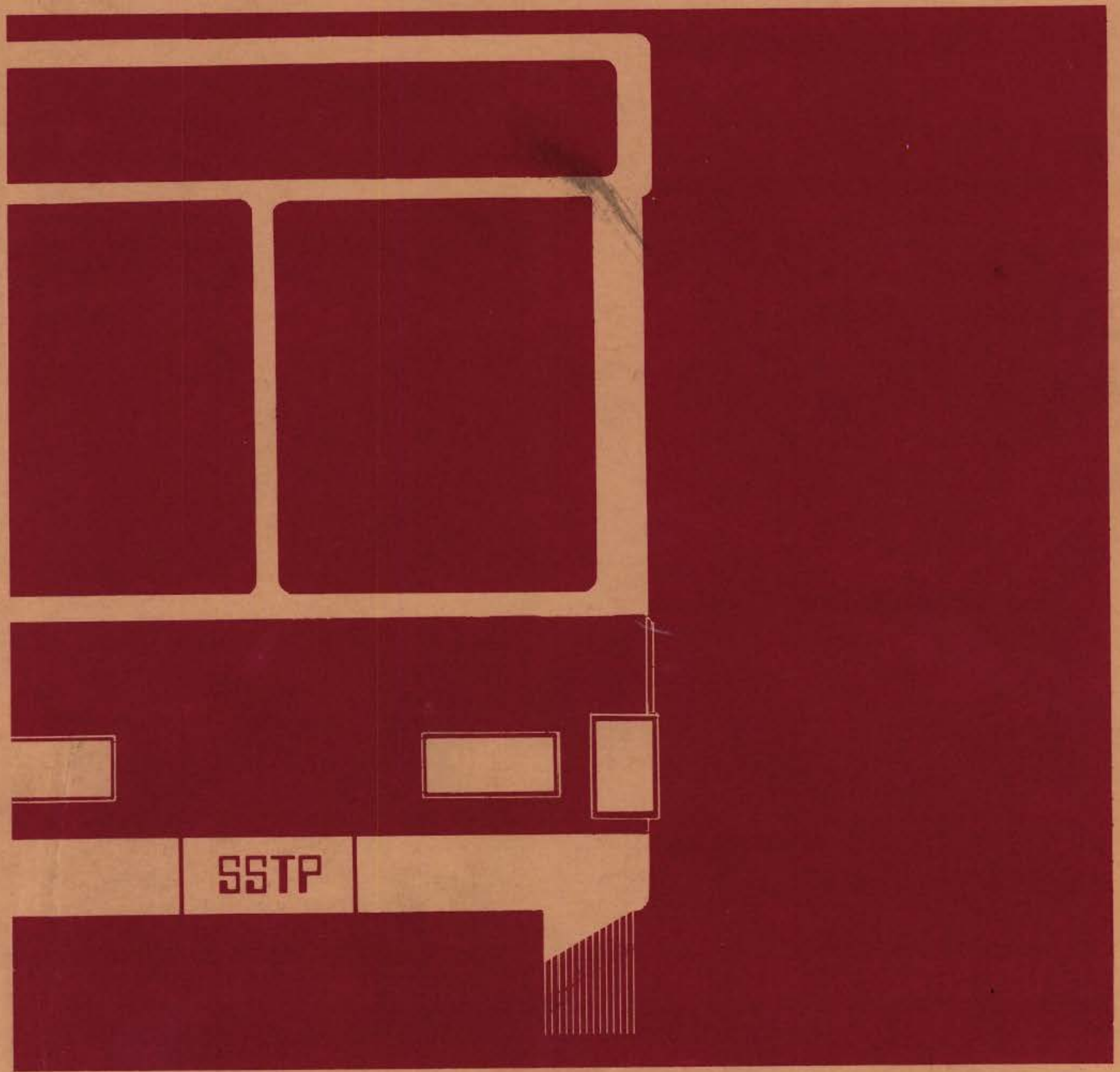
U.S. Department of
Transportation

Transit Data Collection Design Manual

June 1985



Transit Data Collection Design Manual

Final Report
June 1985

Prepared by
Multisystems, Inc.
1050 Massachusetts Avenue
Cambridge, Massachusetts 02138

