. In this LOS range, walking speeds and passing abilities are becoming restricted but are generally considered adequate for peak-period conditions. There will be some conflicts between opposing pedestrian traffic streams.

CALCULATION EXAMPLE 6: COMPLEX MULTILEVEL STATION

Derived from a study of Town Hall Station in Sydney, Australia.

The Situation

A complex urban rail transit station currently experiences congestion during peak periods and is expected to witness significant ridership growth over the next 20 years. Various improvement and expansion schemes will be developed and tested to increase the capacity of the station and improve passenger comfort and convenience.

The Question

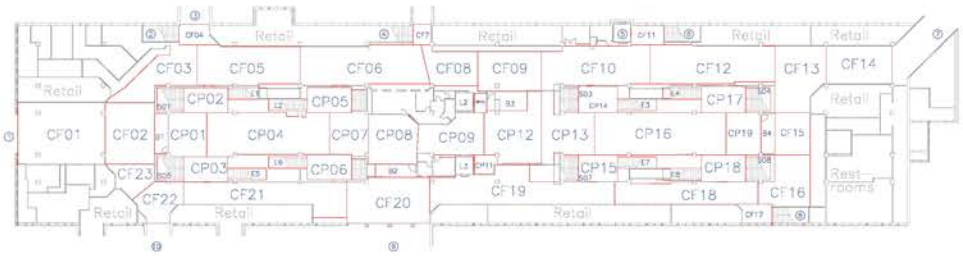
In order to identify potential improvements within the station, it is desirable to identify congested areas throughout the station, both on the platforms and on vertical circulation elements. Alternate station improvement and expansion schemes would then be laid out and tested in the same manner as the existing configuration.

The Facts

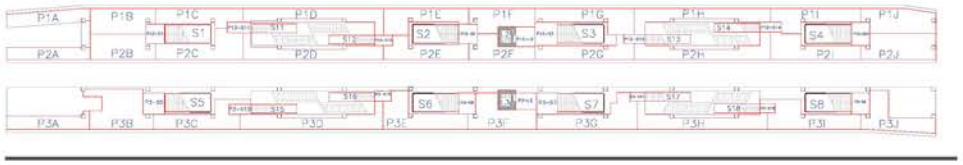
- The station has three levels underground: a concourse level and two platform levels that each have two platforms and three tracks. As shown in Exhibit 10-42, the concourse level includes a paid area surrounded by a free area lined with narrow retail establishments. The bottom image shows the upper platform level with vertical circulation passing through to reach the lower platform level. On each level one platform operates as an island serving two tracks and the other serves the third track.
- Because the station is an important transfer point, it experiences significant numbers of transfers, including same-track and cross-platform transfers, and transfers requiring changes between platforms and levels.
- Extensive surveys have been conducted to count the number of people passing through each entrance and using each vertical circulation element. Passenger interviews have been conducted to identify patterns of movement between platforms and the various access points and transfers within the station.

Exhibit 10-42
Calculation Example
6: Station Layout

Station Concourse



Upper Platform Level



Computational Steps

Outline of Solution

This example presents an approach based on traditional time-space analysis using a computer spreadsheet model to assess circulation. An alternate method using pedestrian simulation software is increasingly being applied to problems of this nature and is described in Example 7.

The station is subdivided into discrete circulation zones including areas of the concourse and platform levels and each of the vertical circulation elements. Zones and their identifying codes are shown in the concourse and platform plans in Exhibit 10-42. Extensive spreadsheets are used to assign peak-period pedestrians moving between distinct origin and destination points within the station to routes that either pass through or stay within each zone within the station. Additional spreadsheets organize data on the area of each zone, distinguish between persons walking and standing in each zone, and calculate levels of service in each zone.

Due to the extensive nature of this type of analysis, which is only practical with large spreadsheet models, this example presents the sequence of spreadsheets applied to the task without showing the lengthy equations, which, due to extensive cross-referencing of tables, are only meaningful in the spreadsheet environment.

Determining Pedestrian Volumes by Origin and Destination

The station has a total of 16 possible origins and destinations, comprising six platforms and ten external access/egress points. A pedestrian volume worksheet presents existing or future forecast volumes between any combination of the 16 origin–destination (O–D) points, including those who transfer from platform to platform and pedestrians who enter the free area of the concourse, but do not enter the station. Allowance is also made for those who may transfer to a different train on the same platform or enter and leave the concourse by the same door, as a person might do when visiting one of the shops on the concourse.

The data are input into the model in the form of a.m. and p.m. peak 5-min O–D matrices.

Assigning Pedestrian Routes

This worksheet includes an assignment by percent of people traveling between each of the 16 origins and destinations (256 combinations) to any of the 171 elements or zones (resulting in 43,776 assignment cells). Due to a change in direction of two escalators from the morning to the evening and different use of ticket gates at one entrance, different assignments are needed for each period. Additional modified routing assignment tables are required to analyze any proposed physical changes to the station.

Calculating Walk Volumes

This worksheet calculates the pedestrian volumes passing through each zone by multiplying the O–D volumes with the percentage assignment for each zone.

Calculating Walk Time

This worksheet includes the approximate time in seconds to walk through each analysis zone. Different walk times through a zone, representing different paths, can be associated to each origin and destination pair. The three typical choices are (*a*) the full length of the zone, (*b*) half the length, either as an average for people who end their walk in the zone or cut through it diagonally, or (*c*) a cross measurement that may be used for particular routes across some zones. Walk time is calculated based on distance in feet or meters divided by an assumed walking speed of 4.0 ft/s (1.2 m/s).

Calculating Percentage of Passengers Dwelling Within an Analysis Zone

This worksheet indicates the percent of pedestrians passing through a particular zone that dwell within that zone, either to wait for a train, to purchase a ticket, to make a purchase, or for other purposes. No dwell time is assumed on stairs, escalators, or fare control barriers but may be applied to the zones approaching these elements.

Calculating Dwell Time Within an Analysis Zone

This worksheet includes an average time in seconds that pedestrians who dwell in a zone spend there. On platforms, this time is related to train headways. On a system with very frequent service where people do not time their arrivals, this will generally be half the average headway. On a system with less-frequent service in which passengers time their arrivals to a train schedule, it will generally be less than half of the average headway. Appropriate times are also assigned for ticketing, browsing, or other dwell activities based on observations. A function based on volumes through circulation elements (e.g., turnstiles, stairs, escalators) representing crowding at the approach to these circulation elements may be added to this worksheet. The dwell time for the zones prior to the circulation elements, at the base of escalators and stairs, is based on a function related to the capacity of the element. When the circulation element approaches capacity, the dwell times in the prior zones are increased by the formula.

Determining Time–Space Demand

The demand for walk time–space is calculated for each analysis zone by multiplying pedestrian volumes in each zone by the walk time required and by an assumed design

standard of 1.4 m^2 per person. The demand for dwell time–space is calculated by multiplying pedestrian volumes in each zone by the dwell percent, the average dwell time, and an assumed dwell space of 0.65 m^2 per person. The two are totaled for a combined time–space demand in each zone.

Calculating LOS by Analysis Zone

The operating condition of each zone is assessed by levels of service. Design capacity for all elements is considered to be the threshold between LOS C and D. In order to calculate an LOS from a combination of walking and standing, the time–space demand is converted into a volume-to-*design* capacity ratio for each zone or element that is proportional to the LOS standards, as shown in the following table.

Level of Service	Volume-to-Design Capacity Ratios for Walk/Standing Zones	Volume-to-Design Capacity Ratios for Escalators/Fare Controls
LOS A	< 0.4	< 0.6
LOS B	0.4 – 0.6	0.6 – 0.8
LOS C	0.6 – 1.0	0.8 – 1.0
LOS D	1.0 – 1.5	1.0 – 1.1
LOS E	1.5 – 2.8	1.1 – 1.2
LOS F	2.8 +	1.2 +

Note: Ratios have no units and may be applied with any units of measure.

The Results

The product of this analysis is an LOS for each platform or mezzanine zone and each stairway, and a volume-to-capacity ratio for each fare control array and escalator. To provide a spatial representation of passenger congestion, station plans can be colored based on the rating for each zone using a geographic information system or other graphic software. By using a suitable range of colors to represent free-flow to congested conditions, the relative congestion of areas throughout the station can be observed.

CALCULATION EXAMPLE 7: APPLICATION OF PEDESTRIAN MICROSIMULATION SOFTWARE

Application of pedestrian simulation software to analyze passenger flow in a station.

Introduction

Pedestrian microsimulation software is increasingly being applied to passenger circulation studies for a wide range of transit facilities. Simple models can be developed relatively easily to study discrete areas within stations and more complex models can be developed to study passenger circulation in complete stations and complex multi-level intermodal stations.

The inputs required for a model vary depending on the type and extent of the area being analyzed and the outputs desired vary depending on the key issues of concern in a particular facility or part of a facility. Each of the available software programs also vary somewhat in the specific inputs, outputs, and terminology applied. This example, instead of looking at a specific situation and laying out calculations or specific parameters, describes in general terms the typical inputs, outputs, and considerations that go into developing a simulation model for any transit station facility.

Model Development Steps

Step 1: Collect and Format Data

When creating a model, the first elements required are some form of pedestrian flow data for the area and plans of that area. Data should be summarized to the appropriate timeframe of the simulation. In a simple model, the flow of pedestrians might be relatively uniform, but where data or operational circumstances dictate, volumes may be more variable. A common method of entering pedestrian volumes is an origin–destination matrix that corresponds to the model entry and exit locations. Pedestrian flow data can be entered in this fashion, for the time period desired by the type of pedestrian. From there, data can be refined down to the smallest time increment needed, allowing the data to be peaked as needed.

As with other types of modeling exercise, it is common practice to create a base year model first (where existing transit facilities exist), and to agree upon all relevant future year data assumptions and forecasts at the outset. In some cases, it may also be relevant to plan for the creation of a future year "do nothing" model scenario to allow the implications of a proposed project to be identified.

Step 2: Prepare CAD Plans

The layout of the area to be modeled is typically entered into the model in a standard format CAD plan drawing file. CAD plans from architects or engineers typically require editing before they are suitable for importing into pedestrian simulation software. At a minimum, a CAD layer showing only boundaries to movement is required; some linework in typical CAD files would be interpreted as barriers to movement by the pedestrian simulation software. Additional linework and other graphic elements may be required for clarity in outputs, but must be separated for use with the software. It is therefore helpful to edit the CAD files into two types of layers:

- Presentation CAD and
- Simulation CAD.

Presentation CAD layers provide useful contextual information about the pedestrian venue but they are not obstacles to movement; examples include:

- Text labels;
- Stair steps and landings;
- Escalator landings, comb lines, and work points;
- Door swing paths; and
- Overhead elements.

Presentation CAD can also provide useful reference points for laying out control objects in the pedestrian simulation software.

Simulation CAD lines represent objects that are genuine obstacles to pedestrians; examples include:

- Walls,
- Balustrades and railings,
- Faregates,

- Windows,
- Door jambs,
- Furniture, and
- Vehicles.

The more CAD lines that are retained for use in a simulation, the longer a simulation may take to run, so the simulation CAD layer should be the minimum CAD necessary to define the pedestrian-accessible space. When running a simulation, the presentation CAD can be kept aside, which may speed up the simulation time.

The simulation layer should also be flattened, to ensure that all lines truly intersect. Further, it should be examined for small gaps in the linework that define the boundaries of accessible space. Any gaps discovered should be closed to prevent models from assuming there is a means of passing the line.

Step 3: Model Building

To use the data created in Step 1 with the CAD plans created in Step 2, a simulation must have model objects created within it to inform simulated pedestrians what area they are passing through, and how those elements are linked to one another. In this step, vertical circulation elements need to be created if present, and their operations defined (i.e., escalator directionality, elevator speed, escalator incline). Model entry points have to be created and demand data associated with them. Model exits are created and linked to entries. Any special spatial objects and their controls need to be created (e.g., queues for ticket vending machines, waiting areas, directional controls, train announcements, and boarding calls if applicable). Once model elements have been created, validated, and checked, the simulation can be run.

Step 4: Model Calibration and Validation

Models generally need a series of debugging and calibrating runs to establish proper functioning and appropriate behavior. Some issues may be noticeable early in a simulation run, allowing the user to stop the run early and make corrections. Other issues may not be recognizable until a model has run through a significant portion of the simulation period. Once a model is running through its full timeframe without errors or inappropriate behaviors, full simulations may be run and variations assessed.

Validation of base year model flows against survey data is complicated when using simulation software that incorporates dynamic route assignment functionality, due to the absence of the types of statistical tests developed for the purpose of validating roadway models (e.g., the GEH test).

Step 5: Model Analysis

Analytical measures can be coded into the model as it is being developed to produce selected statistics, graphs, maps, or video clips. After successful model validation, these analytical measures can be recorded for subsequent model runs and variations on the design or operation. Most software programs can produce analyses for cordon counts, travel times, or area analyses and display those results in either graphical or video formats.

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APPENDIX A: EXHIBITS IN METRIC UNITS

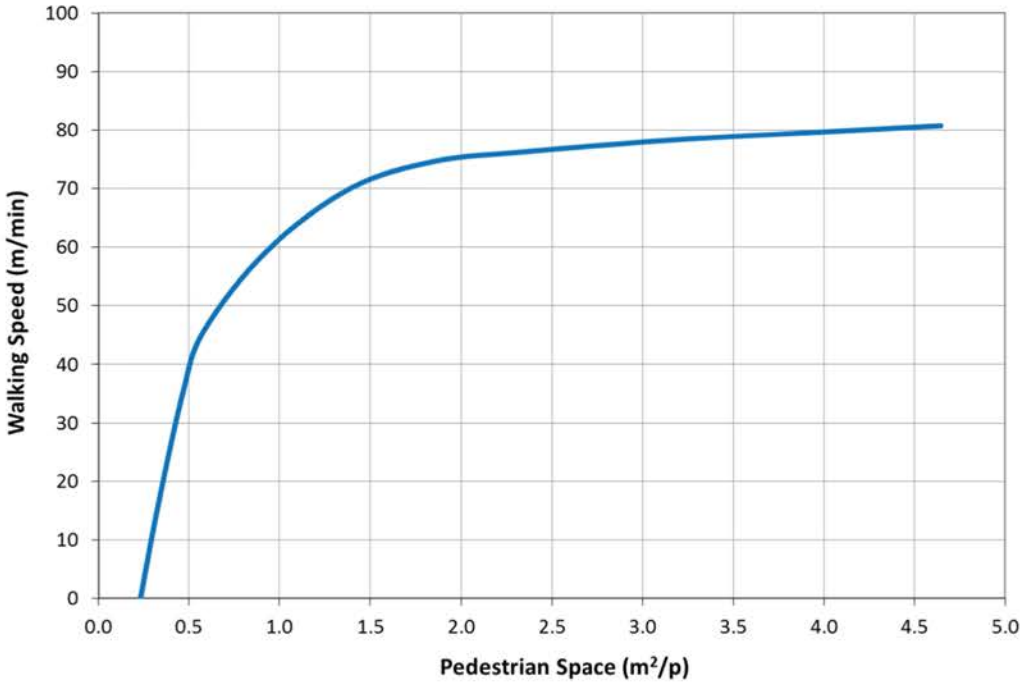


Exhibit 10-10m
Pedestrian Speed on Walkways

Source: Derived from Fruin (*2*).

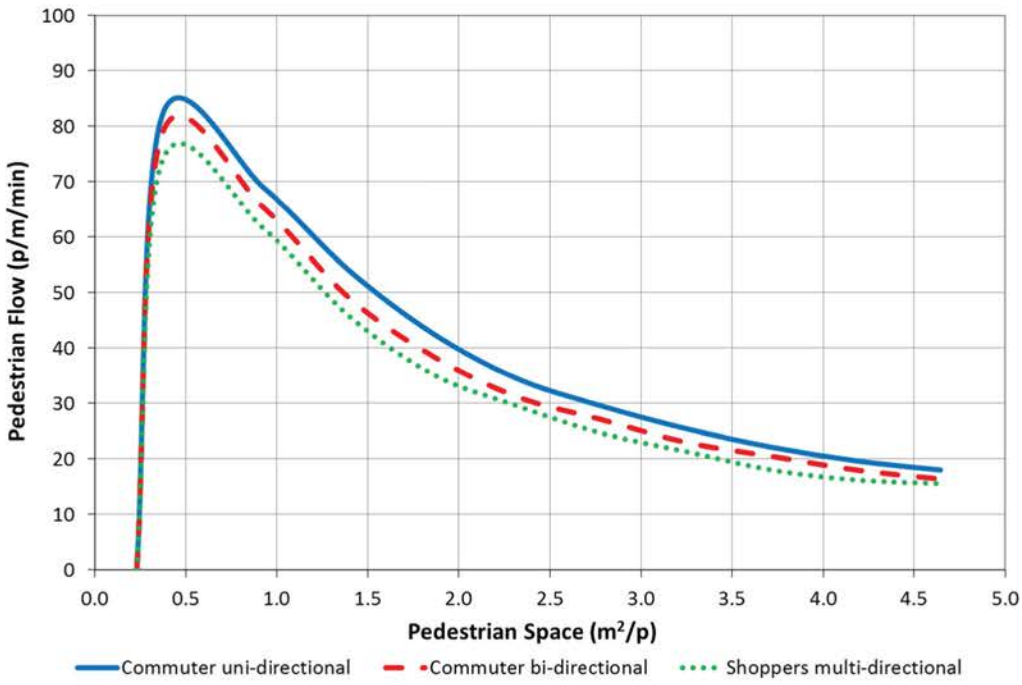
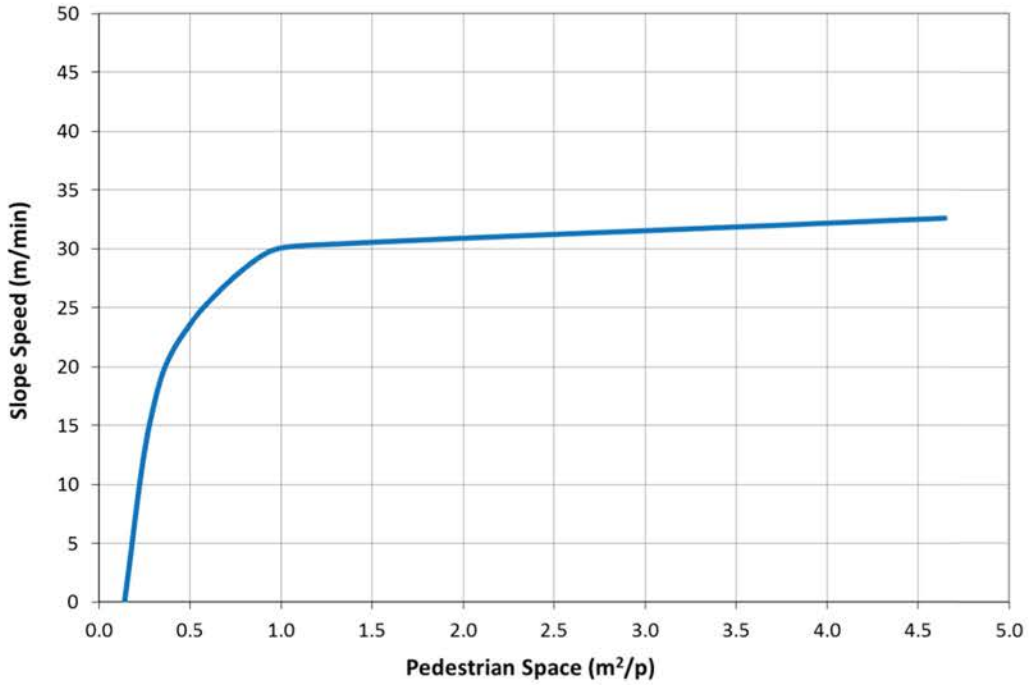


Exhibit 10-11m
Pedestrian Flow on Walkways by Unit Width and Space

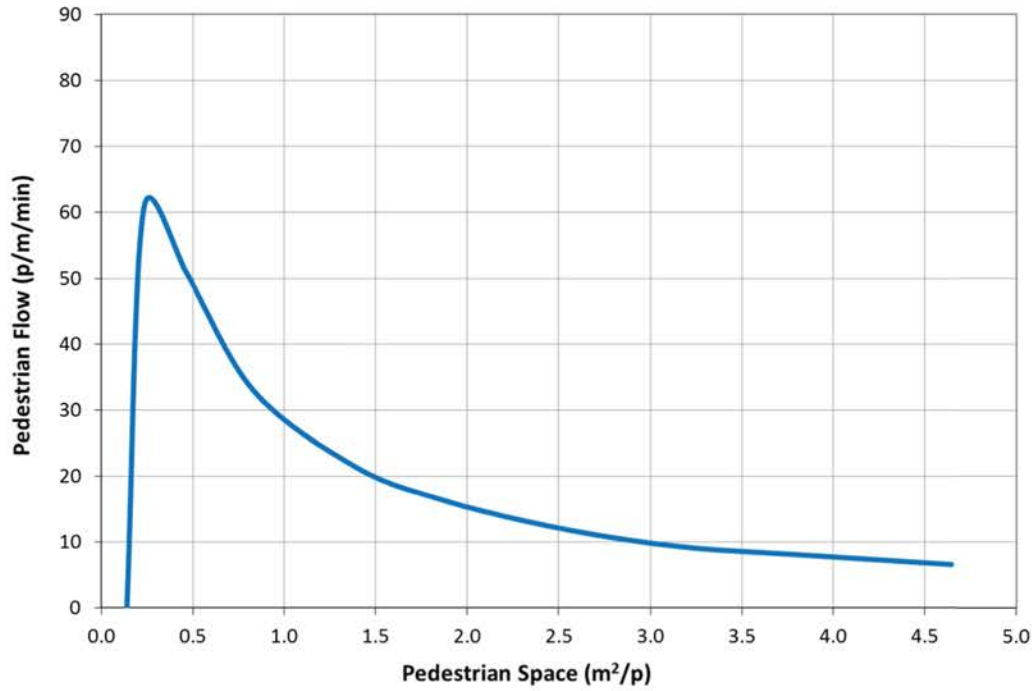
Source: Derived from Fruin (*2*).

Exhibit 10-15m
Pedestrian Ascent Speed on Stairs



Source: Derived from Fruin (*2*).

Exhibit 10-16m
Pedestrian Flow Volumes on Stairs



Source: Derived from Fruin (*2*).

CHAPTER 11
GLOSSARY AND SYMBOLS

1. User's Guide
2. Mode and Service Concepts
3. Operations Concepts
4. Quality of Service Concepts
5. Quality of Service Methods
6. Bus Transit Capacity
7. Demand-Responsive Transit
8. Rail Transit Capacity
9. Ferry Transit Capacity
10. Station Capacity
11. **Glossary and Symbols**
12. Index

CONTENTS

1. GLOSSARY 11-1

A 11-1
B 11-4
C 11-8
D 11-14
E 11-16
F 11-17
G 11-20
H 11-21
I 11-22
J 11-23
K 11-24
L 11-24
M 11-27
N 11-29
O 11-30
P 11-32
Q 11-36
R 11-36
S 11-40
T 11-47
U 11-56
V 11-58
W 11-59
Y 11-59
Z 11-60

2. LIST OF SYMBOLS 11-61

1. GLOSSARY

This chapter presents definitions for the various transit terms discussed and referenced in the TCQSM. Other important terms related to transit planning and operations are included so that this glossary can serve as a readily accessible and easily updated resource for transit applications beyond the evaluation of transit capacity and quality of service. As a result, this glossary includes local definitions and local terminology, even when these may be inconsistent with formal usage in the manual.

Many systems have their own specific, historically derived, terminology: a motorman and guard on one system can be an operator and conductor on another. Modal definitions can be confusing. What is clearly light rail by definition may be termed streetcar, semi-metro, or rapid transit in a specific city. It is recommended that in these cases local usage should prevail.

AADT — annual average daily traffic; see *traffic, annual average daily.*

AAR — Association of American Railroads; see *organizations, Association of American Railroads.*

AASHTO — American Association of State Highway and Transportation Officials; see *organizations, American Association of State Highway and Transportation Officials.*

AAWDT — annual average weekday traffic; see *traffic, annual average weekday.*

ABS — automatic block signal; see *control system, automatic block signal.*

AC — alternating current.

ADA — Americans with Disabilities Act of 1990; see *legislation, Americans with Disabilities Act of 1990.*

ADB — advanced design bus; see *bus, advanced design* and *ATTB.*

ADT — average daily traffic; see *traffic, average daily.*

ATTB — Advanced Technology Transit Bus.

AFC — automatic fare collection; *see fare collection system, automatic.*

AGT — automated guideway transit; automated guided transit; see *transit system, automated guideway.*

ALRT — advanced light rail transit, see *transit system, light rail.*

APC— automatic passenger counter.

APM — automated people mover, see *people mover.*

APTA — American Public Transportation Association; see *organizations, American Public Transportation Association.*

APTS — Advanced Public Transportation Systems.

ATC system — automatic train control system.

ATIS — Advanced Traveler Information Systems.

ATO — automatic train operation.

ATP — automatic train protection.

ATS — automatic train supervision; automatic train stop system.

ATU — Amalgamated Transit Union; see *union, transit.*

AVL — automatic vehicle location system.

AW0, AW1, AW2, AW3 — see *car, weight designations.*

absolute block — see *block, absolute.*

absolute permissive block — see *block, absolute permissive.*

acceleration — increase in velocity per unit time; in transit, usually measured in feet per second squared (meters per second squared) or, in the United States, sometimes in miles per hour per second.

access, limited (controlled access) — in transportation, to have entry and exit limited to predetermined points, as with rail rapid transit or freeways.

accessibility — 1. a measure of the ability or ease of all people to travel among various origins and destinations. **2.** in transportation modeling and planning, the sum of the travel times from one zone to all other zones in a region, weighted by the relative attractiveness of the destination zones involved. **3.** in traffic assignment, a measure of the relative access of an area or zone to population, employment opportunities, community services, and utilities.

accessibility, persons with disabilities (full accessibility) — the extent to which facilities are free of barriers and usable by persons with disabilities, including wheelchair users.

accessibility, station — a measure of the ability of all people within a defined area to get to a specific transit station.

accessibility, transit — 1. a measure of the availability of all people to travel to and from various origins and destinations by transit. **2.** a

measure of the ability of all people to get to and from the nearest transit stop or station and their actual origin or destination. **3.** in common usage, often used to mean the ability of persons with disabilities to use transit.

accessible station — see *station, accessible.*

accessible vehicle — see *vehicle, accessible.*

accessible transit system — see *transit system, accessible.*

accessible transportation facilities — transportation facilities that are barrier-free, allowing their use by all travelers, including elderly, transportation disadvantaged, and persons with disabilities.

access mode — see *mode, access.*

access time — see *time, access.*

active vehicle — see *vehicle, active.*

activity center — see *major activity center.*

act — see *legislation.*

ADA paratransit eligible individual — individuals whose disabilities, permanent or temporary, prevent their independent use of fixed-route transit service. Transit agencies must establish an eligibility process to determine which individuals qualify for ADA complementary paratransit services. See also *legislation, Americans with Disabilities Act of 1990 (ADA)* and *paratransit, complementary.*

add fare — 1. an additional fare to upgrade an existing ticket. **2**. an additional fare paid on exit from a distance based fare system when there are insufficient funds remaining on a stored value ticket, see also *fare, differential*.

adult cash fare — see *fare, adult cash.*

advanced design bus — see *bus, advanced design.*

Advanced Public Transportation Systems — collection of technologies to increase efficiency of public transportation systems and offer users greater access to information on system operation.

Advanced Railroad Grade Crossing — National ITS Architecture Market Package that manages highway traffic at *highway-rail intersections* where operational requirements demand advanced features (e.g., where rail speeds are greater than 80 mph or 128 km/h). It includes all capabilities from the *Standard Railroad Grade Crossing Market Package* and augments these with additional safety features to mitigate the risks associated with higher rail speeds.

Advanced Traveler Information Systems — technologies that provide travelers and transportation professionals with the information they need to make decisions, from daily individual travel decisions to larger-scale decisions that affect the entire system, such as those concerning incident management.

advisory committee — see *organizations, citizen advisory committee.*

aerial lift — ropeways on which passengers are transported in cabins or on chairs and that circulate in one direction between terminals without reversing the travel path.

aerial structure — in transportation, any structure other than a culvert that carries a roadway or track or other guideway above an earth or water surface; see also *guideway, elevated*.

aerial tramway — ropeways on which passengers are transported in cable-supported carriers and are not in contact with the ground or snow surface, and in which the carrier(s) reciprocate between terminals. Also called a *reversible tramway*.

agencies, federal — see *U.S. Government.*

agency, regional planning — see *organizations, regional planning agency.*

agency, transit — see *transit district.*

air brake — see *brake, air;* and *brake, automatic air.*

air distance — see *distance, air.*

alight — to get off or out of a transportation vehicle.

alignment — in transportation, the horizontal and vertical layout of a roadway, railroad, transit route, or other facility as it would appear in plan and profile. The alignment is usually described on the plans by the use of technical data, such as grades, coordinates, bearings, and horizontal and vertical curves, see also *roadbed* and *formation.*

all-or-nothing trip assignment — see *trip assignment, all-or-nothing.*

all-stop station — see *station, all-stop.*

alternate fuel — alternatives to conventional diesel fuel for urban transit buses, intended to reduce pollution, includes methanol, propane, CNG (compressed natural gas), LNG (liquefied natural gas), hydrogen (for fuel cells) and biomass derived fuels. All carry premium costs that trend in larger or more cost-conscious operators toward "clean diesel" solutions. See also *buses, hybrid.*

alternating-current motor — see *motor, alternating-current.*

alternative fuel — see *fuel, alternative.*

Amalgamated Transit Union — see *union, transit.*

amenity, passenger — see *passenger amenity.*

American Association of State Highway and Transportation Officials — see *organizations, American Association of State Highway and Transportation Officials.*

American Public Transit Association — see *organizations, American Public Transportation Association.*

American Public Transportation Association — see *organizations, American Public Transportation Association.*

a.m. peak — see *peak.*

Amtrak — see *U.S. Government, National Railroad Passenger Corporation.*

annual average daily traffic — see *traffic, annual average daily.*

annual average weekday traffic — see *traffic, annual average weekday.*

area, auto-free — see *auto-free zone.*

area, auto-restricted — see *auto-restricted zone.*

area, coverage — in transit operations, the geographical area that a transit system is considered to serve, normally based on acceptable walking distances (e.g., ¼ mile, 0.4 km) from loading points. For suburban rail transit that depends on automobile access (park-and-ride or kiss-and-ride), coverage may extend several miles (kilometers). Coverage is usually computed for *transit-supportive areas.* See also *area, service.*

area, fare paid — **1.** an area that a passenger may enter only after having paid a fare or with proper credentials. **2.** the area in a station that is set off by barriers, gates, or other structures to permit ready access to transit only by those who have paid fares or secured passes before entering.

area, free — a portion of a transportation facility that people are permitted to enter without the payment of a fare.

area, fringe — the portion of a municipality immediately outside the central business district or the portion of an urban area outside of a central city or cities (urban fringe) that is characterized by a variety of business, industrial, service, and some residential activity.

area, loading — see *loading area.*

area, service — **1.** the jurisdiction in which the transit property operates. **2.** the geographic region in which a transit system provides service or that a transit system is required to serve. See also *area, coverage.*

area, transit-supportive — an area with sufficient population and/or employment density to warrant at least hourly fixed-route transit service.

area, urbanized (UA) — as defined by the Bureau of the Census, a population concentration of at least 50,000 inhabitants, generally consisting of a central city and the surrounding, closely settled, contiguous territory *(suburbs).* The boundary is based primarily on a population density of at least 1,000 people/mi^2 (370 people/km^2) but also includes some less densely settled areas, as well as such areas as industrial parks and railroad yards, if they are within areas of dense urban development. The boundaries of UAs, the specific criteria used to determine UAs, or both may change in subsequent censuses. It should be noted that some publications abbreviate urbanized area *UZA.*

area occupancy — in station and other facility design and in pedestrian movement, the area provided per person.

arterial roadway — a signalized street that primarily serves through traffic and secondarily provides access to abutting properties; signal spacing is typically 2 miles (3 km) or less.

arterial service — see *service, arterial.*

articulated bus or articulated trolleybus — an extra-long, high-capacity bus or trolleybus that has the rear body section or sections flexibly but permanently connected to the forward section. The arrangement allows the vehicle to bend in curves and yet have no interior barrier to movement between the two parts. The *puller* type features a powered center axle while the *pusher* type features a powered rear axle. Articulated buses with powered center and rear axles exist but are not common. Typically, an articulated bus is 54-60 ft (16-18 m) long with a passenger seating capacity of 60 to 80 and a total capacity of 100 to 140.

articulated rail vehicle (articulated car) — **1.** an extra-long rail vehicle with two or more bodies connected by joint mechanisms that allow bending in curves yet provide a continuous interior Typically, the vehicle is 55-100 ft (17-33 m) long. It is common on light rail but is also found on several heavy rail systems. **2.** rapid transit cars with separate bodies that share a common center truck.

aspect, signal — see *signal aspect.*

assignment, traffic or trip — see *trip assignment.*

Association of American Railroads — see *organizations, Association of American Railroads.*

attendant — the individual assigned to particular duties or functions in the operation of a ropeway. Also called a *conductor*.

attraction, trip — see *trip attraction*.

attributes, service — see *service attributes.*

authority, transit — see *transit district.*

authorized speed — see *speed, reference*.

automated guideway transit — see *transit system, automated guideway.*

automated people mover — see *people mover.*

automatic block signal — see *signal, automatic block.*

automatic block signal control system — see *control system, automatic block signal.*

automatic coupler — see *coupler, automatic.*

automatic fare collection — see *fare collection system, automatic.*

automatic passenger counter (APC) — an automated system that counts the number of passengers boarding and alighting a transit vehicle. The information may be used for later data analysis, or for real-time activities, such as providing signal priority only to buses that are at least half full.

automatic signal — see *signal, automatic.*

automatic train control system (ATC system) — **1**. a system for automatically controlling train movement, enforcing train safety, and directing train operations by computers; see also *automatic train operation, automatic train protection,* and *automatic train supervision.* **2.** a trackside system working in conjunction with equipment installed on the train, arranged so that its operation will automatically result in the application of the brakes

to stop or control a train's speed at designated restrictions, should the operator not respond. The system usually works in conjunction with cab signals (more correctly called *automatic train stop*).

automatic train operation (ATO) — the subsystem within automatic train control that performs such functions as speed control, programmed stopping, and (sometimes) door operation.

automatic train protection (ATP) — the subsystem within automatic train control that provides fail-safe protection against collisions, and sometimes against excessive speed or other hazardous conditions.

automatic train stop system (ATS) — a system that works in conjunction with equipment installed on the electric rail car or locomotive to apply the brakes at designated restrictions or on a dispatcher's signal, should the operator not respond properly.

automatic train supervision (ATS) — the subsystem within automatic train control that monitors trains, adjusts the performance of individual trains to maintain schedules, and provides data for adjusting service to minimize the inconveniences otherwise caused by irregularities. May also be used for systems that merely display train status and rely on staff intervention for any corrective action.

automatic vehicle location system (AVL) — a system that determines the location of vehicles carrying special electronic equipment that communicates a signal back to a central control facility. AVLs are used for detecting irregularity in service and are often combined with a computer-aided dispatch system.

automobile equivalent unit (AEU) — measure of a vessel's capacity to transport vehicles that reflects the amount of space used by each vehicle type. Vehicle types are assigned a size in AEUs based on the space they occupy compared with a standard automobile.

automobile or auto occupancy — see *vehicle occupancy.*

availability, transit system — see *transit system availability.*

average daily traffic — see *traffic, average daily.*

average fare — see *fare, average.*

average speed — see *velocity, effective.*

average trip length — passenger miles divided by unlinked passenger trips. Can be computed for pedestrian trips and vehicle trips, based on special surveys.

B

barn — older term for streetcar storage building (also known as a *carhouse),* or for buses (*garage),* infrequently applied for light and heavy rail vehicles (alternates: *yard, depot, shop, maintenance and storage facility*.)

barrier free — containing no obstacles that would prevent use by persons with disabilities or any other person.

barrier-free fare collection system — see *fare collection system, self-service barrier free.*

base fare — see *fare, base.*

base headway — see *headway, base.*

base period (off-peak period) — in transit, the time of day during which vehicle requirements and schedules are not influenced by peak-period passenger volume demands (e.g., between morning and afternoon peak periods). At this time, transit riding is fairly constant and usually moderate in volume when compared with peak-period travel. See also *off peak.*

base-period fleet — in transit, the number of transit units (vehicles or trains) required to maintain base-period schedules.

base-period service — see *service, base-period.*

basic fare — see *fare, base.*

basic operating unit — in rail rapid transit, the smallest number of rapid transit vehicles that can operate independently in revenue service, usually one to three (exceptionally more) cars.

battery bus — see *bus, electric.*

bay, bus — see *bus bay.*

beacon — short-range roadside transceiver for communicating between vehicles and the traffic management infrastructure. Common transmission technologies include microwave and infrared.

belt, passenger — see *moving walkway*.

berth, bus — see *bus bay.*

berth, ferry — see *ferry berth.*

berth, train — see *train berth.*

bicable system — an *aerial ropeway* that uses track cable(s) to support the carriers and separate haul rope(s) to control motion of the carriers (see also *monocable system*).

bicycle-friendly — characterized by features and elements that make bicycling safe and convenient. A bicycle-friendly environment at a transit stop might include bicycle parking that is well lit, sheltered, secure, and easily accessed.

bicycle locker — a lockable, enclosed container used for storing a bicycle. Typically provided at major transit stops and stations and rented on a monthly basis.

bicycle rack — **1.** a fixed post or framework to which bicycles may be secured and locked, typically provided on a first-come, first-served basis. **2.** a device mounted to a transit vehicle that allows bicycles to be transported outside the passenger compartment. Typically provided on a first-come, first-served basis; many transit operators require that passengers obtain a permit to use them.

bidirectional car — see *car, bidirectional.*

bidirectional transit unit — see *double-ended transit unit.*

bi-level car — see *car, bi-level.*

blister — see *bus bay.*

block — 1. A section of track or guideway of defined limits on which the movement of trains is governed by block signals, cab signals, or both; also known as a *signal block.* ***2.*** A section of track of defined length, the occupancy of which is regulated by fixed signal(s), telephone or radio orders, or timetables; also known as a *block section.* ***3.*** The daily operating schedule of a transit unit (vehicle or train) between pull-out and pull-in, including scheduled and deadhead service. A block may consist of a number of runs.

block, absolute — a signal block that no train may enter while the block is occupied by another train.

block, absolute permissive — a signal system for a single track or guideway that prevents simultaneous opposing train movements between sidings but permits following movements at a safe distance.

block, signal — a standard railroad signal system that uses a fixed signal at the entrance of a block to govern the separation of trains entering the block; see also *block.*

block control system, dynamic — see *control system, moving block.*

block control system, fixed — see *control system, fixed block.*

block control system, manual — see *control system, manual block.*

block control system, moving — see *control system, moving-block*.

block indicator — a device, generally located near a turnout switch, that is used to indicate the presence of a train in the block or blocks leading to that switch.

block section — see *block.*

block signal — see *signal, block.*

block signal control — see *control system, block signal;* and *control system, automatic block signal.*

board — to go on to or into a transportation vehicle.

boarding island — 1. a pedestrian refuge within the right-of-way and traffic lanes of a highway or street. It is provided at designated transit stops for the protection of passengers from traffic while they wait for and board or alight from transit vehicles; also known as a *pedestrian* or *loading island.* **2.** a protected spot for the loading and unloading of passengers. It may be located within a rail transit or bus station. **3.** on streetcar and light rail systems, a passenger loading platform in the middle of the street, level with the street or more usually raised to curb height, often protected with a *bollard* facing traffic, also known as a *safety island.*

bollard — an upright fixed block (usually metal or concrete) used to prevent the unauthorized or unintended entry of vehicles into an area.

brake, air — a brake in which the mechanism is actuated by manipulation of air pressure. The term is often used to describe brakes that employ air pressure above atmospheric pressure, in contrast to vacuum brakes, which employ pressure below atmospheric.

brake, blended — see *brake, dynamic*.

brake, continuous (trainlined brake) — a system of brakes interconnected among rail cars so that the brakes on all cars in the train can be operated simultaneously from the locomotive or from any car in a multiple-unit train.

brake, disc — a brake used primarily on rail passenger cars that uses brake shoes clamped by calipers against flat steel discs.

brake, dynamic (electric brake, electrodynamic brake, motor brake) — a system of electrical braking in which the traction motors, used as generators, retard the vehicle by converting its kinetic energy into electrical energy. This energy is absorbed by resistors. See also *brake, regenerative.* Dynamic brakes may be used to control train speed and to brake a train to a low speed, after which air brakes are blended in to bring the train to a full stop.

brake, electric or electrodynamic — 1. alternate to air brake for some streetcars and light rail vehicles — most notably immediately post-war **Presidents' Conference Committee (PCC)** cars. **2.** braking through electric motors, see *brake, dynamic.*

brake, electromagnetic — see *brake, track.*

brake, electropneumatic (pneumatic brake) — an automatic air brake that has electrically controlled valves to expedite applying and releasing the brakes.

brake, friction (mechanical brake) — a brake that presses brake shoes against the running wheel tread or pads against inboard or outboard disc surfaces.

brake, hydraulic — hydraulically operated brake typical of automotive practice, used on small buses and vans and entering use on some rail vehicles as alternate to air brake.

brake, magnetic — see *brake, track.*

brake, mechanical — see *brake, friction.*

brake, motor — see *brake, dynamic.*

brake, pneumatic — see *brake, electropneumatic.*

brake, regenerative — a form of dynamic brake in which the electrical energy generated by braking is returned to the power supply line instead of being dissipated in resistors. In rare cases the traction sub-stations can return this power to the electric utility or burn it in resistors, then the line is always receptive, eliminating onboard resistors.

brake, service — l. the primary train brake system. **2.** the braking rate used for normal deceleration requirements, in contrast to emergency braking, which may provide greater retardation. Typically 0.13 *g*, 3.0 mi/h/s, or 1.3 m/s^2, a level beyond

which standing passengers become uncomfortable or may lose their balance.