Prepared for
Office of Planning Assistance
Urban Mass Transportation Administration
Washington, D.C. 20590

Distributed in Cooperation with
Technology Sharing Program
Office of the Secretary of Transportation

DOT-I-85-38

FOREWORD

The Bus Transit Monitoring Study was undertaken in 1979 to develop techniques and procedures for transit systems to use in the design and implementation of bus service data collection programs. The first Bus Transit Monitoring Manual was completed in August, 1981. Since then additional experience in monitoring bus service has permitted the testing of assumptions made in the original manual and, subsequently, the simplification of some of the recommended procedures and techniques.

This manual is intended to replace the two volume, August 1981 version. It presents revised procedures for determining sample size requirements, including default values for key parameters in the sample size formulas, and additional guidance for planning the data collection effort. A significant revision in the methodology is the elimination of the need for the extensive set of sample size tables that comprised the second volume of the 1981 manual.

Further information about the Bus Transit Monitoring Study can be obtained from Brian McCollom, Office of Methods and Support, Urban Mass Transportation Administration.

Brian McCollom

Brian McCollom
Office of Methods and Support
Urban Mass Transportation Administration
400 Seventh Street, S.W.
Washington, D.C. 20590

Norman G. Paulhus, Jr.
Office of Technology and Planning Assistance
Office of the Secretary of Transportation
400 Seventh Street, S.W.
Washington, D.C. 20590

The preparation of this report has been financed through a contract from the U.S. Department of Transportation, under the Urban Mass Transportation Act of 1964, as amended. The contents of this report were prepared by Multisystems, Inc., and do not necessarily reflect the official views or policies of the U.S. Department of Transportation or the Urban Mass Transportation Administration.

ACKNOWLEDGEMENTS

This report was prepared by Multisystems, Inc. It is a major revision of an earlier report, Bus Transit Monitoring Manual (1981), which was prepared by Multisystems, Inc., with the assistance of ATE Management and Service Co., Inc. The authors of the earlier report, much of whose material remains in this report, are John Attanucci, Imogine Burns, and Nigel Wilson. The author of the revisions, and primary author of this report, is Peter Furth. Technical assistance in preparing the revised manual was received from Jim Wensley and Gary Ruprecht.

The authors would like to thank Brian McCollom of UMTA for his valuable comments and assistance throughout the project and in preparing this report.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

LIST OF TABLES

LIST OF FIGURES

HOW TO USE THIS MANUAL

This manual describes the various components of a comprehensive data collection program, from a "baseline" data collection phase through to a plan for monitoring and updating the data. Part I, comprising the first seven chapters, provides a framework for the step-by-step program design procedures which are presented in an instruction/example format in Part II (Chapters 8 and 9). As such, it is important for the user of this manual to read Part I before attempting to use the procedures outlined in Part II. Once familiar with the basic concepts and practical considerations which are discussed in detail in Part I, the user can proceed to use the design procedures in Part II where the underlying framework and assumptions are largely unstated.

PART I

ELEMENTS OF A DATA COLLECTION PROGRAM

CHAPTER 1

INTRODUCTION

In recent years, there has been a growing awareness of the need to use public transportation resources more efficiently. It has become more important to evaluate (or re-evaluate) all services, both current and planned. Recent research has considerably advanced the state-of-the-art of transit evaluation methods. A number of transit properties, large and small, have adopted sets of service performance measures and standards, and have developed systematic evaluation programs.

In many cases, however, improved evaluation procedures have not been supported by comprehensive data collection programs. Cost-effective programs are needed to provide the passenger-related performance data required by individual properties.

1.1 Previous Transit Data Collection Research

A detailed study of U.S. transit data collection practices was conducted by the American Transit Association (ATA) more than thirty years ago. Between 1946 and 1949, ATA published several reports describing techniques for traffic checking and schedule preparation. In 1946, the Manual of Traffic and Transit Studies (Reprinted July 1982, PB 84-154582) was released describing detailed procedures for conducting twenty different data collection "studies." In 1947, APTA began a four-part study into techniques for traffic checking and schedule development. The first part consisted of an in-depth description of "sample" procedures based on methods used by the New Orleans Public Service Inc. In the second part, a survey of scheduling practices was carried out with responses reported from over seventy transit systems in North America. The third part of the study was a symposium of industry practices which provided commentary on the results of the first two parts of the study. In the last part of the study, selected areas for improved techniques were investigated.

For more than three decades, these ATA reports have constituted the only comprehensive reference source on techniques for data collection and analysis. While the reports have been extremely valuable to transit properties, they have significant limitations. First, the reports do not take into account operating changes of recent years, such as multiple fare types and transit passes. More importantly, the ATA manual does not explore issues such as the amount of data to be collected and the frequency of data collection. Since many systems have very different practices with respect to sample size and frequency of collection, it is likely that some collect too little data, while others collect too much.

In 1979 UMTA began a study to improve the state-of-the-art in transit data collection and service monitoring practices. As part of that study the first Bus Transit Monitoring Manual was completed in 1981. This manual builds upon earlier experiences with the techniques and procedures presented in the 1981 manual.

1.2 The Bus Transit Monitoring Study

The objective of the present study is to develop a comprehensive, statistically-based data collection program that will enable transit operators to collect in a cost-effective manner the passenger-related operations data that they need. Procedures have been developed which will allow systems to conduct the following tasks:

1) select efficient data collection strategies;

2) select the appropriate data collection techniques;

3) determine necessary sample sizes; and

4) efficiently schedule data collection activities to meet varying sample size requirements.

These procedures have been summarized in a step-by-step approach which can be used to determine data needs and design data collection programs in individual transit systems.

A panel of experts in transit operations has assisted in this study. The panel, consisting primarily of managers and planners of both small and large transit systems, reviewed all findings and assisted in planning the general direction of the study. In addition, the review panel included a representative of the American Public Transit Association (APTA) and a statistical expert familiar with transit operations.

The initial phase of the study focused on defining the data needed by the transit industry for operations planning and management decision-making, and on the techniques currently used to collect these data. This information was collected through:

1) a review of reports prepared by a number of transit systems;

2) a survey conducted by the Massachusetts Bay Transportation Authority and the Tidewater Transportation District Commission; and

3) interviews with forty-one transit properties.

The results of this phase are described in Interim Report #1, <u>Bus Transit Monitoring Study: Data Needs and Data Collection Techniques</u> (April 1979, NTIS PB80-161409).

Using the information obtained from this review, a preliminary design of a general data collection program was developed. The preliminary program was then field-tested in the Chicago metropolitan area, with the cooperation of the Northeastern Illinois Regional Transportation Authority (RTA) and the Chicago Transit Authority (CTA). Data were collected on a small number of bus routes according to plans specified in the general program. In addition to analyzing the collected data for statistical accuracy, the CTA and RTA staffs were interviewed to obtain their reactions to the design of the program. The information obtained from the Chicago field-test was then used to revise the preliminary approach.

The revised approach was then field tested in a similar manner on selected bus routes belonging to the Metropolitan Transit Commission (MTC) system in the Minneapolis - St. Paul region. Data obtained in these tests confirmed the methods described in this manual and added to the database from which default values of key parameters were estimated.

1.3 Three-Phase Data Collection: Baseline, Monitoring and Follow-up

The proposed approach includes three distinct data collection phases. In the first phase, or the baseline data collection phase, the "base conditions" are defined for each route in the system. Base conditions include all the data needed for effective operations planning including total boardings, loads at key points on the route, running time and schedule adherence, revenues, and passenger characteristics. The baseline phase presents a snapshot of system performance within a relatively short time span. Comprehensive route data files are developed from these data which facilitate comparisons among routes in specific subareas, garage divisions, function types, and across the system as a whole. Since the baseline phase includes the collection of all data items needed for service evaluation, including origin-destination data from a passenger survey, it provides an excellent opportunity to analyze the potential for major route restructuring or reallocation of buses.