brake, slip-slide control — an electronic control used on most current rail vehicles to sense and correct wheel slip or slide by modulating braking or reducing acceleration.

brake, track (electromagnetic brake, magnetic brake) — a brake that consists of electromagnets suspended above the track rail between the two wheels on both sides of a truck. When applied, the brakes are attracted onto the steel rails, exerting braking force through friction. The brakes are difficult to apply gradually and so are reserved for emergencies (often from battery power) and are always supplementary to another braking system. This type of brake is used on most light rail vehicles and streetcars and on some heavy rail cars (modulated electromagnetic track brakes are used on the Vancouver SkyTrain.)

brake, trainlined — see *brake, continuous.*

brake shoe — the non-rotating portion of a tread or disc brake assembly. The shoe is pressed against the tread, disc, or drum when the brake is applied.

braking, closed loop — braking under continuous modulation by means of feedback from the train control system.

braking, emergency (emergency application) — in rail operations, applying the brakes to stop in the minimum distance possible for the equipment, usually at a higher retardation rate than that obtained with a maximum service brake application. Once the brake application is initiated, it often cannot be released until the train has stopped or a predetermined time has passed.

braking, full service — see *braking, maximum service.*

braking, maximum service (full service braking) — in rail operations, a non-emergency brake application that obtains the maximum brake rate that is normally regarded as comfortable for passengers and consistent with the design of the primary brake system.

braking, open-loop — unmodulated braking without feedback control from the train control system.

braking, programmed — automatically controlled braking that causes a train to stop or reduce its speed to a predetermined level at a designated point within a specified range of deviation.

braking rate — see *deceleration.*

braking, service (service application) — in rail operations, retardation produced by the primary train braking system at the maximum rate of retardation regarded as comfortable for repeated use in service stopping. See *brake, service* for rates.

bridgeplate — a retractable metal plate used to span the gap between a station platform and the vehicle door.

broad gauge — see *gauge, broad.*

Broadcast Traveler Information — National ITS Architecture Market Package that provides the user with a basic set of ATIS services. It involves the collection of traffic conditions, advisories, general public transportation, toll and parking information, incident information, and air quality and weather information, and the dissemination of this information over a wide area through existing infrastructures and low-cost user equipment (e.g., FM subcarrier, cellular data broadcast).

bulb — see *bus bulb.*

bull wheel — a terminal sheave that deflects the haul rope 150 degrees or more. When under power, the sheave is referred to as a drive sheave (or drive bull wheel). When acting as a movable tensioning device, it is referred to as a tension sheave (or tension bull wheel). When it is acting simply as a fixed return for the haul rope, it is referred to as a fixed return sheave (or fixed return bull wheel).

bunching — with transit units, a situation that occurs when passenger demand is high and dwell times at stops are longer than scheduled. Headways become shorter than scheduled, and platoons of transit units (vehicles or trains) develop, with longer intervals between platoons. The same effect (one transit unit caught by the following) can also be caused by lack of protection from general road traffic congestion or by traffic signal timing. Bunching can become cumulative and can result in delay to passengers and unused capacity.

bus — a self-propelled, rubber-tired road vehicle designed to carry a substantial number of passengers (at least 16, various legal definitions may differ slightly as to minimum capacity), commonly operated on streets and highways. A bus has enough headroom to allow passengers to stand upright after entering. Propulsion may be by internal combustion engine, electric motors or hybrid; see also *alternate fuels*. Smaller capacity road transit vehicles, often without full headroom, are termed vans.

bus, advanced design (ADB) — a prototype bus, originally introduced in the mid-1970s, that incorporates new styling and design features specified by the then Urban Mass Transportation Administration.

bus, articulated — see *articulated bus or articulated trolleybus.*

bus, battery — see *bus, electric.*

bus, commuter — see *service, commuter.*

bus, cruiser — name for highway coaches used in transit service (probably a contraction of Scenicruiser or Americruiser), high floor over luggage compartments with depressed aisle, usually with single, swing front door.

bus, double-decker — a high-capacity bus that has two levels of seating, one over the other, connected by one or two stairways. Total bus height is usually 13-14.5 ft (4.0-4.4 m), and typical passenger seating capacity ranges from 60 to 80 people.

bus, dual-mode — 1. a bus designed to operate both on city streets and on rails or other types of guideway; also known as a *dual-control bus.* **2.** sometimes used to refer to a trolleybus with a diesel or gasoline engine that can operate away from overhead wires; also known as a *dual-powered bus.*

bus, electric (battery bus) — a bus that is propelled by electric motors mounted on the vehicle. The power source, usually a battery or battery pack, is located in the vehicle or on a trailer.

bus, express — see *service, express bus.*

bus, hybrid — a bus combining two power sources, usually a small diesel, gas, or Sterling engine and batteries. The engine drives an electrical generator at constant speed, optimizing efficiency and minimizing pollution. When maximum power is required, the generator plus batteries feed the traction motor(s), often hub type. At other times the generator and regenerative braking power charges the batteries. Combinations can include fuel cells and/or flywheels.

bus, intercity (over-the-road coach) — a large bus with luggage space, used primarily for transportation between cities. It usually has reclining seats and restroom facilities.

bus, limited stop — see *service, limited stop.*

bus, local — see *service, local bus.*

bus, low-floor — a bus without steps at entrances and exit. The low floor may extend throughout the bus or may use a ramp or steps to access the raised rear portion over a conventional axle and drive train. Wheelchair access is provided by a retracting ramp.

bus, motor (motor coach) — a bus that has a self-contained source of motive power, usually a diesel engine.

bus, New Look — generally refers to a bus model manufactured by General Motors in the United States and Canada between 1959 and 1983. New Look buses are characterized by large slanting windows, often with an additional row of small windows to allow standing passengers to see out. Also similar designs from other makers. Colloquial term: *fishbowl.*

bus, owl — see *run, owl.*

bus, replica streetcar — see *bus, trolley replica.*

bus, school — 1. a vehicle operated by a public or private school or by a private contractor for the purpose of transporting children (through grade 12) to and from school or to and from other school-sponsored activities. The vehicle is externally identifiable as a school bus, typically by color (yellow) and lettering that identifies the school or school district served by the vehicle. This definition includes vehicles designed and built as school buses as well as other vehicles, such as vans and station wagons. See also *service, school bus.* **2.** a vehicle designed and built as a school bus, typically with body-on-chassis construction. Such a vehicle may be used for other purposes than school bus service (e.g., military or church service).

bus, small — bus that is less than 20 ft (6 m) long.

bus, standard urban (transit coach, urban transit bus) — a bus for use in frequent-stop service with front and (usually) center doors, normally with a rear-mounted engine and low-back seating. Typically 35-40 ft (10-12 m) long.

bus, subscription — see *service, subscription bus.*

bus, suburban transit (suburban coach) — a bus with front doors only, normally with high-backed seats, reading lights, and without luggage compartments or restroom facilities for use in longer-distance service with relatively few stops.

bus, trolley — see *trolleybus.*

bus, trolley replica — a bus with an exterior (and usually an interior) designed to look like a vintage streetcar.

bus, urban transit — see *bus, standard urban.*

bus bay — 1. a branch from or widening of a road that permits buses to stop, without obstructing traffic, while laying over or while passengers board and alight; also known as a *blister, duckout, turnout, pullout, pull-off* or *lay-by.* As reentry of the bus into the traffic stream can be difficult, many transit agencies discourage their construction. **2.** a specially designed or designated location at a transit stop, station, terminal, or transfer center at which a bus stops to allow passengers to board and alight; also known as a *bus dock* or *bus berth*. **3.** a lane for parking or storing buses in a garage facility, often for maintenance purposes.

bus bay, angle — a bus bay design similar to an angled parking space that requires buses to back up to exit; allows more buses to stop in a given linear space. Typically used when buses will occupy the berth for a long period of time (for example, at an intercity bus terminal).

bus bay, drive-through (pull-through) — a bus bay design providing several adjacent loading islands, between which buses drive through, stop, and then exit. Allows bus stops to be located in a compact area. Sometimes used at intermodal transfer centers, as all buses can wait with their front destination signs facing the direction passengers will arrive from (e.g., from a rail station exit).

bus bay, linear — a bus bay design where buses stop directly behind each other; requires the bus in front to leave its bus bay before the bus behind it can exit. Often used when buses will use the bus bay only for a short time (e.g., at an on-street bus stop). Also called *on-line bus stop*.

bus bay, sawtooth — a bus bay design where the curb is indented in a sawtooth pattern, allowing buses to enter and exit bus bays independently of other buses. Often used at transit centers.

bus berth — see *bus bay* and *loading area.*

bus bulb — an extension of the sidewalk into the roadway for passenger loading without the bus

pulling into the curb, gives priority to buses and eases reentry into traffic, often landscaped and fitted with bus shelter and other passenger amenities. Also called *bus bulge*, *curb bulge*, and *curb extension*.

bus dock or turnout — see *bus bay.*

bus gate — 1. a bus priority signal control for intersection approaches. Signals located upstream from the intersection stop traffic in regular lanes while the bus lane remains open, allowing buses to proceed to any lane at the intersection signal ahead of other traffic. **2.** in some areas, a crossing gate on highway ramps that opens only for buses. **3.** a bus-only passageway between suburban sub-divisions, controlled by a gate, or a pit that is too wide for automobiles to pass — examples in Calgary, also known as a *vehicle trap*.

business district — see *central business district* and *outlying business district.*

bus lane — see *lane, bus.*

bus mile (bus kilometer) — one bus operated for 1 mile (kilometer) .

bus-only street — see *street, bus-only.*

bus platoon — several buses operating together as a convoy, with each bus following the operating characteristics of the one in front.

buspool — group of people who share the use and cost of a special bus transportation service between designated origins and destinations on a regular basis; for example, daily trips to work.

bus priority lane — see *lane, bus.*

bus priority system — a system of traffic controls in which buses are given special treatment over general vehicular traffic (e.g., bus priority lanes, preemption of traffic signals, or adjustment of green times for buses.)

bus priority system, metered freeway — a means of giving buses preferential access to enter a freeway by restraining the entrance of other vehicles through the use of ramp metering; see also *freeway, metered.*

bus rapid transit — see *transit system, bus rapid.*

bus run — see *run, bus.*

bus shelter — see *transit shelter.*

bus stop — see *stop, transit.*

bus turnout — see *bus bay.*

busway — a special roadway designed for exclusive use by buses. It may be constructed at, above, or below grade and may be located in separate rights-of-way or within highway corridors. Variations include grade-separated, at-grade, and median busways. Sometimes called a *transitway.*

bypass, queue — see *queue jumper.*

bypass lane — see *queue jumper.*

CBD — central business district.

CNG — Compressed natural gas.

CTC — Centralized traffic control; see *control system, centralized traffic.*

CUTA — Canadian Urban Transit Association; see *organizations, Canadian Urban Transit Association.*

cab — l. the space or compartment in a locomotive or a powered rail car containing the operating controls and providing shelter and seats for the engine crew or motor operator **2.** a taxicab.

cab car — see *car, cab.*

cab signal — see *control system, cab signal.*

cabin — an enclosed or semi-enclosed compartment for transporting passengers. Most often used on aerial tramways and detachable-grip aerial lifts.

cable — wire rope consisting of several strands twisted together.

cable, track — a wire rope or strand used to support a carrier or carriers on a bicable system.

cable car — see *car, cable.*

cable-hauled automated people mover — see *people mover.*

cableway — a *ropeway* similar to an *aerial tramway,* but having the added ability to raise and lower a load during transport. Generally only used for freight movement.

CAD or CADD — computer aided drafting (and design), software programs and the digital drawing files created with them representing two- or three-dimensional design drawings.

call, road — see *road call.*

cam controller — a device to regulate direction, accelerating, running, and braking of an electric vehicle with switched resistor control. Cams on a rotating shaft open or close spring-loaded contacts that make or break electric circuits between the power supply and the traction motors.

Canadian Urban Transit Association — see *organizations, Canadian Urban Transit Association.*

capacity, achievable — see *capacity, design.*

capacity, bus — the vehicle capacity of a loading area, bus stop, or bus facility. See *capacity, vehicle.*

capacity, constraints — in demand-responsive transit, the service characteristics that may limit the ability to meet passenger demand especially during specific times of the day. ADA regulations prohibit capacity constraints for ADA complementary paratransit. A transit agency cannot deny requests for trips by ADA eligible riders, as long as the trip requests are within the prescribed service area and services hours of fixed-route service.

capacity, crush (crush load) — the maximum feasible passenger capacity of a vehicle, that is, the capacity at which one more passenger cannot enter without causing serious discomfort to the others. Note that the crush load specification for some rail transit vehicles does not relate to an achievable passenger loading level but is an artificial figure

representing the additional weight for which the car structure is designed or for which the propulsion and braking system will meet minimum performance criteria.

capacity, design — 1. the maximum number of transit vehicles that can reliably pass a given point in a given period of time (typically 1 hour). **2.** the maximum number of persons that can reliably be transported past a given point in a given period of time, at a design passenger loading level.

capacity, fleet (rolling stock capacity) — 1. the total number of passenger spaces in all vehicles of a transit fleet. **2.** maximum system or line capacity when the entire fleet, less maintenance spares, are deployed, *not in common use.*

capacity, line — the vehicle capacity of a rail line. See *capacity, vehicle.*

capacity, maximum — the maximum number of persons or transit vehicles that can pass a given point in a given period of time, without regard to reliability or passenger comfort. This is a theoretical value that should not be used for planning in most cases.

capacity, passenger — the number of persons that can be carried in a given transit vehicle at a given passenger loading level, expressed in persons per vehicle.

capacity, person — the maximum number of persons that can be carried past a given location during a given time period under specified operating conditions without unreasonable delay, hazard, or restriction. Usually measured in terms of persons per hour. See also *capacity, scheduled.*

capacity, practical — see *capacity, design.*

capacity, productive — a measure of efficiency or performance. The product of person capacity along a transit line and speed.

capacity, rolling stock — see *capacity, fleet.*

capacity, scheduled— the number of persons that can be carried past a given location during a given time period under specified operating conditions without unreasonable delay, hazard, or restriction, when operating a specified number of transit vehicles. See also *capacity, person.*

capacity, seating (seated capacity) — the number of passenger seats in a vehicle.

capacity, standing — the number of standing passengers that can be accommodated in a vehicle under specified comfort standards, expressed in area per standee.

capacity, theoretical — see *capacity, line.*

capacity, vehicle — the maximum number of transit vehicles (buses, trains, vessels, etc.) that can pass a given location during a given time period at a specified level of reliability.

capacity, vessel — the vehicle capacity of a ferry berth, dock, or route. See *capacity, vehicle.*

capital cost — nonrecurring or infrequently recurring costs of long-term assets, such as land, guideways, stations, buildings, and vehicles. These costs often include related expenses: for example, depreciation and property taxes. See also *operating costs.*

captive (transit) rider — see *rider, captive transit.*

car — 1. a vehicle running on rails, for example, streetcar, light rail car, rapid transit car, railroad car. **2.** an automobile.

car, articulated — see *articulated rail vehicle.*

car, bidirectional (double-ended) (DE) — a powered rail car that has controls at both ends and symmetrically designed sides and ends for operation in either direction.

car, bi-level — a rail car that has two levels for passenger accommodation. The upper level may extend through the entire length of the car or only over a part of it. In this latter case the car has three different levels, two in the middle and an intermediate level over the trucks at each end, hence the term *tri-level* is occasionally seen. Bi-level cars include double-deck and gallery cars.

car, cab — 1. a rail car with a driving cab. **2.** a passenger-carrying car used in push-pull service and fitted with a cab at one end, to be used to operate the train when the locomotive is pushing; see also *car, commuter rail.*

car, cable — 1. an individually controlled rail passenger vehicle operating in mixed-street traffic and propelled by gripping a continuously moving endless cable located in an underground slot between the rails. The cable (which can haul many cable cars simultaneously) is powered by a large stationary motor at a central location. **2.** A term sometimes applied to *aerial tramways.*

car, commuter rail — a passenger rail car designed for commuter rail services, usually with more seats than a conventional long-distance rail passenger car. The car may be hauled by a locomotive, have a self-contained internal combustion engine, or be electrically propelled by power from a third rail or overhead wire. See also *car, cab.*

car, diesel multiple-unit — see *car, multiple-unit.*

car, diesel rail — see *car, rail diesel.*

car, double-deck — a bi-level rail car with a second level that covers the full width of the car but may or may not extend the full length.

car, electric multiple-unit — see *car, multiple-unit.*

car, electric rail — an electric rail car powered by current from an overhead wire or third rail..

car, gallery — a bi-level rail car that has seating and access aisles on a second level along each side of an open well. Tickets of passengers on the second level can be inspected or collected from the lower level. Now unique to Chicago and Montreal.

car, light rail (LRV, light rail vehicle) — a streetcar or rail vehicle similar to a streetcar, often articulated, operating on light rail systems with substantial amounts of segregated track and higher speeds than traditional *on-street* streetcar

operation. Designs available with folding steps, capable of boarding and discharging passengers at either track or car-floor level, as in San Francisco and Hannover. See also *car, streetcar.*

car, light rail vehicle, low-floor — a light rail vehicle with low floor for level boarding and exiting. Floor height is 10-14 in. (250-350 mm), requiring a platform or raised curb at this height. Wheelchair access is provided directly or by a hinged or removable bridge plate, or by an electrically operated retractable plate. Partial low-floor light rail vehicles have internal steps to access high-floor area(s) over trucks and (rarely) any articulations. In this way conventional trucks and propulsion equipment can be used.

car, motor — see *car, rail motor.*

car, multiple-unit (MU) — a powered rail car arranged either for independent operation or for simultaneous operation with other similar cars, when connected to form a train of such cars. It may be designated as *DMU (diesel multiple-unit)* or *EMU (electric multiple-unit),* depending on the source of power.

car, PCC (PCC, Presidents' Conference Committee car) — a streetcar first produced in 1935. Its performance and efficiency were significantly improved over those of any streetcar previously built. The PCC car, characterized by lightweight construction, smooth and rapid acceleration and deceleration, and soft ride, became the standard for U.S. streetcars for many years. About 5,500 cars were manufactured in North America, 16,000 in Europe, and many using PCC features in Russia, as recently as 1997. See *organizations, Presidents' Conference Committee.*

car, powered — see *car, rail motor.*

car, rail diesel (RDC, diesel rail car) — a self-powered rail car, usually with two diesel engines capable of multiple-unit operation; see also *car, diesel multiple-unit* and *car, multiple-unit.*

car, rail motor (motor car, powered car, self-powered car, self-propelled car) — a rail car that is propelled by an electric motor or internal combustion engine located on the car itself, see *car, electric rail* and *car, rail diesel.*

car, rail rapid transit (rapid transit car, subway car, heavy rail car) — bidirectional rail car for rapid transit systems, usually powered, multiple unit equipped, and with a control cab at one or both ends. Characterized by multiple double doors per side, designed for fast boarding and alighting from high-level platforms.

car, self-propelled or self-powered — see *car, rail motor.*

car, single-unit (SU) — a powered rail car, equipped with a control cab at one or both ends, that operates alone.

car, streetcar — an electrically powered rail car, with width and turning radius suitable for operating on city streets and equipped with lower skirt and safety devices to protect pedestrians from falling under car; see also *car, light rail.*

car, track — a self-propelled rail car (e.g., burro crane, highway rail car, detector car, weed burner, tie tamper) that is used in maintenance service and that may or may not operate signals or shunt track circuits.

car, trailer — 1. an unpowered rail car operated in trains with powered cars (rapid transit) or towed by locomotives (regional rail). **2.** in some rail rapid transit systems, a trailer may be powered; however, it does not have operator control and thus can only be operated in consists with cars that do.

car, trolley — 1. a local term for a streetcar. **2.** recently, also a local term for a bus with a body simulating that of an old streetcar (see *streetcar, replica*).

car, unidirectional — a rail car (usually light rail or streetcar) that has doors on one side and an operating cab at only one end so that it must be turned around by separate means (loop tracks or wyes) at terminals.

car, urban rail — a light rail, rail rapid transit, or commuter rail car.

car, weight designations — AW0, empty weight, AW1, weight with seated passenger load, AW2, weight with average peak-hour passenger load, AW3, crush loaded weight. Passengers are usually assumed to weigh an average of 155 lb (70 kg). Peak-hour passenger load is normally based on 0.4 p/ft² (4 passengers/m²) of floor space in North America, 0.4-0.5 p/ft² (4-5 p/m²) in Europe and 0.5-0.6 p/ft² (5-6 p/m²) in Asia, after discounting space used for cabs, stairwells and seated passengers at 0.2/ft² (2/m²). Crush loads are 0.6, 0.6-0.7, and 0.8 p/ft² (6, 6-7 and 8 p/m²) respectively. *Caution:* some systems and manufacturers use different designations, some systems report loading in excess of 0.8 p/ft² (8 p/m²).

car equivalence, passenger — see *passenger car equivalence.*

carhouse — see *barn.*

car operator — see *operator, train.*

carpool — an arrangement in which two or more people share the use, cost, or both of traveling in privately-owned automobiles between fixed points on a regular basis; see also *vanpool.*

carpool, casual — an informal carpool where commuters gather at a location to be picked up at random by motorists who do not have sufficient passengers to use an HOV facility (U.S. West Coast usage). See also *slug.*

carpool lane — see *lane, carpool;* and *lane, exclusive carpool.*

carrier — 1. a person or company in the business of transporting passengers or goods. **2.** the structural and mechanical assemblage in or on which the passengers of a ropeway system are transported. Unless qualified, the carrier includes the carriage or grip, hanger, and cabin or chair.

carrier, common — in urban transportation, a company or agency certified by a regulatory body to carry all passengers who fulfill the contract (e.g., pay the required fare). The service is open to the public.

catamaran — commonly used type of ferry vessel. Water jet propulsion combines relatively good fuel economy with speed and passenger comfort.

catenary system — that form of electric overhead contact system (OCS) in which the overhead contact wire is supported from one or more longitudinal wires or cables *(messengers),* either directly by hangers *(simple catenary)* or by hangers in combination with auxiliary conductors and clamps *(compound catenary).* Attachment of the contact wire to the messenger is made at frequent and uniform intervals to produce a contact surface nearly parallel to the top of the running rails.

center, major activity — see *major activity center*.

center, modal interchange — see *transit center.*

center platform — see *platform, center*.

central business district (CBD) — defined by the Bureau of the Census, an area of high land valuation characterized by a high concentration of retail businesses, service businesses, offices, hotels, and theaters, as well as by a high traffic flow. A CBD follows census tract boundaries; that is, it consists of one or more whole census tracts. CBDs are identified only in central cities of *metropolitan statistical areas* (*MSA*s) and other cities with populations of 50,000 or more. See also *outlying business district.*

central city — as defined by the Bureau of the Census, the largest city, or one of the largest cities, in a metropolitan statistical area or urbanized area. The criteria for designating a central city vary with the type of area and the particular census.

centralized traffic control system — see *control system, centralized traffic.*

chair — an open or semi-open seat used on an aerial lift.

check — in transit operations, a record of **1.** the passenger volume on all transit units that pass a specific location or time point (also known as a *passenger riding count* or *check)*, **2.** the actual time the unit passes it (also known as a *schedule check)*, **3.** the number of passengers who board and alight at each stop on a route or line (also known as an *on-and-off count* or *check),* or any combination of these items. The checker may ride the transit unit (an *onboard* or *ride check),* follow it in another vehicle, or check the transit units from a particular location (a *point* or *corner check).*

checkpoint dial-a-ride — see *point deviation* and *service, point deviation.*

choice rider — see *rider, choice.*

chopper — solid-state electronic device that controls electric current flow to traction motors by rapidly turning the power on and off, resulting in gradual vehicle acceleration at reduced current use. Replaced less efficient switched resistor controls from 1960s. Now replaced with more advanced power conversion units (PCU) feeding three phase alternating current motors, which may themselves contain a "chopper," usually to control regenerative braking.

circuit, track — see *track circuit.*

circulator service — see *service, circulator.*

city, central — see *central city.*

city transit service — see *service, city transit.*

civil speed limit — in rail operations, the maximum speed authorized for each section of track, as determined primarily by the alignment, profile, and structure.

clearance time — see *time, clearance.*

clearing time — see *time, clearing.*

clock headway — see *headway, clock.*

close-in time — see *time, close-in.*

close-up — in rail transit operations the process in which a train approaching a station will close-up to the train berthed in the station to the minimum distance permitted by the signaling or train control system. This is usually the critical line condition that, combined with the dwell at the maximum load section station, establishes the minimum headway.

closed-loop braking — see *braking, closed-loop.*

coach, motor — see *bus, motor.*

coach, over-the-road — see *bus, intercity.*

coach, suburban — see *bus, suburban transit.*

coach, transit — see *bus, standard urban.*

coach, trolley — see *trolleybus.*

coasting (freewheeling) — of a vehicle, running without influence of either the propulsion or braking systems, that is, with tractive and braking forces at zero. Use of coasting on rail transit sometimes increased outside peak periods to reduce energy consumption. Desirable feature of automatic train operation.

coefficient, riding frequency or habit — see *riding frequency coefficient.*

coefficient, utilization — see definition of *load factor.*

coefficient of directness — **1.** the ratio of the length (measured in units of either distance or time) of a transit trip between two points and the length of the most direct highway route between the two points. **2.** the ratio of the length (measured in units of either distance or time) of a trip between two points by one mode and the length of the trip by another mode.

coefficient of variation — the standard deviation divided by the mean. Usually expressed as a percentage.

cog railway (rack railway, mountain railway) — a rail transportation mode with auxiliary or full traction provided by a geared wheel in the middle of a powered axle that is engaged with a rack (toothed bar) installed along the track center. This

system is used to overcome steep gradients. Similar *Fell system* uses adhesion grip on center rail without gear teeth.

collector, current — see *current collector.*

command and control system (C&C) — in rail systems, any means of adjusting and maintaining prescribed headways; affecting starting and stopping, merging, and switching; and controlling other such functions. It is usually considered to include transit unit (car or train) protection, transit unit operation, and line supervision to ensure safe movement of the transit unit within the system. Preferred usage is *train control system.* See also *control system.*

common carrier — see *carrier, common.*

commission — 1. eastern Canadian term for transit agency — particularly in Ontario. **2.** to prepare new transit vehicles or other hardware for revenue service.

communication based control system — see *control system, moving-block.*

commute — regular travel between home and a fixed location (e.g., work, school). The term is often applied only to travel in the direction of the main flow of traffic, to distinguish from reverse commute.

commute, reverse — a commute in the direction opposite to the main flow of traffic, for example, from the central city to a suburb during the morning peak. Increasingly common with growth in suburban employment. Valuable to operator as it provides additional passengers and revenue at little or no marginal cost.

commute ticket — in rail systems, a ticket sold at a reduced rate for a fixed or unlimited number of trips in a designated area during a specified time period.

commuter — a person who travels regularly between home and a fixed location (e.g., work, school.)

commuter bus — see *service, commuter.*

commuter lane — see *lane, high-occupancy vehicle.*

commuter rail — see *transit system, commuter rail.*

commuter rail car — see *car, commuter rail.*

commuter service — see *service, commuter.*

compound catenary — see *catenary system.*

concession — in transit, the right to operate a transit service for a given number of years. May or may not include public contribution to capital and operating costs, regulation of service standards and fares charged, design or construction of any facilities.

concourse, station — a circulation and waiting area separate from but connected to station platforms. May be above, below, or at the same level as platforms and often includes ticket sales and other passenger amenities.

conductor — 1. in rail transit operations, the operating employee who may control the doors on rail transit vehicles, or who may have fare-collecting duties, or both. Also called a *guard* on some systems. **2.** in railroad operations, the operating employee in charge of the train and train crew. **3.** in some bus operations, an operating employee (other than the bus driver) who collects fares and may control doors. 4. the individual assigned to particular duties or functions in the operation of a ropeway.

confidence level — a statement of assurance of the accuracy of a statistical statement, e.g., if it is asserted that a population parameter is indeed within the computed confidence interval at confidence level α, this means that the risk of error is $1 - \alpha$. For example, a 95% confidence level has a risk of 5%.

confidence limit — a boundary of the confidence interval, usually referred to as lower and upper confidence limits.

connectivity — the ability of a public transportation network to provide service to the maximum number of origin-and-destination trip pairs through the optimal integration of routes, schedules, fare structures, information systems, and modal transfer facilities.

connector service — see *demand-response connector* and *service, feeder.*

consist — in rail systems, the makeup or composition (number and specific identity) of individual units of a train. Pronounced with the first syllable emphasized.

constraining headway — see *headway, ruling.*

contact rail — see *rail, third.*

contact shoe, overhead — see *overhead contact shoe.*

contact wire (trolley wire) — an overhead electric conductor that supplies power to electric rail vehicles and trolleybuses.

continuous brake — see *brake, continuous.*

continuous inductive train control system — see *control system, continuous train.*

continuous train control system — see *control system, continuous train.*

continuous welded rail — see *rail, continuous welded.*

contraflow — movement in a direction opposite to the normal flow of traffic. The term usually refers to flow opposite to the heavier flow of traffic. See also *commute, reverse.*

contraflow lane — see *lane, contraflow.*

control, deadman — see *deadman control.*

control, quality — see *quality control.*

control device, grade crossing traffic — see *grade crossing traffic control device.*

controlled access — see *access, limited.*

controlled access right-of-way — see *right-of-way, limited.*

controller, cam — see *cam controller.*

controls, passenger — see *passenger controls.*

control system, automatic block signal (ABS) — a system of governing train separation in which the signals are controlled by the trains themselves. The presence or absence of a train in a block is determined by a track circuit. If the circuitry fails, a restrictive signal is displayed.

control system, automatic train — see *automatic train control system.*

control system, block signal — a standard railroad signal system that uses a fixed signal at the entrance of a block to govern the separation of trains entering the block.

control system, cab signal — in rail systems, a signal located in the cab, indicating a condition affecting the movement of a train and used in conjunction with interlocking signals and in conjunction with or in lieu of block signals. Can indicate status of next signal(s) or show designated maximum speed.

control system, centralized traffic (CTC) — in rail systems, a traffic control system in which signals and switches are controlled from a remotely located (centralized traffic control) panel.

control system, communication based — see *control system, moving-block.*

control system, fixed-block — an automatic train control system that records the presence of a train (or a part of it) in each track section (block) and activates the signals on the line to indicate the block is occupied. In some cases, a following train is prevented from entering the block by a forced emergency stop, see *automatic train stop*.

control system, manual-block — a system of manually governing train movement in a block or a series of consecutive blocks by means of signals, train orders, telephone, or radio.

control system, manual train — system in which train movement is controlled by the operator (motorman) or engineer.

control system, moving-block — an automatic train control system that spaces trains according to their location and relative velocity, and stopping performance, plus a safety distance. Often includes automatic train operation. Moving-block signaling systems are also called transmission or communication based systems. The latter is becoming the preferred term.

control system, multiple-unit — a system that controls the operation of two or more rail motor cars in a train through the simultaneous control of the train by one operator.

control system, overlay — A train control system, usually software controlled, that is overlaid on top of a conventionally fixed-block control system. Permits closer headway of trains equipped for the overlay while providing operation and safe separation of non-equipped trains.

control system, traffic — see *control system, centralized traffic.*

control system, transmission based — see *control system, moving block.*

controlling dwell — the dwell, usually at the busiest station on a rail transit line, that, added to the minimum separation time of the train control system for the applicable speed, sets the closest headway possible. Can also apply to a bus line.

conventional rail transport — transportation systems that consist of steel-wheeled trains running on duo-rail tracks. Trains may be self-propelled or hauled by locomotive, with diesel or electric propulsion.

conveyor, passenger or pedestrian — see *moving walkway.*

cordon count — in planning, a count of vehicles and people across a designated (cordon) line to determine **1.** the total flow (people and vehicles by mode and time period) into and out of the study area and **2.** the accumulation (people and vehicles) within the cordon area by time of day.

cordon line — in planning, an imaginary line circumscribing a specific geographic study area.

corner check — see *check.*

corridor — in planning, a broad geographical band that follows a general directional flow or connects major sources of trips. It may contain a number of streets and highways and transit lines and routes.

cost recovery ratio — the ratio of total revenues to total costs; the inverse of operating ratio. It is often used for evaluation of alternative plans. Usually total direct operating and maintenance costs are used although outside the United States; many agencies include annualized capital costs and/or depreciation in the calculation. *Farebox recovery ratio* is the ratio of operating revenue to operating costs.

costs — see *capital costs* and *operating costs.*

count — 1. in transportation, a process that tallies a particular movement of people or vehicles past a given point during a stated time period. It may be a directional or a two-way value and is also known as a *traffic count* **2.** In transportation, a volume of people or vehicles.

count, cordon — see *cordon count.*

count, on-and-off — see *check.*

count, passenger — see *passenger count.*

count, passenger riding — see *check.*

count, traffic — see *traffic count.*

coupler — a device for connecting one rail vehicle to another. The mechanism is usually placed in a standard location at both ends of all rail cars and locomotives.

coupler, automatic — **1.** a coupler that operates automatically. It may also be capable of uncoupling automatically. May have to take place on tangent track although some designs have automatic centering and can be used on curves. **2.** an automatic connector that joins electric or pneumatic train lines together between rail cars.

coverage area — see *area, coverage.*

critical line condition — in rail transit operations the factor that constrains headway. This is usually the close-in at the maximum load section station or the terminal turnback process, occasionally at junctions.

crossing, grade (railroad grade crossing) — a crossing or intersection of highways, railroad tracks, other guideways, or pedestrian walks, or combinations of these at the same level or grade.

crossing, highway/railroad — a place, at grade or grade separated, where highway traffic crosses railroad tracks.

crossing, railway — see *crossing, track.*

crossing, track (railway crossing) — an assembly of rails and frogs that allows crossing of two tracks at grade.

crossing control device, grade — see *grade crossing traffic control device.*

crossover — 1. in rail systems, a track with two switches that connects two parallel tracks. **2.** pedestrian or vehicular links (at grade or grade separated) across a transportation facility.

crosstie (railroad tie, tie) — the transverse member of the track structure to which the rails are fastened. Its function is to provide proper gauge and to cushion, distribute, and transmit the stresses of traffic through the ballast to the roadbed; normally wood or concrete; can be metal or plastic. Also known as a *sleeper*.

crosstown service — see *service, crosstown.*

cruise speed or velocity — see *velocity, cruise.*

cruiser — see *bus, cruiser.*

crush load — see *capacity, crush.*

curb bulb — see *bus bulb*.

curb extension — see *bus bulb.*

current collector — the mechanical component on an electric rail car that makes contact with the conductor that distributes the electric current; see also *overhead contact shoe, pantograph, third-rail shoe,* and *trolley pole.*

customer satisfaction survey — see *survey, customer satisfaction*.

cut-and-cover — a method of construction that consists of excavating the terrain from ground level, placing a structure in the excavation, and then filling over the structure.

cutting — see *run cutting.*

D

DC — 1. District of Columbia. **2.** direct current.

DE — double ended, rail or streetcar with driving positions at both ends.

DHV — design hourly volume.

DMU — diesel multiple-unit car; see *car, multiple-unit.*

DOT — department of transportation; see *organizations, department of transportation;* and *U.S. Government, Department of Transportation.*

DPM — downtown people mover; see *people mover, downtown.*

DRT — demand-responsive transportation system; see *transportation system, demand-responsive.*

day pass or daypass — ticket for unlimited travel for one day, usually to end of service the following day, may be for one or more zones of travel, may be restricted in morning peak period, may be good for one adult, one concession rider or for a family or similar group. Can be valid through a weekend. Often contains "scratch" panels for user to designate day and month of use.

deadhead — an unproductive or non-revenue move without passengers aboard, often to and from a garage, or from one route to another. (Some agencies carry passengers on these runs and still use the term deadhead.)

deadman control — a pedal, handle, or other form of switch, or combination thereof, that the operator must keep in a depressed or twisted position while a rail vehicle (or train) is moving. If the control is released, the power is cut off and the brakes are applied.

deceleration, retardation, braking rate — decrease in velocity per unit time; in transit practice, often measured in ft/s² (m/s²) or, in the United States, mph/s.

deck, vessel — a platform in a vessel that accommodates passengers and/or autos.

default value — a design value that is based on experience or on studied conclusions and that is used as a substitute value when an actual value is not available.

defensible space — a concept in architecture and urban design that precludes designs resulting in dark alleys, corners, or spaces where visibility and openness to other people is severely limited.

delay, reentry — the time required for a suitable gap in traffic to occur to allow a bus to reenter the street from an off-line stop; a component of clearance time. Reentry delay is influenced by the traffic volume in the curb lane and upstream traffic signals.

delay time — see *time, delay.*

demand — 1. the quantity (of transportation) desired. **2.** in an economic sense, a schedule of the quantities (of travel) consumed at various levels of price or levels of service offered (by the transportation system.)

demand, effective — the number of people or vehicles prepared to travel in a given situation, at a given price.

demand jitney service — see *service, jitney.*

demand-response connector — provides demand responsive service within a defined zone that has one or more scheduled transfer points to fixed-route transit. The transfer points may be bus stop

for peak-period express or other bus service, or a rail service. See also *service, feeder.*

Demand Response Transit Operations — National ITS Architecture Market Package that performs automatic driver assignment and monitoring as well as vehicle routing and scheduling for demand-responsive transit services.

demand-response transportation system — see *transportation system, demand response.*

demand stop — see *service, flag stop.*

denial, service — see *service denial.*

density, pedestrian — average number of pedestrians per unit of area within a walkway or queuing area; expressed as pedestrians per square foot or meter.

density, population — average number of people per unit area; typically expressed as persons per square mile or square kilometer.

density, train — see *train density.*

department of transportation — see *organizations, department of transportation;* and *U.S. Government, Department of Transportation.*

departments, U.S. — see *U.S. Government.*

dependent, transit — see *transit dependent.*

depot — see *garage, terminal, carhouse,* and *barn.*

derail — **1.** to run off the track. **2.** a track safety device designed to guide a rail car off the rails at a selected location to prevent collisions or other accidents, commonly used on spurs or sidings to prevent unattended rolling cars from fouling the main line; also known as a *derailer.*

derailment — an instance of the wheels of a rail vehicle coming off the track.

deropement — the term used when a rope or cable leaves its operating position relative to the groove of a sheave, carriage wheel, or saddle.

design capacity — see *capacity, design.*

design hourly volume (DHV) — the amount of traffic a transportation facility is designed to carry in 1 hr.

desire line — a straight line on a map that connects the origin and destination of a trip (theoretically, the ideal or most desirable route) and may indicate by its width or density the volume of trips between that origin and destination.

destination — **1.** the point at which a trip terminates. **2.** in planning, the zone in which a trip ends.

destination sign or blind — a sign on a transit unit (vehicle or train) indicating the route and/or route number or letter, direction, destination of the unit, or any combination thereof. Destination signs are most commonly located on the front of the transit unit but may also be located on the back, side, or both. Includes roll signs printed on cloth or plastic and electronic signs, most usually dot matrix. See also *head sign.*

detachable-grip lift — a ropeway system on which carriers circulate around the system alternately attaching to and detaching from a moving haul rope. The ropeway system may be *monocable* or *bicable.*

deviation, point — see *point deviation.*

device, grade crossing traffic control — see *grade crossing traffic control device.*

device, signal-actuating — see *pedestrian signal-actuating device* and *vehicle signal-actuating device.*

device, traffic control — see *traffic control device.*

dial-a-bus or dial-a-ride — see *transportation system, dial-a-ride.*

diamond lane — see *lane, diamond.*

diesel-electric locomotive — see *locomotive, diesel-electric.*

diesel multiple-unit car (DMU) — see *car, multiple-unit.*

diesel rail car — see *car, rail diesel.*

differential fare — see *fare, differential.*

direct current (DC) — fixed polarity electrical distribution system universally used for heavy rail, light rail and trolleybuses. For a given load at the voltages used, there are lower losses and longer distances possible between feeder points and sub-stations than with alternating current (AC).

direct current motor — see *motor, direct current.*

directional route miles — see *route miles.*

directional split — the proportional distribution between opposite flows of traffic on two-way facilities.

directness, coefficient of — see *coefficient of directness.*

disability, public transportation — see definition of *persons with disabilities.*

disadvantaged, transportation — see *transportation disadvantaged.*

disc brake — see *brake, disc.*

discharge — in transit operations, to let passengers exit the vehicle.

disembark — to transfer from a vessel to shore.

disincentive — something that discourages people from acting in a certain way. For example, high parking fees or tolls are disincentives to automobile use.

dispatcher — **1.** in bus operations, the individual who assigns buses to runs, makes up work assignments to fill runs, directs the operators at the start of their assignments, and in some cases, maintains a constant awareness of status of the operation, via radio, telephone, or other means. **2.** in rail operations, an operating person whose function it is to dispatch transit units (cars or trains), monitor their operation, and intervene in the event of disruption of schedule or when any change in service or routing is required. **3.** In demand-responsive transportation, the person who assigns the vehicles to customers and notifies the appropriate drivers and who may schedule and route vehicles and monitor their operation.

dispatching — 1. in rail operations, the process of starting a transit unit (car or train) into service from a terminal, yard, or transfer track. **2.** in demand-responsive transportation systems, the process of relaying service instructions to drivers. The procedure may include vehicle scheduling, routing, and monitoring, and it can be manual or partly or fully automated. **3.** the relaying of service instructions to vehicle drivers or operators.

distance, air — straight-line measure of walking distance between two points that does not consider the availability, connectivity, or condition of pathways between the two points; used in planning-level calculation of service coverage. Compare with *distance, walk.*

distance, linked trip — see *trip distance, linked.*

distance, maximum walking — the maximum distance that people will walk to transit; affected by grade, pedestrian environment, and pedestrian characteristics.

distance, total travel — see *trip distance, linked.*

distance, walk —measure of walking distance between two points following continuous pathways or sidewalks. Compare with *distance, air.*

distribution, flow — see *trip assignment.*

distribution, trip — see *trip distribution.*

district, central business — see *central business district.*

district, outlying business — see *outlying business district.*

diversity, loading — a measure of the unevenness of the passenger loading of transit vehicles in time (e.g., between buses or trains on the same route) or location (e.g., between cars of a train). See also *peak-hour factor.*

dock — 1. Facility defined as a multiple number of berths providing access to vessels. **2.** The process of "parking" a vessel and tying it into its berth.

door, double-stream — a door on a transit vehicle with sufficient width (generally 3.75-4.5 ft or 1.14-1.37 m) to permit two passengers to board and/or alight simultaneously. A handrail may or may not be provided to separate the two passenger streams.

door, platform screen — half- or full-height doors on the platform edge that open directly adjacent to transit vehicle doors, used for dwell time control, improve platform edge safety, and (potentially) climate control.

door, single-stream — a door on a transit vehicle that allows passenger flow in only one direction at a time.

district, transit — see *transit district.*

door-to-door service — see *service, door-to-door*.

double — see *extra section.*

double-deck car — see *car, double-deck.*

double-decker bus — see *bus, double-decker*.

double-ended car — see *car, bidirectional.*

double-ended transit unit (bidirectional transit unit) — rail car or train with an operating cab at each end.

downtown people mover — see *people mover, downtown.*

draft — the depth of a vessel's keel below the water line.

driving wheels — wheels that are powered by a motor or engine and that provide the tractive effort, through contact with the running surface, that propels the vehicle.

dual control or mode — see *transit system, dual-mode;* and *bus, dual-mode.*

dual-mode bus — see *bus, dual-mode.*

dual-mode light rail — see *transit system, light rail, dual-mode.*

dual-mode transit system — see *transit system, dual-mode.*

dual-mode vehicle — see *vehicle, dual-mode.*

dual-powered bus — see *bus, dual-mode.*

dual-powered locomotive — see *locomotive, dual-powered.*

dual-power propulsion system — see *propulsion system, dual-power.*

dwell time — see *time, dwell.*

dynamic block control system — see *control system, moving block.*

dynamic brake — see *brake, dynamic.*

Dynamic Ridesharing — National ITS Architecture Market Package that enhances the Interactive Traveler Information package by adding an infrastructure providing dynamic ridesharing/ride matching capability.