The baseline phase is also used to identify relationships among data items which may be used to reduce the effort needed to monitor performance. For example, if the number of boarding passengers can accurately be predicted from farebox revenue, then farebox revenue could be used with an "average fare factor" to estimate total boardings and eliminate the need to measure boardings directly. Similarly, conversion factors can be estimated between other related pairs of data items such as peak load and boardings, or load at one end of a branch and boardings on the branch.

The second or monitoring phase of the data collection program has two purposes. First, it involves the tracking of data items such as peak load, schedule adherence, and boardings, for which current information is vital to the regular scheduling process or is necessary to meet reporting requirements. Second, it involves checking key data items, called change indicators, to establish (within a given accuracy range) whether a change has occurred which requires follow-up action. If none of the monitored data items changes significantly, it is assumed that the other data items checked during the baseline phase (e.g., passenger origins and destinations, fare category distribution) have also remained stable.

When possible, conversion factors estimated in the baseline phase can be used to lower data collection costs in the monitoring phase. With conversion factors, one or more difficult-to-collect data items can be estimated by measuring an easier-to-collect data item.

The follow-up phase of the data collection process complements the other phases by provided updated and/or more accurate data on specific routes as needed. For some planning applications, such as detailed study of problem routes, the data gathered in the other two phases may not be accurate enough, and so follow-up will be called for on routes for which those applications will be performed. Follow-up for the purpose of updating baseline data is needed when a major change is detected in one or more of the key data items checked in the monitoring phase, or when an external change such as a major fare increase occurs. This phase generally replicates the baseline phase, except that it is targeted only to the routes, time periods, and data items affected. The results of the follow-up phase become the base conditions for comparisons with future monitoring data.

1.4 Cost of a Monitoring Program

Cost is an obvious concern (and probably a manager's first question) in the development of a comprehensive data collection program. While the cost may vary greatly depending on specific system characteristics and ridership patterns, some guidelines are provided to estimate the cost of a monitoring program.

By far the most costly component is the use of on-board traffic checkers to monitor total boardings. This cost can be avoided if, as is often the case, a system can obtain reliable data from drivers or if automatic passenger counters are used. Other techniques can also be substituted for on-board data collection during the monitoring phase if a strong relationship exists between total boardings and farebox revenue or maximum load on a particular route. These factors can have a dramatic impact on the total resources required by a system to carry out a comprehensive monitoring program.

Based on information from Chicago and other systems studied in this project, the range of checker resources required for typical bus system sizes has been estimated using typical values for data variability, desired accuracy and route characteristics. The (full-time) traffic checker staff requirements shown in Table 1.1 assume that every route in the system is monitored, using manual techniques, four times a year. (If less frequent monitoring is acceptable, these requirements can be reduced proportionally.) Generally, the lower end of the ranges given in Table 1.1 represents the case where reliable boarding data can be obtained by the operator; the upper end represents the case where operators do not collect boarding data. The range also reflects differences among system and route characteristics which have a direct impact on required sample sizes and, therefore, total checker requirements. To determine the data collection program cost for a particular system, the detailed procedures outlined in Part II (Chapters 8 and 9) should be applied on a route-by-route basis.

Staff requirements for the baseline data collection phase for most properties would fall near the upper end of the indicated ranges (the baseline phase may extend over a period of about 3 months). In addition, the cost of an on-board passenger survey on all routes should be added to the staff requirements in Table 1.1 for the baseline phase.

1.5 "Section 15" Data Requirements

The data collection program outlined in this manual will provide a transit system with a wealth of information concerning the utilization of the system, including the data required by UMTA for the Section 15 "Transit Service Consumed Schedule" (Form 655). Section 15 requires two data items that lie within the scope of this manual: unlinked passenger trips and passenger miles. These items are required on a systemwide basis for specified time periods during an average weekday, Saturday, and Sunday. The data collection design procedures detailed in this manual include these data items, and allow a system to sample at the route level rather than on a systemwide random trip basis so that the data can be useful for route planning as well as for meeting Section 15 requirements. Section 5.1.2 explains how data collected at the route level can be compiled to satisfy the UMTA Section 15 reporting requirements.

1.6 Organization of Manual

Part I of this manual, comprising the first seven chapters, introduces the elements of a data collection program. It provides the framework upon which the step-by-step procedures of Part II (Chapters 8 and 9) are built.