Dynamic Route Guidance — National ITS Architecture Market Package that offers the user advanced route planning and guidance which is responsive to current conditions.

dynamic routing — in demand-responsive transportation systems, the process of constantly modifying vehicle routes to accommodate service requests received after the vehicle began operations, as distinguished from predetermined routes assigned to a vehicle.

E

EMU — electric multiple-unit car; see *car, multiple-unit.*

EPA — Environmental Protection Agency; see *U.S. Government, Environmental Protection Agency*.

edge treatment — A standardized surface feature or a physical barrier built in or applied to the walking surface to warn visually impaired people of hazards along the path of travel.

effective demand — see *demand, effective.*

effective width — see *width, effective.*

effectiveness — 1. in transportation, the correspondence of provided service to intended output or objectives, particularly the character and

location of service; in other words, producing the intended result (doing the right things). **2.** in transit, the degree to which the desired level of service is being provided to meet stated goals and objectives; for example, the percentage of a given service area population that is within the desired ¼ mi (400 m) of a transit stop.

effectiveness, measure of — see *performance indicator*.

effective operating speed — see *speed, overall trip.*

effective velocity — see *velocity, effective.*

egress time — see *time, egress.*

el — abbreviation for elevated (railway), mainly east coast; see *transit system, rail rapid.*

elasticity — the percentage change in demand for service for each 1% change in the price or amount of that service.

electric brake — see *brake, dynamic.*

electric bus — see *bus, electric.*

electric locomotive — see *locomotive, electric.*

electric motor — see *motor.*

electric multiple-unit car — see *car, multiple-unit.*

electric rail car — see *car, electric rail.*

Electric Railway Presidents' Conference Committee — see *organizations, Presidents' Conference Committee.*

electric sub-station — transformers, breakers (and rectifiers) to convert supply from electric utility to direct current supply for rapid transit, streetcar or trolleybus systems.

electric trolleybus — see *trolleybus.*

electrification (railway electrification) — in rail systems, a term used to describe the installation of overhead wire or third-rail power distribution facilities to enable operation of electrically powered transit vehicles.

electrodynamic brake — see *brake, dynamic.*

electromagnetic brake — see *brake, track.*

electropneumatic brake — see *brake, electropneumatic.*

elevated, the — see *transit system, rail rapid.*

elevated guideway — see *guideway, elevated.*

elevated-on-fill guideway — see *guideway, elevated-on fill.*

elevator — a mechanical device for moving people vertically between different levels of a building or transit station.

elevator, inclined — see *inclined elevator.*

eligibility, limited — refers to limited eligibility demand-responsive transportation that operates similarly to general public DRT except that only defined rider groups are served, often older adults and people with disabilities. May be referred to as *specialized transportation.*

embark — 1. to transfer from shore to a vessel. **2.** to board a vessel.

emergency application or braking — see *braking, emergency.*

En-Route Transit Information — National ITS Program User Service that provides information to travelers using public transportation after they begin their trips.

end, head — see *head end.*

end, trip — see *trip end.*

end wall — see *station end wall.*

engine, gas turbine — an internal combustion engine in which the hot compressed gases of combustion drive a turbine.

engine, internal combustion (ICE) — an engine in which the power is developed through the expansive force of fuel that is fired or discharged within a closed chamber or cylinder.

equity — in transportation, a normative measure of fairness among transportation users.

equivalence, passenger car — see *passenger car equivalence.*

escalator — a device providing a continuous series of pallets or treads for standing pedestrians, transporting pedestrians both vertically and horizontally.

exact fare — see *fare, exact.*

excess time — see *time, excess.*

exclusive bus lane — see *lane, exclusive transit.*

exclusive carpool lane — see *lane, exclusive carpool.*

exclusive right-of-way — see *right-of-way, exclusive.*

exclusive transit facilities — transportation system infrastructure elements that are set aside for the use of transit vehicles only. Examples include some freeway ramps, queue jumpers, bus lanes, off-street bus loading or unloading areas, and separated and fully controlled rights-of-way.

exclusive transit lane — see *lane, exclusive transit.*

exclusive transit right-of-way — see *right-of-way, exclusive transit.*

exclusive transitway — see *transitway.*

express bus — see *service, express bus.*

express service — see *service, express.*

expressway — a divided arterial highway for through traffic. An expressway has full or partial control of access and generally has grade separations at major intersections.

extra section (double) (overload) (duplicate *Br.***)** — a second bus added to accompany a regularly scheduled bus to handle passenger overloads.

F

FHWA — Federal Highway Administration; see *U.S. Government, Federal Highway Administration.*

FRA — Federal Railroad Administration; see *U.S. Government, Federal Railroad Administration.*

FTA — Federal Transit Administration; see *U.S. Government, Federal Transit Administration*.

facilities, accessible transportation — see *accessible transportation facilities.*

facilities, exclusive transit — see *exclusive transit facilities.*

facility, intermodal transfer — see *transit center.*

factor, K — see *K factor.*

factor, load — see *load factor.*

factor, peak-hour — see *peak-hour factor.*

factor, travel time — see *travel time factor.*

fail-safe — incorporating a feature that ensures that malfunctions that affect safety will cause the system to revert to a state that is safe.

fall-back crewing — an operating practice at a turnback where an extra engineer or operator is positioned at the rear end of the terminal platform as a train enters the station. The fallback engineer enters the rear cab of the train as the train's incoming engineer exits the front cab, saving the time required for the incoming engineer to walk to the opposite end of the train. In this type of operation, each engineer drops back to the following train at the terminal station, so only one additional engineer per shift is required to make such an operation work.

far-side stop — see *stop, far-side.*

fare — 1. the required payment for a ride on a public transportation vehicle. It may be paid by any acceptable means, for example, cash, token, ticket, transfer, farecard, voucher, or pass or user fee. **2.** a passenger who pays a fare.

fare, adult cash — basic full fare paid by one adult for one ride, may exclude transfer and zone charges.

fare, average — the arithmetic average of all fares paid by all revenue passengers, including those who received special or reduced fares. It is usually derived by or generally equivalent to dividing total fare revenue by total origin-to-destination trips, although it may be based on unlinked trips.

fare, base (basic fare, regular fare, full fare) — the price (with no discounts) charged to an adult for regular local service or, for systems with zone pricing, a one-zone fare with no discounts, that is, what it costs an adult paying a single cash fare to take a one-zone ride. On systems with time-based fares it is normally the peak-period fare,

fare, concession — British and Canadian term for a reduced fare for various classes or passengers: children, students, seniors. A single concession fare reduces the complexity of having multiple fares for different classes of passengers into two, full and concession.

fare, exact — a transit operations policy that precludes the making of change for passengers. A passenger must therefore have the correct change for the fare or else overpay it. Almost universal on North American transit except where ticket kiosks or ticket vending machines make change.

fare, flat — method of travel pricing that uses a single fare for the entire service area regardless of the trip's distance, time of day, area of travel, or other characteristics.

fare, graduated — a fare that is proportional to the distance traveled (also known as mileage fare) or to the length of time that a passenger may ride on a service.

fare, mileage — see *fare, graduated.*

fare, off-peak or peak — see *fare, time-of-day.*

fare, peak-period surcharge — see *fare, time-of-day.*

fare, pre-paid — any fare not paid onboard a transit vehicle (e.g., a transit pass, a ticket purchased at a machine prior to boarding a vehicle, or a fare paid prior to entering a fare-paid area).

fare, reduced — a special fare for children, students, senior citizens, or others that is less than the regular fare.

fare, regular — see *fare, base.*

fare, single-coin— a fare that can be paid with a single coin (e.g., a quarter) or token.

fare, time-of-day — a fare that varies by time of day. It is usually higher during peak travel periods (peak fare) and lower during non-peak travel periods (off-peak fare).

fare, zone (zoned fare) — a method of transit pricing that is based on the geographical partitioning of the service area. The price is determined by the location and number of zones traversed. Zone fares are frequently used as a method of charging graduated or distance-based fares but may also be used to provide for differential fares for certain markets.

farebox — a device that accepts coins, bills, tickets, tokens, or other fare media given by passengers as payment for rides.

farebox, registering — a farebox that counts the money and fare media processed and records fare information.

farebox recovery ratio — see *fare recovery ratio.*

farebox revenue — see *revenue, farebox.*

farecard — see *magnetic farecard.*

farecard reader — a device that determines the value stored in a farecard when the farecard is inserted. A farecard reader may also be used for appropriately altering the value stored in a farecard when used in conjunction with a passenger turnstile, gate, or registering farebox.

fare collection system — the procedures and devices used to collect fares and to accumulate and account for fares paid.

fare collection system, automatic (AFC) — the controls and equipment that automatically admit passengers on insertion of the correct fare in an acceptable form, which may be coins, tokens, tickets, or farecards (magnetically encoded or smart card). On systems with distance based fares stored value farecards must be inserted again on

exit, at which point an additional fare may be subtracted. The system may include special equipment for transporting and counting revenues.

fare collection system, proof of payment, self-service, barrier-free, open — various names for an open fare collection system that has no turnstiles or fare gates. *Proof of payment is the preferred name.* It requires that the passenger displays proof of payment (e.g., validated ticket, prepaid pass, valid transfer) while on board the transit vehicle or in other designated *fare paid* areas. Enforced through random checking by specific transit employees, security staff or police with the power to collect premium "onboard" fares (more common in Europe) or issue tickets or citations, typically resulting in revenue loss below 2-3%. Widely used in Europe and on North American light rail systems, the system combines flexibility and low cost with the fewest impediments to passengers with disabilities. Often combined with "self-service" ticket vending machines. Erroneously called an "honor" system, a name that applies only to systems without enforcement.

fare recovery ratio (farebox recovery ratio) — the ratio of fare revenue to direct operating expenses; see also *operating ratio.*

fare-registering fare gate (turnstile) — a fare gate that records the fares paid.

fare structure — the system set up to determine how much is to be paid by various categories of passengers using the system in any given circumstance.

fare gate — a device that unlocks to allow a passenger to enter the paid area after a pass, smart card, farecard, or the correct amount of money or tokens has been inserted into it.

federal agencies — see *U.S. Government.*

Federal Highway Administration — see *U.S. Government, Federal Highway Administration.*

Federal Railroad Administration — see *U.S. Government, Federal Railroad Administration.*

Federal Transit Act of 1964 — see *legislation, Federal Transit Act of 1964.*

Federal Transit Administration — see *U.S. Government, Federal Transit Administration.*

feeder service — see *service, feeder.*

ferry — a vessel that carries passengers, vehicles, and/or goods over a body of water, usually for short distances and with frequent, regular service. A ferry is generally a conventional shallow-draft boat, but hydrofoils, catamarans, and hovercraft are also used. Often such vessels are double-ended with a pilot house at each end for control purposes so that the vessel need not be turned around for the next trip.

ferry, urban — Ferries that have at least one terminal within an urbanized area, excluding international, rural, rural interstate, island, and urban park ferries.

ferry berth — a platform extending from a shore over water and supported by piles or pillars, used to secure and provide access to vessels.

ferry passenger loading platform — see *platform, ferry.*

few-to-few service — see *service, few-to-few.*

few-to-many service — see *service, few-to-many.*

first-track miles or kilometers — see *right–of-way miles.*

fishbowl — see, *bus, New Look.*

fixed-block control system — see *control system, fixed-block.*

fixed-grip lift — ropeway system on which carriers remain attached to a haul rope. The ropeway system may be either continuous or intermittently circulating, and either *monocable* or *bicable.*

fixed guideway transit system — see *transit system, fixed guideway.*

fixed route — *see transportation system, fixed route.*

fixed signal — see *signal, fixed.*

flag stop service — see *service, flag stop.*

flange, wheel — see *wheel flange.*

flat fare — see *fare, flat.*

fleet, (rolling stock) — the vehicles in a transit system. Usually, "fleet" refers to highway vehicles and "rolling stock" to rail vehicles.

fleet, base-period — see *base-period fleet.*

fleet capacity — see *capacity, fleet.*

flexible transit services — a range of user-oriented forms of public transportation that share attributes of demand-responsive transit and fixed-route transit.

flex route — see *service, route deviation.*

flexible route segments — see *segments, flexible route.*

flotsam — floating refuse or debris.

flow, passenger — see *passenger flow.*

flow distribution — see *trip assignment.*

flow rate (rate of flow) — in transportation, the number of units (passengers or vehicles) passing a point on a transportation facility during some period of time, usually counted or recomputed in units per hour. For example, if 8 buses pass a point in the first half hour and 15 in the second, the volume for the hour is 23. However, the flow rate for the first half hour is 16 buses/h, and for the second half hour the flow rate is 30 buses/h. See also *volume.*

flying junction — see *junction, flying.*

force, tractive — see *tractive effort.*

forecasting — in planning, the process of determining the future conditions, magnitudes, and patterns within the urban area, such as future population, demographic characteristics, travel demand.

free area — see *area, free.*

free transfer — see *transfer, free.*

freeway — a divided highway for through traffic that has full access control and grade separations at all intersections. In some countries, it is also known as a motorway.

freeway, metered — a freeway to which access is controlled by entrance ramp signals that use fixed-time signal settings or are regulated by a computerized surveillance system. This procedure is used to prevent freeway congestion. See also *bus priority system, metered freeway.*

freewheeling — see *coasting*.

frequency, service — see *service frequency.*

frequency coefficient, riding — see *riding frequency coefficient.*

frequency distribution, trip length — see *trip length frequency distribution.*

friction brake — see *brake, friction.*

fringe, urban — see *urban fringe.*

fringe area — see *area, fringe.*

frog — a track component used at the intersection of two running rails to provide support and guidance for the wheels. It allows wheels on each rail to cross the other rail. Also applied to similar overhead components on electric rail or trolleybus systems. On streetcar systems the flangeway at the frog can be ramped up. Cars run on their flanges substantially reducing track noise.

fuel, alternative — a non-petroleum fuel with lower pollution that traditional diesel; includes alcohol fuels, mineral fuels, methanol, propane, hydrogen, compressed and liquefied natural gas.

full accessibility — see *accessibility, persons with disabilities.*

full service braking — see *braking, maximum service.*

funicular railway — a passenger transportation mode consisting of a pair of rail vehicles (or short trains) permanently attached to two ends of the same cable, counterbalancing each other. It may have a single track with a turnout or a double track. In the former case, wheels on one side of the car(s) will have double flanges, on the other side, no flanges. This system is used to overcome steep gradients. See also *ropeway*, *inclined plane*, and *inclined elevator.*

funitel —a form of detachable-grip *aerial lift* that uses two track cables to support the carrier, rather than the usual one, in order to provide greater stability during windy conditions. The name was coined from the words funicular and télépherique, the French-Swiss name for *gondolas.*

furniture, street — see *street furniture.*

G

GIS — geographic information system.

GPS — global positioning system.

GRT — group rapid transit; see *transit system, group rapid.*

GTO — Gate turn-off thyristor, used in chopper controls for electric rail cars and trolleybuses.

gallery car — see *car, gallery.*

gangway — a walking surface that spans any two marine facilities or vessels. Gangways are not fixed and their slope depends on the relative position of the facilities they are spanning.

garage — in bus systems, the location in which buses are stored and serviced and where operators report for work and receive supplies and assignments. Also sometimes known as a *depot* or *barn.*

gas turbine engine — see *engine, gas turbine.*

gate, bus — see *bus gate.*

gather service — see *service, many-to-one.*

gauge, broad (wide gauge) — a rail track gauge greater than standard, wide gauge is slightly greater, broad gauge is substantially greater.

gauge, narrow — rail track gauge that is less than standard, commonly 3 ft 3.4 in. or 1,000 mm (meter gauge), or 3 ft 6 in. or 1,067 mm (Cape gauge).

gauge, standard — a rail track gauge that is 4 ft 8.5 in. (1,435 mm) wide.

gauge, track — the distance between the inside faces of the two rails of a track measured 5/8 in. (16 mm) below the top of the rails and perpendicular to the gauge line.

gauge, wide — see *gauge, broad.*

gauntlet track — a track configuration where the four rails are interlaced without switches. Used as an alternative to single-track sections where insufficient space exists for double tracks, saving capital and maintenance costs, as well as potential operating problems due to frozen or clogged switch points.

gear, running — see *running gear.*

generation, trip — see *trip generation.*

generator, trip — see *trip generator.*

geographic Information System (GIS) — a computerized database management system in which geographic databases are related to one another via a common set of location coordinates. GIS can provide a spatial, interactive visual representation of transit operations and allows users to make queries and selections of database records based on geographic proximity and attributes such as bus stop activity levels and demographic data.

global positioning system (GPS) — A system that determines the real-time position of vehicles using communications with a satellite. Also, refers more specifically to a government-owned system of 24 Earth-orbiting satellites that transmit data to ground-based receivers and provides extremely accurate latitude/longitude ground positions.

gondola — 1. a cabin used on an aerial lift. **2.** name popularly used to describe a continuously circulating aerial lift using cabins.

government, U.S. — see *U.S. government.*

governor — 1. a device that keeps a transit vehicle from exceeding a set (maximum) speed. **2.** a device that holds the rotational speed of an engine approximately constant regardless of the load or prevents it from exceeding a predetermined value.

grade — or gradient, rise in elevation within a specified distance. As an example, a 1% grade is a 1-ft (m) rise in elevation in 100 ft (m) of horizontal distance, in Britain expressed as 1/100 or 1 in 100, and in Europe 10°/1000.

grade crossing — see *crossing, grade.*

grade crossing protection signal — see *signal, grade crossing protection.*

grade crossing traffic control device — any form of protective or warning device installed at a railroad or transit guideway grade crossing for the protection of highway or street traffic.

grade separation — a vertical separation of intersecting facilities (road, rail, etc.) by the provision of crossing structures.

graduated fare — see *fare, graduated.*

grid network — see *network, grid.*

grips, detachable — grips that are attached and detached from the moving haul rope at station(s) or terminal(s) during normal operation.

grips, fixed — grips that remain continuously attached to the haul rope during normal operation.

group, low mobility — see *transportation disadvantaged.*

group rapid transit — see *transit system, group rapid.*

group riders — see *riders, group.*

guided busway — see *busway, guided.*

guideway — in transit systems, a track or other riding surface (including supporting structure) that supports and physically guides transit vehicles specially designed to travel exclusively on it.

guideway, elevated — a grade-separated guideway on a structure that provides overhead clearance for vehicles at ground level; see also *aerial structure.*

guideway, elevated-on-fill — a grade-separated guideway above the prevailing surface of the terrain that is supported by an embankment instead of by a structure.

guideway, open cut — a guideway below the prevailing surface of the terrain in a trench like excavation (cut or cutting).

HCM — Highway Capacity Manual.

HEP — head end power, see *locomotive, passenger*.

HOV — high-occupancy vehicle; see *vehicle, high-occupancy*.

HOV lane — high-occupancy-vehicle lane; see *lane, high-occupancy-vehicle*.

HOV Lane Management — National ITS Architecture Market Package that manages HOV lanes by coordinating freeway ramp meters and connector signals with HOV lane usage signals. Preferential treatment is given to HOV lanes using special bypasses, reserved lanes, and exclusive rights-of-way that may vary by time of day.

HRI — highway-rail intersection.

habit coefficient, riding — see r*iding frequency coefficient*.

handicapped — see *persons with disabilities.*

hanger — structural element connecting a cabin, chair, or other passenger-carrying device to the ropeway track cable carriage or haul rope grip.

haul rope — a wire rope used on a ropeway that provides motion to carriers and is powered by the drive sheave.

head end — the beginning or forward portion of any train.

head sign — a sign indicating the destination of the transit unit (vehicle or train), usually located above the windshield.

headway — the time interval between the passing of the front ends of successive transit units (vehicles or trains) moving along the same lane or track (or other guideway) in the same direction, usually expressed in minutes; see also *service frequency*.

headway, base — the scheduled headway between transit unit (vehicle or train) trips, between peak periods.

headway, clock — the scheduled headway between transit unit (vehicle or train) trips, based on even times, i.e., 60, 30, 20, 15, 10 and 7½ minutes.

headway, constraining — see *headway, ruling*.

headway, interference — headway that is so close that one vehicle or train interferes with or delays the next.

headway, non-interference — headway such that in normal operations one train does not delay another.

headway, policy — 1. headway prescribed by reasons other than matching capacity to demand. **2.** the maximum permissible headway as established by the transit agency or (often) the policy board, usually for off-peak, low-demand periods.

headway, ruling — the maximum of the headways calculated (or observed) at each signal on the line.

headway adherence — the consistency or evenness of the scheduled interval between transit vehicles. A reliability measure based on the coefficient of variation of headways of transit vehicles serving a particular route arriving at a stop.

headway management — a technique for managing the operation of transit units (vehicles or trains) that focuses on maintaining a certain spacing between units on the same line, instead of on adhering to a timetable. For example, if units become bunched, corrective measures might include delaying the units at the rear of the bunch

to provide regular headways and hence load distribution, even at the expense of reducing timetable adherence.

heavy rail — see *transit system, rail rapid*.

high-occupancy vehicle — see *vehicle, high-occupancy*.

high-occupancy-vehicle lane — see *lane, high-occupancy-vehicle.*

high platform — see *platform, high*.

high voltage — see *voltage, high*.

highway, street, or road — **1.** general terms denoting a public way for purposes of vehicular travel, including the entire area within the right-of-way. The recommended usages are as follows: in urban areas, highway or street; in rural areas, street or road. **2.** street, in common general usage, refers to the vehicular travel way, as distinguished from the sidewalk (the pedestrian travel way).

Highway Capacity Manual — A standard reference used to calculate the capacity and quality of service of roadway facilities.

Highway-Rail Intersection (HRI) — National ITS Program User Service that integrates ITS technology into already existing HRI warning systems to enhance their safety effectiveness and operational efficiency. At railroad grade crossings, HRI technologies located both in-vehicle and along the roadside ensure that train movements are coordinated with traffic signals and that drivers are alerted to approaching trains.

highway/RR crossing — see *crossing, highway/railroad*.

home-based trip — see *trip, home-based*.

honor system — type of fare collection system without controls or checks, once common only in the Soviet Union and Eastern Europe but now rapidly disappearing. Often incorrectly used to describe enforced proof of payment fare collection system, see *fare collection system, open*, *proof of payment*, *self-service*, and *barrier-free*.

hot, running — see *running hot*.

hour(s), rush — see *peak*.

hours of service — **1.** the number of hours during the day between the start and end of service on a transit route, also known as the service span. **2.** for calculating transit level of service, the number of hours during a day when service is provided at least hourly on a transit route.

hub (timed transfer focal point) — transit center or interchange for connections or transfers between modes and/or routes. Connections are usually timed in clock-headway pulses and allow convenient transfer between local routes and to express routes. The express routes can connect to the city center and to other hubs, thus offering better suburb-to-suburb trips than possible with a radial route system. Hubs are best located at activity centers such as shopping malls, suburban town centers, and campuses.

hub-and-spoke — type of route structure based on timed connections that increases connectivity and productivity, see *hub*.

hub miles (hub kilometers) — actual logged miles (kilometers) of vehicle operation, usually read from a hubometer or odometer.

hull — the frame or body of a vessel, exclusive of masts, engines, or superstructures.

human service transportation — see *service, human service transportation.*

ISTEA — Intermodal Surface Transportation Efficiency Act of 1991.

ITE — Institute of Transportation Engineers; see *organizations, Institute of Transportation Engineers.*

ITS — Intelligent Transportation Systems.

ITS America — Intelligent Transportation Society of America. A nonprofit, public/private scientific and educational corporation that works to advance a national program for safer, more economical, more energy efficient, and environmentally sound highway travel in the United States. Federal advisory committee used by the U.S. Department of Transportation.

ITS Data Mart — National ITS Architecture Market Package that provides a focused archive that houses data collected and owned by a single entity (e.g., agency). This focused archive typically includes data covering a single transportation mode and one jurisdiction that is collected from an operational data store and archived for future use.

ITS Data Warehouse — National ITS Architecture Market Package that includes all the data collection and management capabilities provided by the *ITS Data Mart*, and adds the functionality and interface definitions that allow collection of data from multiple agencies and data sources spanning across modal and jurisdictional boundaries.

impedance — l. in transportation generally, any condition that restricts or discourages travel, or a measure of that condition. **2.** in transportation modeling, any such condition explicitly accounted for within the model. Time and costs are the factors usually considered, but others may also be examined.

inbound trip — see *trip, inbound.*

inclined elevator —an elevator capable of both horizontal and vertical movement along a fixed path. Differs from *inclined planes* in that only one cabin is used and no attendant is needed to operate it.

inclined plane (incline, inclined railway) — a special type of rail vehicle permanently attached to and hauled by a cable, used for steep gradients, operating on one or two tracks. When two counter-balanced vehicles operate on railway-type tracks, it is also known as a *funicular railway.*

index — a performance measure developed by weighting two or more other performance measures.

indication, signal — see *signal indication.*

indicator, block — see *block indicator.*

indicator, performance — see *performance indicator*

induced demand or traffic — see *traffic, induced.*

induction loop sensor — see *loop detector.*

induction motor — see *motor, induction.*

information, service or user — see *user information.*

information services — see *Railroad Research Information Service, Transportation Research Information Services,* and *Urban Mass Transportation Research Information Service.*

infrastructure — l. in transit systems, all the fixed components of the transit system, such as rights-of-way, tracks, signal equipment, stations, park-and-ride lots, bus stops, maintenance facilities. **2.** in transportation planning, all the relevant elements of the environment in which a transportation system operates.

inspector (road supervisor, route supervisor, street supervisor, road foreman) — a transit employee who evaluates performance, enforces safety and work rules, and attempts to solve problems; an inspector may be mobile (covering several districts in a radio-equipped vehicle) or fixed (assigned to a post at a designated intersection).

Institute of Transportation Engineers — see *organizations, Institute of Transportation Engineers.*

insulated rail joint — see *rail joint, insulated.*

intelligent transportation systems (ITS) — electronics, communications, or information processing used singly or in combination to improve the efficiency or safety of a surface transportation system.

integration, intermodal — see *intermodal integration.*

Interactive Traveler Information — National ITS Architecture Market Package that provides tailored information in response to a traveler request. The traveler can obtain current information regarding traffic conditions, transit services, ride share/ride match, parking management, and pricing information.

interchange — 1. facility for passenger transfers or connection between routes or modes, see *hub*. **2.** the system of interconnecting ramps between two or more intersecting travel ways (highways, transit guideways, etc.) that are grade separated.

interchange center, modal — see *transit center.*

intercity bus — see *bus, intercity.*

intercity transportation — 1. transportation between cities. **2.** transportation service provided between cities by certificated carriers, usually on a fixed route with a fixed schedule.

interface, transportation — see *transportation interface.*

interline — 1. interchange of passengers between one or more bus lines, rail transit lines, or railroads. **2.** transfer of transit vehicles or trains between routes during a day to improve staff or vehicle assignment efficiency.

interlocking — in rail systems, an arrangement of switch, lock, and signal devices that is located where rail tracks cross, join, separate, and so on. The devices are interconnected in such a way that their movements must succeed each other in a predetermined order, thereby preventing opposing or conflicting train movements.

interlocking limit — the track length between the most remote opposing home signals of an interlocking.

interlocking, solid-state — an interlocking with logic based on computers rather than traditional relays or, now obsolete, mechanical locks.

intermodal — 1. the ability to connect, and make connections between, modes of transportation. **2.** those issues or activities that involve or affect more than one mode of transportation, including transportation connections, choices, cooperation, and coordination of various modes.

intermodal integration — service coordination between two or more different transportation modes. This arrangement may include joint (transfer) stations, coordinated scheduling, joint fares, and combined public information activities.

intermodal transfer facility — see *transit center.*

intermodalism — seamless integration of multiple travel modes.

internal combustion engine — see *engine, internal combustion.*

International Union of Public Transport — see *organizations, International Union of Public Transport.*

interrupted flow — transit vehicles moving along a roadway or track and having to make service stops at regular intervals.

intersection — the point at which two or more roadways meet or cross.

intersection, point of — see *point of intersection.*

interurban — see *transit system, interurban.*

iron maiden — full height tri-part turnstile with interlocking metal bars, impervious to fraud or vandalism, used mainly on older East Coast rapid transit systems, mainly for exiting station. platforms, also on Toronto subway for unattended, token actuated, entrances.

island platform — see *center platform.*

island, loading or pedestrian — see *boarding island.*

J

jaywalk — to illegally cross a street in the middle of the block or against a pedestrian signal.

jerk — time rate of change of acceleration or deceleration of a vehicle, measured in ft/s³ (m/s³).

jitney — A transit mode composed of passenger cars or vans operating on fixed routes (sometimes with minor deviations) as demand warrants without fixed schedules or fixed stops. See also *transportation system, jitney; service, jitney;* and *público.*

journey, linked — see *trip, linked.*

journey time — see *time, journey.*

jumper, queue — see *queue jumper*.

junction — 1. in transit operations, a location at which transit routes or lines converge or diverge. **2.** *(Br.)* in traffic engineering, an intersection.

junction, flying — a grade-separated rail junction, allowing merging and diverging movements to be made without conflict and with minimal impact on capacity.

K&M — see *pendulum suspension*.

K&R — kiss and ride.

K factor — in vehicle operations, the ratio of the minimum operating separation between two vehicles to the maximum emergency stopping distance. Normally, the factor is greater than 1 to provide a margin of safety.

kilometer— for all terms containing "kilometer" see equivalent term with "mile."

kiosk — in the transportation context, an interactive computer center for traffic- or travel-related information. Usually located in shopping malls, hotels, airports, businesses, and transit terminals, kiosks provide pre-recorded and real-time information using text, sound, graphics, and video clips.

kiss-and-ride (kiss 'n' ride, K&R) — An access mode to transit whereby passengers (usually commuters) are driven to a transit stop and left to board a transit unit and then met after their return trip. Transit stations, usually rail, often provide a designated area for dropping off and picking up such passengers.

knot — nautical unit of speed; equivalent to 1 nautical mile (1.15 mi or 1.852 km) per hour.

"L" — abbreviation for elevated (railway), mainly Chicago, see *transit system, rail rapid.*

LIM — linear induction motor; see *motor, linear induction.*

LNG — liquefied natural gas.

LOS — level of service.

LRT — light rail transit; see *transit system, light rail.*

LRV — light rail vehicle; see *car, light rail.*

lane, bus (bus priority lane, preferential bus lane, priority bus lane) — a highway or street lane reserved primarily for buses, either all day or during specified periods. It may be used by other traffic under certain circumstances, such as making a right or left turn, or by taxis, motorcycles, or carpools that meet specific requirements described in the traffic laws of the specific jurisdiction.

lane, bypass — see *queue jumper.*

lane, carpool — a highway or street lane intended primarily for carpools, vanpools, and other high-occupancy vehicles, including buses, either all day or during specified periods. It may be used by other traffic under certain circumstances, such as while making a right turn. Minimum occupancy is contentious, many requirements for a minimum of three passengers have been reduced to two through political pressure or legal action.

lane, contraflow — a highway or street lane on which vehicles operate in a direction opposite to what would be the normal flow of traffic in that lane. Such lanes may be permanently designated contraflow lanes, or, more usually, they may be used as contraflow lanes only during certain hours of the day. Frequently, the use of a contraflow lane is restricted to public transit and (possibly) other specially designated vehicles.

lane, diamond — a high-occupancy-vehicle lane physically marked by diamonds painted on the pavement and often indicated by diamond-shaped signs as well. Often used synonymously with high-occupancy-vehicle lane.

lane, exclusive carpool — a highway or street lane reserved for carpools and vanpools.

lane, exclusive transit (reserved transit lane) — a highway or street lane reserved for buses, light rail vehicles, or both.

lane, high-occupancy-vehicle (HOV lane) — a highway or street lane reserved for the use of high-occupancy vehicles (HOVs), see *lane, carpool*.

lane, priority — a highway or street lane reserved (generally during specified hours) for one or more specified categories of vehicles, for example, buses, carpools, vanpools.

lane, ramp meter bypass — a form of preferential treatment in which a bypass lane on metered freeway on-ramps is provided for the exclusive use of high-occupancy vehicles.

lane, reserved transit — see *lane, exclusive transit.*

lane, reversible — a highway or street lane on which the direction of traffic flow can be changed to use maximum roadway capacity during peak-period demands.

lane, reversible bus — a highway or street lane that is reserved for the exclusive use of buses and other high-occupancy vehicles and that can be operated in alternate directions during the two peak-hour periods. It may be the center lane in an arterial street that is used for left-turning traffic in off-peak hours. Usually, bus operators who use this facility are required to have special training and a permit, and the buses may be subject to access or operation controls or both. See *lane, contraflow*.

lane, stair — the portion of a stair's width normally occupied by a single line of pedestrians, typically 22 to 36 in. (56 to 92 cm) wide, depending on stair width.

lay-by — l. In rail systems, a side track. **2.** In bus systems, see *bus bay.*

layover, vehicle — see *time, layover.*

layover time — see *time, layover.*

layover zone — a designated stopover location for a transit vehicle at or near the end of the route or line or at a turnback point.

legislation, Americans with Disabilities Act of 1990 (ADA) — federal civil rights law which ensures people with disabilities equal opportunity to fully participate in society, the ability to live independently, and the ability to be economically sufficient.

legislation, Federal Transit Act of 1964 — federal legislation enacted in 1964 that established the federal mass transportation program. Formerly known as the Urban Mass Transportation Act of 1964. Repealed in 1994 and reenacted as chapter 53 of title 49, United States Code.

legislation, Intermodal Surface Transportation Efficiency Act (ISTEA) — signed into federal law on December 18, 1991, it provided authorizations for highways, highway safety, and mass transit for 6 years and served as the basis of federal surface transportation programs. Renewed and amended in 1998 for 6 years as TEA-21, see *legislation, TEA-21.*

legislation, Moving Ahead for Progress in the 21st Century Act (MAP-21) — signed into federal law on July 6, 2012, this act provided authorizations for highways, highway safety, and public transportation for 2 years. A significant aspect of the act is an emphasis on performance and outcome-based management of the transportation system.

legislation, National Environmental Policy Act of 1969 (NEPA) — a comprehensive federal law requiring an analysis of the environmental impacts of federal actions, such as the approval of grants, and the preparation of an environmental impact statement for every major federal action that significantly affects the quality of the human environment.

legislation, Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) — signed into federal law on August 10, 2005, this act provided authorizations for highways, highway safety, and public transportation for 4 years and served as the basis of federal surface transportation programs. Its funding formulas were subsequently extended multiple times by Congress until the MAP-21 legislation was passed in 2012.

legislation, TEA-21 — 1998 Transportation Efficiency Act for the 21st Century, provides authorizations for highways, highway safety, and mass transit for 6 years and is the basis of federal surface transportation programs, replaces ISTEA.

legislation, Title 49 United States Code, Chapter 53–Mass Transportation — federal legislation establishing the federal mass transportation program. Formerly known as the Federal Transit Act of 1964, and before that, the Urban Mass Transportation Act of 1964.

legislation, Title 49 United States Code, Chapter 53–Mass Transportation, Section 5335 — the section of the United States Code that authorizes the Secretary of Transportation to request and receive statistical information about the financing and operations of public mass transportation systems eligible for Section 5307 grants on the basis of a uniform system of accounts and records. This information is compiled in the *National Transit Database.* Formerly Section 15 of the Federal Transit Act of 1964.

legislation, Urban Mass Transportation Act of 1964 — see *legislation, Federal Transit Act of 1964.*

level of service (LOS) — l. a designated range of values for a particular service measure (e.g., "A" through "F"), based on users' perceptions (see *quality of service*) of the aspect of transportation performance being measured. **2.** the amount of transit service provided.

levitation, magnetic — see *magnetic levitation.*

lift, wheelchair — see *wheelchair lift.*

light rail — see *transit system, light rail;* and *transit system, light rail rapid.*

light rail car — see *car, light rail.*

light rail, dual-mode— see *transit system, light rail, dual-mode.*

light rail rapid transit — see *transit system, light rail rapid.*

light rail transit — see *transit system, light rail.*

light rail vehicle — see *car, light rail.*

limit, civil speed — see *civil speed limit.*

limited access — see *access, limited.*

limited eligibility —see *eligibility, limited.*

limited service — see *service, limited.*

limited-stop service — see *service, limited-stop.*

limits, interlocking — see *interlocking limits.*

limits, yard — see *yard limits.*

line — 1. a transportation company (e.g., a bus line). **2.** a transit service operated over a specified route or combination of routes. **3.** an active (in-use) railroad track or AGT guideway. **4.** in network coding, a route and its service level, including mode designation (type of service), line number, headway, and sequence of transfer points (nodes). These factors describe the line's route as an ordered set.

line, cordon — see *cordon line.*

line, desire — see *desire line.*

line, main — the principal roadway, rail tracks, or other type of transportation right-of-way over which all or most of the traffic moves.

line speed — see *speed, line.*

line-of-sight — a mode of rail operation where the transit vehicle operator is responsible for maintaining a safe distance from the preceding vehicle.

linear electric motor — see *motor, linear electric.*

linear induction motor — see *motor, linear induction.*

line capacity — see *capacity, line;* and *capacity, theoretical line.*

line-clear — in rail transit, operation such that trains do not have to stop or slow down due to the train ahead but receive a succession of green signals. See also *headway, non-interference.*

line haul — see *service, line haul.*

line miles (line kilometers, miles or kilometers of directional roadway) — the sum of the actual physical length (measured in only one direction) of all streets, highways, or rights-of-way traversed by a transportation system (including exclusive rights-of-way and specially controlled facilities), regardless of the number of routes or vehicles that pass over any of the sections; see also *route miles.*

line volume — see *passenger volume.*

link — in planning, a section of a transportation system network defined by intersection points (nodes) at each end; that is, a link connects two nodes. It may be one way or two way.

linked journey or trip or passenger trip — see *trip, linked.*

linked trip distance — see *trip distance, linked.*

linked trip time — see *time, linked trip.*

link load — in planning, the assigned volume of traffic on a link; see also *link volume.*

link volume — in planning, the total number of highway vehicles or transit passengers assigned to a network link.

load, crush — see *capacity, crush.*

load, link — see *link load.*

load, passenger — see *passenger load.*

load, scheduled design — the maximum number of people that agency policy calls for being on board a transit vehicle at a given time. It can be expressed as an average load over a half-hour, hour, or other time period, or as a value not to be exceeded more than a certain percentage of time (or at all). Service is scheduled to ensure that sufficient vehicles are operated that passenger loads do not exceed the limits set by the agency policy.

load factor — 1. the ratio of used capacity to offered capacity of equipment or a facility during a specified time period. It is usually expressed as a percentage of seats occupied at a given point or (in continuous form) passenger miles (km) divided by seat miles (km). For rail services, the load factor is sometimes expressed as passenger miles (km) per train mile (km) to account for the ability to couple rail cars together to achieve efficiency. **2.** the ratio of passengers actually carried versus the total passenger capacity of a vehicle; also known as a *utilization coefficient.*

load point, maximum — see *maximum load point.*

load section, maximum — see *maximum load section.*

load shedding — 1. reducing the amount of conventional transit service at peak hours by encouraging the use of paratransit operations to carry some of the peak-period passengers. **2.** disconnecting part of electric traction network at time of power shortage or sub-station failure. Available power will then be rotated from section to section of line to move all trains into a station , or to keep part of the line operating normally.

loading, link — see *link loading.*

loading area — a curbside space where a single bus can stop load and unload passengers. Bus stops include one or more loading areas. See also *bus bay* and *stop, transit.*

loading island — see *boarding island.*

local bus or service — see *service, local bus.*

local train — see *train, local.*

location referencing — technology that more precisely identifies locations of vehicles, locations, and travelers. Used with GPS and AVL technologies.

location, vehicle — see *automatic vehicle location system.*

locomotive — a powered rail vehicle used for towing rail cars. It does not carry passengers and is usually powered by electric motors or diesel engines.

locomotive, diesel-electric — a locomotive that uses one or more diesel engines to drive electric generators that in turn supply electric motors geared to the driving axles. By far the dominant type of locomotive in North America.

locomotive, dual-powered — a locomotive that is capable of both diesel and electric operation, generally specific to services entering New York City (Grand Central Terminal) where diesel operation is limited.

locomotive, electric — a locomotive in which the propulsion is affected by electric motors mounted on the vehicle. The electric power comes from an external source, usually overhead catenary.

locomotive, passenger — a locomotive commonly used for hauling passenger trains and generally designed to operate at higher speeds and lower tractive effort than a freight locomotive of equal power. Usually equipped with head-end power that, through power take-off from the existing generator, a separate generator, or power conversion unit(s), provides heat, light, and air conditioning power for the passenger cars.

loop — l. a transit route or guideway layout that is of a closed continuous form, such as a circle. **2.** a terminal track layout or bus driveway that reverses the direction of a vehicle without the vehicle itself reversing.

loop detectors — a loop of wire embedded in the roadbed that carries a small electric current used to sense a passing vehicle and to yield information about the presence of the vehicle. Loop detectors are also used to actuate traffic signals and detect roadway incidents.

LOS — see *level of service (LOS).*

low-floor bus — see *bus, low-floor.*

low-floor light rail vehicle — see *car, light rail vehicle, low-floor*.

low-floor streetcar — see *car, light rail vehicle, low-floor*.

low mobility group — see *transportation disadvantaged.*

low platform — see *platform, low.*

low voltage — see *voltage, low.*

MAC — major activity center.

MAC system — major activity center system; see *transit system, major activity center.*

MAGLEV — magnetic levitation.

MAP-21 — Moving Ahead for Progress in the 21st Century Act: see *legislation, Moving Ahead for Progress in the 21st Century (2012)*.

MG set —see *motor-generator.*

MLP — maximum load point.

MLS — maximum load section.

MSA — metropolitan statistical area.

MU — multiple unit; see *car, multiple-unit.*

MUTCD — *Manual on Uniform Traffic Control Devices.*

magnetic brake — see *brake, track.*

magnetic farecard — a card containing a magnetic tape strip or other electronic means of indicating the value purchased. The card is usually obtained from a vending machine and must be inserted into a farecard reader to gain access to the paid area of the transit system. In systems with fares by distance the card must also be inserted into a farecard reader to exit the paid area, see also *smart card* and *fare collection system, automatic.*

magnetic levitation (MAGLEV) — support technology that keeps a vehicle vertically separated from its track or riding surface by magnetic force, either attractive or repulsive. After interest in the 1970s and 1980s this technology has been discredited for urban transit use and is essentially moribund.

main line — see *line, main.*

maintenance — the upkeep of vehicles, plant, machinery, and equipment. It may be scheduled, planned, progressive, or periodic on the basis of pre-established intervals of time, hours, or mileage, and employ preprinted checklists *(preventive maintenance)*, or it may be unscheduled or corrective, in which case it is generally not interval based.

major activity center (MAC, activity center) — a geographical area characterized by a large transient population and heavy traffic volumes and densities; for example, central business district, major air terminal, large university, large shopping center, industrial park, sports arena.

major activity center transit system — see *transit system, major activity center.*

mall, transit — see *street, transit.*

management, headway — see *headway management.*

management, transportation system — see *transportation system management.*

manual block control system — see *control system, manual block.*

Manual on Uniform Traffic Control Devices — standard reference published by the U.S. Department of Transportation guiding the usage of traffic and on-street light rail control devices.

manual train control — see *control system, manual train.*

many-to-few service — see *service, many-to-few.*

many-to-many service — see *service, many-to-many.*

many-to-one service — see *service, many-to-one.*

market — **1.** the potential or actual consumers (or both) of a (transportation) product or service. A general market denotes the entire population of a designated geographical area, whereas a specialized market denotes particular groups, such as the elderly, persons with disabilities, or students. **2.** the extent of demand for a transportation commodity or service.

Market Package — the building blocks of the National ITS Architecture. Derived from the User Services, the Market Packages provide a finer-grained breakdown tailored to fit—separately or in combination—real-world transportation problems and needs.

market share — the percentage of a (transportation) market realized by or available to a particular (transportation) provider.

married pair — two semi-permanently coupled rail cars (A car and B car) that share some mechanical and electrical equipment and must be operated together as a unit.

mass transit, mass transportation — urban public transport by bus, rail, or other conveyance, either publicly or privately owned, providing general or special service to the public on a regular and continuing basis (not including school bus, charter, or sightseeing service). The term has developed a negative connotation and its use is discouraged in favor of urban transport, transit, public transit, public transport, or public transportation.

maximum load point (MLP) — see *maximum load section*.

maximum load section (MLS) — the section of a transit line or route that carries the highest total number of passengers for that line or route and direction. *Maximum load point* is commonly but inaccurately used in place of this term.

maximum service braking — see *braking, maximum service.*

maximum theoretical velocity — see *velocity, maximum theoretical.*

measure of effectiveness — see *performance measure* and *service measure, transit.*

mechanical brake — see *brake, friction.*

median (median strip) — the portion of a divided highway or guideway that separates the opposing flows of traffic.

messenger — see definition of *catenary system.*

metered freeway — see *freeway, metered.*

metered freeway bus priority system — see *bus priority system, metered freeway.*

metering, ramp — see *ramp metering.*

Metro — short for metropolitan railway, the most common international term for subway, heavy rail, rail rapid transit, increasingly used in North America, see *transit system, rail rapid.*

metropolitan railway — see *transit system, rail rapid.*

mezzanine, station — a circulation area of a station that is above the platforms, usually connected to platforms by stairs, escalators, or elevators.

micro-peaking — short peak periods and surges within the 15-minute or hourly peak. For stations and stops, micro-peaking is likely to occur just after a transit vehicle arrives and discharges passengers; may result in increased crowding for a short duration.

microsimulation, pedestrian — application of a software program that analyzes flows based on the aggregate movements of individual people.

mid-block stop — see *stop, mid-block.*

midibus — a bus with a passenger capacity of approximately 20-30 people.

mileage fare — see *fare, graduated.*

miles of route or roadway — see *route miles.*

miles of travel, vehicle — see *vehicle miles of travel.*

mini-high platform — see *platform, mini-high.*

minibus — a small bus, typically capable of carrying 20 passengers or fewer. It is most often used for making short trips, demand-responsive transportation, community services, or bus pools.

missed trip — see *trip, missed*.

mixed-mode street — see *street, mixed mode.*

mixed or mixed-flow traffic — see *traffic, mixed.*

mixed-traffic operations — the operation of transit vehicles on nonexclusive rights-of-way with non-transit vehicles.

mobility — the ability to satisfy the demand to move a person or good.

modal interchange center — see *transit center.*

modal split (mode split) — 1. the proportion of total person trips that uses each of various specified modes of transportation. **2.** the process of separating total person trips into the modes of travel used; see also *urban transportation modeling system* and *model, sequential.*

mode — 1. a transport category characterized by specific right-of-way, technological and operational features, **2.** a particular form of travel, for example, walking, traveling by automobile, traveling by bus, traveling by train.

mode, access — a feeder mode to the principal mode of transportation; for example, walking, kiss-and-ride, park-and-ride.

mode, dual — see *transit system, dual-mode.*

mode, transit — a category of transit systems characterized by common characteristics of technology, right-of-way, and type of operation. Examples of different transit modes are regular bus service, express bus service, light rail transit, rail rapid transit, and commuter rail.

model — l. a mathematical or conceptual presentation of relationships and actions within a system. It is used for analysis of the system or its evaluation under various conditions; examples include land use, economic, socioeconomic, transportation. **2.** a mathematical description of a real-life situation that uses data on past and present conditions to make a projection about the future.

mode split — see *modal split.*

monocable system — a ropeway system that uses a single haul rope to both support and control motion of the carriers.

monorail — see *transit system, monorail.*

monthly pass — see *pass, monthly.*

mooring — a secure object to which a vessel may be tied.

motor (electric motor) — a machine that transforms electrical energy into mechanical energy (torque).

motor, alternating-current — an electric motor (asynchronous, synchronous, induction, etc.) that operates on alternating current, generally three phase. The dominant motor type on modern electric transit vehicles from the mid-1990s.

motor, direct current — an electric motor (shunt, compound, etc.) that operates on direct current.

motor, electric — see *motor.*

motor, induction — an asynchronous alternating-current rotary motor that converts alternating-current electric power, delivered to the primary winding (usually the stator) and carried as induced current by the secondary winding (usually the rotor), into mechanical power.

motor, linear induction (LIM), single-sided linear induction, linear electric — an electric

motor that produces mechanical force through linear, instead of rotary, motion, used to propel vehicles along a track or other guideway. The vehicle borne motor creates a "moving" magnetic field that is translated into linear motion via an inert steel guideway reaction rail, often laminated and aluminum covered. Used on the ALRT and AGT systems in Vancouver, Toronto (Scarborough), Detroit, New York JFK Airport, and Kuala Lumpur.

motor, series-wound — a motor in which the field circuit is connected in series with the armature circuit, often called a *traction motor.*

motor, shunt — a type of rotary electric motor in which the field coils are connected in parallel with the motor armature.

motor, synchronous — a synchronous machine that transforms electrical power from any alternating-current system into mechanical power. The average speed of normal operation is equal to the frequency of the power system to which it is connected.

motor, traction — an electric motor, usually direct current and series wound, that propels a vehicle by exerting its torque through the wheels; see also *motor, series-wound.*

motor brake — see *brake, dynamic.*

motor bus — see *bus, motor.*

motor car, rail — see *car, rail motor.*

motor coach — see *bus, motor.*

motor-generator (MG set) — an electrical motor, usually at line voltage, mechanically coupled to a direct current generator to provide low voltage (*12, 24 or 32 volts, sometimes higher)* supply for rail transit cars and trolleybuses. Now replaced with solid-state DC-DC converters.

motor operator or motorman — see *operator, train.*

move, reverse — see *reverse move.*

mover, people — see *people mover.*

moving block control system — see *control system, moving block.*

moving ramp — see *ramp, moving.*

moving sidewalk — see *moving walkway.*

moving walkway (moving sidewalk, passenger or pedestrian conveyor, passenger belt, travelator) — a fixed, level, or gently inclined (up to 12°) conveyor device (usually a flexible belt) on which pedestrians may stand or walk while being transported; see also *ramp, moving.*

Multi-modal Coordination — National ITS Architecture Market Package that establishes two-way communications between multiple transit and traffic agencies to improve service coordination. Intermodal coordination between transit agencies can increase traveler convenience at transfer points and also improve operating efficiency. Coordination between traffic and transit management is intended to improve on-time performance of the transit system to the extent that this can be accommodated without degrading overall performance of the traffic network.

multimodal —the availability of transportation options using different modes within a system or corridor.

multimodal transit agency — a transit agency operating more than one mode of service.

multiple-unit car — see *car, multiple-unit.*

multiple-unit control system — see *control system, multiple-unit.*

NCHRP — National Cooperative Highway Research Program.

NCTRP — National Cooperative Transit Research and Development Program.

NEPA — National Environmental Policy Act; see *legislation, National Environmental Policy Act of 1969.*

NFPA — NFPA 130 — National Fire Prevention Association 130. Standards for fire and life safety on fixed-guideway transit systems. Adopted into law in Canada and the United States, and, in part or whole, in some other jurisdictions. Even where not adopted the standards are generally applied in designing new fixed guideway systems worldwide. Older rail transit systems are not required to retrofit to these standards, first issued in 1983. Separate standards issued in 1998 for automated guideway transit. Available from NFPA, Batterymarch Park, Quincy, MA 02269 USA.

NPTS — Nationwide Personal Transportation Study.

NTD — see *National Transit Database.*

NTSB — National Transportation Safety Board; see *U.S. Government, National Transportation Safety Board.*

narrow gauge — see *gauge, narrow.*

National Cooperative Highway Research Program (NCHRP) — a program established by the American Association of State Highway Officials (now American Association of State Highway and Transportation Officials) to provide a mechanism for a national coordinated program of cooperative research employing modern scientific techniques. The NCHRP is administered by the Transportation Research Board.

National Environmental Policy Act of 1969 — see *legislation, National Environmental Policy Act of 1969.*

National ITS Architecture — a common framework for ITS interoperability. The National ITS Architecture comprises the logical architecture and physical architecture that satisfy a defined set of User Services. The National ITS Architecture is maintained by the U.S. DOT and is available on the DOT web site at http://www.its.dot.gov/.

National Railroad Passenger Corporation — see *U.S. Government, National Railroad Passenger Corporation*

National Transit Database (NTD) — a database compiled by the Federal Transit Administration of operating and financial statistics for over 600 transit agencies in the United States (those systems eligible for grants under Title 49 United States Code, Chapter 53–Mass Transportation, Section 5307.) Formerly known as Section 15 of the Federal Transit Act.

National Transportation Safety Board — see *U.S. Government, National Transportation Safety Board.*

Nationwide Personal Transportation Study (NPTS) — the NPTS, conducted periodically by the Bureau of the Census, has been the primary source of national data on travel patterns and frequency, transit use for all purposes, and the characteristics of transit users versus all travelers.

near-side stop — see *stop, near-side.*

network — 1. in planning, a system of links and nodes that describes a transportation system. **2.** in highway engineering, the configuration of highways that constitutes the total system. **3.** in transit operations, a system of transit lines or routes, usually designed for coordinated operation.

network, grid — 1. in planning, an imaginary network of evenly spaced horizontal and vertical bars or lines that divides a study area into small geographic zones. **2.** in transit operations, a service pattern in which two sets of parallel routes intersect each other at right angles.

network, radial — in transit operations, a service pattern in which most routes converge into and diverge from a central hub or activity center (e.g., central business district), like the spokes of a wheel. The hub may serve as a major transfer point.

New Look Bus — see *bus, New Look, fishbowl.*

node — in planning, a point that represents an intersection of two or more links, highways, or transit lines or routes or a zone centroid; used in trip assignment.

non-exclusive transitway — see *transitway.*

non-fixed route — see *transportation system, non-fixed route.*

non-home-based trip — see *trip, non-home–based.*

non transportation revenue — see *revenue, non transportation.*

normal vehicle capacity — see *capacity, vehicle.*

not-in-service time — see *time, deadhead.*

OBD — outlying business district.

OCS — overhead contact system.

O–D study — origin–destination study.

occupancy, area — see *area occupancy.*

occupancy, vehicle — see *vehicle occupancy.*

off line — not in the main flow of traffic or not on the main line of traffic, for example, off-line station.

off-line station — see *station, off-line.*

off peak — the periods of time outside the peak periods; see also *base period.*

off-peak fare — see *fare, time-of-day.*

off-peak period — see *base period.*

off-street terminal — see *terminal, off-street.*

on-and-off check or count — see *check.*

onboard check — see *check.*

one-to-many service — see *service, one-to-many.*

one-way trip — see *trip.*

one-zone ride — a transit ride within the limits of one fare zone.

on line — in the main flow of traffic.

on-line station — see *station, on-line.*

on-time performance — the proportion of the time that a transit system adheres to its published schedule times within stated tolerances; for example, a transit unit (vehicle or train) arriving, passing, or leaving a predetermined point (time point) along its route or line within a time period that is no more than *x* minutes earlier and no more than *y* minutes later than a published schedule time. [Values of 0 minutes for *x* and 5 minutes for *y* are the most common. On frequent rail services the headway can be used for *x*, with greater values indicating that the late train interferes with (delays) the following one.]

open cut guideway — see *guideway, open cut.*

open-loop braking — see *braking, open-loop.*

open fare system — see *fare collection system, proof of payment, self-service, barrier-free, open.*

operating costs — the sum of all recurring costs (e.g., labor, fuel) that can be associated with the operation and maintenance of the system during the period under consideration. Operating costs usually exclude such fixed costs as depreciation on plant and equipment, interest paid for loans on capital equipment, and property taxes on capital items. See also *capital costs.*

operating employees (operating personnel) — 1. employees whose major function is operating the service, such as station employees, bus drivers, train operators, and conductors. **2.** in rail operations, those employees that have direct and supervisory responsibility for the movement of transit units (cars or trains), embodying both onboard and wayside duties.

operating expenses — the total of all expenses associated with operation of an individual mode by a given operator. In the United States, total operating expense is reported on line 14 of Form 301 for a single mode system, and is derived from Form 310 for a multimodal system. Operating expenses include distributions of "joint expenses" to individual modes, and exclude "reconciling items" such as interest expenses and depreciation. Do not confuse with "vehicle operations expense."

operating margin — 1. the amount of time that a train can run behind schedule without interfering with following trains. **2.** imprecise reference to operating ratio.

operating ratio — the ratio of operating expenses to operating revenue; the inverse of cost recovery ratio. It is used as a measure of financial efficiency. See also *fare recovery ratio.*

operating revenue, total — see *revenue, total operating.*

operating speed — see *speed, running;* and *speed, schedule.*

operating speed, effective — see *speed, overall trip.*

operating time — see *time, operating.*

operating unit — see *basic operating unit.*

operation — see *operator* and *property.*

operation, automatic train — see *automatic train operation.*

operation, single track — see *single-track operation.*

operation, train — see *train operation.*

operational characteristic — any characteristic of transit service operation, i.e., this route is frequently overcrowded.

operations, mixed-traffic — see *mixed-traffic operations.*

operator — 1. an employee of a transit system whose workday is spent in the operation of a transit unit (vehicle or train), such as a bus driver or train operator. Such an employee may also be known as a *platform operator.* **2.** the organization that runs a transportation system on a day-to-day basis. also known as an *operation, property, agency* or *system;* see also *property.*

operator, car — see *operator, train.*

operator, motor — see *operator, train.*

operator, rapid transit — see *operator, train.*

operator, streetcar — see *operator, train.*

operator, train (motor operator, engineer) — the operating employee who controls the movement of a rail transit unit (vehicle or train.) Specific titles are also used, such as *car operator, rapid transit operator, streetcar operator.*

order, slow — see *slow order.*

orders — authorization to move a train, as given by a train dispatcher either in writing or orally.

organizations — see also *U.S. Government* and *union, transit.*

organizations, American Association of State Highway and Transportation Officials (AASHTO) — membership includes state and territorial highway and transportation departments and agencies and the U.S. Department of Transportation. Its goal is to develop and improve methods of administration, design, construction, operation, and maintenance of a nationwide integrated transportation system. It studies transportation problems, advises Congress on legislation, and develops standards and policies.

organizations, American Public Transportation Association (APTA) — a nonprofit international industry association made up of transit systems and other organizations and institutions connected to or concerned with the transit industry. It performs a variety of services for the industry, and its objectives include promotion of transit interests, information exchange, research, and policy development. Known as the American Public Transit Association prior to 2000.

organizations, Association of American Railroads (AAR) — an industry association made up of individual railroads in the United States, Canada, and Mexico. It performs a variety of technical services for the railroads, and its purposes include the promotion of railroad interests and the standardization and coordination of operating and mechanical activities within the railroad industry.

organizations, Canadian Urban Transit Association (CUTA) — an industry association made up of individual transit operators and suppliers in Canada.

organizations, department of transportation (DOT) — a municipal, county, state, or federal agency responsible for transportation; see also *U.S. Government, Department of Transportation.*

organizations, Institute of Transportation Engineers (ITE) — a society of professionals in transportation and traffic engineering. It promotes education, research, the development of public awareness, and the exchange of professional information in these areas with the goal of contributing individually and collectively toward meeting human needs for mobility and safety.

organizations, International Union of Public Transport (UITP) — an association that pools information and experience of urban and interurban transportation undertakings for joint study and research and promotes technical and economic development.

organizations, Presidents' Conference Committee (PCC, Electric Railway Presidents' Conference Committee) — a group of leading streetcar producers and operators who, between 1930 and 1935, sponsored the development of the PCC car. This car had performance characteristics superior to any previous model of streetcar and became the standard of U.S. streetcars for many years. See also *car, PCC.*

organizations, Public Utilities Commission (PUC, Public Service Commission, PSC) — a state agency whose responsibilities include regulation of for-hire (public and private) carriers of passengers and goods within a state. Other jurisdictions (e.g., a city) may also have a PUC or PSC that regulates for-hire carriers within that jurisdiction.

organizations, regional planning agency (RPA) — a nonprofit, quasi-public organization whose policy board is composed of member municipal government representatives. It makes recommendations related to land use, the environment, human resources, housing, and transportation for a specific region.

organizations, Transportation Research Board — a unit of the National Research Council, operating under the corporate authority of the private and nonprofit National Academy of Sciences. The purpose of TRB is to advance knowledge concerning the nature and performance of transportation systems by stimulating research and disseminating the information derived therefrom. Its affiliates and participants include transportation professionals in government, academia, and industry.

origin — 1. the point at which a trip begins. **2.** in planning, the zone in which a trip begins.

origin–destination service — see *service, origin–to-destination.*

origin–destination study (O–D study) — a study of the origins and destinations of the trips of vehicles or travelers. It may also include trip purposes and frequencies.

out of service (not in service) — a transit vehicle or facility that is not available for transporting passengers.

outbound trip — see *trip, outbound.*

outlying business district (OBD) — the portion of an urban area that is normally separated from the central business district and fringe area but that supports considerable business activity and has its own traffic circulation, superimposed on some through traffic.

overall travel time — see *time, linked trip.*

overall trip speed — see *speed, overall trip.*

overhead — colloquial abbreviation for overhead contact system in electric traction, see *OCS.*

overhead contact shoe (contact shoe, trolley shoe) — a metal bar, usually with graphite insert, for collecting current from an overhead conductor along which it slides. It is held in place by a trolley pole, pantograph or bow.

overhead contact system (OCS) — the overhead electric supply system for rail and trolleybus systems, including contact wire, catenary, messenger wires, supporting masts, span wires and bracket arms.

overload — see *extra section.*

overload factor — a safety factor applied in designing a vehicle staging lot. The factor is obtained by dividing the vessel vehicle carrying capacity into the staging lot capacity. Allows for storage for more vehicles than can be accommodated on the vessel.

overspeed governor — see *governor.*

over-the-road coach — see *bus, intercity.*

owl bus or run — see *run, owl.*

owl service — see *service, owl.*

P

P&R — park and ride.

PCC — Presidents' Conference Committee; see *organizations, Presidents' Conference Committee;* and *car, PCC.*

PCC car — Presidents' Conference Committee car; see *car, PCC.*

PCE — passenger car equivalence.

PRT — personal rapid transit; see *transit system, personal rapid,* and *transit system, automated guideway transit.*

PSC — Public Service Commission; see *organizations, Public Utilities Commission.*

PTC — see *positive train control.*

PUC — Public Utilities Commission; see *organizations, Public Utilities Commission.*

paid area — see *area, paid.*

paid-area transfer — see *transfer, paid-area.*

paid miles — see *revenue vehicle miles.*

paid transfer — see *transfer, paid.*

pair, married — see *married pair.*

pantograph — a device for collecting current from an overhead conductor, characterized by a hinged vertical arm operated by springs or compressed air and a wide, horizontal contact surface that glides along the wire. Older versions usually consist of two parallel, hinged, double-diamond frames.

paratransit — forms of transportation services that are more flexible and personalized than conventional fixed-route, fixed-schedule service but not including such exclusory services as charter bus trips. The vehicles for paratransit service are usually low- or medium-capacity highway vehicles, and the service offered is adjustable in various degrees to individual users' needs. The term paratransit originally referred broadly to categories of service that are public, which is available to any user who pays a pre-determined fare (e.g., taxi, jitney, dial-a-ride), and semi-public, which is available only to people of a certain group, such as older adults, employees of a company, or residents of a neighborhood (e.g., vanpools, subscription buses). However, more recently, paratransit is often used to refer more specifically to ADA complementary paratransit. See also *paratransit, complementary* and *transit system, demand-responsive.*

paratransit, complementary — paratransit service required within a certain distance of any local fixed-route transit service to accommodate passengers whose disabilities prevent their independent use of the fixed-route service. Required by the Americans with Disabilities Act.

park-and-ride (park 'n' ride, P&R) — an access mode to transit in which patrons drive private automobiles or ride bicycles to a transit station, stop, or carpool/vanpool waiting area and park the vehicle in the area provided for that purpose (park-and-ride lot, park-and-pool lot, commuter parking lot, bicycle rack or locker). They then ride the transit system or take a car or vanpool to their destinations.

parking facility — an area, which may be enclosed or open, attended or unattended, in which automobiles may be left, with or without payment

of a fee, while the occupants of the automobiles are using other facilities or services.

parking turnover — the ratio of the total number of parked vehicles accommodated during a given period in a specified area to the total number of parking spaces in that area.

pass — **1.** a means of transit prepayment, usually a card, that a transit passenger displays to the operator, conductor, or fare inspector, or processes through automatic fare collection equipment instead of paying a cash fare. Passes are usually sold by the week or month. In some areas, to encourage tourism, they are also sold for shorter periods, sometimes with restricted hours for their use. **2.** a means, usually a card, of granting free access to a transit system. This type of pass is issued to employees, visiting dignitaries, police, and so on. Employee passes usually carry some form of identification. See also *daypass*.

pass, monthly — a pass valid for unlimited riding within certain designated zones for a 1-month period, or sometimes for a 30-day period from purchase or initial use.

passenger — a person who rides a transportation vehicle, excluding the operator or other crew members of that transportation vehicle; see also *customer*.

passenger, revenue — a passenger who pays (or has prepaid) a fare.

passenger, transfer — a passenger who changes from one route or line to another route or line.

passenger amenity — an object or facility (such as a shelter, telephone, or information display) intended to enhance passenger comfort or transit usability.

passenger belt — see *moving walkway*.

passenger car equivalence (PCE) — the representation of larger vehicles, such as buses, as equal to a quantity of automobiles (passenger cars) for use in level of service and capacity analyses.

passenger controls — **1.** a system of railings, booths, turnstiles, fare gates, and other fixtures for collecting fares and otherwise directing the movement of passengers. The controls may also be used to maintain the distinction between fare-paid and unpaid people. **2.** on proof-of-payment fare collection systems, the process of checking and enforcing fare payment.

passenger conveyor — see *moving walkway*.

passenger count — a count of the passengers on a vehicle or who use a particular facility.

passenger environment survey — see *survey, passenger environment*.

passenger flow (passenger traffic) — the number of passengers who pass a given location in a specified direction during a given period.

passenger load — the number of passengers on a transit unit (vehicle or train) at a specified point.

passenger locomotive — see *locomotive, passenger*.

passenger mile (passenger kilometer) — the transportation of one passenger a distance of 1 mile (km).

passenger miles (passenger kilometers) — the total number of passengers carried by a transit system for a unit of time multiplied by the number of miles (kilometers) they travel. The ratio of passenger miles (kilometers) and seat or place miles (kilometers) provides a measure of efficiency.

passenger miles per train mile (passenger kilometers per train kilometer) — the number of passenger miles (kilometers) accomplished by a given train mile (kilometer). The measure is the equivalent of load factor for buses, boats, or aircraft, but it also adjusts for distortions introduced as cars are added to trains. As an example, 100 people in one rail car of 100-passenger capacity is a load factor of 100%. If a car is added for 10 more passengers, the load factor drops to 55%, yet in many ways, productivity has gone up, not down.

passenger platform — see *platform*.

passenger riding count or check — see *check*.

passenger service time — see *time, passenger service*.

passenger station — see *station*.

passenger traffic — see *passenger flow*.

passenger trip — see *trip, linked; trip, passenger;* and *trip, unlinked*.

passenger vehicle — see *vehicle, passenger*.

passenger volume (line volume) — the total number of passengers carried (boarded) on a transit line during a given period.

passing track — see *siding*.

pass-up — circumstance in which a bus or train is full when it arrives at a stop and waiting passengers are forced to wait for the next vehicle or find another means of making their trip.

path — in planning, any series of links where each succeeding link has the ending node of a previous link as its beginning node.

patron — see *rider*.

patronage — see *ridership*.

peak (peak period, rush hours) — **1.** the period during which the maximum amount of travel occurs. It may be specified as the morning (a.m.) or afternoon or evening (p.m.) peak. **2.** The period when demand for transportation service is heaviest.

peak/base ratio (peak/off-peak ratio) — **1.** the ratio between the number of vehicles operating in passenger service during the peak hours and that during the base period. **2.** the ratio between the number of passengers carried during the peak hours and during the base period. A low ratio (<2-3) characterizes large cities with healthy transit systems.

peak fare — see *fare, time-of-day*.

peak-hour conversion factor — see *peak-hour factor*.

peak-hour factor (peak-hour conversion factor) — 1. the ratio of the volume during the peak hour to the maximum rate of flow during a selected period within the peak hour, usually 15 min. **2.** the ratio of the volume during the peak hour to the volume during the peak period, usually the peak 2 hours, typically 60%.

peak-hour pricing — see *pricing, peak-hour.*

peak period — see *peak.*

peak-period surcharge — see *fare, time-of-day.*

peak service — see *service, peak.*

pedestrian — a person traveling on foot.

pedestrian conveyor — see *moving walkway.*

pedestrian density — see *density, pedestrian*.

pedestrian-friendly — characterized by features and elements that make walking safe and convenient. A pedestrian-friendly environment near a transit stop might have pedestrian pushbuttons at street crossings and direct, paved access to adjacent development.

pedestrian island — see *boarding island.*

pedestrian refuge — a space designed for the use and protection of pedestrians, including both the safety zone and the area at the approach that is usually outlined by protective deflecting or warning devices; see also *loading island.*

penalty, transfer — see *transfer penalty*.

pendulum suspension (K&M) — type of overhead suspension for trolleybuses that provides more flexible wire and allows faster speeds — particularly around curves. Attributed to dominant Swiss manufacturer, Kummler+Matter.

people mover — an automated transportation system (e.g., continuous belt system or automated guideway transit) that provides short-haul collection and distribution service, usually in a major activity center. Preferred term is *automated guideway transit* although some regard people mover as a subset of AGT.

people mover, downtown (DPM) — a people mover that primarily serves internal movements in a central business district.

performance, on-time — see *on-time performance.*

performance measure (performance indicator, measure of effectiveness) — a quantitative measure of how well an activity, task, or function is being performed. In transportation systems, it is usually computed by relating a measure of service output or use to a measure of service input or cost.

performance measurement system — the measures, data collection procedures, evaluation methods, goals, and reporting methods used to monitor an agency's effectiveness, efficiency, service quality, and goal achievement for the purposes of improving decision making and meeting objectives.

period, base or off-peak — see *base period.*

period, peak — see *peak.*

peripheral parking — see *parking, fringe.*

permissive block — see *block, absolute permissive.*

person capacity — see *capacity, person*.

person trip — see *trip, person.*

personal rapid transit — see *transit system, personal rapid.*

Personal Transportation Study, Nationwide — see *Nationwide Personal Transportation Study.*

Personalized Public Transit — National ITS Program User Service in which flexibly routed transit vehicles offer more convenient service to customers.

personnel, operating — see *operating employees.*

persons with disabilities —people who have physical or mental impairments that substantially limit one or more major life activities. In the context of transportation, the term usually refers to people for whom the use of conventional transit facilities would be impossible or would create a hardship.

plan, sketch — see *sketch planning.*

plan, system — see *system planning.*

platform — on a bus or streetcar, the front portion where passengers board.

platform, ferry — a platform (usually floating) located between the stable approach and vessel, from which passengers embark onto, or disembark from, the vessel.

platform, passenger — that portion of a transit facility directly adjacent to the tracks or roadway at which transit units (vehicles or trains) stop to load and unload passengers. Within stations, it is often called a *station platform.*

platform, center (island) — a passenger platform located between two tracks or guideways so that it can serve them both.

platform, high — a platform at or near the floor elevation of the transit unit (vehicle or train), eliminating the need for steps on the transit unit.

platform, low — a platform at or near the top of the running surface of the transit unit (vehicle or train), requiring the passenger to use steps to board and alight.

platform, mini-high (high-block platform) — a small high-level platform that usually provides access only to the first door of a light rail train in order to allow boarding by wheelchairs, scooters, etc.

platform, side — a passenger platform located to the outside of the tracks or guideways, as distinguished from a center platform located between the tracks or guideways.

platform, station — the area of a station providing direct access to transit vehicles.

platform operator — see *operator.*

platform screen door — see *door, platform screen.*

platform time — see *time, platform.*

platoon, bus — see *bus platoon.*

p.m. peak — see *peak.*

pneumatic brake — see *brake, electropneumatic.*

pocket track — a third track to store spare or disabled trains, or to act a crossover or a turnback, often located between the two main tracks and often with switches at both ends.

point, maximum load — see *maximum load point.*

point, time — see *time point.*

point, turnover — see *turnover point.*

point check — see *check.*

point deviation — a transit routing pattern in which the vehicle passes through pre-specified points in accordance with a prearranged schedule but is not given a specific route to follow between these points. It may provide door-to-door or curb-to-curb service. May be called *checkpoint dial-a-ride*. See also *service, point deviation.*

points — a pair of linked, movable tapered rails used in rail switches that allow a train to pass from one line to another. Points are also used for the same function in overhead wiring for trolleybuses.

pole, trolley — see *trolley pole.*

policy headway — see *headway, policy.*

pool — see *buspool, carpool,* and *vanpool.*

positive train control — a system that improves the safe operation of trains by overriding the discretion of the train engineer to pass a stop signal or operate at a higher-than-permissible speed.

power, dual — see *propulsion system, dual-power* and *bus, hybrid.*

powered car — see *car, rail motor.*

power rail — see *rail, third.*

power-to-weight ratio — a measure of the performance of locomotives. A higher power-to-weight ratio provides better acceleration characteristics.

preemption, signal — see *signal preemption.*

preferential bus lane — see *lane, bus.*

premium service — demand-responsive transportation services that exceed the minimum requirements for ADA complementary paratransit.

pre-metro system — see *transit system, pre-metro.*

Pre-Trip Travel Information — National ITS Program User Service that provides information for selecting the best transportation mode, departure time, and route.

Presidents' Conference Committee — see *organizations, Presidents' Conference Committee;* and *car, PCC.*

Presidents' Conference Committee car — see *car, PCC.*

preventive maintenance — see *maintenance.*

pricing — a strategy for charging users. It may be used to ration demand (change behavior), cover costs, or achieve other policy objectives.

pricing, peak-hour — charging higher prices for peak-period service than for off-peak service.

pricing, time-of-day — varying the price of service during the day.

priority lane — see *lane, priority.*

priority lane, bus — see *lane, bus.*

priority system, bus — see *bus priority system.*

private transportation — **1.** any transport service that is restricted to certain people and is therefore not open to the public at large. **2.** owned or operated by an individual or group, for his, her, or its own purposes or benefit, not by a governmental entity.

productions, trip — see *trip productions.*

productive capacity — see *capacity, productive.*

productivity — the ratio of units of transportation output to units of input (consumed resource); for example, vehicle miles (vehicle kilometers) per operator hour, or passenger miles (passenger kilometers) per unit cost of operation.

Program, National Cooperative Highway Research — see *National Cooperative Highway Research Program* and *National Cooperative Transit Research and Development Program.*

Program, Research, Development, and Demonstration — see *Research, Development, and Demonstration Program.*

Program, Service and Methods Demonstration — see *Service and Methods Demonstration Program.*

programmed braking — see *braking, programmed.*

progression, automatic — see *automatic progression.*

progression, signal — coordination of a set of traffic signals such that vehicles moving down a street receive green signal indications at several traffic signals in a row.

proof-of-payment — see *fare collection system, proof of payment.*

property (operation, operator, system) — in the transit industry, a public transit agency or a private transit company with responsibility for transportation services such as bus, ferry, rail; see also *transit district.*

propulsion, ferry — the process of driving or propelling by way of a machine consisting of a power-driven shaft with radiating blades, placed so as to thrust air or water in a desired direction when spinning.

propulsion system — the motors, driving mechanism, controls, and other devices that propel a vehicle, frequently assumes electric operation.

propulsion system, dual-power — a propulsion system that is capable of operation from two different types of power sources, for example, an internal combustion engine and electricity.

protection, train — see *automatic train protection.*

proximity card — see *smart card.*

public automobile service system — see *transportation system, public automobile service.*

Public Service or Utilities Commission — see *organizations, Public Utilities Commission.*

public service vehicle — see *vehicle, public service.*

public transit — passenger transportation service, usually local in scope, that is available to any person who pays a prescribed fare. It operates on established schedules along designated routes or lines with specific stops and is designed to move relatively large numbers of people at one time. Examples include bus, light rail, rapid transit.

public transit agency — see *property, transit district.*

public transportation — transportation service to the public on a regular basis using vehicles that transport more than one person for compensation, usually but not exclusively over a set route or routes from one fixed point to another. Routes and schedules of this service may be predetermined by the operator or may be determined through a cooperative arrangement. Subcategories include public transit service and paratransit services that are available to the general public.

public transportation, urban — see *urban public transportation.*

public transportation disability — see *persons with disabilities.*

Public Transportation Management — National ITS Program User Service that automates operations, planning, and management functions of public transit systems.

Public Travel Security — National ITS Program User Service that creates a secure environment for public transportation patrons and operators.

public way — any public street, road, boulevard, alley, lane, or highway, including those portions of any public place that have been designated for use by pedestrians, bicycles, and motor vehicles.

publicly owned transit system — see *transit system, publicly owned.*

público — In Puerto Rico, a transit mode consisting of passenger vans or class C buses operating with fixed routes but no fixed schedules. Públicos are a privately owned and operated mass transit service that is market-oriented and unsubsidized but regulated through a public service commission, state, or local government. Públicos are operated under franchise agreements, fares are regulated by route, and there are special insurance requirements. Vehicle capacity varies from 8 to 24, and the vehicles may be owned or leased by the operator.

puller — an articulated bus with the center axle powered.

purpose, trip — see *trip purpose.*

push-pull train — see *train, push-pull.*

push-through — a bus-operating technique used in busy peak-hour street operations when heavy passenger loads can combine with general road traffic delays to create bunching. A push-through is an unscheduled bus that is held at a key point to be inserted by an inspector or street supervisor into a route when a serious gap occurs. It is used to prevent worsening of service.

pusher — an articulated bus with the rear axle powered.

Q

quadrant analysis — method of evaluating customer satisfaction survey results in which the customer-rated importance of an attribute is plotted against the customer-rated satisfaction with that attribute.

quality, ride — see *ride quality.*

quality, service — see *level of service.*

quality control — the system of collection, analysis, and interpretation of measurements and other data concerning prescribed characteristics of a material, process, or product, for determining the degree of conformance with specified requirements.

quality of service — the overall measured or perceived quality of transportation service from the user's or passenger's point of view, rather than from the operating agency's point of view. Defined for transit systems, route segments, and stops by *level of service*.

queue — A line of vehicles or people waiting to be served by the system in which the rate of flow from the front of the line determines the average speed within the line. Slowly moving vehicles or people joining the rear of the queue are usually considered a part of the queue.

queue jump(er) — **1.** a short section of exclusive or preferential lane that enables specified vehicles to bypass an automobile queue or a congested section of traffic. A queue jumper is often used at signal-controlled freeway on-ramps in congested urban areas to allow high-occupancy vehicles preference. It is also known as a *bypass lane* or *queue bypass.* **2.** a person who violates passenger controls.

R

RDC — rail diesel car; see *car, rail diesel.*

ROW — right-of-way.