In Chapter 2, the service-related data needs of the typical transit system are discussed. Guidance is provided on the determination of the data requirements for a specific system.

Table 1.1

Typical Checker Requirements for a Manual Data Collection Program

Peak Buses	Off-Peak Buses	Average Daily Service Hours	Number of Traffic Checkers Required
25	22	12	] - 1
50	40	12	1 - 2
100	70	14	1]- 4
300	215	15	3 - 7
500	250	16	6 - 13
750	470	17	8 - 15
1000	600	18	10- 19
2000	1100	19	20- 38

Data collection techniques are described in Chapter 3. The capabilities and limitations of each technique are outlined, and sample forms are provided for several techniques.

In Chapter 4, an overview of the process of designing a data collection program is presented. Special attention is given to the role of conversion factors, which can lower the cost of a data collection program by making it possible to estimate a data item by measuring a related, easier-to-collect item.

Chapter 5 introduces the competing forces behind the need for sampling: the desire for accuracy versus the variability of the data. Measures of accuracy and variability are described, and default values of these measures are provided.

In Chapter 6, tables and formulas are presented by which the sample size necessary to achieve a desired accuracy level can be calculated. Another set of tables and formulas are provided to help determine, after collecting a sample of data, the accuracy level achieved by that sample.

Chapter 7 discusses the design of sampling plans to meet a given set of sampling requirements. Included are issues of choosing data collection techniques, coordinating data collection efforts over different data items, routes, and time periods, and scheduling checkers and other data collection activities.

Two procedures are given in Part II of this manual. In Chapter 8 the overall design procedure is discussed, covering the design of a data collection program from the baseline phase through to monitoring and updating. Once the reader is familiar with Part I of this manual, Chapter 8 can be used as a guide to the entire manual as a transit system goes through the process of building its data collection program. In Chapter 9 a procedure is presented for scheduling checkers and other data collection activities; as such it is a substep in the overall procedure of Chapter 8 that must be performed for all three phases (baseline, monitoring, update) of the data collection program.

Each of the procedures of Part II is illustrated by an example that parallels the procedure throughout. Both examples make use of worksheets, which are included as part of the examples.

All of the tables used for determining sample size and tolerance attained are collected in Appendix A for ease in reference.

Blank worksheets are presented in Appendix B for the convenience of the reader.

CHAPTER 2

DATA NEEDS

The first step in designing a data collection program is to identify the data items required. Section 2.1 elaborates on the need for an inventory of data needs. Section 2.2 reports the results of a survey of the data needs of North American systems. Section 2.3 suggests appropriate levels of detail for commonly measured data items.

2.1 Taking Inventory of Data Needs

The data required by transit systems vary depending on the size and type of system operated and on the specific management objectives of the system. It is important, therefore, to contact all appropriate management and supervisory personnel within the system to identify their data needs. The departments or staff to be contacted may include:

- planning
- scheduling
- finance/revenue/budget
- transportation
- general manager

Each department (staff member) contacted should be asked to list the service-related data items used, how they are used, and how often they are used. Once a preliminary list of data needs has been compiled in this manner, it should be circulated to those originally contacted for review. The final list of data should also include those items required by outside agencies, such as a governing board, city council, state agency and the Urban Mass Transportation Administration (with special attention to UMTA Section 15 requirements).

2.2 Typical Data Needs of North American Transit Systems

The first task of this study was to determine the data needs of a typical bus system. This was done through a review of the data needs reported by more than one hundred bus transit systems in North America. This review included an analysis of the material collected from 71 transit properties by the Massachusetts Bay Transportation Authority (MBTA) in Boston and the Tidewater Transportation District Commission (TTDC) in Norfolk, Virginia.* These materials were supplemented by discussions with 41 other systems concerning the data required by these systems and the data collection techniques currently employed.

Through these efforts, a set of data items was identified (Table 2.1) that is needed by a large majority of the systems contacted. Each of these data items was reported as being useful in one or more aspects of service management, including route planning, scheduling, marketing, funding reimbursement or deficit allocation, and external reporting.