RPA — regional planning agency; see *organizations, regional planning agency.*

RRIS — Railroad Research Information Service.

rack railway — see *cog railway.*

radial network — see *network, radial.*

rail, contact — see *rail, third.*

rail, continuous welded (CWR) — a number of standard length rails welded together into a single length of 400 ft or more (120 m or more). It provides a smoother running surface and ride than jointed rail.

rail, girder — rail with a built in flange groove used on streetcar and light rail lines that are laid in-street where other motor vehicles must travel.

rail, power — see *rail, third.*

rail, running — a rail that supports and guides the flanged wheels of the rail vehicle.

rail, standard — a 39-ft (11.89-m) section of rail.

rail, third (contact rail, power rail) — an electric conductor, located alongside the running rail, from which power is collected by means of a sliding shoe attached to the truck of electric rail cars or locomotives. Traditionally made of mild steel, composite rail, often aluminum with a stainless steel cover, is appearing on some new systems.

rail, welded — two or more rails welded together at their ends to form a length less than 400 ft (120 m); see also *rail, continuous welded.*

railbus — a light, self-propelled rail vehicle with a body resembling that of a bus or using bus components, two-axle versions are noted for poor ride quality.

rail car, electric — see *car, electric rail.*

rail car, type — see *car, type designations.*

rail car, urban — see *car, urban rail.*

rail car, weight — see *car, weight designations.*

rail diesel car — see *car, rail diesel.*

rail motor car — see *car, rail motor.*

rail rapid transit — see *transit system, rail rapid.*

rail rapid transit car — see *car, rail rapid transit.*

railroad, commuter — see *transit system, commuter rail.*

railroad grade crossing — see *crossing, railroad grade.*

Railroad Research Information Service (RRIS) — a computer-based information storage and retrieval system developed by the Transportation Research Board with financial support from the Federal Railroad Administration. It consists of summaries of research projects in progress and abstracts of published works.

railroad tie — see *crosstie.*

rail transit system — see *transit system, rail.*

rail transport, conventional — see *conventional rail transport.*

rail vehicle, articulated — see *articulated rail vehicle.*

railway — alternate term for railroad, especially Canadian and British.

railway, cog — see *cog railway.*

railway, funicular — see *funicular railway.*

railway, inclined plane (incline) — see *inclined plane.*

railway, metropolitan — see *transit system, rail rapid.*

railway, rack — see *cog railway.*

railway, street — old term for streetcar system, see *transit system, streetcar.*

railway crossing — see *crossing, track.*

railway electrification — see *electrification.*

ramp, moving — an inclined moving walkway.

ramp, meter bypass lane — see *lane, ramp meter bypass.*

ramp metering — **1.** the process of facilitating traffic flow on freeways by regulating the amount of traffic entering the freeway through the use of control devices on entrance ramps. **2.** the procedure of equipping a freeway approach ramp with a metering device and traffic signal that allow the vehicles to enter the freeway at a predetermined rate.

rapid bus— see *transit system, bus rapid.*

rapid, the — see *transit system, rail rapid.*

rapid rail transit — see *transit system, rail rapid.*

rapid transit— generic term introduced in the 1890s to denote any transit that was faster than its predecessor , most particularly for the replacement of horsecars with electric streetcars, now generally used for rail systems on exclusive right-of-way, i.e., heavy rail or metro. See adjacent listings and specific entries under *transit systems.*

rapid transit car — see *car, rail rapid transit.*

rapid transit operator — see *operator, rapid transit.*

rapid transit system — see *rapid transit* and specific entries under *transit systems: bus rapid, group rapid, light rail rapid, personal rapid, rail rapid, rapid.*

rate of flow — see flow *rate.*

ratio, cost recovery — see *cost recovery ratio.*

ratio, fare or farebox recovery — see *fare recovery ratio.*

ratio, operating — see *operating ratio.*

ratio, peak/base or peak/off-peak — see *peak/base ratio.*

ratio, power-to-weight — see *power-to-weight ratio*.

ratio, travel time — see *travel time ratio.*

reader, farecard — see *farecard reader.*

recovery ratio — see *cost recovery ratio* and *fare recovery ratio.*

recovery time — see *time, layover.*

rectifier station — see *electric sub-station.*

reduced fare — see *fare, reduced.*

re-entry delay — see *delay, re-entry.*

reference speed — see *speed, reference*.

refuge, pedestrian — see *pedestrian refuge.*

regenerative brake — see *brake, regenerative.*

regional planning agency — see *organizations, regional planning agency.*

regional rail service — see *service, regional rail.*

regional transit service — see *service, regional transit.*

register or registering farebox — see *farebox, registering.*

regular fare — see *fare, base.*

relationship, speed-flow — see *speed-flow relationship.*

relay, track — see *track relay.*

relay time — see *time, layover.*

reliability — how often transit service is provided as promised; affects waiting time, consistency of passenger arrivals from day to day, total trip time, and loading levels.

request stop —see *service, request stop.*

reroute — to divert to a route other than the scheduled route, usually with preplanning and for a longer period than that for a detour.

research information service — see *Highway Research Information Service, Railroad Research Information Service, Transportation Research Information Services,* and *Urban Mass Transportation Research Information Service.*

research program — see *National Cooperative Highway Research Program, National Cooperative Transit Research and Development Program,* and *Transit Cooperative Research Program.*

reserved transit lane — see *lane, exclusive transit.*

response time — see *time, response.*

retardation — see *deceleration.*

revenue, farebox — the passenger payments for rides, including cash, farecards, tickets, tokens, pass receipts, and transfer and zone charges but excluding charter revenue.

revenue, non-transportation (other) — revenue earned by activities not associated with the provision of the system's transit service, for example, sales of maintenance services, rental of vehicles and buildings, non-transit parking lots, sale of advertising space, and investment income.

revenue, total operating — the sum of regular passenger revenue, charter revenue, and other miscellaneous revenues, such as those from advertising or concessions.

revenue miles (revenue kilometers) — miles (kilometers) operated by vehicles available for passenger service.

revenue passenger — see *passenger, revenue.*

revenue passenger trips — the number of fare-paying transit passengers with each person counted once per trip; excludes transfer and non-revenue trips.

revenue seat mile (revenue seat kilometer) — the movement of one transit passenger seat over 1 mile (km). In other words, the total number of revenue seat miles (kilometers) for a vehicle is obtained by multiplying the number of revenue seats in the vehicle by the number of revenue miles (kilometers) traveled.

revenue service — see *service, revenue.*

revenue track miles or kilometers — see *track miles, revenue.*

revenue vehicle — see *vehicle, revenue.*

revenue vehicle miles (revenue vehicle kilometers, paid miles or kilometers) — the distance in miles (kilometers) that a revenue vehicle is operated while it is available for passenger service.

reverse commute — see *commute, reverse.*

reverse move — the forward movement of a train going against the normal direction of traffic.

reversible bus lane — see *lane, reversible bus.*

reversible lane — see *lane, reversible.*

ride, check — see *check ride.*

Ride Matching and Reservation — National ITS Program User Service that makes ride sharing easier and more convenient.

ride, one-zone — see *one-zone ride.*

ride, shared — see *shared ride.*

ride quality — a measure of the comfort level experienced by a passenger in a moving vehicle, including the vibration intensity and frequency, accelerations (longitudinal, transverse, and vertical), jerk, pitch, yaw, and roll.

rider — 1. a passenger on any revenue service vehicle; also known as a *patron.* **2.** In government reporting, someone making an unlinked trip.

rider, captive — a person limited by circumstances to use one mode of transportation; see also *transit dependent* and *transportation disadvantaged.*

rider, captive transit — a person who does not have a private vehicle available or cannot drive (for any reason) and who must use transit to make the desired trip; see also *transit dependent* and *transportation disadvantaged.*

rider, choice — a person who has at least two modes of travel available and selects one to use.

riders, group — riders who have a common origin and destination or some demographic variable in common and travel together in the same vehicle.

ridership (patronage) — the number of people making one way trips on a public transportation system in a given time period.

ridesharing — a form of transportation, other than public transit, in which more than one person shares in the use of the vehicle, such as a bus, van, or automobile, to make a trip.

riding check or count, passenger — see *check.*

riding frequency coefficient (riding habit coefficient) — the number of passenger trips during a designated time period divided by the resident population of the area served, such as transit trips per capita per year.

right-of-way (ROW) — 1. a general term denoting land, property, or interest therein, usually in a strip, acquired for or devoted to transportation purposes. For transit, rights-of-way may be categorized by degree of their separation: fully controlled without grade crossings, also known as *grade-separated, exclusive,* or *private ROW;* longitudinally physically separated from other traffic (by curbs, barriers, grade separation, etc.) but with grade crossings; or surface streets with mixed traffic, although transit may have preferential treatment. **2.** the precedence accorded to one vehicle or person over another.

right-of-way, controlled access — lanes restricted for at least a portion of the day for use by transit vehicles and/or other high-occupancy vehicles. Use

of controlled access lanes may also be permitted for vehicles preparing to turn. The restriction must be sufficiently enforced so that 95% of vehicles using the lanes during the restricted period are authorized to use them.

right-of-way, exclusive — roadway or other right-of-way reserved at all times for transit use and/or other high occupancy vehicles.

right-of-way, exclusive transit — a right-of-way that is fully grade separated or access controlled and is used exclusively by transit.

right-of-way, segregated — roadway or right-of-way reserved for transit use, but which permits other modes to cross the right-of-way at defined locations such as grade crossings.

right-of-way, shared — roadway or right-of-way that permits other traffic to mix with transit vehicles, as is the case with most streetcar and bus lines.

right-of-way miles (right-of-way kilometers, first-track miles or kilometers) — the length of right-of-way occupied by one or more lanes or tracks; see also *route miles.*

road — see *highway, street, or road.*

road, collector — see *street, collector-distributor.*

roadbed — 1. in railroad construction, the foundation on which the ballast and track rest. **2.** in highway construction, the graded portion of a highway within top and side slopes, prepared as a foundation for the pavement structure and shoulder.

road call — a mechanical failure of a bus in revenue service that necessitates removing the bus from service until repairs are made.

road miles (road kilometers) — linear miles (kilometers) of highway as measured along the centerline of the right-of-way.

road supervisor — see *inspector.*

roadway — that portion of a highway built, designed, or ordinarily used for vehicular travel, except the berm or shoulder. If a highway includes two or more separate roadways, the term means any such roadway separately but not all such roadways collectively.

rolling stock — see *fleet.*

rolling stock capacity — see *capacity, fleet.*

rope — in ropeways, the term rope means wire rope, which consists of several strands twisted together. The terms rope, wire rope, and cable are interchangeable except where, by the context, the general term cable refers to either a wire rope or strand used as a track cable.

ropeway — includes all devices that carry, pull, or push along a level or inclined path (excluding elevators) by means of a haul rope or other flexible element that is driven by a power unit remaining essentially at a single location. See *aerial lift*, *aerial tramway*, *cableway*, *funicular railway*, *inclined plane*, and *surface lift.*

ropeway, continuously circulating — a ropeway providing multiple carriers, cars, or trains that move around a route forming a loop. Examples include *aerial lifts* (*gondolas*), *cable cars,* and *cable-hauled automated people movers.*

ropeway, reversible — a ropeway that operates in a back-and-forth, shuttle manner. Usually operates with two carriers, but sometimes only one. Examples include *inclined planes* and *aerial tramways.*

round trip — see *trip, round.*

route — 1. the geographical path followed by a vehicle or traveler from start to finish of a given trip. **2.** a designated, specified path to which a transit unit (vehicle or train) is assigned. Several routes may traverse a single portion of road or line. **3.** in traffic assignments, a continuous group of links that connects two centroids, normally the path that requires the minimum time to traverse. **4.** in rail operations, a determined succession of contiguous blocks between two controlled interlocked signals.

route deviation service — see *service, route deviation.*

Route Guidance — National ITS Program User Service that provides travelers with simple instructions on how to best reach their destinations.

route miles (route kilometers) — various definitions exist for this statistic: **1.** one-way duplicating is total mileage (kilometers) of routes, where the roadway or guideway segments of each individual route are summed up in one direction. For example, a 1-mile (km) segment over which buses operate in both directions would be reported as 2 miles (km); also known as *directional route miles* (kilometers) or *miles (kilometers) of roadway or route*. **2.** one-way non-duplicating is total mileage (kilometers) of routes, where a particular roadway or guideway segment is only counted once regardless of number of routes or direction of travel on that segment; also known as *line miles (kilometers)* or *miles (kilometers) of directional roadway. 3.* two-way mileage (kilometers) is total mileage (kilometers) of each route covered from start to finish. No attention is given to direction of routes or number of routes using any particular segment of roadway or guideway.

route segments, flexible —predominantly fixed-route service but converts to demand-responsive transit for a limited and defined portion of the route.

route structure — **1.** a network of transit routes. **2.** the pattern of transit routes, for example, grid, radial. See *network.*

route supervisor — see *inspector.*

routing, dynamic — see *dynamic routing.*

routing, through — see *through routing.*

rule — in rail operations, a law or order authoritatively governing conduct or action.

ruling headway — see *headway, ruling.*

run — 1. the movement of a transit unit (vehicle or train) in one direction from the beginning of a route to the end of it; also known as a *trip.* **2.** an operator's assignment of trips for a day of operation; also known as a *work run.*

run, bus — the daily assignment of a bus, numbered and listed in a master schedule. Each vehicle displays its bus run number.

run, owl — a run that operates during the late night through early morning hours; most commonly, midnight to 0400h or the start of the next day's service. Some systems designate hours after midnight, when operated by vehicles starting the previous day, as 2500h, 2600h and so on.

run cutting — the process of organizing all scheduled trips operated by the transit system into runs for the assignment of operating personnel and vehicles.

run number — a two- or three-digit number displayed on a hand set or flip-dot display in the lower windscreen displaying the run or schedule slot the vehicle is in; primarily used as information to inspectors, street supervisors, or checkers.

running gear — the vehicle parts whose functions are related to the movement of the vehicle, including the wheels, axles, bearings, and suspension system.

running hot (running sharp) — running ahead of schedule. Unacceptable practice on most systems.

running rail — see *rail, running.*

running speed — see *speed, running.*

running time — see *time, running.*

rush hour(s) — see *peak.*

SAFETEA-LU — Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users: see *legislation, Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (1995).*

SE — Single ended, rail or streetcar with driving position only at one end, requires loop to turn around at end of line.

SLT — shuttle-loop transit; see *transit system, shuttle-loop.*

SOV — single-occupant vehicle; see *vehicle, single-occupant.*

SU — single unit; see *car, single-unit.*

saddle monorail — see *transit system, monorail.*

safety distance — 1. minimum separation of trains with various control systems **2.** in a moving-block signaling system, the specific distance between the target point and the train or obstruction ahead. See *control system.*

safety island — see *boarding island.*

scatter service — see *service, one-to-many.*

schedule — 1. a listing or diagrammatic presentation in time sequence of every trip and every time point of each trip, from start to finish of service, on a transit line or route. **2.** in transit or railroad operations, a published table of departure or arrival times (or both) for arranged service over a transit line or route or a specific section of railroad; see also *timetable.*

schedule check — see *check.*

schedule checker — see *checker.*

schedule recovery time — see *time, layover.*

schedule speed — see *speed, schedule.*

scheduling — in transit operations, the process of preparing the operating plan (schedule) for a transit line or network on the basis of passenger demand, policy or level of service, and operating elements (travel times, etc.).

school bus — see *bus, school.*

school bus service — see *service, school bus.*

scratch ticket — a ticket on which the user can scratch overprinting off to indicate, zone, and/or month, day (and time) of validity. Commonly used on day passes.

seating or seated capacity — see capacity, seating.

seating, 2+1 — ("two-by-one") transverse seating arrangement providing three seats per row, two on one side of the aisle and one on the other side of the aisle.

seating, 2+2 — transverse seating arrangement providing four seats per row, two on each side of the aisle.

seating, 2+3 — transverse seating arrangement providing five seats per row, two on one side of the aisle and three on the other side of the aisle; not popular with passengers. This seating arrangement constrains aisle width, which may make the provision of wheelchair access difficult.

seating, longitudinal — seats that are placed parallel to the sides of a transit vehicle, so that passengers sit sideways relative to the direction of travel. This seating arrangement increases the aisle width, allowing more standing room, but may be less comfortable for seated passengers.

seating, transverse — seats that are placed perpendicular to the sides of a transit vehicle, so that passengers face forward or backward relative to the direction of travel. This seating arrangement is often used when it is desired for most passengers to have a seat, although it is also possible to have single transverse seats on either side of the vehicle, with a wide aisle in between.

seat mile, revenue — see *revenue seat mile.*

section — for sections of legislation, see *legislation* entries.

section, block — see *block.*

section, extra — see *extra section.*

section, maximum load — see *maximum load section.*

self-propelled locomotive — see *locomotive, self-propelled.*

self-propelled or self-powered car — see *car, rail motor.*

self-service, barrier-free fare collection system — see *fare collection system, open, barrier-free, proof of payment, self-service.*

semi-exclusive transitway — see *transitway.*

semi-metro system — see *transit system, semi-metro.*

sensor, induction loop — see *induction loop sensor.*

separation, grade — see *grade separation.*

separation, track — see *track separation.*

separation, train — see *train separation.*

series, time — see *time series.*

series-wound motor — see *motor, series-wound.*

service, arterial — generally major (long or heavily patronized) transit routes that operate on principal or major surface arterial streets.

service, base-period — the level of transit operations during the base period.

service, bus rapid transit — see *transit system, bus rapid transit.*

service, circulator — bus service confined to a specific locale, such as a downtown area or a suburban neighborhood, with connections to major traffic corridors.

service, city transit — transit serving an urban area, as distinguished from short-haul and regional transit service.

service, community — short feeder or loop route serving a local community, often operated with smaller buses.

service, commuter — transportation provided on a regularly scheduled basis during peak-travel periods for users commuting to work, school, and similar destinations.

service, crosstown — non-radial transit service that does not enter the central business district.

service, demand jitney — see *service, jitney.*

service, door-to-door — a service that picks up passengers at the door of their place of origin and delivers them to the door of their place of destination. This service may necessitate passenger assistance between the vehicle and the doors. See also *service, curb-to-curb.*

service, express — service that has fewer stops and a higher operating speed than regular service. Often used an alternative term for *limited-stop service*; when agencies provide both types of service, the express service tends to have much longer sections of non-stop running.

service, express bus — bus service with a limited number of stops, either from a collector area directly to a specific destination or in a particular corridor with stops en route at major transfer points or activity centers. Express bus service usually uses freeways or busways where they are available.

service, feeder — 1. local transportation service that provides passengers with connections with a major transportation service. **2.** local transit service that provides passengers with connections to main-line arterial service; an express transit service station; a rail rapid transit, commuter rail, or intercity rail station; or an express bus stop or terminal, see also *service, community.*

service, few-to-few — a service that picks up passengers at a limited number of origins and delivers them to a limited number of destinations.

service, few-to-many — a service that picks up passengers at a few pre-selected origins, typically activity centers or transfer points, and delivers them to many destinations.

service, flag stop — l. in paratransit operations, a service accessed by hail. **2.** in rail operations, a nonscheduled stop that may be served if proper notice is given by a passenger or prospective passenger.

service, flexible-route — a variant of demand-responsive transportation service, sharing aspects of fixed-route service. Flexible-route vehicles operated along a regular route, with or without marked bus stops, and flex off that route to serve demand-response trips within a zone around the route. See also *service, route deviations.*

service, gather — see *service, many-to-one.*

service, human service transportation — shared-ride, advance-scheduled transportation for users and clients of human service programs; human service transportation is an ancillary service provided by many human service agencies so that their clients can access the agency's primary mission.

service, jitney — a route deviation service in which small or medium-sized vehicles, such as large automobiles, vans, or minibuses, are used. The vehicles are usually owned by the drivers and the service is often independently operated. However it is authorized or regulated and distinct from unofficial, and usually illegal, "jitney service" where often-uninsured private cars or vans solicit passengers — often running ahead of transit buses. See also *transportation system, jitney.*

service, level of — see *level of service.*

service, limited — l. a transit service that operates only during a certain period of the day, or that serves only specific stops (also known as *limited-stop service)* or in a specified area, or that serves only certain segments of the population. **2.** line service with some restrictions on boarding and alighting.

service, limited-stop — a bus service, often operated in conjunction with a local service, that does not serve every stop, providing a higher operating speed. It represents a middle ground between high-access, low-speed local service and low-access, higher-speed express service.

service, line haul — 1. transportation service along a single corridor, without branches, with

stops along the way. Usually service is intensive (high capacity) and may use exclusive right-of-way. **2.** may also be used to describe express service or even main-line service, as opposed to feeder service.

service, local — 1. transit service that involves frequent stops and consequent low average speeds, the purpose of which is to deliver and pick up transit passengers close to their destinations or origins. **2.** transit operation in which all transit units (vehicles or trains) stop at all stations. **3.** transit service in a city or its immediate vicinity, as distinguished from regional transit service or interurban lines.

service, local bus — a bus service that picks up and discharges passengers at frequent, designated places (stops) on city streets.

service, many-to-few — a service that picks up passengers at many different origins and delivers them to a few destinations.

service, many-to-many — a service that picks up passengers at many different origins and delivers them to many different destinations within the service area.

service, many-to-one (gather service) — a service that collects passengers from many origins and delivers them to a specific point, for example, an office building, train station, or bus stop.

service, one-to-many (scatter service) — a service that picks up passengers at one point of origin and delivers them to many destinations.

service, origin-to-destination — service in which the passenger-carrying vehicle will not stop along the way to pick up additional passengers.

service, owl — transit service provided late at night, usually from midnight to between 0300h and start of service the next day.

service, peak — service during peak periods.

service, point deviation — public transportation service in which the transit vehicle is required to arrive at designated transit stops in accordance with a prearranged schedule but is not given a specific route to follow between these stops. It allows the vehicle to provide curbside service for those who request it. May also be called checkpoint dial-a-ride. See also *point deviation.*

service, public automobile — see *transportation system, public automobile service.*

service, radial — service that connects the CBD with outlying areas.

service, regional rail — alternate term for commuter rail, specific to East Coast; see *transit system, commuter rail.*

service, regional transit — long bus or rail transit lines with few stations and high operating speeds. They primarily serve long trips within metropolitan regions, as distinguished from city transit service and local short-haul transit service.

service, request stop — transit service that is predominantly traditional fixed-route, fixed-schedule service but which also provides service to a limited number of defined stops close by the route at the request of a passenger.

service, research information — see *Railroad Research Information Service, Transportation Research Information Services,* and *Urban Mass Transportation Research Information Service.*

service, revenue — 1. transit service excluding deadheading or layovers. **2.** any service scheduled for passenger trips.

service, route deviation — public transportation service on an exclusive basis that operates along a public way on a fixed route (but not a fixed schedule). The vehicle may deviate from the route occasionally in response to demand for service or to take a passenger to a destination, after which it returns to its route. It is a form of demand-responsive transit. See also *service, flexible-route.*

service, scatter — see *service, one-to-many.*

service, school bus — service designed to transport children to or from any regularly conducted public or private school or school-related activities, either on an exclusive or nonexclusive basis.

service, shoppers' special — service provided during off-peak hours that is designed to carry passengers to or from shopping areas.

service, short-haul transit — low-speed transit service for circulation within small areas that usually have high travel density, such as central business districts, campuses, airports, exhibition grounds, and other major activity centers.

service, shuttle — 1. service provided by vehicles that travel back and forth over a particular route, especially a short one, or one that connects two transportation systems or centers, or one that acts as a feeder to a longer route. Shuttle services usually offer frequent service, often without a published timetable. **2.** for rail and other guideway systems, a service in which a single vehicle or train operates on a short line, reversing direction at each terminal.

service, skip-stop — service in which alternate transit units (vehicles or trains) stop at alternate sets of stations on the same route. Each set consists of some joint and some alternate stations.

service, subscription bus — l. a bus service in which routes and schedules are prearranged to meet the travel needs of riders who sign up for the service in advance. The level of service is generally higher than that of regular passenger service (fewer stops, shorter travel time, and greater comfort), and the buses are usually obtained through charter or contractual arrangements. **2.** commuter bus express service operated for a guaranteed number of patrons from a given area on a prepaid, reserved seat basis. Subscription buses are often arranged for and partly subsidized by an employer to serve a specific work location.

service, subscription van — service similar to that provided by a subscription bus, except that the van

may be privately owned, leased from a public or private company, or provided by the employer. The driver is usually a member of the group.

service, subsidized taxi — a taxicab service in which the fares are lower than actual taxi fares and the taxi company is reimbursed the difference. The service may be provided to the general public or to special groups, such as elderly people. Funds for the subsidy can come from a variety of sources, including local taxes or social service agency program funds. Often an economical way to provide better off-peak service in low-density areas that cannot support fixed routes.

service, taxicab (exclusive-ride taxi, taxi service) — demand-responsive public transportation service on an exclusive-ride basis, in a vehicle licensed to render that service; see also *shared ride* and *service, subsidized taxi.*

service application — see *braking, service.*

service area — see *area, service.*

service attributes — those aspects of a transportation system that affect travel decisions about its use, such as travel time, reliability, comfort (e.g., crowding, standees), cost, ease of use, and safety.

service brake — see *brake, service.*

service braking — see *braking, service;* and *braking, maximum service.*

service coverage — see *area, coverage*

service denial — circumstance in which a demand-responsive transportation trip cannot be provided at the passenger's requested time, even though service is operated at that time.

service frequency — the number of transit units (vehicles or trains) on a given route or line, moving in the same direction, that pass a given point within a specified interval of time, usually 1 hour; see also *headway.*

service information — see *user information.*

service measure, transit — 1. a quantitative performance measure that best describes a particular aspect of transit service and represents the passenger's point of view. **2.** a transit performance measure for which transit levels of service are defined, referred to in the *Highway Capacity Manual* as a *measure of effectiveness.*

service performance or quality — see definition of *level of service.*

service span — see *hours of service.*

service track miles (kilometers) — see *track miles, service.*

service volume — the maximum number of vehicles that can pass a given point during a specified period while a specified level of service is maintained.

set-back crewing — see *fall-back crewing.*

share, market — see *market share.*

shared ride — a trip, other than by conventional public transit, on which the passengers enter at one or more points of origin and disembark at one or more destinations and for which each passenger is charged an individual fare. Is contrasted to an exclusive-ride trip. Shared-ride taxi service is a way of using taxicabs for paratransit.

sharp, running — see *running hot.*

sheaves — pulleys or wheels grooved for rope.

shedding, load — see *load shedding.*

shelter — see *transit shelter.*

shoe, brake — see *brake shoe.*

shoe, overhead contact — see *overhead contact shoe.*

shoe, third-rail — see *third-rail shoe.*

shoe, trolley — see *overhead contact shoe.*

shoofly — a temporary track to allow rail operations to bypass construction activities.

shop — see *workshop.*

shoppers' special service — see *service, shoppers' special.*

short-haul transit service — see *service, short-haul transit.*

short turn — see *turn back.*

shunt — in rail operations, to shift or switch, as a train car; also the railroad switch itself.

shunt motor — see *motor, shunt.*

shuttle-loop transit — see *transit system, shuttle-loop.*

shuttle service — see *service, shuttle.*

shuttle system — see *transit system, shuttle.*

side platform — see *platform, side.*

side track — see *siding.*

sidewalk, moving — see *moving walkway.*

siding (passing track, side track) — a track adjacent to a main or a secondary track, for meeting, passing, or storing cars or trains, see also *pocket track*.

sign, dash — see *dash sign.*

sign, destination — see *destination sign.*

sign, dot matrix — a type of destination, dash, side, or rear sign consisting of electrically actuated dots that present either a matte black or bright (usually fluorescent yellow) face that make up individual letters or numbers. Early designs had very poor visibility and reliability, but improvements and the ability to display upper and lower case and double lines, have made the signs acceptable. Versions with back-lit liquid crystal displays or high intensity light emitting diodes were introduced in late 1990s. Favored for the ease with which signs can be reprogrammed and buses transferred from garage to garage, but this flexibility is often abused by alternating unnecessary messages, such as HAVE A GOOD DAY, that can confuse potential passengers.

sign, head — see *head sign.*

signal, automatic — a signal that is controlled automatically by certain conditions of the track section that it protects.

signal, automatic-block — a system in which signals are actuated automatically by the presence of a train on the track section, usually with an electric track circuit to detect the presence of any vehicle, and any broken rails.

signal, block — a fixed signal installed at the entrance of a block to govern trains entering and using that section of track.

signal, cab — see *control system, cab signal.*

signal, fixed — in rail operations, a signal at a fixed location that indicates a condition that affects the movement of a train.

signal, grade crossing protection — a railroad crossing flashing light signal or automatic gate actuated by the approach of a train at a grade crossing.

signal, wayside — in rail operations, a fixed signal that is located along the track right-of-way.

signal, traffic — see *traffic signal.*

signal-actuating device — see *pedestrian signal-actuating device* and *vehicle signal-actuating device.*

signal aspect — **1.** the appearance of a fixed signal conveying an indication, as viewed from the direction of an approaching rail unit. **2.** the appearance of a cab signal conveying an indication, as viewed by an observer in the cab of a rail unit.

signal block — see *block.*

signal indication — the information conveyed by a signal.

signal preemption — in highway operations, an automatic or manual device for altering the normal signal phasing or the sequence of a traffic signal to provide preferential treatment for specific types of vehicles, such as buses or trains.

signal progression — see *progression, signal.*

simple catenary — see *catenary system.*

single-occupant vehicle (SOV) — see *vehicle, single-occupant.*

single-track operation — the bidirectional operation of trains on a single track, with opposite directions served alternately. Single-track operation can be a permanent feature of a line or be in use on a temporary basis due to track maintenance or other reasons.

single-unit car — see *car, single-unit.*

ski lift — a continuously circulating *aerial lift* using chairs as carriers.

skip-stop service — see *service, skip-stop.*

slack time — see *operating margin.*

sleeper — **1.** an inert passenger who remains on a transit vehicle at end of run, often inebriated. **2.** a railroad tie; see *crosstie.*

slow order — a location where trains must temporarily travel more slowly than maximum authorized track speed for that location.

slug — **1.** a commuter, who, lacking membership in a carpool, regularly waits at designated pick-up points, hoping to catch a ride in a carpool vehicle with an unfilled seat. (particular to U.S. East Coast). See also *carpool, casual.* **2.** persons who, for a fee, will ride in a car so as to increase the occupancy to allow the car to use an HOV lane.

small bus — see *bus, small.*

smart card — stored-value ticket with built-in semiconductor chip. The chip is loaded with monetary value which is decremented for each ride, in flat amounts or, with exit checks, for distance-based fares. Early variants required insertion or contact with farebox or fare gate and were time consuming. Most versions in transit are proximity cards and require only to be held close to the farebox or fare gate inductive detector plate.

soft suspension — see *pendulum suspension.*

space — in the context of transportation vehicle capacity, a space is a seat or the standing area for one passenger, typically a seat consumes 5 ft^2 (0.5 m^2) of floor space and a standing passenger 2.5 ft^2 (0.25 m^2).

space, defensible — see *defensible space.*

spacing — the distance between consecutive vehicles, measured front to front.

special trackwork — see *trackwork, special.*

special work —term for both special trackwork and junctions on overhead electric collection systems.

specialized transportation — see *eligibility, limited.*

speed — see *velocity.*

speed, authorized — see *speed, reference.*

speed, average — see *velocity, effective.*

speed, cruise — see *velocity, cruise.*

speed, cycle — see *speed, overall trip.*

speed, effective operating — see *speed, overall trip.*

speed, line — the speed of the *haul rope* used on a ropeway system, measured in ft/s or m/s.

speed, operating — vague term with different interpretations, see *speed, running;* and *speed, schedule.*

speed, overall trip (effective operating speed, cycle speed) — in transit operations, the average speed achieved per round trip, including layover and recovery time but excluding deadheading time. It is calculated by individual trips, by running time periods, or for the entire schedule.

speed, reference — the maximum allowable speed for the block occupied by a train.

speed, running — the highest safe speed at which a vehicle is normally operated on a given roadway or guideway under prevailing traffic and environmental conditions; the speed between points, not including stopped time. In some areas, also known as *operating speed,* sometimes *civil speed.*

speed, schedule — the one-way distance between terminals divided by the scheduled travel time between the terminals; exclusive of layover or

recovery time, in some areas, also known as *operating speed.*

speed-flow relationship — the relationship between the flow (volume) of units on a transportation facility and the speed of those units. As flow increases, speed tends to decrease.

speed limit, civil — see *civil speed limit.*

spill-back — a situation that may occur in on-street light rail transit operations when trains or motor vehicles fail to clear a signalized intersection and so prevent the following train from entering that block. Particularly acute in downtown streets where the light rail train can be the full length of the block.

split, directional — see *directional split.*

split, modal or mode — see *modal split.*

spot time — see *time, layover.*

stable approach — relative to the passenger loading platform or vessel, the last non-floating structure, including land, that passengers access on their way to the vessel.

staging lot, vehicle — the area provided for vehicles waiting to load onto auto ferries.

standard gauge — see *gauge, standard.*

standard rail — see *rail, standard.*

Standard Railroad Grade Crossing — National ITS Architecture Market Package that manages highway traffic at *highway-rail intersections* where operational requirements do not dictate more advanced features (e.g., where rail speeds are greater than 80 mph or 128 km/h). Both passive (e.g., the crossbuck sign) and active warning systems (e.g., flashing lights and gates) are supported.

standard urban bus — see *bus, standard urban.*

standees — the number of standing passengers on a transit vehicle.

standing capacity — see *capacity, standing.*

station — 1. an off-street facility (typically) where passengers wait for, board, alight, or transfer between transit units (vehicles or trains). A station usually provides information and a waiting area and may have boarding and alighting platforms, ticket or farecard sales, fare collection, and other related facilities; also known as a *passenger station.* **2.** the location to which operating employees report and from which their work originates. **3.** in transportation planning, the location along a cordon line at which interviews are made. **4.** in railroad operations, a place designated in the timetable by name, at which a train may stop for traffic or to enter or leave the main track, or from which fixed signals are operated.

station, accessible — a public transportation passenger facility that provides ready access, is usable, and does not have physical barriers that prohibit and/or restrict access by individuals with disabilities, including individuals who use wheelchairs.

station, all-stop — in transit systems with skip-stop schedule or express service, a station that is served by all scheduled transit units (vehicles or trains).

station, cornfield — a transit station provided in a relatively undeveloped area, to allow for low-cost parking, to protect against future increases in land costs once the area develops, and/or to allow the planned development of transit-oriented uses around the station.

station, off-line — a station at which a transit unit (vehicle or train) stops outside the main track or travel lane so that other units can pass while passengers board and alight; found on a few automated guideway transit systems and busways.

station, on-line — a station in which transit units (vehicles or trains) stop on the main track or travel lane. This is the common design, and the term is used only to distinguish this station from off-line stations.

station, passenger — see *station.*

station accessibility — see *accessibility, station.*

station platform — see *platform, passenger.*

stepwell — on a high-floor transit vehicle, the recessed area next to a vehicle door where the stairs are located.

stinger — a portable cable to connect electric rail vehicles to traction power while in the workshop.

stock, rolling — see *fleet.*

stop, far-side — a transit stop located beyond an intersection. It requires that transit units (vehicles or trains) cross the intersection before stopping to serve passengers.

stop, mid-block — a transit stop located at a point away from intersections.

stop, near-side — a transit stop located on the approach side of an intersection. The transit units (vehicles or trains) stop to serve passengers before crossing the intersection.

stop, off-line — see *station, off-line.*

stop, on-line — see *station, on-line.*

stop, terminal — a transit stop located at either end of a transit route or line.

stop, transit — an area where passengers wait for, board, alight, and transfer between transit units (vehicles or trains). It is usually indicated by distinctive signs and by curb or pavement markings and may provide service information, shelter, seating, or any combination of these. Stops are often designated by the mode offering service, for example, bus stop, car stop.

stopped time — see *time, stopped.*

stored-value card— a magnetic striped or smart (electronic) farecard, purchased with a set monetary value, from which the cost of each trip is decremented, see also *fare collection system, automatic* and *smart card*.

street — see *highway, street,* or *road.*

street, bus-only — a street devoted to bus traffic only.

street, mixed-mode — a street carrying mixed traffic, that is, having no exclusive transit lanes or priority lanes for transit.

street, transit — a street reserved for transit vehicles only.

streetcar — an electrically powered rail car that is operated singly or in short trains in mixed traffic on track in city streets. In some areas, it is also known as a *trolley car* and, primarily in Europe, and in Australia, as a *tram*.

streetcar, heritage — an old streetcar or streetcar built to resemble an older vehicle, electrically operated on rail tracks, generally in downtown areas, for local distribution and tourists. Not to be confused with rubber-tired replica streetcars (see *bus, trolley replica*). Also known as a *vintage streetcar* or *vintage trolley.*

streetcar, vintage — see *streetcar, heritage.*

streetcar, low-floor — a streetcar with low floor for level boarding and exiting. Floor is typically 12-14 in. (300-350 mm) high requiring a platform or raised curb at this height. Wheelchair access is provided directly or by a hinged or removable bridge plate.

streetcar, partial low-floor — a low-floor streetcar with steps or ramps to access high-floor area(s) over trucks and/or any articulations. In this way conventional trucks and propulsion equipment can be used; sometimes termed *hybrid low-floor*.

streetcar operator — see *operator, train.*

streetcar, replica — see *bus, trolley replica.*

streetcar system — see *transit system, streetcar.*

street furniture — equipment placed on the street (off the vehicle lanes), such as lights, benches, signs, bus shelters, kiosks, and plants in containers.

street railway — early term for streetcar system. see *transit system, streetcar.*

street supervisor — see *inspector.*

strip, median — see *median.*

structure, aerial — see *aerial structure.*

structure, fare — see *fare structure.*

structure, route — see *route structure.*

stub terminal — see *terminal, stub.*

study, origin–destination — see *origin–destination study.*

subscription bus service — see *service, subscription bus.*

subscription van service — see *service, subscription van.*

subsidized taxi service — see *service, subsidized taxi.*

sub-station— see *electric sub-station*.

suburb — see definition of *area, urbanized.*

suburban coach or suburban transit bus — see *bus, suburban transit.*

subway — 1. that portion of a transportation facility or system that is constructed beneath the ground surface, regardless of its method of construction. **2.** an underground rail rapid transit system or the tunnel through which it runs. **3.** in local usage, sometimes used for the entire heavy rail or rapid transit system, even if it is not all beneath the ground surface.

subway car — see *car, rail rapid transit.*

superelevation — l. in track construction, the vertical distance that the outer rail is set above the inner rail on a curve, expressed as the vertical distance of the outer rail over the inner rail or as the transverse grade percent. Permits increased operating speed on curves, cannot exceed a maximum, typically 10%, to allow for trains that may stop or operate at below design speed on the curve. **2.** in highway construction, the banking of the roadway on a curve.

supervision, train — see *automatic train supervision.*

supervisor, road, route, or street — see *inspector.*

supported monorail — see *transit system, monorail.*

surface lift— a ropeway on which passengers are propelled by means of a circulating overhead wire rope while remaining in contact with the ground or snow surface. Connection between the passengers and the wire rope is by means of a device attached to, and circulating with, the haul rope, known as a "towing device."

survey, customer satisfaction — survey used to help transit operators identify the quality of service factors of greatest importance to customers; can identify areas and trends of existing passenger satisfaction and the degree to which particular factors influence customer satisfaction.

survey, passenger environment — survey in which trained checkers travel through the transit system and rate trip attributes (such as vehicle cleanliness and audibility of station announcements) to provide a quantitative evaluation of factors that passengers would think of qualitatively.

survey, travel — the collection of data that describes the social, economic, and travel characteristics of people who make trips by various modes of transportation.

suspended monorail — see *transit system, monorail.*

switch — 1. the movable rails of a turnout that divert the wheels of passing rolling stock from one track to either one of two branching from it. **2.** to move rail cars from one place to another within a defined territory, such as an industry, a yard, or a terminal.

switch, track — see *turnout.*

switch throw and lock time — see *time, switch throw and lock.*

symmetrical monorail — see *transit system, monorail.*

synchronous motor — see *motor, synchronous.*

synfuel or synthetic fuel — see *fuel, synthetic.*

system — see *operator* and *property.*

system, automated highway — see *automated highway system.*

system, automatic train control — see *automatic train control system.*

system, automatic train stop — see *automatic train stop system.*

system, automatic vehicle location — see *automatic vehicle location system.*

system, bus priority — see *bus priority system.*

system, catenary — see *catenary system.*

system, command and control — see *command and control system.*

system, control — see *control system.*

system, fare collection — see *fare collection system.*

system, honor — see *fare collection system, self-service, barrier free.*

system, performance measurement — see *performance measurement system.*

system, propulsion — see *propulsion system.*

system, transit — see *transit system.*

system, transportation — see *transportation system.*

system, trolley — see *transit system, streetcar.*

system effectiveness — system effectiveness is the probability that the system can successfully meet a proper operational demand within a prescribed acceptable time when operated under specified conditions.

system management, transportation — see *transportation system management.*

system performance — see definition of *level of service.*

system planning — in transportation, a procedure for developing an integrated means of providing adequate facilities for the movement of people and goods, involving regional analysis of transportation needs and the identification of transportation corridors involved.

system safety — the application of operating, technical, and management techniques and principles to the safety aspects of a system throughout its life to reduce hazards to the lowest level possible through the most effective use of available resources.

system safety engineering — the application of scientific and engineering principles during the design, development, manufacture, and operation of a system to meet or exceed established safety goals.

TCRP — Transit Cooperative Research Program.

TDM — transportation demand management.

TEA-21 — Transportation Efficiency Act for the 21st Century. See *legislation, TEA-21.*

TRB — Transportation Research Board; see *organizations, Transportation Research Board.*

TRIS — Transportation Research Information Services.

TSM — transportation system management.

TTS — timed transfer system.

TVM — ticket vending machine.

TWU — Transport Workers Union; see *union, transit.*

target point — a continually advancing or fixed stopping point in a moving-block signaling system at which a train must always be able to stop under the most adverse conditions , including partial braking failure. See *control system, moving-block.*

taxicab — a passenger automobile or a specially designed vehicle driven by a professional driver in a for-hire taxi.

taxicab service — see *service, taxicab.*

taxi service, subsidized — see *service, subsidized taxi.*

telecommuting — the substitution, either partially or completely, of transportation to a conventional office through the use of computer and telecommunications technologies (e.g., telephones, personal computers, modems, facsimile machines, electronic mail).

terminal — **1.** the end station or stop on a transit line or route, regardless of whether special facilities exist for reversing the vehicle or handling passengers; also known as a *terminus.* **2.** An assemblage of facilities provided by a railroad or intercity bus service at a terminus or at an intermediate location for the handling of passengers and the receiving, classifying, assembling, and dispatching of trains or dispatching of buses; also known as a *depot.*

terminal, off-street — a transit terminal or turnaround point for transit vehicles that is located away from other vehicular traffic.

terminal, stub — a dead-end terminal in which the entering rail (or other guided) transit unit must depart by the same guideway on which it entered. Because no loop is provided, a bi-directional transit unit (vehicle or train) is necessary.

terminal layout sheet — see *sheet, terminal layout.*

terminal stop — see *stop, terminal.*

terminal time — see *time, terminal.*

terminus — see *terminal.*

territory, train control — see *train control territory.*

theoretical line capacity — see *capacity, theoretical line.*

third rail — see *rail, third.*

third-rail shoe — a graphite sliding contact attached to the trucks of electric rail vehicles for the purpose of collecting current from the third-rail distribution system; uses gravity or spring pressure.

throughput — **1.** the volume of vehicles passing or people transported past a point or series of points during a given period of time. **2.** traffic.

through routing — the efficient practice of joining the ends of radial transit routes, with similar demand, to travel through downtown instead of having each route turn back in the downtown and return to its origin.

ticket — **1.** a printed card or piece of paper that gives a person a specific right to ride on a train or transit vehicle. **2.** to provide a ticket or tickets.

ticket, commutation — see *commutation ticket.*

tie — see *crosstie.*

time, access — the time elapsed on a trip from the moment of leaving the point of origin (e.g., home or work) to the moment of boarding a vehicle.

time, clearance — all time losses at a stop other than passenger dwell times. It can be viewed as the minimum time between one transit vehicle leaving a stop and the following vehicle entering, including any delay associated with waiting for a sufficient gap in traffic to allow a transit vehicle to reenter the travel lane.

time, clearing — the time it takes for the signal aspect or cab-signal code to return to its highest-speed signal aspect or code after the first train passes (typically on the order of 3 s), plus an allowance for the reaction time of the engineer or operator of the following train to recognize that the preceding signal has cleared (typically 3–4 s).

time, close-in — the minimum time from when a train starts to leave the most restrictive station until the following train can berth at that station (without speed restrictions or stops).

time, deadhead (not-in-service time) — time spent moving a revenue vehicle in non-revenue service.

time, delay — the amount of time by which a transit unit (vehicle or train) in service is delayed from its scheduled time.

time, dwell — the time a transit unit (vehicle or train) spends at a station or stop, measured as the interval between its stopping and starting.

time, egress — the time elapsed on a trip from the moment of alighting from a vehicle to the moment of arriving at the point of destination.

time, excess — time delay associated with travel to or between major transit routes, for example, time spent walking, waiting, or transferring.

time, layover (recovery time, relay time, spot time, turnaround time) — time built into a schedule between arrivals and departures, used for the recovery of delays and preparation for the return trip. The term may refer to transit units (also known as *vehicle layover)* or operators. Note that layover time may include recovery time and operator rest time as two specific components.

time, linked trip (overall travel time, total travel time) — in transportation planning, the time duration of a linked trip, that is, from the point of origin to the final destination, including waiting and walking time at transfer points and trip ends.

time, not-in-service — see *time, deadhead.*

time, operating — the actual time required for a transit unit (vehicle or train) to move from one point to another, including making stops.

time, overall travel — see *time, linked trip.*

time, passenger flow, passenger service — the average time a single passenger takes to pass through a transit vehicle doorway when boarding or alighting, includes any fare collection time.

time, platform — **1.** the time a transit unit is in revenue service **2.** the period during which an operator is charged with the operation or care of a transit unit (vehicle or train), including operating time in revenue service and deadhead, layover, and other time that the unit may be in operation but not in passenger service. **3.** the time the operator is actually on the assigned transit unit; also known as *work time.*

time, recovery — see *time, layover.*

time, response — in demand-responsive operations, the time between a passenger's request for service and the passenger pickup.

time, running — the actual time required for a transit unit (vehicle or train) to move from one point to another, excluding time for stops.

time, schedule recovery — see *time, layover.*

time, slack — see *operating margin.*

time, stopped — time on a trip spent stationary because of the stoppage of other traffic.

time, switch throw and lock — the time required for the *points* of a rail switch to move from being lined for one direction of travel to being lined for the alternative direction of travel, including any time needed for the points to be safely locked into the new position.

time, terminal — **1.** for passengers, the time required at the ends of trips to park and pick up their private vehicles, including any necessary walking time. **2.** for rail vehicles, the time allowed at a terminal between arrival and departure for turning vehicles, recovering delays, and preparing for the return trip. **3.** the time required for a passenger to pass through a terminal when there is a change of mode.

time, total travel — see *time, linked trip.*

time, transfer — the time required to effect a change of mode or to transfer between routes or lines of the same mode. In transportation modeling this time is weighted, typically by a factor of 1.5.

time, trip — see *time, linked trip;* and *time, unlinked trip.*

time, turnaround — see *time, layover.*

time, unlinked trip — in planning, the time duration of an unlinked trip, that is, one made on a single vehicle.

time, wait — the time spent waiting for a transit vehicle.

time, weighted — a measure of travel time where certain components (e.g., wait time) are factored upward, see also *time, transfer*.

time, work — see *time, platform.*

timed connection or transfer — see *transfer, timed.*

timed transfer focal point — see *hub*.

timed transfer system — a transit network consisting of one or more nodes (transit centers) and routes or lines radiating from them. The system is designed so that transit vehicles on all or most of the routes or lines are scheduled to arrive at a transit center simultaneously and depart a few minutes later; thus transfers among all the routes and lines involve virtually no waiting. Typically used in suburban areas and for night service where headways are long. Transit centers (also known as *timed transfer focal points or hubs)* are ideally located at major activity centers, see also *hub.*

time-of-day fare — see *fare, time-of-day.*

time-of-day pricing — see *pricing, time-of-day.*

time point (timepoint) — a point on a line or route for which the time that transit units (vehicles or trains) are scheduled to pass is specified; usually, the leaving time is used.

time window — a period of time during which a demand-responsive trip is scheduled to arrive, e.g., 9:45 to 10:15 am. If the vehicle arrives within that window, it is considered "on time." Time windows are used because the unpredictability of traffic and the shared-ride nature of DRT service make it difficult to predict the exact vehicle arrival time.

timetable — 1. usually refers to a printed schedule for the public. **2.** a listing of the times at which transit units (vehicles or trains) are due at specified time points; also known as a *schedule. **3.*** in railroad operations, the authority for the movement of regular trains subject to the rules. It contains classified schedules with special instructions for the movement of trains and locomotives.

token — 1. a pre-paid, non-monetary stamped piece used in payment for transit service, usually one trip, usually metal, sometimes plastic, sometimes with punched-out center or bi-metal to deter forgery. **2.** an object allowing a train operator possession of a single track section of line, handed-off to a signalman or the operator of the opposing train.

total bus mile equivalents — the number of vehicle miles that would have been operated by a transit mode if the service had been provided by motor buses. Based on average seating plus standing capacity of the vehicle as compared with the capacity including standees of a standard-size motorbus.

total operating revenue — see *revenue, total operating.*

total travel distance — see *distance, linked trip.*

total travel time — see *time, linked trip.*

total vehicle capacity — see *capacity, vehicle.*

towing device — a carrier, fixed or detachable, used on surface lifts and tows to pull passengers. Classification or description is by the device configuration and action of the extension element (i.e., handle, button, J-bar, T-bar, platter, etc.).

track — 1. an assembly of rails, supporting ties, and fastenings over which rail vehicles travel. **2.** a linear cam or way that physically guides (and usually supports) any matching vehicle used for transportation. **3.** the width of a wheeled vehicle from wheel to wheel, usually measured between the outsides of the rims. **4.** the distance between the centers of the tread of parallel wheels, as of an automobile.

track brake — see *brake, track.*

track cable — see *cable, track*.

track car — see *car, track.*

track circuit — an electrical circuit that makes use of both rails to detect train occupancy of the track and, in response, to actuate signals, train control devices, and grade-crossing protective equipment.

track crossing — see *crossing, track.*

track, double — a section of rail right-of-way where two parallel tracks are provided (i.e., four running rails).

track gauge — see *gauge, track.*

track, passing — see *siding.*

track, pocket — see *pocket track.*

track, side — see *siding.*

trackless trolley— trolleybus, mainly East Coast usage, see *trolleybus.*

track miles (track kilometers) — the sum of the one-way linear miles (kilometers) of all trackage in a system, including all main track and trackage in yards, car barns, switches, and turnouts.

track miles, revenue (revenue track kilometers) — the number of miles (kilometers) of track used in passenger-carrying service.

track miles, service (service track kilometers) — the number of miles (kilometers) of track used exclusively in non-revenue service.

track separation — the distance between tracks. Significant in calculating terminal layover time at turnbacks and junctions.

track special work — see *trackwork, special.*

track switch — see *turnout.*

track trip — a device that is located near the track and interconnected with the signal system so that it triggers the emergency brakes of any train that passes when the signal is red.

trackless trolley— trolleybus, mainly East Coast usage, see *trolleybus.*

trackwork — the rails, switches, frogs, crossings, fastenings, pads, ties, and ballast or track-support slab over which rail cars are operated.

trackwork, special (track special work) — all rails, track structures, and fittings, other than plain unguarded track, that is neither curved nor fabricated before laying.

traction — 1. colloquial term for all electric transit. **2.** grip of wheel on rail or tire on road.

traction motor — see *motor, traction.*

traction interlock, traction safety interlock — in rail transit, a series circuit of electrical switches at each door that prohibit a train from starting unless all passenger doors are closed and locked.

traction pole — pole, mast, or standard supporting electric overhead for streetcars and trolleybuses, sometimes other electric traction modes.

traction sub-station — see *electric sub-station.*

tractive effort (tractive force) — the force exerted by a locomotive or other powered vehicle on its driving wheels. It is equal to the weight on the driving wheels times the coefficient of adhesion.

trade union — see *union.*

traffic, annual average daily (AADT) — daily traffic that is averaged over a calendar or fiscal year.

traffic, annual average weekday (AAWDT) — daily traffic that is averaged over a calendar or fiscal year and that includes only weekdays (Mondays through Fridays). It may also exclude holidays.

traffic, average daily (ADT) — the average number of vehicles that pass a specified point during a 24-hour period.

traffic, mixed (mixed-flow traffic) — traffic that contains different vehicle categories or different modes.

traffic, passenger — see *passenger flow.*

traffic assignment — see *trip assignment.*

traffic checker — see *checker.*

traffic control device, grade crossing — see *grade-crossing traffic control device.*

traffic control system, centralized — see *control system, centralized traffic.*

traffic count — a record of the number of vehicles, people aboard vehicles, or both, that pass a given checkpoint during a given time period. It may be classified by type of vehicle. See also *count.*

traffic operations, mixed — see *mixed-traffic operations.*

traffic signal — a traffic control device that allocates time among conflicting traffic movements that seek to use the same space; uses combinations of green, yellow, and red indications.

trailer car — see *car, trailer.*

train — 1. two or more transit vehicles physically connected and operated as a unit; see also *transit unit.* **2.** one or more locomotives or self-propelled rail cars, with or without other cars, but with marker lights.

train, bad order — a train that is in need of repair.

train, local — a train that stops at every station on the line; see also *service, local.*

train, push-pull — a locomotive and a set of cars equipped with one or more cab cars from which the locomotive can be controlled. The train is either pulled and controlled from the locomotive in the conventional manner or pushed by the locomotive and controlled from the leading car.

train berth — in rail operations, the space designated for a train of given length to occupy when it is stopped at a station platform, in a terminal, on a transfer track, or at some other designated place.

train control — see *automatic train control system.*

train control system, manual — see *control system, manual train.*

train control territory — the portion of a railroad division or district that is equipped with an automatic train control system.

train density — 1. the number of trains that can be operated safely over a segment of railroad in each direction during a 24-hour period. **2.** the average number of trains that pass over a specified section of railroad in a specified period. In rail transit, usually expressed in trains per hour.

trainlined brake — see *brake, continuous.*

train operation — the way in which a train is operated, for example, automatic with automatic overspeed control, or manual with either automatic or manual speed control, or skip-stop.

train operation, automatic — see *automatic train operation.*

train operator — see *operator, train.*

train performance — see *performance, train.*

train protection, automatic — see *automatic train protection.*

train separation — in a train signaling system, the minimum distance between trains for a train to come to a complete stop, with a suitable safety margin between it and the train ahead.

train stop system, automatic — see *automatic train stop system.*

train supervision, automatic — see *automatic train supervision.*

tram — see *streetcar.*

tramway — see *transit system, streetcar.*

tramway, aerial — see *aerial tramway.*

transfer — l. a passenger's change from one transit unit (vehicle or train) or mode to another transit unit or mode. **2.** a slip of paper, card, or other instrument issued to passengers (either free or with a transfer fee) that gives the right to change from one transit unit or mode to another according to

certain rules that may limit the direction of travel or the time in which the change may be made.

transfer, free — a transfer that requires no additional payment.

transfer, paid — a transfer that requires an additional payment *(transfer fee),* either at the time of purchase or at the time of boarding another transit unit (vehicle or train).

transfer, paid area — a transfer in a controlled area, within which all patrons will have paid a fare, that allows boarding of transit units (vehicles or trains) through all doors, without fare inspection — most notably in Toronto.

transfer, timed — **1.** a transfer that is valid only for a specified time. **2.** the scheduling of intersecting transit routes so that they are due to arrive at a transfer point simultaneously, eliminating waiting time for transfer passengers; also known as a *timed connection.* See also *timed transfer system.*

transfer center — see *transit center.*

transfer facility, intermodal — see *transit center.*

transfer fee — see definition of *transfer, paid.*

transfer passenger — see *passenger, transfer.*

transfer penalty — a time value representing additional disutility associated with transferring between transit routes or services beyond passenger-perceived differences in transfer and in-vehicle time.

transfer surcharge — see *transfer, paid.*

transfer time — see *time, transfer.*

transit, mass or public — see *public transit.*

transit accessibility — see *accessibility, transit.*

transit agency or authority — see *transit district.*

transit bus — see *bus, standard urban;* and *bus, suburban transit.*

transit car — see *car, rail rapid transit.*

transit center — a transit stop or station at the meeting point of several routes or lines or of different modes of transportation. It is located on or off the street and is designed to handle the movement of transit units (vehicles or trains) and the boarding, alighting, and transferring of passengers between routes or lines (in which case it is also known as a *transfer center)* or different modes (also known as a *modal interchange center, intermodal transfer facility* or an *hub).*

Transit Cooperative Research Program — a major transit research program provided for in the Intermodal Surface Transportation Efficiency Act of 1991 and established by the Federal Transit Administration in 1992. The program is administered by the Transportation Research Board on behalf of the Federal Transit Administration and the American Public Transportation Association. The program emphasizes the distribution of research information for practical use.

transit dependent — having to rely on transit services instead of the private automobile to meet one's travel needs; see also *rider, captive; rider, captive transit;* and *transportation disadvantaged.*

transit district — a geographical or political division created specifically for the single purpose of providing transportation services. It is a separate legal entity and usually possesses the authority to impose a property tax. Transit agencies can directly operate transit service or contract out for all or part of the total transit service provided. Such political divisions may also be known as a *transit agency* or *transit authority;* see also *property.*

transit facilities, exclusive — see *exclusive transit facilities.*

Transit Fixed-Route Operations — National ITS Architecture Market Package that performs automatic driver assignment and monitoring, as well as vehicle routing and scheduling for fixed-route services.

transit lane, exclusive or reserved — see *lane, exclusive transit.*

Transit Maintenance — National ITS Architecture Market Package that supports automatic maintenance scheduling and monitoring.

transit mall — see *street, transit.*

transit mode — see *mode, transit.*

Transit Passenger and Fare Management — National ITS Architecture Market Package that allows for the management of passenger loading and fare payments on board vehicles using electronic means. The payment instrument may be either a stored value or credit card.

transit performance measure — a quantitative or qualitative factor used to evaluate a particular aspect of transit service. See *quality of service.*

transit priority measures — a blanket term for measures such as *busways, queue jumpers, signal preemption,* etc. that give transit vehicles priority over other road users.

Transit Security — National ITS Architecture Market Package that provides for the physical security of transit passengers. An onboard security system is deployed to perform surveillance and warn of potentially hazardous situations. Public areas (e.g., stops, park-and-ride lots, stations) are also monitored.

transit service measure — a quantitative performance measure that best describes a particular aspect of transit service and represents the passenger's point of view. See *quality of service.*

transit shelter — a building or other structure constructed at a transit stop. It may be designated by the mode offering service, for example, *bus shelter.* A transit shelter provides protection from the weather and may provide seating or schedule information or both for the convenience of waiting passengers.

transit stop — see *stop, transit.*

transit street — see *street, transit.*

transit-supportive area — see *area, transit-supportive.*

transit system — the facilities, equipment, personnel, and procedures needed to provide and maintain public transit service.

transit system, accessible — a transit system that can transport any mobile person, including those who are physically disabled, and in which the vehicles and stops or stations are designed to accommodate patrons who are confined to wheelchairs.

transit system, automated guideway (automated guideway transit, AGT) — A transportation system in which automated, driverless vehicles operate on fixed guideways with exclusive right-of-way.

transit system, bus rapid (bus rapid transit, BRT) — an inexact term describing a bus operation providing service similar to rail transit, at a lower cost. BRT systems are characterized by several of the following components: exclusive transitways, enhanced stations, easily identified vehicles, high-frequency all-day service, simple route structures, simplified fare collection, and ITS technologies. Integrating these components is intended to improve bus speed, reliability, and identity.

transit system, commuter rail — The portion of passenger railroad operations that carries passengers within urban areas, or between urban areas and their suburbs, but differs from rail rapid transit in that the passenger cars generally are heavier, the average trip lengths are usually longer, there are few standing passengers, and the operations are carried out over tracks that are part of the railroad system in the area. In some areas it is called *regional rail.*

transit system, diesel light rail (DLR) — A rail transit system similar to *light rail,* but with trains drawing power from diesel engines, rather than from overhead electric wires, and often using freight tracks for a portion of the route. DLR systems differ from commuter rail in that the vehicles used are not FRA-compliant in terms of crashworthiness, and therefore must be separated from freight operations in either space (separate trackage) or time (freight movements only allowed during times when the DLR system is not operating).

transit system, dual-mode — a broad category of systems wherein vehicles may be operated in both of two different types of operation or propulsion, for example, manually steered and guided, on highways and on guideways, or with diesel and electric traction.

transit system, fixed guideway — **1.** a transportation system composed of vehicles that can operate only on their own guideways, which were constructed for that purpose. Examples are heavy rail, light rail, and monorail. **2.** federal usage of the term in funding legislation also includes bus priority lanes, exclusive right-of-way bus operations, trolley coaches, and ferryboats as fixed guideway transit.

transit system, group rapid (GRT) — an automated guideway transit system that uses medium-sized vehicles operating automatically as single units or coupled trains on exclusive rights-of-way with special guideways. The vehicles are usually rubber tired and electrically propelled. The systems are sometimes referred to as *people mover systems* but the preferred term is *automated guideway transit.*

transit system, heavy rail — see *transit system, rail rapid.*

transit system, interurban — electric rail transit service between cities and towns, often running on-street within towns. Once common in North America, the Chicago, South Shore & South Bend is the only remaining system.

transit system, light rail (LRT) — as defined by the TRB Subcommittee on Light Rail Transit, "a metropolitan electric railway system characterized by its ability to operate single cars or short trains along exclusive rights-of-way at ground level, on aerial structures, in subways, or occasionally, in streets, and to board and discharge passengers at track or car floor level." Automated systems sharing some characteristics of heavy rail are often called *advanced light rail systems.* See also *transit system, diesel light rail.*

transit system, light rail, dual-mode — light rail transit with operation extended over railroad trackage that is shared with other trains. First examples in Karlsruhe and Saarbrucken, Germany, with cars equipped to operate at 750 volts DC and 15,000 volts AC.

transit system, light rail rapid — A Buffalo-only designation referring to a subway system with light rail type equipment and operation on a downtown mall.

transit system, major activity center (MAC system) — a transit system that provides service for short trips within small, densely populated major activity centers, such as shopping centers and downtown areas.

transit system, monorail — a transit system consisting of vehicles supported and guided by a single guideway (rail or beam), usually elevated. The basic types are *supported or straddle,* in which vehicles straddle the guideway or are laterally supported by it; and *suspended,* in which vehicles hang directly below the guideway *(symmetrical monorail)* or to one side of it *(asymmetrical monorail).*

transit system, personal rapid (PRT) — a theoretical concept for an automated guideway transit system that would operate small units (two to six passengers) under computer control over an elaborate system of guideways. Off-line stations would provide demand-responsive service (except, perhaps, during peak periods) with very short headways with travel between origin and destination stations without stopping. Only system

with some of these features is in Morgantown, West Virginia.

transit system, pre-metro — a light rail transit system designed with provisions for easy conversion to heavy rail (rail rapid transit).

transit system, publicly-owned — a transit system owned by any municipality, county, regional authority, state, or other governmental agency, including a system operated or managed by a private company under contract to the government agency owner.

transit system, rail — any of the family of transit modes with rail technology, see adjacent listings.

transit system, rail rapid (heavy rail, rapid rail) — a transit system using trains of high-performance, electrically powered rail cars operating in exclusive rights-of-way, usually without grade crossings, with high platform stations. The tracks may be in underground tunnels, on elevated structures, in open cuts, at surface level, or any combination thereof. Some local terms used are *elevated, the el, the "L," the rapid, the subway, metro*, (*for metropolitan railway), underground* (British), and *U-Bahn* (Untergrundbahn) and *Stadtbahn* (German). (Note that Stadtbahn is distinct from S-Bahn, which is generally a commuter-rail type operation.)

transit system, rapid — transit service that is operated completely separate from all other modes of transportation. The term "rail rapid transit" frequently refers both to operation of light rail transit vehicles over exclusive right-of-way and heavy rail transit vehicles; the term "bus rapid transit" refers to operation of motor buses over exclusive bus roads or busways.

transit system, semi-metro — a light rail transit system that uses exclusive right-of-way for much of its length, usually at surface grade but occasionally in tunnels or on aerial structures. Also similar to *transit system, pre-metro*—built for later conversion to heavy rail. Particular to several European countries and now little used.

transit system, shuttle — a transit system that is characterized by a back-and-forth operation, usually over a short distance.

transit system, streetcar (street railway, tramway, trolley) — a street transit system consisting of electrically powered rail vehicles operating in single or multiple-unit, mostly on surface streets with mixed traffic.

transit system availability — a measure of the capability of a transit system to be used by potential passengers, including such factors as the hours the system is in operation, route spacing, and accessibility to persons with disabilities.

Transit Traveler Information — National ITS Architecture Market Package that provides transit users at transit stops and on board transit vehicles with ready access to transit information. The information services include transit stop annunciation, imminent arrival signs, and real-time transit schedule displays that are of general interest to transit users. Systems that provide custom transit trip itineraries and other tailored transit information services are also represented by this market package.

transit union — see *union, transit.*

transit unit — one or more transit vehicles coupled and operated together. The term includes single vehicles (bus, rail, or other guideway) and multi-car trains (rail or other guideway).

transit unit, bidirectional or double-ended — see *double-ended transit unit.*

Transit Vehicle Tracking — National ITS Architecture Market Package that provides for an AVL system to track the transit vehicles' real-time schedule adherence and updates the transit system's schedule in real-time.

transitway — A right-of-way or roadway used by transit vehicles (buses or trains). Sometimes used, as in Ottawa, as a synonym for *busway.* Can be described as an *exclusive, semi-exclusive,* or *non-exclusive* transitway to indicate the degree of separation from other traffic.

transmission-based control system — see *control system, moving-block.*

transponder — electronic device designed to store information. Electronic readers access the information stored on these devices for such functions as toll collection, trucking activities, and transit signal priority.

transport, conventional rail — see *conventional rail transport.*

Transport Workers Union — see *union, transit.*

transportation, department of — see *organizations, department of transportation;* and *U.S. Government, Department of Transportation.*

transportation, intercity — see *intercity transportation.*

transportation, mass — see *mass transportation.*

transportation, private — see *private transportation.*

transportation, public — see *public transportation.*

transportation, purchased — see *purchased transportation.*

transportation, urban public — see *urban public transportation.*

transportation demand management (TDM) — the concept of managing or reducing travel demand rather than increasing the supply of transportation facilities. It may include programs to shift demand from single-occupant vehicles to other modes such as transit and ridesharing, to shift demand to off-peak periods, or to eliminate demand for some trips.

transportation disadvantaged (low-mobility group) — people whose range of transportation alternatives is limited, especially in the availability of relatively easy-to-use and inexpensive

alternatives for trip making. Examples include the young, the elderly, the poor, persons with disabilities, and those who do not have automobiles. See also *transit dependent; rider, captive;* and *rider, captive transit.*

transportation facilities — see *accessible transportation facilities.*

transportation improvements, low-capital — see *low-capital transportation improvements.*

transportation interface — the point or facility at which two or more modes of transportation meet or at which two or more transit system routes or lines meet.

transportation modeling system, urban — see *urban transportation modeling system.*

transportation planning process, urban — see *urban transportation planning process.*

Transportation Research Board — see *organizations, Transportation Research Board.*

Transportation Research Information Services (TRIS) — a national network of transportation research information services developed by the Transportation Research Board. TRIS consists of the Air Transport Information Service, Highway Research Information Service, Maritime Research Information Service, Railroad Research Information Service, and Urban Mass Transportation Research Information Service.

Transportation Study, Nationwide Personal — see *Nationwide Personal Transportation Study.*

transportation system — 1. a system that provides for the movement of people, goods, or both. **2.** a coordinated system made up of one or several modes serving a common purpose, the movement of people, goods, or both.

transportation system, demand-actuated — see *transportation system, demand-responsive.*

transportation system, demand-responsive (demand-actuated transportation system, demand-response transportation system) — a form of public transportation characterized by flexible routing and scheduling of small- to medium-size vehicles (passenger cars, vans or small buses typically less than 25 seats) operating in shared-ride mode between pick-up and drop-off locations according to passengers' requests. A demand-responsive operation is characterized by the following: (*a*) the vehicles do not operate over a fixed route or on a fixed schedule except, perhaps, on a limited basis to serve specific origins or destinations; (*b*) passengers make a personal request for a reservation or service consideration (the reservation may be required several days in advance of the requested trip or on board the vehicle depending on the type of demand-responsive operation), and (*c*) typically, the vehicle may be dispatched to pick up several passengers at different pick-up points before taking them to their respective destinations and may stop en route to these destinations to pick up other passengers. The following types of operations fall under the above definitions provided they are not on a scheduled fixed-route basis: many origins–many destinations, few origins–few destinations, many origins–one destination, one origin–many destinations, and one origin–one destination.

transportation system, dial-a-ride — a demand-responsive system in which passengers call the transportation operator, who then dispatches a vehicle to pick up the passengers and take them to their destinations. It is also known as dial-a-bus when buses are the vehicles used.

transportation system, fixed-route — service provided on a repetitive, fixed-schedule basis along a specific route with vehicles stopping to pick up and deliver passengers to specific locations; each fixed-route trip serves the same origins and destinations, unlike demand response. Includes route deviation service, where revenue vehicles deviate from fixed routes on a discretionary basis.

transportation system, jitney — public transportation rendered in small- or medium-sized vehicles that are licensed to render that service at a fixed rate or fare for each passenger. The vehicles operate on fixed routes along public ways, from which they may deviate from time to time in response to a demand for service or to take passengers to their destinations, thereafter returning to the fixed route. The scheduling and organization of this type of system vary among jurisdictions. It is used extensively in cities of developing countries that have inadequate transit service. See also *service, jitney* and *público.*

transportation system, non-fixed route — service not provided on a repetitive, fixed-schedule basis along a specific route to specific locations. Demand response is the only non-fixed route mode.

transportation system, urban — the system of transportation elements (both private and public) that provides for the movement of people and goods in an urban area. The components include transit systems, paratransit services, and highway or road systems, including private vehicles and pedestrians.

transportation system management (TSM) — that part of the urban transportation planning process undertaken to improve the efficiency of the existing transportation system. The intent is to make better use of the existing transportation system by using short-term, low-capital transportation improvements that generally cost less and can be implemented more quickly than other system development actions.

trap — in railway cars, a manually raised and lowered floor section that covers the steps at the ends of the car. When raised, the trap allows passengers to use the car steps at stations without high platforms. When lowered, the trap provides nearly level boarding at high-platform stations, and keeps passengers out of the step area when the train is in motion.

Travel Demand Management — National ITS Program User Service that supports policies and regulations designed to mitigate the environmental and social impacts of traffic congestion. See also *Transportation Demand Management.*

travel distance — see *trip distance, linked.*

travel survey — see *survey, travel.*

travel time, overall or total — see *time, linked trip.*

travel time difference — the door-to-door difference between automobile and transit travel times, including walking, waiting, and transfer times as applicable. A quality of service measure representing how much longer (or in some cases, shorter) a trip will take by transit.

travel time factor — an empirically determined set of factors in which each factor expresses the effect of one particular travel time increment of trip interchanges between zones.

travel time ratio — the ratio that compares travel times between a pair of points via two different modes or facility types.

Traveler Services Information — National ITS Program User Service that provides a business directory, or "yellow pages," of service information.

treatment, edge — see *edge treatment.*

treatment, preferential — see *preferential treatment.*

trip — **1.** a one-way movement of a person or vehicle between two points for a specific purpose; sometimes called a *one-way trip* to distinguish it from a round trip. **2.** in rail operations, a mechanical lever or block signal that, when in the upright position, activates a train's emergency braking system. **3.** the movement of a transit unit (vehicle or train) in one direction from the beginning of a route to the end of it; also known as a *run.*

trip, inbound — a trip toward the central urban area, into the central business district, or to a timed transfer point or major activity center.

trip, linked (linked journey, linked passenger trip) — a trip from the point of origin to the final destination, regardless of the number of modes or vehicles used.

trip, missed — demand-responsive transit trip that is scheduled and booked but for which the transit vehicle does not show up. A measure of reliability.

trip, non-home-based — a trip that has neither its origin nor its destination at a residence.

trip, one-way — see *trip.*

trip, outbound — a trip away from the central urban area, out of the central business district, or away from a timed transfer point or major activity center.

trip, passenger — one passenger making a one-way trip from origin to destination.

trip, person — a trip made by a person by any mode or combination of modes for any purpose.

trip, round — the movement of a person or a vehicle from a point of origin to a destination and then back to the same point of origin.

trip, track — see *track trip.*

trip, unlinked — **1.** a trip made in a single vehicle. **2.** the boarding of one transit vehicle in revenue service; also known as an *unlinked passenger trip.* ***3.*** any segment of a linked trip.

trip, vehicle — the one-way movement of a vehicle between two points.

trip arm — see *track trip.*

trip assignment (flow distribution, traffic assignment) — in planning, a process by which trips, described by mode, purpose, origin, destination, and time of day, are allocated among the paths or routes in a network by one of a number of models; see also *urban transportation modeling system.*

trip attraction — in transportation planning, the non-home end of a home-based trip or the destination of a non-home-based trip.

trip distance, linked (total travel distance) — the distance traveled on a linked trip, that is, the distance from the point of origin to the final destination, including the walking distance at trip ends and at transfer points.

trip distance, unlinked — the distance traveled on an unlinked trip, for example, a trip on a single vehicle.

trip distribution — in planning, the process of estimating movement of trips between zones by using surveys or models; see also *urban transportation modeling system* and *model, sequential.*

trip end — a trip origin or a trip destination.

trip generation — in planning, the determination or prediction of the number of trips produced by and attracted to each zone; see also *urban transportation modeling system* and *model, sequential.*

trip generator — a land use from which trips are produced, such as a dwelling unit, a store, a factory, or an office.

tripper — **1.** in transit operations, a short piece of work that cannot be incorporated into a full day's run, usually scheduled during peak hours. **2.** in transit operations, a short work schedule for operators, usually 1-3 hours long; for example, during peak periods. **3.** on some transit properties, a short run that is less than 8 hours long. **4.** on some transit properties, a transit service that operates on only a portion of a route, usually at peak hours.

trip productions — in planning, the number of trips, daily or for a specified time interval, that are produced from and return to a given zone, generally the zone of residence. Trip productions can also be defined as the home end of home-based trips or the origin of non-home-based trips.

trip purpose — the primary reason for making a trip, for example, work, shopping, medical appointment, recreation.

trip time — see *time, linked trip* and *time, unlinked trip.*

trolley — **1.** an apparatus, such as a grooved wheel or shoe, at the end of a pole, used for collecting electric current from an overhead wire and transmitting it to a motor of a streetcar, trolleybus, or similar vehicle, where it is used for traction and other purposes. **2.** colloquial term for streetcar, and in some cities, trolleybus, vintage, and/or replica streetcar (see *bus, trolley replica).*

trolley bus — alternate spelling for *trolleybus,* the single word is recommended.

trolleybus (electric trolleybus, trolley coach, trackless trolley) — an electrically propelled bus that obtains power via two trolley poles from a dual (positive and negative) overhead wire system along routes. It may be able to travel a limited distance using battery power or an auxiliary internal combustion engine. The power-collecting apparatus is designed to allow the bus to maneuver in mixed traffic over several lanes.

trolleybus, articulated — see *articulated bus or articulated trolleybus.*

trolley car — see *car, trolley.*

trolley coach — see *trolleybus.*

trolley pole — **1.** a swiveling spring-loaded pole attached on the roof of a trolleybus or streetcar that holds a wheel or sliding shoe in contact with the overhead conductor (which usually takes the form of a thick wire), collects current from it, and transmits the current to the motor on the vehicle, for example, a streetcar or trolleybus. **2.** inexact reference to traction pole or mast support trolleybus or streetcar overhead contact wiring.

trolley replica bus — see *bus, trolley replica.*

trolley shoe — see *overhead contact shoe.*

trolley system — see *transit system, streetcar.*

trolley wire — see *contact wire.*

truck (bogie, *British usage***)** — in rail transportation, a rail vehicle component that consists of a frame, normally two axles, brakes, suspension, and other parts, which supports the vehicle body and can swivel under it on curves. A truck usually also contains traction motors.

turbine engine — see *engine, turbine.*

turn, short — see *turn back.*

turnaround time — see *time, layover.*

turn back — **1.** in transit operations, to cut short a transit trip (to turn back before reaching the end of the route or line), usually to get back on schedule or to meet peak-passenger demands; also known as a *short turn.* **2.** in rail operations, a point along a track at which a train may reverse direction.

turn down — a demand-response trip that cannot be accommodated by a service provider at the passenger's desired time and cannot be taken by the passenger at alternate times when capacity is available.

turnout — **1.** in rail transportation, the assembly of a switch and a frog with closure rails by which rolling stock or trains can travel from a track onto either one of two diverging tracks; also known as a *track switch.* **2.** A short-side track or passage that enables trains, automobiles, and similar vehicles to pass one another. **3.** a short passing lane on a highway.

turnout, bus — see *bus bay.*

turnover, parking — see *parking turnover.*

turnover point — a point along a transit route at which a large proportion of passengers leave and board a transit unit.

turnstile — a mechanical device used to control and/or measure pedestrian entry or exit from an area. It uses a bar that rotates out of the way when a pedestrian presses against it. When used as a fare gate, the bars unlock only after the correct fare has been paid.

turnstile, fare-registering — see *fare-registering fare gate.*

turntable — a circular, rotating mechanical device that allows a rail car to be turned in place to change its direction of travel. It may be motorized, or as in the case of San Francisco's cable cars, require operators to physically push the car to turn it around.

U

UA — urbanized area; see *area, urbanized.*

UITP — see *organizations, International Union of Public Transport.*

UMTA — Urban Mass Transportation Administration; previous name for FTA, see *U.S. Government, Federal Transit Administration.*

UMTRIS — Urban Mass Transportation Research Information Service.

U.S. DOT — U.S. Department of Transportation; see *U.S. Government, Department of Transportation.*

UTU — United Transportation Union; see *union, transit.*

UZA — used by some to indicate an urbanized area, although the Bureau of the Census uses UA; see *area, urbanized.*

underground — see *transit system, rail rapid.*

unidirectional car — see *car, unidirectional.*

uninterrupted flow — transit vehicles moving along a roadway or track without stopping. This term is most applicable to transit service on freeways or on its own right-of-way.

union, transit — one of the many unions representing various segments of the transit industry's work force. Three major ones in the United States and Canada are the *Amalgamated Transit Union (ATU),* the *Transport Workers Union (TWU),* and the *United Transportation Union (UTU).*

Their membership is limited to operators, mechanics, and other non-supervisory employees. A non-affiliated *Independent Canadian Transit Union* has raided older unions and represents some transit systems in Canada, the largest being BC Transit.

unit, basic operating — see *basic operating unit.*

unit, transit — see *transit unit.*

United States Government — see *U.S. Government.*

United Transportation Union — see *union, transit.*

unlimited access — see *access, unlimited.*

unlinked passenger trip — see *trip, unlinked.*

unlinked trip — see *trip, unlinked.*

unlinked trip distance — see *trip distance, unlinked.*

unlinked trip time — see *time, unlinked trip.*

urban ferryboat — see *ferryboat, urban.*

urban fringe — that part of an urbanized area outside the central city or cities.

Urban Mass Transportation Act — see *legislation, Urban Mass Transportation Act of 1964.*

Urban Mass Transportation Administration — see *U.S. Government, Federal Transit Administration.*

Urban Mass Transportation Research Information Service (UMTRIS) — a computer-based information storage and retrieval system developed by the Transportation Research Board under contract to the Federal Transit Administration. It consists of summaries of research projects in progress and abstracts of published works. See also *Transportation Research Information Services.*

urban place — a U.S. Bureau of the Census designated area (less than 50,000 population) consisting of closely settled territory not populous enough to form an urbanized area.

urban public transportation — transportation systems for intraurban or intraregional travel, available for use by any person who pays the established fare. It consists of transit and paratransit.

urban rail car — see *car, urban rail.*

urban transit bus — see *bus, standard urban.*

urban transportation system — see *transportation system, urban.*

urbanized area — see *area, urbanized.*

U.S. Department of Transportation — see *U.S. Government, Department of Transportation.*

user information (service information) — information on fares, stopping places, schedules, and other aspects of service essential to the efficient use of public transit. The term also refers to devices employed to convey such information, including bus stop signs, timetable brochures or books, telephone inquiries, and computerized user-interactive systems.

User Services — services available to users of ITS (drivers, passengers, system operators) as set forth by ITS America.

U.S. Government, Amtrak — see *U.S. Government, National Railroad Passenger Corporation.*

U.S. Government, Department of Energy (DOE) — a cabinet-level federal agency whose responsibilities include improving the energy efficiency of transportation.

U.S. Government, Department of Health, Education, and Welfare (HEW) — a cabinet-level federal agency that provides funds for many specialized transportation services in urbanized and rural areas as part of its social service programs.

U.S. Government, Department of Transportation (DOT) — a cabinet-level federal agency responsible for the planning, safety, and system and technology development of national transportation, including highways, mass transit, aircraft, and ports.

U.S. Government, Federal Highway Administration (FHWA) — a component of the U.S. Department of Transportation, established to ensure development of an effective national road and highway transportation system. It assists states in constructing highways and roads and provides financial aid at the local level, including joint administration with the Federal Transit Administration of the 49 USC Section 5311 (formerly Section 18 of the Federal Transit Act) program.

U.S. Government, Federal Railroad Administration (FRA) — an agency of the U.S. government, established in 1966 as part of the U.S. Department of Transportation. It coordinates government activities that are related to the railroad industry.

U.S. Government, Federal Transit Administration (FTA) — a component of the U.S. Department of Transportation, delegated by the Secretary of Transportation to administer the federal transit program under Chapter 53 of Title 49, United States Code and various other statutes. Formerly known as the Urban Mass Transportation Administration.

U.S. Government, National Railroad Passenger Corporation (Amtrak) — an agency created by Congress in 1970 to operate the national railroad passenger system. It also operates commuter rail service under contract, usually to metropolitan transit agencies.

U.S. Government, National Transportation Safety Board (NTSB) — an independent agency of the federal government whose responsibilities include investigating transportation accidents and conducting studies, and making recommendations on transportation safety measures and practices to government agencies, the transportation industry, and others.

U.S. Government, Urban Mass Transportation Administration (UMTA) — former name of the

Federal Transit Administration; see *U.S. Government, Federal Transit Administration.*

utilization coefficient — see *load factor.*

VKT — vehicle kilometers of travel; see *vehicle miles of travel.*

VMT — vehicle miles of travel.

validation — the marking of a ticket, pass, or transfer for the purpose of verifying its legitimate use for paid travel, usually giving time and place of marking.

validator — component of ticket vending machine or separate machine that stamps date, time, and sometimes location on pre-purchased ticket or pass to validate or cancel same.

value, default — see *default value.*

van — vehicles having a typical seating capacity of five to 15 passengers and classified as a van by vehicle manufacturers. A modified van is a standard van that has undergone some structural changes, usually made to increase its size and particularly its height. The seating capacity of modified vans is approximately nine to 18 passengers.

van, subscription — see *service, subscription van.*

vanpool — vans and/or buses seating less than 25 persons operating as a voluntary commuter ride-sharing arrangement, which provides transportation to a group of individuals traveling directly between their homes and their regular places of work within the same geographical area. The vans should have a seating capacity greater than seven persons, including the driver. It is a mass transit service operated by a public entity, or in which a public entity owns, purchases, or leases the vehicles. Other forms of public participation to encourage ridesharing arrangements such as the provision of parking spaces, utilization of high-occupancy vehicle (HOV) lanes, and coordination or clearing house service, do not necessarily qualify as public vanpools.

vehicle, accessible — public transportation revenue vehicles that do not restrict access, are usable, and provide allocated space and/or priority seating for individuals who use wheelchairs.

vehicle, active — the vehicles that are available to operate in revenue service, including vehicles temporarily out of service for routine maintenance and minor repairs.

vehicle, articulated rail — see *articulated rail vehicle.*

vehicle, dual-mode — a vehicle that operates both manually on public streets and automatically on an automated guideway. May also be used to describe vehicles with more than one source of power; for example, a bus that can be propelled by a diesel engine or an electric motor.

vehicle, high-occupancy (HOV) — any passenger vehicle that meets or exceeds a certain predetermined minimum number of passengers, for example, more than two or three people per automobile. Buses, carpools, and vanpools are HOV vehicles.

vehicle, light rail — see *car, light rail.*

vehicle, public service — a vehicle used for public passenger transport.

vehicle, revenue — a vehicle used to provide passenger transit service for which remuneration is normally required. It is distinct from non-revenue equipment, which is used to build or maintain facilities, provide supervision, and so on.

vehicle, single-occupant (SOV) — a vehicle occupied by the driver only.

vehicle capacity — see *capacity, vehicle.*

vehicle hours — The hours a vehicle travels while in revenue service (vehicle revenue hours) plus deadhead hours. For rail vehicles, vehicle hours refer to passenger car hours. Vehicle hours exclude hours for charter services, school bus service, operator training and maintenance testing.

vehicle layover — see *time, layover.*

vehicle location system — see *automatic vehicle location system.*

vehicle miles (or kilometers) — the miles a vehicle travels while in revenue service (vehicle revenue miles plus deadhead miles). For rail vehicles, vehicle miles refer to passenger car miles. Vehicle miles exclude miles for charter services, school bus service, operator training, and maintenance testing.

vehicle miles, revenue — see *revenue vehicle miles.*

vehicle miles of travel (VMT; vehicle kilometers of travel, VKT) — 1. on highways, a measurement of the total miles (kilometers) traveled by all vehicles in the area for a specified time period. It is calculated by the number of vehicles times the miles (kilometers) traveled in a given area or on a given highway during the time period. **2.** in transit, the number of vehicle miles (kilometers) operated on a given route or line or network during a specified time period.

vehicle occupancy — the number of people aboard a vehicle at a given time; also known as *auto* or *automobile occupancy* when the reference is to automobile travel only.

vehicle signal-actuating device — a device to control traffic signals that is activated by vehicles.

vehicle staging lot — see *staging lot, vehicle.*

vehicle trip — see *trip, vehicle.*

velocity (speed) — the distance passed per unit of time, or the rate of change in location relative to time. For transportation vehicles, it is usually measured in miles (kilometers) per hour.

velocity, cruise (cruise speed) — the forward velocity that a vehicle maintains when it is neither accelerating nor decelerating. It is usually less than maximum design speed but can be equal to it.

velocity, effective (average speed) — 1. the average velocity at which a vehicle travels. For

transit vehicles, it includes dwell times at stops or stations, acceleration, and deceleration. **2.** vehicle miles divided by vehicle hours.

velocity, maximum theoretical — the highest theoretical velocity that a vehicle is physically capable of achieving, usually specified on level, tangent road, or track with full service load.

viaduct — see *aerial structure.*

vintage streetcar — see *streetcar, heritage.*

vintage trolley — see *streetcar, heritage.*

voltage, high — in rail transportation, the prime propulsion power voltage supplied by an overhead wire or third rail, usually 550, 650, 750, 1,000, 1,500 and 3,000 volts DC; and 11,000, 15,000, and 25,000 volts AC.

voltage, low — in rail transportation, the voltage used for most auxiliary systems (e.g., illumination, fans, public address systems), usually 24 or 72 volts DC or 110 to 240 volts AC.

voltage drop — the decrease in voltage in a current-carrying conductor.

volume — in transportation, the number of units (passengers or vehicles) that pass a point on a transportation facility during a specified interval of time, usually 1 hour; see also *flow rate.*

volume, design hourly — see *design hourly volume.*

volume, line — see *passenger volume.*

volume, link — see *link volume.*

volume, passenger — see *passenger volume.*

volume, service — see *service volume.*

wait assessment — A measure of headway regularity. Defined as the percentage of transit vehicle arrivals where the actual headway exceeds the scheduled headway by more than 3 min.

wait time — see *time, wait.*

walkway, moving — see *moving walkway.*

walk distance — see *distance, walk.*

walking distance — see *distance, walking.*

wake — wave motion that is left behind the path of a moving vessel.

water sheet — the horizontal surface area of the water available for maneuvering and docking or mooring at a shore facility.

water taxi — **1.** a ferry system in which small watercraft serve short cross-waterway or waterway circulation routes. **2.** ferry service providing personal, demand-responsive service over water, similar to a taxi. **3.** the type of small watercraft used by water taxi systems.

way, bicycle — see *bicycle route.*

way, public — see *public way.*

wayside — along the right-of-way, usually of rail system.

wayside control system — see *control system, wayside.*

wayside lift — see *wheelchair lift.*

wayside signal — see *signal, wayside.*

weighted time — see *time, weighted.*

welded rail — see *rail, welded.*

wheelchair lift — a device used to raise and lower a platform that facilitates transit vehicle accessibility for wheelchair users and other persons with disabilities. Wheelchair lifts may be attached to or built into a transit vehicle or may be located on the station platform *(wayside lifts).*

wheel flange — in rail systems, a projecting edge or rim on the circumference of a steel wheel that is designed to keep the wheel on a rail.

wheels, driving — see *driving wheels.*

wide gauge — see *gauge, broad.*

width, clear — the width of a stairway, ramp, or walkway between the face of handrails or other obstructions.

width, effective — the minimum width available for pedestrian movement after deducting for obstructions and buffers along the side of walls and obstructions.

width, tread — the width of stair treads, which is often wider than the clear width between handrails.

windscreen card — a printed or handwritten card usually placed in the bottom of the curb-side windscreen to denote a destination or service information such as "via…", express, limited stop, short turn, and so forth. Often used when the destination blind does not contain the desired destination or to display a secondary destination or route deviation.

wire, contact or trolley — see *contact wire.*

workshop (shop) — section of yard, depot, maintenance and storage facility, or garage where maintenance is carried out on vehicles.

wye — a triangular rail junction to turn trains or streetcars around without the need for a loop.

yard — **1.** in rail systems, a facility within defined limits that has a system of tracks used for making up trains, storing rail cars, and other purposes. **2.** in transit systems, an open storage lot for light rail vehicles, streetcars, electric trolley buses, and motor buses.

yard limits — a slow-speed area on main railroad tracks that often extends 5-10 mi (8-16 km) from either end of a yard. For transit operations, this distance is much shorter: it is usually confined to the yard itself or to a short lead, usually less than 1 mi (1.6 km) in length.

Yellow Pages and Reservation — National ITS Architecture Market Package that enhances the *Interactive Traveler Information* package by making infrastructure-provided yellow pages and reservation services available to the user.

Z

zone, auto-free — see *auto-free zone.*

zone, auto-restricted — see *auto-restricted zone.*

zone, layover — see *layover zone.*

zone or zoned fare — see *fare, zone.*

zone route — a type of flexible transportation that combines demand-responsive transit service within defined zones along a corridor with scheduled departure and arrival times at one or more end points.

2. LIST OF SYMBOLS

This section lists all of the symbols used in equations in the TCQSM and their units. In the few cases where a given symbol has different meanings in different chapters, the chapter number is provided next to the symbol definition.

a = average bus acceleration rate to running speed (ft/s², m/s²) [Chapter 6]
a = initial service acceleration rate (ft/s², m/s²) [Chapter 8]
a_g = acceleration due to gravity (ft/s², m/s²)
A_d = number of disembarking autos (auto equivalent units)
A_e = number of embarking autos (auto equivalent units)
b = separation safety factor (unitless)
B = bus facility design capacity (bus/h)
B_l = loading area bus capacity (bus/h)
B_{max} = maximum bus capacity of the curb lane (bus/h)
B_s = bus stop capacity (bus/h)
$B_1 \ldots B_n$ = critical bus stop capacity of a given skip-stop pattern (bus/h)
c_a = capacity of the adjacent lane (veh/h)
c_{cl} = curb lane capacity at intersection (veh/h)
c_f = conversion factor (ft/mi × h/s, m/km × h/s)
c_{re} = capacity of the re-entry movement (veh/h)
c_{rt} = capacity of right-turn movements from the curb lane (veh/h)
c_{th} = capacity of through movements in the curb lane (veh/h)
c_v = coefficient of variation of dwell times (unitless)
c_{vh} = coefficient of variation of headways (unitless)
C = traffic signal cycle length (s)
C_d = disembarking capacity at the constraining point (p/min)
C_e = embarking capacity at the constraining point (p/min)
C_f = fare collection capacity (p/min);
C_g = gangway capacity (p/min);
C_h = cars operated per hour (car/h)
C_{max} = longest traffic signal cycle length in the line's on-street section (s)
C_x = walkway exit capacity (p/min)
d = average bus deceleration rate from running speed (ft/s², m/s²) [Chapter 6]
d = service deceleration rate (ft/s², m/s²) [Chapter 8]
d_c = average carrier/train/car spacing on the line (ft/carrier, m/carrier)
d_{eb} = distance from the front of stopped train to start of station exit block (ft, m)

d_{ec} = pedestrian crossing delay exceeding 30 s (s)
d_p = average pedestrian delay (s)
$d_{re,1}$ = average reentry delay for Case 1 (s)
$d_{re,2fs}$ = average reentry delay for far-side stops in Case 2 (s)
$d_{re,2ns}$ = average reentry delay for near-side stops in Case 2 (s)
$d_{re,3}$ = average reentry delay for Case 3 (s)
d_{ts} = track separation (ft, m)
d_x = distance from cross-over to platform (ft, m)
d_1 = distance for one-block stop pattern (ft, m)
d_2 = distance for multiple-block stop pattern (ft, m)
D = pedestrian density (p/ft^2, p/m^2)
D_{bs} = bus stop distance from the nearest upstream traffic signal (mi, m)
D_{max} = maximum distance for Case 3 (mi, m)
E = ridership elasticity with respect to changes in the travel time rate (unitless)
f = scheduled frequency (veh/h, bus/h)
f_a = arrival type factor (unitless)
f_b = buffer area coefficient (unitless)
f_{bb} = bus–bus interference factor (unitless)
f_{br} = braking safety factor (unitless)
f_{eff} = effective frequency (bus/h)
f_g = grade factor (unitless)
f_h = headway factor (unitless)
f_i = adjacent lane impedance factor (unitless)
f_k = capacity adjustment factor for skip-stop operations (unitless)
f_l = bus stop location factor (unitless)
f_{min} = minimum frequency to accommodate peak 15-min passenger demands without overcrowding (bus/h)
f_{pl} = passenger load weighting factor (unitless)
f_{pop} = population factor (unitless)
f_{px} = pedestrian crossing factor (unitless)
f_S = motorized vehicle speed adjustment factor (unitless)
f_{sa} = switch angle factor (unitless)
f_{sc} = street connectivity factor (unitless)
f_{sp} = stop pattern adjustment factor
f_{sw} = sidewalk width coefficient (unitless)
f_{tb} = traffic blockage adjustment factor (unitless)

f_{tt} = perceived travel time factor (unitless)

f_v = motorized vehicle volume adjustment factor (unitless)

f_w = cross-section adjustment factor (unitless)

g = effective green time (s)

g_s = queue service time for the adjacent lane (s)

g_{Walk} = effective green time for pedestrians (WALK time + 4 s of flashing DON'T WALK) (s)

g/C = green time ratio, the ratio of effective green time to total traffic signal cycle length (unitless)

G_i = grade into station (decimal)

G_o = grade out of station (decimal)

h_c = controlling headway (s)

h_{gc} = non-interference headway associated with stations with grade crossings on departure (s)

h_j = limiting headway at junction (s)

h_{ni} = non-interference headway (s)

h_o = average observed headway (min)

h_{os} = minimum on-street section train headway (s)

h_{row} = minimum headway associated with the right-of-way type (s)

h_{st} = minimum single-track headway (s)

h_v = average vehicle headway (s/auto)

$I_{p,}$ = pedestrian environment score (unitless)

l_{pt} = average passenger trip length (mi)

l_v = line voltage as percentage of specification (decimal)

L = longest train length (ft, m)

L_{ad} = total distance traveled at less than running speed (ft, m)

L_f = average passenger load factor (p/seat)

L_{fac} = facility length (mi, km)

L_i = length of section *i* (mi, km)

L_l = line length (ft, m)

L_{mk} = length of a mile or kilometer (ft, m)

L_p = platform length (ft, m)

L_r = distance between gangway and front of vehicle staging area (ft, m)

L_{rs} = distance traveled at running speed per mile or kilometer (ft/mi, m/km)

L_{st} = length of single-track section (ft, m)

L_{sta} = length of station speed zone (ft, m)

L_t = train length (ft, m)

L_w = walkway length (ft, m)
M = pedestrian space (ft²/p, m²/p)
N_b = number of berths at the dock (berths)
N_{bm} = number of different bus models operated on the facility (bus models)
N_c = number of cars per train (cars/train)
N_{ca} = number of channels for automobiles (channels)
N_{el} = number of effective loading areas at the bus stop (loading areas)
N_i = number of buses of bus model *i* scheduled to use the facility during the hour (bus/h)
N_{la} = number of loading areas at the bus stop (loading areas)
N_s = average stop spacing (stops/mi, stops/km)
N_{sec} = number of sections forming the facility (sections)
N_{ss} = number of alternating skip-stops in sequence (bus stops)
N_{st} = number of stations (stops, stations)
N_{TVM} = number of required ticket vending machines (machines)
N_v = number of vehicles (vehicles)
p_{be} = proportion of stops on segment with benches (decimal)
p_{pk} = proportion of on-street parking occupied (decimal)
p_{sh} = proportion of stops on segment with shelters (decimal)
p_t = proportion of arriving passengers purchasing a ticket (decimal)
p_v = proportion of vehicles arriving during the green indication (decimal)
P = design person capacity (p/h)
$P_{a,i}$ = alighting passengers through door channel *i* (p)
P_{arr} = design number of arriving passengers at a station or entrance (p/h)
$P_{b,i}$ = boarding passengers through door channel *i* (p)
P_c = maximum design load per car (p/car)
P_d = disembarking passenger volume (p)
P_e = positioning error (ft, m) [Chapter 8]
P_e = embarking passenger volume (p) [Chapter 9]
P_h = passenger volume during the peak hour (p)
P_i = number of people involved in activity *i* (p)
P_{max} = weighted average maximum schedule load for buses using the facility (p/bus)
$P_{max,i}$ = maximum schedule load for bus model *i* (p/bus)
P_s = scheduled person capacity (p/h)
P_{15} = passenger volume during the peak 15 min (p)
PHF = peak-hour factor (unitless)
q = arrival flow rate (veh/s)

q_g = arrival flow rate during the effective green time (veh/s)
q_r = arrival flow rate during the effective red time (veh/s)
Q_r = queue size at the end of the effective red time (veh)
r = effective red time (s)
r_s = transit stop service radius (mi, m)
r_0 = ideal transit stop service radius (mi, m)
s = standard deviation of dwell times (unitless)
s_f = saturation flow rate (veh/s)
$s_{w\text{-}r}$ = transit wait–ride score (unitless)
S = average travel speed of transit vehicles along the segment (mi/h) [Chapter 6]
S = pedestrian speed (ft/min, m/min) [Chapter 10]
S_{avail} = space available within the area analyzed (ft², m²)
S_f = average facility speed (mi/h, km/h)
S_i = space required for activity *i* (ft²/p, m²/p)
S_m = speed margin
S_{mb} = moving-block safety distance (ft, m)
S_R = average motorized vehicle running speed in the segment, including delay at the downstream intersection (mi/h)
S_s = average section speed (mi/h, km/h)
$t_{a,i}$ = average alighting passenger service time for door channel *i* (s/p)
t_{acc} = acceleration time (s/stop)
$t_{b,i}$ = average boarding passenger service time for door channel *i* (s/p)
t_{bl} = boarding lost time (s)
t_{br} = brake system reaction time (s)
t_c = clearance time (s)
t_{ch} = critical headway for the re-entry movement (s)
t_{cs} = train control separation (s)
t_d = average dwell time (s)
$t_{d,crit}$ = average dwell time at the controlling station (s)
$t_{d,maxgc}$ = longest average dwell time of stations with grade crossings on departure (s)
t_{dec} = deceleration time (s/stop)
t_{dt} = average dwell time of all stops within the section (s/stop)
t_{ed} = total embarking and disembarking time (s/vessel)
t_{ex} = excess wait time due to late arrivals (min)
t_f = follow-up time for the re-entry movement (s)
t_{fac} = facility travel time (min)
t_{gca} = minimum time from when the crossing cycle is manually activated to when a

train can depart (s)

t_i = dwell time value that will not be exceeded more often than the desired failure rate (s)

t_{jl} = time lost to braking jerk limitation (s)

t_l = additional running time losses (min/mi, min/km)

t_{oc} = door opening and closing time (s)

t_{om} = operating margin (s)

t_{os} = time for overspeed governor to operate (automatic systems), driver sighting and reaction time (manual systems) (unitless)

$t_{pf,i}$ = passenger flow time for door channel *i* (s)

$t_{pf,max}$ = maximum passenger flow time of all door channels (s)

t_r = base bus running time rate (min/mi, min/km)

t_{re} = re-entry delay (s)

t_{rs} = time spent traveling at running speed (s/mi, s/km)

t_s = section running time rate (min/mi, min/km)

$t_{s,I}$ = section running time rate for section *i* (min/mi, min/km)

t_{st} = time to cover single-track section (s)

t_{sta} = station travel time (s/stop)

t_{su} = minimum time for a bus to start up, travel its own length, and the next bus to pull into the loading area (s)

t_{sw} = switch throw and lock time (s)

t_t = average transaction time (s/p)

t_{tl} = terminal layover time (s)

t_u = unimpeded running time rate (min/mi, min/km)

t_v = design vessel service time (s/vessel)

t_w = average wait time (min)

T = directional line capacity (trains/h, carriers/h)

T_{at} = perceived amenity time rate (min/mi)

T_{avail} = time available as defined for the analysis period (s)

T_{btt} = base travel time rate (min/mi)

T_{ex} = excess wait time rate due to late arrivals (min/mi)

T_i = time required for activity *i* (s)

T_{ptt} = perceived travel time rate (min/mi)

TS_{avail} = time-space available (ft^2-s, m^2-s)

TS_{req} = time-space required (ft^2-s, m^2-s)

v = demand flow rate in the curb (rightmost) travel lane (veh/h) [Chapter 6]

v = pedestrian flow per unit width (p/ft/min, p/m/min) [Chapter 10]

v/c = volume-to-capacity ratio (unitless)
v_a = station approach speed (ft/s, m/s)
v_{al} = traffic volume in the adjacent lane (veh/h)
v_b = bus volume in curb lane (bus/h)
v_{cl} = curb lane traffic volume at intersection (veh/h)
v_d = disembarking passenger speed on walkway (ft/min, m/min)
v_e = embarking passenger speed on walkway (ft/min, m/min)
v_l = average line speed (ft/s, m/s)
v_m = outside lane motorized vehicle demand flow rate at mid-segment (i.e., lane closest to the subject sidewalk) (veh/h)
v_{max} = maximum line speed (ft/s, m/s)
$v_{max,st}$ = maximum speed on single-track section (ft/s, m/s)
v_{run} = bus running speed on the facility, typically the posted speed (mi/h, km/h)
v_v = vehicle entering/exiting speed (ft/s, m/s)
V = dock vessel capacity (vessels/h)
V_b = vessel capacity of the berth (vessels/h)
V_{bi} = vessel capacity of berth *i* (vessels/h)
V_c = vessel's passenger (auto) capacity (p/vessel, autos/vessel)
W_{aA} = adjusted available sidewalk width (ft)
W_A = available sidewalk width (ft)
W_{buf} = buffer width between roadway and available sidewalk (ft)
W_v = effective total width of outside through lane, bicycle lane, and shoulder (parking lane) as a function of traffic volume (ft)
W_1 = effective width of combined bicycle lane and shoulder (ft)
Z = standard normal variable corresponding to a desired failure rate (unitless)

CHAPTER 12
INDEX

1. User's Guide
2. Mode and Service Concepts
3. Operations Concepts
4. Quality of Service Concepts
5. Quality of Service Methods
6. Bus Transit Capacity
7. Demand Responsive Transit
8. Rail Transit Capacity
9. Ferry Transit Capacity
10. Station Capacity
11. Glossary and Symbols
12. **Index**

When an entry has several page numbers associated with it, page numbers shown in **bold** indicate locations where terms are defined or concepts explained. Page numbers shown in *italics* indicate locations of illustrations.

acceleration
  bus, 6-4, 6-88
  commuter rail train, 8-68
access time, 4-11, 4-29
access to transit, 4-3, 5-8, 5-78
  automobile, 4-23, 5-21
  bicycle, 4-18, 4-21, 5-20, 9-4, 10-36
  pedestrian, 4-18, 4-19, 4-20, 5-9, 6-53, 6-54, 9-4
  special events, 8-43
  stations, 10-2, **10-15 to 10-20**
accessibility
  persons with disabilities, 10-2
activity centers, 5-72
ADA. *See* Americans with Disabilities Act
ADA paratransit, 2-7, **2-10**, 2-43, 4-32, 4-37, 5-47, 5-55, 6-54, 7-3
advanced light rail transit, 2-15
aerial lifts, 2-25, 8-120, *See also* aerial ropeways
  cabin sizes, 8-80
  capacity, *8-89*
aerial ropeways, 2-24, *2-25*
  capacity, 8-77
  capacity, calculation example, 8-120
  mode-specific capacity issues, 8-8
  passenger boarding, 8-40
  wheelchair access, 8-40
aerial tramways, 2-25, 8-120, *See also* aerial ropeways
  cabin sizes, 8-80
  capacity, *8-88*
AGT. *See* automated guideway transit
air conditioning, 4-35, 4-36
alternatives analysis
  capacity and speed applications, 6-98
  station design applications, 10-62
amenities. *See* stations, amenities *and individual amenities*
Americans with Disabilities Act, 1-18, 2-7, 2-10, 4-17, 4-20, 4-32, 6-49, 6-54, 8-34, 8-35, 8-59, 9-10, 9-13, 10-6, 10-17, 10-19, 10-27, 10-63
  requirements, 3-38, 5-20, 5-55, 7-3, 8-8, 8-21, 8-35, 8-38, 10-2, 10-3, 10-5, 10-8, 10-17, 10-28, 10-29
Amtrak, 2-14, 8-91
APC. *See* automatic passenger counters
appearance, 4-35, 5-38
applications
  bus capacity and speed, 6-98 to 6-101
  quality of service, 5-71 to 5-78
  rail capacity, 8-81 to 8-107
  station capacity, 10-62 to 10-73
  TCQSM, 1-9
art, 10-10, 10-11, *10-12*
auto equivalent units, 9-7, 9-29
auto service time
  ferry transit, calculation example, 9-32
automated guideway transit, 2-21, *2-22*, 2-27
  automatic train operation, 8-21
  capacity, 8-75
  capacity, calculation example, 8-118, 8-119
  linear loading levels, 8-35
  minimum train separation, 8-76
  mode-specific capacity issues, 8-8
  off-line stations, 8-77
  off-line stations, calculation example, 8-119
  passenger loads, 8-77
  performance, train, 8-76
  platform screen doors, use of, 8-32
  signaling, 8-75
  stations, 10-8
  train control, 8-75
  vehicle performance differences, 8-75
automatic passenger counters, 3-18, 4-38, 5-40, 5-41, 5-75, 5-77, 5-93, 6-40, 6-43, 6-53, 6-85, 6-99, 6-127
automatic train control, 8-18

automatic train operation, 8-21, 8-32
  capacity, impact on, 8-21
  dwell times, impact on, 8-27
automatic train stops, 8-18
automatic train supervision, 8-21, 8-61
automatic vehicle location, 4-38, 5-28, 5-29, 5-33, 5-34, 5-40, 5-48, 5-49, 5-59, 5-75, 5-77, 5-92, 6-36, 6-40, 6-43, 6-53, 6-54, 6-67, 6-96, 6-97, 6-100
AVL. *See* automatic vehicle location
benches, 4-36, 5-41, 10-5, 10-10, 10-11, *10-12*
berth capacity
  calculation example, 9-33
berths, bus. *See* loading areas
berths, ferry
  capacity, 9-22
  defined, 9-10
  parallel, 9-6
bicycles
  as transit access mode, 4-18, 5-20
  bike sharing, 4-22, *10-37*
  cages, 10-36, *10-37*
  dwell time, impact on, 6-70
  integrating with transit, 4-21
  interactions with curb extensions, 6-50
  loading, 6-69
  lockers, 10-36, *10-37*
  on board transit vehicles, 4-22, *4-23*, 10-9
  parking, 10-5, 10-8, 10-9
  racks, 3-24, 5-21, 6-7, 6-70, 10-36, *10-37*
  space occupied, 4-22
  speeds, typical, 4-22
  stair channels, 10-36
  storage, 4-22, 5-21
blocks, city
  train length constraint, 8-12
blocks, signal. *See* signals, train, blocks
boarding
  passenger distribution among doors, 6-68
boarding islands, 6-12, 6-48, *6-49*, 8-23, 10-5
boarding lost time, *6-3*, **6-5**, 6-17
  calculation, 6-69
body ellipse, 5-25
bollards, 10-34
budgeted wait time, 5-92
bunching, 4-31, 4-33, 5-30, 5-93, 6-9
  person capacity, impact on, 6-129
bus. *See also* bus transit
  acceleration, 6-4, 6-88
  articulated, 2-2, *2-4*, 6-4
  bicycle racks, 4-22
  community bus, *2-4*
  commuter, *2-4*
  door configuration. *See* doors, bus, configuration
  double-deck, *2-4*
  floor height, 6-6, 6-7
  high-floor, *2-4*
  low-floor, 2-3, 2-4, *2-5*
  minibus, 2-2
  over-the-road coach, *2-4*, 6-4
  passenger capacity, 6-20
  percent passengers by door channel, 6-68
  propulsion, 2-2
  replica trolley, *2-4*
  seating configuration, 2-3
  shoulder use, *6-31*
  special-purpose, *2-4*, 6-33, 10-7
  vehicle types, *2-5*, 6-19, 6-20
bus berths. *See* loading areas
bus bridge, 8-42
bus capacity. *See* capacity, vehicle
bus facilities, *6-15*
  capacity, 6-19, **6-81**
  capacity, non-stop facility, 6-81
  capacity, with skip-stop operation, 6-82
  capacity, without skip-stop operation, 6-82
  defined for capacity analysis, 6-61
  defined generally, 6-15
  described, 6-26
  non-stop facility, 6-81
  sectioning, 6-87
  speed, 6-94
bus gates, 6-57
bus lanes, *2-32*, 5-94, *6-32*, 6-57, 6-99
  bi-directional, 6-35, *6-36*
  bus operations, impact on, 6-39
  calculation example, effect on bus capacity and speed, 6-118
  capacity, 6-22
  concurrent-flow, 6-34
  contraflow, *6-35*, 6-38, 6-80
  described, 6-31
  development of, 6-32
  dual, *6-35*, 6-39, 6-40, *6-63*, 6-91

bus lanes (*continued*)
enforcement, *2-33*
interior, 6-34, 6-38
intermittent, 6-36
observed travel time savings, 6-39
offset, 6-34, 6-38
planning guidelines, 6-37, 6-38
reliability, impact on, 6-40
service volumes, 6-21
travel time, impact on, 6-39
types, 6-34, *6-35*, 6-62, *6-63*, 6-80
use of parking restrictions to create, 6-58
bus operations
bus lanes, impact of, 6-39
bus stop consolidation, impact of, 6-55
bus stop relocation, impact on, 6-54
busways, impact of, 6-28
curb extensions, impact of, 6-51
left-side running, 10-7
managed lanes, impact of, 6-28
median busways, impact of, 6-39
movement restriction exemptions, 6-57, *6-58*
operational tools, 6-53 to 6-59
parking restrictions, 6-58
passing opportunities, 2-38, 6-5, 6-14, 6-22, 6-33, 6-56, 6-63, 6-81, 6-91, 10-7
queue jumps, impact of, 6-48
transit signal priority, impact of, 6-44
bus rapid transit, 2-5, 4-39, *6-47*
facility sizing, 6-98, 6-100
fare collection, 10-19
stations, 10-7
bus stop consolidation
impact on, 6-55
bus stop failure, *6-3*, **6-5**, 6-7, 6-18, 6-63
design values, 6-61, 6-64
loading area capacity, relationship to, *6-66*
Z values, 6-65
bus stop position. *See* on-line stops *and* off-line stops
bus stop relocation, 6-53
bus stop relocation
bus operations, impact on, 6-54
bus stop spacing, 3-23, 3-39, 6-10
speed, impact on, 3-42, *3-43*
bus stops, *6-15*, 10-5, *See also* stations
capacity, 6-16, 6-77
consolidation, 6-54
critical. *See* critical stop
defined, 6-15
design, 6-62
freeway, 6-14
location, **6-12**, 6-62
location, impact on capacity, 6-80
off-street, 6-14, 10-31
on-street, 10-34
passenger arrival patterns, 4-28
relocation, 6-53
spacing, 6-58, 6-87, 6-91
bus streets, 6-32
bus transit. *See also* bus
bus mode, 2-5
bus rapid transit. *See* bus rapid transit
capacity, 6-60 to 6-85
capacity, illustrative, 3-10
commuter bus. *See* commuter bus
electric trolleybus. *See* electric trolleybus
overview, 2-2
planning-level capacities, 6-20
shoulder use, 6-30
speeds, illustrative, 3-12
submodes, 2-5
vehicle types, 2-2
bus tunnels, 6-27
bus volumes
speed, impact on, *3-36*, *6-14*, 6-92
bus-bus interference, 3-35, 6-14, 6-87, 6-93
busways, 6-11, 6-19, 6-26, 6-81
at-grade, 6-26, *6-27*
bus operations, impact on, 6-28, 6-39
downtown bus distribution, 6-27
grade-separated, 6-26, 6-80
impact on bus operations, 6-28
median, 6-26, *6-27*, **6-32**, *6-33*
planning guidelines, 6-29
speed, 6-11
stations, 10-7
stations, multiple platform, 6-79
busways, median, 6-80
cable cars, 2-26, 8-78

capacity, 1-6
adjacent lane, 6-83
aerial lifts, *8-89*
aerial ropeways, 8-8, 8-77
aerial ropeways, calculation example, 8-120
aerial tramways, *8-88*
airport transit systems, 2-21, 8-77
automated guideway transit, 8-8, **8-75**
automated guideway transit, calculation example, 8-118, 8-119
automatic train operation, impact of, 8-21
availability, 4-31
BRT facility sizing applications, 6-100
bus facilities, 6-19, 6-81
bus lanes, 6-22
bus method, input data, 6-61
bus stop, 6-16, 6-77
bus stop location, impact of, 6-80
bus transit, 6-60 to 6-85
calculation example, bus, 6-103
city block length as capacity constraint, 8-12
commuter rail, 8-8, 8-14, **8-67**, 8-70, 8-72
commuter rail, calculation example, 8-117
commuter rail, means of increasing, 8-72
concepts, 3-4
constraints, 2-10
consumers of track capacity, commuter rail, 8-68
demand-responsive transit, 7-1, 7-3, **7-6 to 7-8**
design, 1-7, 3-6, 6-15, 6-64, *6-66*, 8-9, 8-13, 8-15, 8-24, 8-30, 9-29, 10-51, 10-59
designing for future growth, 8-81
diagnosing and treating capacity issues, 6-100
dock, 9-27
dock exit, 9-24
doors, impact of, *3-40*
doorway, 10-17, 10-39, 10-40
dwell time variability, impact of, *3-25*
dwell time, impact of, *3-25*, *3-26*
elevators, 10-28, 10-53, 10-54
escalators, 10-27, 10-51
evaluating fare collection technology changes, 6-98
facility selection applications, 6-98
factors influencing, 3-6
faregates, 10-19, 10-42
faregates, emergency evacuation, 10-43
ferry auto-deck, 9-7
ferry berth, 9-22
capacity (*continued*)
ferry berth, calculation example, 9-33
ferry transit concepts, 9-3
grade, impact of, *3-33*
heavy rail, calculation example, 8-108, 8-112
illustrative by mode, 3-8
inclined planes, *8-88*
junction, calculation example, 8-111
junctions, 8-70
light rail, 8-8, 8-55
light rail, in exclusive lanes, *8-87*
loading area type, impact of, 3-41
loading areas, **6-15**, 6-64, **6-70**, 10-32
maximum, 3-5, 3-6, 6-15, 6-64, 6-87, 6-91, 6-93, 8-9, 8-79, 9-29, 10-51, 10-59
mixed-traffic operation, 6-23
mode selection applications, 6-98
moving walkways, 10-47
number of loading areas, *6-18*
number of loading areas, impact of, 3-41
operating environment, impact of, 3-30, 3-33, *3-34*
operating margin, impact of, *3-26*
operation at, 3-8
overview, 3-3
passenger, 1-7, 3-7, 6-19, 6-20
passenger service time, impact of, 3-39, *3-40*
passenger, calculated based on railcar length, 8-66
pedestrian, 10-13, 10-22, 10-38, 10-40
person, 1-7, **3-4**, 3-8, 6-19, 6-84, 6-85, 6-129, 8-9, 8-12, 8-65, 8-74, 8-80, 9-28
platform exit, 10-3
power supply as constraint, 4-41, 8-12, 8-61
productive, 3-8
rail system design, impact of, 8-40
rail transit, 8-44 to 8-80
rail transit, general methodology, 8-44
railcar supply constraints, 8-9, 8-12
ramps, 10-54
reliability, balancing with, 8-54
right-turn, 6-80
ropeways, 8-8, 8-77
single-track, calculation example, 8-115
skip-stop operation, impact of, 6-56, 8-31
stairways, 10-24, 10-26, 10-48, 10-50
station approach speed, impact of, *8-15*
terminal stations, 8-6, 8-70
theoretical. *See* capacity, maximum

capacity (*continued*)
three or four tracks, impact of, 8-31
track ownership and usage as constraint, 8-68
traffic blockage at traffic signals, 6-79
traffic volumes, impact of, *3-32*
train signaling, impact of, *3-32*
turnbacks as capacity constraint, 8-6
vehicle, 1-7, **3-6**, 8-3, 8-4, 8-5, 8-7, 8-8, 8-9, 8-41, 8-44, 8-64, 9-5, 9-21, 9-27, 10-7
vehicle floor height, impact of, *3-40*
vehicle–platform interface, impact of, 3-38
volume-to-capacity ratio check, 6-84
walkways, 10-20, 10-21, 10-45
captive riders, 4-3
cars, rail. *See* railcars
catamarans. *See* ferry transit, vessel types
choice riders, 4-2, 4-24
circulation area. *See* platform, circulation area
clearance time
bus, 6-8, 6-16, 6-70
bus, estimating, 6-71
ferry departure, 9-16, 9-21, 9-22, 9-23, 9-28
light rail, 8-58
platform. *See* platforms, clearance time
clearing time, 8-13
close-in time, 8-21, 8-51
comfort, 4-35
commuter bus, 2-5
commuter rail, **2-18**, *2-19*
capacity, 8-14, **8-67**, 8-70, 8-72
capacity methodology, lines not shared with other trains, 8-44
capacity, calculation example, 8-117
comfort, 2-20
consumers of track capacity, 8-68
defined, 2-18
dwell times, 8-71
fare collection, 10-19
freight railroad relationships, 8-68
infrastructure improvements, 8-73
mode-specific capacity issues, 8-8
passenger flows, 8-71
passenger loads, 2-20
person capacity, 8-74
positive train control, 8-16
ridership response to changes in headway, 4-38
scheduling, 2-19
commuter rail (*continued*)
seating capacities, 8-75
speed, 8-74
stations, 10-9
track ownership and usage as capacity constraint, 8-68
train length, 2-20, 8-75
wheelchair access, 8-39, *8-40*
complaint and compliment tracking, 5-37
complementary paratransit. *See* ADA paratransit
comprehensive operational analysis, 5-75
comprehensive planning, 5-71
constraining headway. *See* headway, minimum
corridor planning, 5-77
cost
analysis, 8-105, 10-63, 10-64, 10-69
automobile usage, 4-35
capital, 2-16, 2-29, 2-34, 3-3, 3-16, 3-19, 4-21, 4-40, 4-41, 5-3, 5-22, 5-94, 6-25, 6-28, 6-33, 6-37, 6-44, 6-45, 6-48, 6-51, 6-98, 6-119, 8-6, 8-16, 8-19, 8-35, 8-42, 8-44, 8-55, 8-59, 8-72, 8-80, 8-90, 8-100, 8-102, 9-4, 9-11, 10-11, 10-13, 10-30, 10-32, 10-34, 10-35, 10-36, 10-37, 10-58, 10-62
generalized, 4-9, 10-71
operating, 2-2, 2-8, 2-30, 2-36, 3-3, 3-10, 3-13, 3-16, 3-19, 3-39, 4-20, 4-32, 4-34, 4-40, 4-41, 5-3, 5-6, 5-20, 5-22, 5-24, 5-30, 5-53, 5-54, 5-58, 5-60, 5-64, 5-65, 5-67, 5-73, 5-78, 5-84, 5-94, 6-3, 6-31, 6-33, 6-45, 6-51, 6-99, 6-130, 7-3, 7-6, 7-7, 7-8, 8-19, 8-21, 8-31, 8-67, 8-90, 8-102, 9-4, 9-18, 10-13, 10-24, 10-28, 10-32, 10-37
operations, 9-11
out-of-pocket, 4-15, 4-35
parking, 6-24
ridership, relationship to, 4-37
critical station, 8-44
critical stop, 6-19, 6-22, 6-54, 6-81, 6-82, 6-87
crossing, rail line. *See* junctions
crossovers, 8-6, 8-99, 8-101
crush loading, 8-9
curb extensions, **6-49**, *6-50*, 6-100, *8-23*
bus operations, impact on, 6-51
calculation example, effect on bus capacity and speed, 6-117
planning guidelines, 6-50
customer relations, 4-36
customer satisfaction research, 4-7
customer satisfaction surveys, 5-37
customer service
as quality of service factor, 5-36
dark territory, 8-73

deceleration
time, bus, 6-88
delay
acceleration. *See* delay, deceleration
deceleration, 3-11, 3-23, 3-28, *6-3*, **6-4**, 6-10, 8-7
harbor traffic, 9-16, 9-17, 9-22
pedestrian, 5-16
pedestrian, street crossing, 5-15
person, 6-25, 8-9
queue service, 6-75
reentry, *6-3*, 6-9, 6-16, 6-58, **6-72**, 6-73, 6-76, *6-77*
roadway traffic at grade crossings, 8-59
sources of, in mixed traffic, 6-32
speed, impact on, 3-11
traffic, 3-28
traffic signal, *6-3*, **6-8**
demand-responsive transit, 2-6
ADA requirements, 2-7, 2-10, 2-45
capacity, 7-6 to 7-8
capacity factors, 7-3
capacity issues, 7-1
capacity, illustrative, 3-10
coordinated transportation, 2-12
development as a mode, 2-6
dwell time, 7-4
flexible transit, 2-7
general public DRT, 2-8
human service transportation, 2-12
jitneys, 2-13
limited eligibility DRT, 2-9
passenger demand, 7-3, **7-8**
passenger demand, peak-period, 7-4
premium service, 2-11
quality of service applications, 5-78
quality of service framework, 4-17, 5-47
service area characteristics, 7-5
service area size, 7-4
service patterns, 2-42
speeds, illustrative, 3-12
transitioning to more or less flexibility, 2-46
trip patterns, 7-5
vehicle types, *2-6*
density, land use, 2-15, 3-19, 5-17
density, pedestrian, 10-20, 10-21, 10-38, 10-43
design load. *See* passenger loads, design
dial-a-ride, 2-6, *See also* demand-responsive transit
diesel light rail. *See* hybrid rail
diverge, rail line. *See* junctions
docks, 9-5, 9-21
doors, bus
configuration, 6-6
door channels, impact on dwell time, 6-67
dwell time, impact on, 3-38
opening and closing time, 6-6, 6-69
doors, train, 8-4
adjustable door height, 8-35, *8-36*
car-mounted lifts, 8-38, *8-39*
dwell time, impact on, 8-32
number of, impact on capacity, *3-40*
opening and closing times, 8-31
passenger flow rates, 8-24, *8-25*, *8-26*
passenger-actuated, 8-31
steps, 8-26
doorways, station, *10-17*
as part of an accessible route, 10-17
capacity, 10-17, 10-39, 10-40
capacity, emergency evacuation, 10-40
determining required number, 10-40
level of service, 10-39
overview, 10-17
pedestrian flow, 10-17
pedestrian headways, 10-40
revolving, 10-17
driver, train
minimum headway, impact on, 8-19
dwell time, 3-3, 3-7, 3-23 to 3-27, **3-23**, *6-3*, 6-61, 6-70, 6-87, 8-24, 8-112
bicycles, impact of, 6-70
bus, **6-6**, 6-67
capacity, impact on, 3-24, *3-25*, *3-26*
commuter rail, 8-71
critical, 8-5, 8-19, 8-44, 8-59
data collection procedure, 6-126
data collection sheet, 6-128
default values, bus, 6-67
demand-responsive transit, 7-4
doors, impact of, 8-32
estimating, bus, 6-66, 6-70
factors, 3-23, 8-7
fare collection, impact of, 3-39
field measurement, 6-66
number of door channels, impact of, 6-67
number of door channels, impact on, 3-38
platform-mounted lifts, impact of, 8-39

dwell time (*continued*)
port, 9-14
rail transit, 8-3, 8-5, 8-7, 8-27, 8-96
rail transit, default values, 8-52
rail transit, estimating, 8-52
rail transit, estimating from passenger flows, 8-53
rail transit, estimating from similar systems, 8-52
rail transit, estimating from the same system, 8-53
rail transit, factors, 8-4
rail transit, observations, 8-28, 8-29, 8-53
ropeways, 8-79
speed, impact on, 3-27
timepoint holding, impact of, 6-70
transfers, impact of, 8-31
variability, **3-24**, *3-25*, 6-7, 6-61, 6-64, 6-69, 6-70, 8-4
wheelchairs, impact of, 6-70, 8-34
elasticity
concept, 4-37
fare changes, 4-39
headway delay variation, 4-38
service "streamlining", 4-39
service expansion, 4-38
service frequency, 4-37, 4-38
unplanned service loss, 4-38
electric trolleybus, 2-5, 8-59
elevators, 8-40, *10-28*
availability, *10-16*
boarding and alighting time, 10-53
capacity, 10-28, 10-53, 10-54
emergency evacuation, 10-54
inclined planes, use for access, *8-40*
level of service, 10-53
location, 10-28
maintenance, 10-28
number of, 8-8
operating characteristics, 10-53
out-of-service, 4-30, 4-31, 10-28
pedestrian space, 10-53, 10-54
public, 2-24
travel time, 10-53
wait time, 10-53
embarking and disembarking time, 9-23, 9-25, 9-26, 9-28
autos, 9-26
parameters, 9-25
emergency evacuation, 10-3, 10-46, 10-47, 10-51, 10-52, 10-54, 10-57
capacity, doorways, 10-40
consideration alongside daily circulation needs, 10-3
faregates, 10-43
stairways, calculation example, 10-79
environmental justice analysis, 5-75, 5-76
escalators, *10-27*
capacity, 10-27, 10-51
destermining required number, 10-52
emergency evacuation, 10-3, 10-4, 10-52
number of, 8-8
platform clearance, role in, 8-33
public, 2-24
queuing area, 10-27, 10-52
queuing area, calculation example, 10-82
speed, 10-27
stairways, supplement to, 10-26, 10-49
usage, 10-26
wait time, 10-52
width, 10-27
excess platform wait time, 5-28, 5-32
excess wait time, 4-38, 5-28, **5-31**, 5-40, 5-92, 5-93, 5-95
exclusive lanes
bus, 6-12, **6-34**
defined, 3-28
light rail, 8-13, 8-57, 8-87
express service
commuter rail, 8-69, 8-70
rail transit, 8-31
failure rate. *See* bus stop failure
fare collection, 3-3, 3-39, 3-41, 6-6, 6-7, 6-67, 6-98, 8-26
bus, **6-7**, 6-8
bus rapid transit, 10-19
commuter rail, 10-19
dwell time, impact on, 3-39
ferry transit, 9-9, 9-15, 9-23, 9-24, 9-26, 10-10
ferry transit, vehicles, 9-8
heavy rail, 10-9, 10-19
light rail, 10-19
proof-of-payment, 3-39, 8-32, 9-15, 10-7, 10-8, 10-9
rail transit, on-board, 8-32
speed, impact on, 3-41, *3-42*
ticket validators, 10-42

fare collection method change
calculation example, bus capacity and speed, 6-113
fare purchase, 9-8, 9-15
addfare, 10-19
commuter rail, 10-9
complexity, 10-18
heavy rail, 10-9
rail transit, on-board, 8-32
service times, ticket machines, 10-41
stations, 10-18
ticket booths, 10-18
ticket machines, *10-18*
farebox recovery, 3-19, 5-17
faregates, *10-19*
capacity, 10-19, 10-42
capacity, emergency evacuation, 10-43
contributors to lower flow rates, 10-43
described, 10-19
determining number of, 10-43
headway, 10-42
maintenance, 10-43
pedestrian flow, 10-19
types, 10-19
fares, 2-10
ridership, impact on, 4-39
far-side stop. *See* bus stops, location
ferries. *See also* ferry transit
auto, 9-4, 9-5, 9-6
auto equivalent units, 9-7
capacity, auto, 9-7
capacity, passenger, 9-29
capacity, vehicle, 9-29
en route stops, 9-29
headway, entering/exiting vehicles, 9-26
loading, 9-7
operating costs, 9-4
speed, entering/exiting vehicles, 9-26
terminals. *See* terminals, ferry
travel time, 9-4
vessels. *See* ferry transit, vessel types
ferry transit. *See also* ferries
capacity concepts, 9-3
capacity, illustrative, 3-10
capacity, regulatory, 9-3
dock capacity, 9-27
fare collection, 9-9, 9-15, 9-23, 9-24, 9-26
fare collection, vehicles, 9-8
ferry transit (*continued*)
integration with other transit services, 9-4
overview, 2-27
person capacity, 9-28
role of, 9-1
security screening, 9-9
service planning, 9-18
service types, 2-28
speed concepts, 9-4
speeds, illustrative, 3-12
terminal examples, 9-11
terminal siting, 9-11
terminals. *See* terminals, ferry
travel time, 9-22
use in emergencies, 2-28
vessel capacity, 9-21
vessel types, 2-29, 9-3
flexible route segments, 2-45
flexible transit service, 2-7
flow
pedestrian, 10-25, 10-38, 10-43, 10-65
pedestrian, relationship to space, *10-22*, *10-26*
stairways, 10-48
freeboard, 9-5, 9-6, 9-10, 9-13
frequency, 4-28, 4-31, 5-3, 5-40, 5-71, 5-72, 5-73, 5-75, 5-76
costs associated with changes, 4-40, 5-3
ferry, 9-29
land use density capable of supporting, 3-19
quality of service. *See* quality of service, frequency
ridership, impact on, 4-37
funicular railways. *See* inclined planes
funitels, 2-25, *See also* aerial ropeways
g/C ratio, 6-8, 6-16, 6-62, 6-71, 6-79, 6-83
illustrative values, 3-30
gangways, 9-10, 9-16, 9-17, 9-21, 9-22, 9-24, 9-25
gondolas, 2-25, *See also* aerial lifts
grade crossings, 8-58, 8-69, 8-72, 8-88
grades, 5-14
capacity, impact on, *3-33*
minimum headway, impact on, 8-48, *8-49*, 8-50
service coverage, impact on, 5-14
walking speed, impact on, *4-19*
grade-separated busways. *See* busways, grade-separated
green extension, 6-99
HCM. *See Highway Capacity Manual*

headway
- adherence, 5-28, 5-31, 8-27
- components, 8-27, 8-29, *8-30*
- impact of voltage drops, 8-48
- junctions, 8-60
- minimum, *8-3*, 8-4, 8-6, 8-13, 8-14, 8-19, *8-47*, *8-48*, 8-50, *8-51*, 8-56, 8-57, 8-59, 8-61
- minimum, impact of grades, 8-48, *8-49*, 8-50
- minimum, impact of voltage drops, *8-49*, 8-50
- minimum, on-street operation, 8-57
- minimum, single-track two-way operation, 8-55
- minimum, station departures adjacent to grade crossings, 8-58
- non-interference, 8-5, 8-59
- pedestrian, 10-40
- rail transit, 8-41
- rail transit observations, 8-28, 8-29

headway adherence, 4-32, 5-30, 6-130, 8-29
- example calculation, 5-31, 5-91

heating, 4-35, 4-36, 10-7, 10-11

heavy rail, ***2-14***
- capacity methodology, 8-44
- capacity, calculation example, 8-108, 8-112
- capacity, planning-level, 8-82
- fare collection, 10-19
- linear loading levels, 8-35
- passenger boarding, 8-25
- platform screen doors, use of, 8-32
- stations, 10-8

high-speed rail, 2-14

Highway Capacity Manual, *1-18*, 3-4, 4-1, 4-6, 5-2, 5-16, 5-20, 5-34, 5-39, 5-40, 5-41, 5-95, 6-72, 6-74, 6-79, 6-81, 6-83, 6-86, 6-90, 6-99, 10-44

hours of service, 5-72, 5-73, 5-75, 5-76, *See also* service span
- calculation, 5-8
- quality of service. *See* quality of service, hours of service

hovercraft. *See* ferry transit, vessel types

hybrid rail, *2-17*

inclined elevators, *2-23*, 2-24

inclined planes, **2-23**, *See also* ropeways
- cabin sizes, 8-80
- capacity, 8-78, *8-88*
- wheelchair access, 8-40

inclines. *See* inclined planes

information, 4-30, 4-36, 5-38, 10-9, 10-15, *10-16*
- audible, *10-16*
- elevator availability, *10-16*
- for persons with disabilities, 10-16
- public address systems, 10-17
- real-time, 4-31, 4-35, 10-5, 10-7, 10-9, 10-11, *10-16*
- real-time, impact on value of time, 4-14
- stations, 10-15
- wayfinding. *See* stations, wayfinding

interlockings. *See* switches

intermodal terminals. *See* terminals, intermodal

international use of the manual, 1-11

in-vehicle time, 4-9, 4-29

jerk limitation time, 8-55

jitneys, 2-13

junctions, 8-3, 8-18, 8-44, 8-74, 8-91, 8-100, 8-105
- capacity, 8-70
- capacity, calculation example, 8-111
- described, 8-6, *8-7*
- flat, *8-7*, *8-60*, 8-61
- minimum headway, 8-7, 8-60
- operation, *8-7*

kiss-and-ride, 8-33, 10-6, 10-8, 10-9, 10-35, *10-36*

landscaping, 10-10

layover, terminal, 8-63

lean bars, 10-11, 10-30

level of service, 1-15, 5-1, 5-39
- design, use in, 10-13
- doorways, 10-39
- elevators, 10-53
- headway adherence, 5-31
- managed lanes, 6-81
- multimodal, 5-39
- multimodal, calculation example, 5-93
- passenger waiting areas, *10-14*
- pedestrian, 10-2, **10-13**
- pedestrian, use in station design, 10-13
- platforms, 10-55
- queuing areas, 10-14, 10-55
- ramps, 10-54
- stairways, 10-48
- waiting areas, 9-9, 10-14, 10-55
- walkways, 10-14, 10-44, 10-45

lifts, platform
- dwell time, impact on, 8-39

light rail, **2-16**, *2-17*
capacity, **8-44**, 8-55
capacity, exclusive lane operation, *8-87*
capacity, planning-level, 8-82, *8-83*
capacity, single-track, *8-86*
clearance time, 8-58
exclusive lanes. *See* exclusive lanes, light rail
fare collection, 10-19
low-floor, 8-24, 8-34, 8-35, 8-36
mode-specific capacity issues, 8-8
on-demand stops, 8-31
single-track operation, 8-86
stations, 10-8
lighting, 4-36, 10-10, 10-11, *10-12*
line capacity. *See* capacity, vehicle
load factor, 5-22, 5-41
loading areas, *6-15*
angle, *6-16*, *10-33*
capacity, 6-15, 6-64, **6-70**, 10-32
defined, 6-15
designs, 6-16
drive-through, *6-16*, *10-33*
effectiveness, 6-16, 6-22, 6-77, 6-78
linear, 3-41, 6-16, 6-17, 6-18, 6-77, 6-78, 10-32, *10-33*
non-linear, *3-41*, 6-16, 6-78
number of, impact on capacity, 3-41
off-line, 3-41
on-line, 3-41
sawtooth, *6-16*, 6-78, 10-32, *10-33*
stations, 10-31
types, 10-32
types, impact on capacity, 3-41
utilization, 6-17
loading diversity, **8-10**, 8-65, 8-77, 8-79
commuter rail, 8-75
load–unload conflict point, *9-9*, 9-10, 9-14, 9-15
local data
use of, 1-8, 10-39, 10-40
long-range transportation planning, 5-71, 5-83
LRT. *See* rail transit, light rail
maintenance, 3-13, 3-37, 4-5, 4-21, 4-30, 4-33, 4-35, 4-40, 5-6, 5-28, 5-52, 6-26, 6-95, 8-12, 8-19, 8-31, 8-41, 8-42, 8-68, 8-90, 8-93, 8-101, 8-102, 8-116, 10-11, 10-24, 10-28, 10-43, 10-49, 10-59, 10-79
managed lanes, 6-11, 6-19, 6-26, **6-29**, *6-30*, 6-81
bus operations, impact on, 6-28
impact on bus operations, 6-28
planning guidelines, 6-28
maneuvering time, 9-16, 9-17
Manual on Uniform Traffic Control Devices, *6-47*, 6-57
maps, 5-71, 10-11, 10-71
maximum design load, 6-129, 8-9, 8-65
measurement units, 1-11
median busways. *See* busways, median
merge, rail line. *See* junctions
mid-block stop. *See* bus stops, location
missed trips, 5-28
mixed-traffic operation, 6-24, 6-31
capacity, 6-23
monohulls. *See* ferry transit, vessel types
monorail, **2-22**
mooring, 9-16, 9-17
movement restriction exemptions. *See* bus operations, movement restriction exemptions
moving walkways, *10-23*
capacity, 10-47
described, 10-23
design factors, 10-24
queuing, 10-47
speed, 10-23, 10-47
multimodal level of service, 5-39 to 5-46
calculation example, 5-93
National Fire Prevention Association (NFPA) 130 standard. *See* NFPA 130
National Household Transportation Survey, *3-18*
National Transit Database, 2-1, 2-21, 3-19, 4-1, 4-5, 5-6, 5-8, 5-9, 5-41, 5-75, 5-76
near-side stop. *See* bus stops, location
NFPA 130, 1-18, 8-33, 10-2, 10-3, 10-40, 10-43, 10-46, 10-47, 10-51, 10-52, 10-54, 10-57, 10-63
non-interference headway
calculation, 8-54
no-shows, 5-67
off-line stops, 3-38, ***6-9***, **6-62**, 6-91
on-line stops, 3-38, ***6-9***, **6-62**
on-time performance, 4-32, 5-28, 5-57
calculation example, 5-90
defined, 5-29
operating costs, 6-24, 6-39

operating environment, 3-28 to 3-37, 6-11
automated guideway transit, 2-21
capacity, impact on, 3-30, 3-33, *3-34*
exclusive, 2-34, 3-29
grade-separated, 2-35, 3-29
mixed-traffic, 2-31, *2-32*, 3-29
overview, 2-31
reliability, impact on, 3-37
semi-exclusive, 2-32, 3-29
speed, impact on, 3-35, 3-36, *3-37*
operating margin, 3-6, 3-24, 6-7, 6-16, 6-64, 6-65, 6-70, 8-4, 8-15, 8-24, **8-27**, 8-29, 8-35, 8-44, 8-53, 8-61, 8-77, 9-17, 9-23
balancing capacity and reliability, 8-54
capacity, impact on, *3-26*
default values, 8-30
estimating, 8-30
selecting, 8-54
operating policies. *See* service standards
organization of the manual, 1-2 to 1-5
paratransit, 2-7, *See also* ADA paratransit *and* demand-responsive transit
park-and-ride lots, 4-18, 6-26, 8-33, 9-4, 10-7, 10-8, 10-9, *10-34*
characteristics of successful facilities, 4-24
demand management, 4-27
market area, 4-26, *4-27*, 5-21
overview, 10-34
parking garages, 10-34
sizing, 10-35
transit-oriented development, 10-34
types, 4-25
user characteristics, 4-24
parking, 6-12, 6-49, 6-95
restrictions, 6-58
passenger boarding, 6-6, 6-7, 8-8, 8-32, 8-35, *See also* passenger service time
aerial ropeways, 8-40
boarding lost time, 6-5, 6-17, 6-69
bus, 2-3
busways, 6-26, 10-7
commuter rail, 2-20, 8-72
dwell time, impact on, 6-66
ferries, 9-15
heavy rail, 8-35
light rail, 2-18
loading height, 8-35, 8-36
passenger capacity. *See* capacity, passenger
passenger circulation. *See also* pedestrians, circulation
vessels, 9-10
passenger circulation area. *See* platform, circulation
passenger demand
amenities, impact of, 10-10
demand-responsive transit, 7-3, 7-4, **7-8**
demographics, relationship to, 3-18
estimating, 4-37, *See* passenger demand, estimating
fares, impact of, 4-39
ferry operations, impact on, 9-21
land use, relationship to, 3-18
peak-hour demand variation, 3-17
quality of service, impact of, 4-3, 4-37
reliability, impact of, 4-38
response to packages of improvements, 4-39
service expansion, impact of, 4-38
service frequency, impact of, 4-37
time-of-day variation, 3-15
transportation demand management, relationship to, 3-21
travel time, impact of, 4-38, 6-39
passenger environment surveys, 5-38
passenger holding area, 9-6, 9-9
passenger loads, 3-3, 5-41, 5-72, 5-73, 5-75, 5-76, 5-77, 5-78, 6-6, 6-7, 8-4, 8-9, *8-105*
as quality of service factor, 4-32, 5-22
automated guideway transit, 8-77
bicycles, space occupied by, 4-22
body ellipse, 5-25
costs associated with changes, 4-40
crush loading, 8-66
design. *See* maximum design load
ferry transit, 9-3, 10-10
load control, 9-9
on-board fare machines, access to, 8-32
policy, 6-84
quality of service. *See* quality of service, passenger loads
real-time information, effect of, 4-31
service disruptions, effect of, 8-11
special events, 8-27, 8-43
standing passenger area, 5-27
value of time, impact on, 4-12, *4-13*
worn and carried objects, space occupied by, 5-26
passenger queuing area. *See* platform, queuing area
passenger rail service
intercity, 2-14

passenger service time. *See also* passenger boarding *and* embarking and disembarking time
bus transit, *6-3*, 6-6, **6-7**, 6-16, 6-68, 6-98
capacity, impact on, 3-39, *3-40*
data collection procedure, 6-126
data collection sheet, 6-127
ferry transit, calculation example, 9-30
rail transit, 8-4, 8-24, 8-32
special events, 8-26, 8-43
speed, impact on, 3-11
wheelchair, 8-34, 8-38
passenger traffic density, 3-9
passenger value of time, 4-9 to 4-14
access, transfer, and wait time, 4-11
bus stop amenities, impact of, 4-13
in-vehicle, 4-9
passenger loads, impact of, 4-12, *4-13*
platform crowding, impact of, *4-12*
real-time arrival information, impact of, 4-14
reliability, impact of, 4-13
trip duration, 4-11
trip purpose and mode, 4-10
passenger waiting areas, 6-49, 9-15, 9-25
amenities, space used by, 10-12
level of service, *10-14*
sizing at bus stops, 10-5
pass-ups, 3-5, 4-31, 5-21, 6-19, 6-129, 8-9
peak-hour factor, 6-21, **6-61**, 6-100, 8-33, 8-65, 8-74, 8-77, 8-79, 9-29
default values, 6-85, 8-66
rail transit, observed, 8-66
pedestrian crossings, 6-49, 6-62, 6-90
impact on capacity, 6-80
pedestrian environment, 4-20, 5-41, 6-11, 6-54
pedestrian flow. *See* pedestrians, flow
pedestrian level of service. *See* level of service, pedestrian
pedestrian space
elevators, 10-53
pedestrian time-space. *See* pedestrians, time-space
pedestrians
access to transit, 5-11
buffer area, 10-38, 10-45, 10-56
buffer width, 10-21, 10-45
capacity, 10-22, 10-38, 10-40
circulation, 8-96, 10-19, 10-20, 10-59, 10-65
circulation areas, multi-activity, 10-22, 10-46
pedestrians (*continued*)
circulation areas, multi-activity, application example, 10-86
circulation areas, multi-activity, calculation example, 10-84
conflicts, 10-20, 10-24
crossing volumes, 6-22
demand, 10-45
density, 10-20, 10-21, 10-38, 10-43
flow, 10-17, 10-38, 10-43, 10-48
flow, relationship to space, *10-22*, *10-26*
space, 9-25, 10-13, 10-21, 10-25, 10-26, 10-38, 10-44, 10-48, 10-52, 10-54, 10-55
space, relationship to speed, *10-21*
speed, 9-25, 10-20, 10-21, 10-25, 10-38, 10-43, 10-54
time-space, 10-23, 10-38, 10-46, 10-47
peer reviews, 5-76
performance measures. *See also* service measures *and* quality of service
pedestrian circulation, 10-70
peer reviews. *See also* service measures *and* quality of service
person capacity. *See* capacity, person
PHF. *See* peak-hour factor
platform screen doors, 6-26, **8-32**, 10-8
platform-mounted lifts, 8-39
platforms
clearance time, 8-33, 10-59
configuration, 8-6, 8-96
crowding, 8-9, 8-32, 8-41
crowding, impact on value of time, 4-12
crowding, value of time, impact on, *4-12*
dead areas, 10-56
design, *6-6*, 8-7, 10-29, 10-55, 10-56
design, impact on line capacity, 8-33
dual-faced, 8-63
elements, 10-55, *10-56*
emergency evacuation, 8-33, 10-52, 10-57
entrance and exit locations, 8-10
exit capacity, 10-3
height, 3-38, 8-35, 10-8, 10-9
height, impact on capacity, *3-40*
high-level, 8-35, *8-36*, 8-39
length, 8-12, 8-81, 10-8, 10-9, 10-55
level of service, 10-14, 10-29, 10-55
location, 10-3, 10-15, 10-29
location options at grade crossings, *8-58*
maximum slopes, ADA, 8-38

platforms (*continued*)
mini-high, 8-34, 8-35, 8-37, 8-39
passenger distribution, 6-5, 8-10, 8-33, 10-9, 10-29, 10-56
position, 3-38
profiled, 8-35, 8-37, *8-38*
queuing area, 10-27, 10-29, 10-55, 10-56
separate unloading, *8-63*
sizing, 10-56
sizing for special events, 8-43
sizing to accommodate loads from disabled trains, 8-41
sizing, calculation example, 10-80
vehicle–platform interface. *See* vehicle–platform interface
waiting areas, 10-29
wheelchair loading, 8-39
width, 8-33, 10-55
platooning, 6-15, **6-56**, 6-62, 6-64, 6-78, 6-82
point deviation service, 2-44
population characteristics
service coverage, impact on, 5-14
positive train control, 8-16
power supply
as capacity constraint, 4-41, 8-12, 8-44, 8-61
PowerPoint presentations, 1-5
power-to-weight ratio, 8-67, 8-74
preemption
traffic signal, 6-40, 8-22, 8-59
productive capacity, 3-8
proof-of-payment. *See* fare collection, proof-of-payment
Public Transportation Fact Book, *2-1*
público, 2-13
quality of service
access to transit, 5-8
activity center analysis applications, 5-72
amenities, 4-35, 10-10
appearance and comfort, 4-35
capacity availability, 4-31
comprehensive operational analysis applications, 5-75
comprehensive planning applications, 5-71
corridor analysis applications, 5-73
corridor planning applications, 5-77
cost, 4-35
customer relations, 4-36
customer satisfaction research, 4-7
quality of service (*continued*)
customer service, 5-36
days of service QOS, demand-responsive, 5-52
defined, 4-6
demand-responsive transit, 5-75
demand-responsive transit operations applications, 5-78
factors, 4-7, 4-15, 4-17 to 4-36, *See also individual factors*
framework, demand-responsive transit, 4-17, 5-47
framework, fixed-route transit, 4-17, 5-3
frequency, 5-3
frequency QOS, fixed-route, 5-4
headway adherence QOS, fixed-route, 5-31
hours of service QOS, demand-responsive, 5-54
hours of service QOS, fixed-route, 5-7
impact on service costs, 4-40
information availability, 4-30
long-range transportation planning applications, 5-71
multimodal level of service, 5-39
no-show QOS, demand-responsive, 5-69
no-shows, 5-67
on-time performance QOS, demand-responsive, 5-58
on-time performance QOS, fixed-route, 5-30
overview, 1-6
passenger demand, impact on, 4-3
passenger load QOS, vehicles designed for mostly seated passengers, 5-23
passenger load QOS, vehicles designed for mostly standing passengers, 5-24
passenger loads, 4-32, 5-22, 6-19, 8-67
performance measures applicable to peer reviews, 5-77
reliability, 4-32, 5-28, 5-56
response time, 5-47
response time QOS, demand-responsive, 5-48
ridership, impact on, 4-37
safety, 5-77
service coverage, 5-74
service coverage QOS, fixed-route, 5-10
service planning applications, 5-77
service span, 5-6, 5-51
spatial availability, 4-17
statewide transportation planning applications, 5-75
temporal availability, 4-28
transit development plan applications, 5-76
transit preferential treatments, effect of, 6-24

quality of service (*continued*)
transit–auto travel time ratio QOS, fixed-route, 5-35
travel time, 4-34, 5-33, 5-63
travel time QOS, demand-responsive, 5-64
trips not served, 4-31
trips turned down QOS, demand-responsve, 5-62
walking access, 5-9
queue bypass
freeway ramp, 6-30
queue jumps, 6-9, 6-25, *6-46*, 6-58, 6-99, *8-23*
bus operations, impact on, 6-48
described, 6-46
planning guidelines, 6-48
transit signal priority, in conjunction with, 6-47
queuing areas. *See also* platforms, queuing areas
escalators, calculation example, 10-82
queue analysis, 10-61
queuing corridor, 9-9
rail operations
accommodating track maintenance, 8-101
analytic needs, 8-89
control and scheduling measures, impact on reliability, 4-34
disabled trains, accommodating, 8-41, *8-42*
disabled trains, impact of, 8-41
single-track, 8-42, 8-44
sketch-planning tools, 8-102
terminals, 8-105
track maintenance, accommodating, 8-42
rail transit
advanced light rail transit, 2-15
aerial ropeways. *See* aerial ropeways
automated guideway transit. *See* automated guideway transit
cable cars. *See* cable cars
capacity, general methodology, 8-44
capacity, illustrative, 3-10
commuter rail. *See* commuter rail
designing for future growth, 8-81
heavy rail. *See* heavy rail
hybrid rail. *See* hybrid rail
inclined planes. *See* inclined planes
junctions. *See* junctions
light rail. *See* light rail
line merges, diverges, and crossings. *See* junctions
mixed freight and passenger operations, 8-2, 8-8, 8-14, 8-39, 8-68, 8-69, 8-70
monorail. *See* monorail
rail transit (*continued*)
operations planning, 8-90, 8-100, 8-105
overview, 2-13
planning-level capacity analysis, 8-81 to 8-89
regional rail, 2-18
scheduling, 2-19
service planning, 8-90
signaling systems. *See* signals, train
sketch-planning tools, 8-102
speed restrictions, 8-3
speeds, illustrative, 3-12
streetcars. *See* streetcars
turnbacks. *See* turnbacks
vintage trolleys. *See* vintage trolleys
wheelchair access, 2-18, 2-20, 8-35, 8-34 to 8-40
railcars
availability, constraint on rail capacity, 8-9, 8-12
bi-level, 8-72
gallery, 8-72
passenger loading diversity, 8-10
ramps, *8-40*, 10-3, 10-27
capacity, 10-54
emergency evacuation, 10-54
level of service, 10-54
number of, 8-8
real-time information. *See also* information, real-time
passenger loads, impact on, 4-31
red truncation, 6-99
reentry delay. *See* delay, reentry
reference speed, 8-19
reliability, 4-33, 5-56, 5-73, 5-75, 5-76, 5-77, 6-24, 6-25, 6-39, 6-84, 8-44, 9-17
as quality of service factor, 4-32, 5-28
at maximum capacity, 6-63
bus, 6-5, 6-95 to 6-97
bus lanes, impact of, 6-40
calculation example, 5-89
capacity, balancing with, 8-54
capacity, relationship to, 3-3
concepts, 3-13
conceptual reliability–throughput relationship, *8-17*
control and scheduling measures, impact on, 4-34
costs associated with changes, 4-41
factors, 3-13, 6-95
headway adherence, 5-31
importance of, 1-7, 3-3
operating environment, impact of, 3-37

reliability (*continued*)
quality of service. *See* quality of service, reliability
rail transit, 8-5, 8-16, 8-17, 8-29, 8-54
ridership, impact on, 4-38
scheduling and holding strategies, 6-96
service characteristics, relationship to, 6-96
use of AVL data, 6-97
value of time, impact on, 4-13
request stops, 2-45
response time, 2-10, 5-47
restrooms, 10-8, 10-9
ridership. *See* passenger demand
ridership estimation. *See* passenger demand, estimating
right turns, 6-12, 6-18, 6-22, 6-50, 6-51, 6-54, 6-62, *6-79*
adjustment factor, 6-80
capacity, 6-80
rights-of-way. *See* operating environments
roles of transit, 4-2
ropeways
capacity, 8-77
described, 2-25
mode-specific capacity issues, 8-8
person capacity, 8-80
types, 2-25
route cycle time, 6-8
route deviation service, 2-44
route network designs, 2-37
ruling headway. *See* headway, minimum
running time
speed, impact on, 3-11
safety, 4-20, 5-35, 5-94, 6-13, 6-48, 6-58, 8-3, 8-18, 8-20, 8-32, 8-50, 8-63, 9-6, 9-13, 10-15, 10-25, 10-34, 10-58
as quality of service factor, 4-34, 5-35
performance measures, 5-77
saturation flow rate, 6-79
default values, 6-75
sawtooth loading areas. *See* loading areas, sawtooth
schedule inconvenience time, 4-30
schedule recovery time, 8-24, 8-27, 8-30, 8-35, 8-41, 8-63, 10-31
security, 4-20, 4-21, 4-36, 9-9, 9-14, 9-15, 10-4, 10-7, 10-8, 10-9, 10-10, 10-11, 10-20
as quality of service factor, 4-34, 5-35
service coverage, 2-10, 4-18, 5-11, 5-55, 5-71, 5-74, 5-75, 5-76, 5-77
calculation example, 5-18, 5-79, 5-85
costs associated with changes, 4-40
coverage area, 5-11, 5-12
grades, impact of, 5-14
measuring, 5-10
population characteristics, impact on, 5-14
quality of service. *See* quality of service, service coverage
ridership, impact on, 4-38
street connectivity, impact of, 5-12
street crossing difficulty, 5-14
service denials, 4-31
service measures, 5-1
service patterns
demand-responsive transit, 2-42
fixed-route transit, 2-36, 6-54, *6-55*
service planning, 5-77, 9-18
service span, 2-10, 4-30, 5-6, 5-51, 5-71, *See also* hours of service
costs associated with changes, 4-40
quality of service. *See* quality of service, hours of service
service standards, 4-35, 5-1, 5-4, 5-22, 5-60, 5-75, 6-58, 7-3, 7-5, 8-9, 8-65
shelters, 4-36, 5-41, 6-49, 10-5, 10-10, 10-11, *10-12*, 10-29, 10-57
short turns, 8-41
shoulder use. *See* bus transit, shoulder use
sidings, 8-72, 8-73, 8-74, 8-102
signals, traffic, 8-57
cycle length, 6-8, 8-87
preemption. *See* preemption, traffic signal
priority. *See* transit signal priority
speed, impact on, *3-35*
transit, *6-47*
signals, train, 8-3, **8-18 to 8-23**
accommodating wrong-side running, 8-42
basic operation, *8-4*
blocks, 8-3, 8-19, 8-41, 8-70, 8-72, 8-73
blocks, shortening, 8-73
cab signaling, 8-13, 8-15, **8-19**, 8-45, 8-47, 8-50, 8-51, 8-83, 8-108
cab signaling, planning-level capacity, *8-84*
capacity, impact on, *3-32*
fixed-block, 8-13, 8-15, **8-18**, 8-45, 8-47, 8-50, 8-51, 8-83, 8-95
hybrid systems, 8-20

signals, train (*continued*)
minimum headway, effect on, 8-7
moving-block, 8-19, 8-21, 8-45, 8-50, 8-51, 8-61, 8-83, 8-108, 8-111
moving-block, planning-level capacity, *8-85*
railroad signaling, 8-70
safety, 8-20
signal aspects, 8-4, 8-18
simulation, pedestrian, 10-2, 10-9, 10-10
application example, 10-89
interpreting results, 10-73
model inputs, 10-69
model outputs, 10-70
multi-activity passenger circulation area analysis, 10-23
overview, 10-68
performance measure calculation, 10-58
simulation, rail transit, 8-2, 8-44, 8-48, **8-91 to 8-102**
applications, 8-91, 8-99
best practices, 8-105
double tracking, 8-72
dwell time, 8-51
evaluating crossover locations, 8-101
evaluating siding locations, 8-102
evaluating single-track operation, 8-102
model calibration and validation, 8-99
model inputs, 8-95
model outputs, 8-96
model types, 8-91
software features, 8-94
simulation, use of. *See also* simulation, pedestrian *and* simulation, rail transit
bus capacity estimation, 6-78
comparison to operating experience, 3-8
pedestrian circulation, 10-47
rail capacity estimation, 8-68
single-track operation
capacity, calculation example, 8-115
commuter rail, 8-69
planning-level capacity, 8-86
simulation, use for evaluation, 8-102
skip-stop operation, 6-15, 6-19, **6-55**, *6-56*, 6-62, 6-79, 6-81, 6-82
adjustment factor, capacity, 6-83
calculation example, bus capacity and speed, 6-115
capacity, impact on, 6-56, 8-31
impact on speed, 6-91
rail transit, 8-31
skip-stop operation (*continued*)
speed, impact on, 6-91
space, pedestrian. *See* pedestrians, space
special events, 3-4, 8-43, 10-43
special signal phasing. *See* transit signal priority, special signal phasing
speed. *See also* travel time
as part of multimodal level of service, 5-41
associated train stopping distance, *8-48*
average section, 6-93
base bus running time rate, 6-91
bus facility, 6-94
bus methodology, 6-86 to 6-94
bus stop failure, impact on, 6-5
bus stop spacing, relationship to, *6-10*
bus volumes, impact of, *3-36*, *6-14*, 6-92
calculation example, bus, 6-110
capacity, relationship to, 3-3
commuter rail, 8-74
comprehensive operations analysis applications, 5-75
concepts, 3-10
creep, 8-79, 8-121
dwell time, impact of, 3-27
escalators, 10-27
evaluating fare collection technology changes, 6-98
factors influencing, 3-11
fare collection, impact of, 3-41, *3-42*
ferry transit concepts, 9-4
grades, impact on, *4-19*
grade-separated busways, 6-11
illustrative by mode, 3-12
importance of, 1-7, 3-3
input data to bus method, 6-87
limits, curves and switches, 8-47
limits, turnouts, 8-48
line, ropeways, 8-78
moving walkways, 10-23, 10-47
operating environment, impact of, 3-35, 3-36, *3-37*
pedestrian, 9-25, 10-25, 10-38, 10-43
pedestrian, relationship to space, *10-21*
pedestrians, on walkways, 10-20
profile, example, *8-97*
rail maximum, by track class, 8-73
reference, 8-19
restrictions, 8-3, 8-18, 8-95
running, 6-88

speed (*continued*)
running time losses, bus, 6-90, 6-100
skip-stop operation, impact of, 6-91
station approach, 8-15, 8-47, 8-50, 8-51, 8-62
station approach, impact on capacity, *8-15*
stop spacing, impact of, 3-42, *3-43*
traffic signals, impact of, *3-35*
transit preferential treatment assessment applications, 6-99
unimpeded bus running time rate, 6-87
used for determining vehicle requirements, 6-98
vehicle–platform interface, impact of, 3-38
speed margin, 8-55
speed restrictions, 3-33
spreadsheets, 1-4, 8-2, 8-45, 8-56, 8-102, 8-105, 10-58
stairways, 10-24
ascending speed, pedestrian, *10-25*
bicycle stair channels, 10-36
capacity, 10-24, 10-26, 10-48, 10-50
capacity, impact of stair rise, 10-51
conflicts, 10-24
design factors, 10-48
determining number of lanes, 10-50
effective width, 10-48
emergency evacuation, 10-4, 10-51
level of service, 10-48
number of, 8-8
pedestrian flow rates, 10-25
pedestrian lanes, 10-24, 10-49
platform clearance, role in, 8-33
queuing, 10-26, 10-51
reverse flow, 10-24, 10-48
sizing, 10-26, 10-38, 10-49, 10-51
sizing, calculation example, 10-77
speed, pedestrian, 10-25
supplement to escalators, 10-49
width, 10-48
width, impact on capacity, 10-24
standard normal distribution, 6-64, *6-65*
standing passenger area
calculation, 5-27
statewide transportation planning, 5-75
station agent, 10-9
stations. *See also* terminals *and* bus stops
access for persons with disabilities, 10-2
alternative station location and features applications, 10-63
stations (*continued*)
alternatives analysis, 10-62
amenities, 4-35, 10-5, 10-6, 10-7, 10-8, 10-9, 10-10, 10-12, 10-29, 10-36
amenities, impact on value of time, 4-13
amenities,impact on ridership, 10-10
automated guideway transit, 10-8
bus rapid transit, 10-7
busway, 10-7
capacity issues, existing stations, 10-64
commuter rail, 10-9
comprehensive passenger circulation analysis, 10-65
critical, 8-51
design capacity, 10-2
emergency evacuation. *See* emergency evacuation
heavy rail, 10-8
horizontal circulation. *See* pedestrians, circulation
information provision, 10-15
light rail, 8-55, 10-7, 10-8
mezzanines, 10-3
multiple-platform, 6-79, *8-71*, 8-77
off-line, 8-77, 8-119
passenger circulation areas, multi-activity, 10-22, *10-23*, 10-46
pedestrian circulation, 10-52, 10-58, 10-59
platforms. *See* platforms
queuing areas, 10-47, 10-52
remodeling applications, 10-63
seating, 10-30
security elements, 10-4, *10-16*
streetcar, 10-8
terminals, sources of common delays, 8-64
terminals, train storage constraints, 8-70
turnaround time, 8-63
vertical circulation, 8-96, 10-3, 10-7, 10-24, *See also* elevators *and* escalators *and* ramps
waiting rooms, 10-30
walkways. *See* walkways
wayfinding, 10-9, 10-10, 10-15, 10-16
stop spacing. *See* bus stop spacing
stopping distance
as a function of speed, *8-48*
street connectivity, 4-20, 5-86
service coverage, impact on, 5-12
street crossing difficulty, 5-86
streetcars, **2-16**, *2-17*
stations, 10-8

string-line chart, *8-92*, 8-97, 8-103, 8-106
subways, 8-6, *See also* heavy rail
switches, 8-7, 8-18, 8-46, 8-47, 8-55, 8-59, 8-60, 8-70, 8-73, 8-77, 8-100
  speed limits, 8-48
synchronization time, 4-29
systen design, rail
  capacity, impact on, 8-40
telephones, 4-36, 10-10, 10-11, *10-12*
terminals. *See also* stations
  bus capacity, 6-81
  ferry, 9-8, 9-5 to 9-13, 10-10
  ferry, as a system, 9-11
  ferry, examples, 9-11
  ferry, passenger flow through, *9-9*
  ferry, siting, 9-11
  intelligent, 10-32
  intermodal, 10-10
  layover, 8-63
  passenger lobby area, 9-8
  systems perspective, 10-2
  vehicle staging area, 9-6, *9-7*
terminology
  lack of consistency, 1-7
ticket machines, 10-7
  determining required number, 10-41
  fare purchase service times, 10-41
tides, 9-1, 9-5, 9-6, 9-12, 10-10
timepoint holding
  dwell time, impact on, 6-70
track circuits, 8-20
track occupancy diagram, 8-97, *8-98*, 8-103, *8-104*, 8-106
track separation
  effect on headway, 8-60
tracks
  double-tracking, 8-72
  gauntlet, 8-55
  pocket, 8-6, 8-41
  single, 8-42
  three or four, impact on capacity, 8-31
traffic calming, 6-57
traffic delay, 3-31
traffic operations, 6-5
traffic volumes
  capacity, impact on, *3-32*
train capacity. *See* capacity, vehicle
train control, 8-18 to 8-23
  automated guideway transit, 8-75
  automatic train control, 8-18
  automatic train operation, 8-21, 8-27, 8-32
  automatic train stops, 8-18
  automatic train supervision, 8-21
  line-of-sight, 8-18
  train signals. *See* signals, train
train operations
  automatic train supervision, 8-61
  line-of-sight, 8-57
  single-track, 8-55, 8-69
train performance calculator, 8-91, 8-93, 8-94, 8-96, 8-103, 8-106
train separation
  minimum, 8-3, 8-4, 8-44, 8-45, 8-46, **8-50**, 8-108
  minimum, AGT, 8-76
  minimum, calculating, 8-48, 8-51
trains
  city block length as train length constraint, 8-12
  disabled, impact on system operation, 8-41
  length, 2-20, 8-12, 8-44, 8-45, 8-55, 8-57, 8-70, 8-75, 8-81, 8-82
  mixed freight and passenger operations. *See* rail transit, mixed passenger and freight operations
  passenger loading diversity, 8-10
  performance, 8-4
  power supply, constraint on train length, 8-12
  vehicle characteristics, impact on line capacity, 8-8
transfer span, 9-5, 9-10
transfers, 6-12, 6-53, 6-54, 8-33, 8-71, 9-4, 9-9, 9-22, 10-4, 10-6, 10-10, 10-15, 10-32
  dwell times, impact on, 8-31
  effect on train loading, 8-10
  transfer time, 4-11, 4-34
transit centers, 6-14, 6-81, 9-22, 10-5, 10-6
  bus berths, number of, 10-31
  bus capacity, 10-6
  sizing, calculation example, 10-74
transit development plans, 5-75, 5-76
transit performance
  community point of view, 4-6
  motorist point of view, 4-6
  overview, 4-4
  passenger point of view, 4-6
  transit agency point of view, 4-5

transit preferential treatments, 4-33, 4-41, 6-12, 6-52, **6-24 to 6-52**, 6-95, *See also individual treatments*
defined, 6-25
evaluation applications, 6-99
keys to success, 6-24
rail transit, 8-21, *8-23*
transit signal priority, 6-8, 6-13, **6-40 to 6-45**, 6-99, 8-22, 8-57, 8-87
active, 6-40
bus operations, impact on, 6-44
conditional, 6-40, 6-43
contrasted with preemption, 6-40
green extension, 6-41, *6-42*
impact on bus operations, 6-48
light rail, 8-8
passive, 6-40
planning guidelines, 6-44
queue jumps, in conjunction with, 6-47, 6-48
real-time, 6-40
red truncation, 6-41, *6-42*
special signal phasing, 6-42
stop relocation, in conjunction with, 6-55
summary of potential treatments, 6-41
technology, 6-43
transit time, 9-16
transit-dependent riders, 4-3
transit-oriented development, 3-21
transit-supportive area, 5-17, 5-82
calculation example, 5-82
example calculation, 5-18
transitway
light rail, 8-22
transportation demand management, 3-21, 4-27, 4-35
special events, 8-43
transportation system management, 3-4
trash receptacles, 4-36, 10-10, 10-11, *10-12*
travel speed, as quality of service factor, 4-6
travel time, 4-34, 5-63, 5-72, 5-75, 5-76, 5-77, 6-24, 6-25, 6-39, 6-98, 8-21, 9-4, 9-22, 9-23, *See also* speed
as quality of service factor, 5-33
bus lanes, impact of, 6-39
costs associated with changes, 4-41
demand-response, example calculation, 5-66
elevators, 10-53
quality of service. *See* quality of service, travel time
ridership, impact on, 4-38, 6-39
single-track sections, 8-55, *8-56*
trip patterns
demand-responsive transit, 7-5
trip purpose, 2-10
trip reservation, 2-6
trip turn-downs, 5-60
turnbacks, 8-3, *8-6*, 8-44, 8-61, *8-62*
United States Coast Guard
regulations, 9-3, 9-9, 9-29
value of time. *See* passenger value of time
vanpools, 2-13, 6-34
vehicle capacity. *See* capacity, vehicle
vehicle propulsion
bus, 2-2, 2-5
commuter rail, 2-19
diesel light rail, 2-17
heavy rail, 2-14
hybrid rail, 2-17
light rail, 2-16
vehicle staging area, 9-6, *9-7*
vehicle types
bus, 2-2, *2-4*, 6-19, 6-20
vehicle–platform interface, 3-38, 6-8, 8-7
capacity, impact on, 3-38
speed, impact on, 3-38
vending machines, 4-36, 10-10, 10-11, *10-12*
vessel capacity. *See* capacity, vehicle
vessels
auto capacity, 9-29
auto service time, calculation example, 9-32
bow loading, 9-5, 9-6
clean-up and resupply, 9-14
examples used for ferry transit, 9-3
fuel consumption, 9-4
load control, 9-9
passenger boarding, 9-11, *9-12*
passenger circulation, 9-10, 9-14, 9-16
passenger service time, calculation example, 9-30
propulsion, 9-4
side loading, *9-6*
vehicle disembarking, 9-8
vehicle loading, 9-6, 9-7
vintage trolleys, **2-16**, *2-17*, 8-38
voltage drops
impact on headway, 8-48
minimum headway, impact on, *8-49*, 8-50
volume-to-capacity ratio
station circulation design, use for, 10-58

wait time, 4-11, 4-29
  elevator, 10-53
waiting areas
  design, 10-30
  level of service, 9-9, 10-14, 10-55
  seating, 10-30
waiting rooms, 10-57
wake wash, 9-1, 9-4, 9-16
walking distance to transit. *See* access to transit, pedestrian
walking time
  vessel embarking and disembarking, 9-10, 9-14, 9-15, 9-24
walkways
  analysis time period, 10-45
  buffer width, 10-21
  capacity, 9-25, 10-20, 10-21, 10-45
  conflicts, 10-20
  effective width, 10-21, 10-38, 10-45
  emergency evacuation, 10-46
  level of service, 10-14, 10-44, 10-45
  micro-peaking, 10-45
  pedestrian speed, 10-20
  sizing, 10-45, 10-46, 10-51
water taxi, 2-28, *See also* ferry transit
wayfinding, stations. *See* stations, wayfinding
website, 1-5
wheelchair access
  aerial ropeways, 8-40
  commuter rail, 2-20, 8-39
  consideration in selecting an operating margin, 8-54
  inclined planes, 8-40
  light rail, 2-18
  rail transit, 8-34 to 8-40
wheelchairs, 10-12
  accessibility, 8-35
  elevators, 10-53
  lifts, 10-28
  loading, 3-24, 3-38, 6-7, 6-69
  loading, impact on bus dwell time, 6-70
  securement, 8-34
yards, 4-41, 8-12, 8-74
yield-to-bus laws, 6-58
Z values. *See* bus stop failure, *Z* values
zone routes, 2-43