Two pairs of data items warrant clarification. The first pair is peak point load vs. true maximum load. Operators typically determine for each route/direction/time period a "peak load point" or "peak point", the point at which the average load per trip is the greatest. "Peak point load" is the load at this point. However, on each individual trip, the point of maximum load need not be this point. "True maximum load" for a trip is the maximum load occurring on that trip,

---

* For further information on this effort, see Bus Service Evaluation Procedures: A Review, prepared by the Massachusetts Bay Transportation Authority and Tidewater Transportation District Commission, April 1979, NTIS Report No. PB79-296314.

Table 2.1

Data Needs in Baseline Phase

Route (or Stop) Specific

Load (at peak point - other key points)*

Running Time

Schedule Adherence

Total boardings (i.e., passenger-trips)

Revenue

Boardings (or revenue) by fare category

Passengers boarding and alighting by stope

Transfer rates between routes

Passenger characteristics and attitudes

- age
- handicap
- sex
- job status
- attitudes toward level of service
- income
- auto ownership
- auto availability
- home location

Passenger travel patterns

- origin/destination
- work and/or school trip location
- time of day of work (school) trip
- work (school) trip mode
- non-work (school) travel patterns
- trip frequency

System-wide

Unlinked passenger trips
Passenger-miles
Linked passenger trips

* At specified points; not averaged throughout a trip.

regardless of where it occurs, and average true maximum load is the average of the individual trip maximum loads. Obviously, peak point load is easier to measure, as it can be measured with a point check, while true maximum load requires measuring ons and offs at every stop. For this reason, many systems choose to deal only with peak point load. On very crowded routes, however, peak point load, which is always less than average true maximum load, may significantly underestimate the level of crowding. Because of the close relationship between these two items, systems who favor the true maximum load measure may be able to estimate it from peak point load using a conversion factor, as discussed in Section 1.3.

Another pair of data items whose names are not self-explanatory are schedule deviation and schedule adherence. Both are measured at a specific checkpoint. For the purposes of this manual, "schedule deviation" is taken to mean number of minutes behind schedule as a bus passes a checkpoint. (Negative values imply a bus is ahead of schedule). Unlike other numerical data items, however, a simple average of this measure conveys little information. For example, if average schedule deviation were 0, it could be that every trip is right on time, or that half the trips are very early and half are very late*. Schedule adherence, on the other hand, is defined in this manual as the percentage of trips that are early, on time, and late. For this purpose, "on-time" can be defined as strictly as desired; a typical definition is 0 to 3 minutes behind schedule.

2.3 Level of Detail

Selecting the appropriate level of detail is important in the design of a data collection program because it is directly related to the level of effort required. Data is often needed

---

* One way to overcome this difficulty is to measure both the mean and standard deviation of schedule deviation. This approach is not pursued, however.

at different levels of detail ranging from trip level to route level, where it may or may not be broken down by direction, day of the week, or time of day. Most data items are between the extremes, and are needed at the route/direction/time period level.

Table 2.2 shows the suggested level of detail for commonly collected data items. For data items used in the regular scheduling process (e.g. load, running time), it is suggested that data be broken down by route, direction, and time period. For data items used primarily in a broader context of route planning (e.g. passenger characteristics and attitudes), less detail is needed. For some of these items, breakdown by time period is not necessary, and for others a breakdown into two aggregate periods, peak and off-peak, may be adequate.

TABLE 2.2

Suggested Level of Detail for Selected Data Systems

	Data Item	Uses	Level of Detail
1.	Load at peak point or other key point	scheduling, planning	route/direction/time period
2.	Running time		
	a. Routes with branching or short-turns	scheduling, planning	route/segment/direction/time period
	b. Simple routes	scheduling, planning	route/direction/time period
3.	Schedule adherence (fraction early/on time/late) at specified point(s)	scheduling, evaluation, control	route/direction/time period
4.	Boardings	evaluation, planning, Section 15 reporting	route/direction/time period
5.	Revenue	evaluation, planning	route/direction/time period
6.	Passenger Miles	evaluation, Section 15 reporting	route/direction/time period
7.	Distribution of boardings by fare category	planning	route/time period (peak/off-peak)
8.	Average boardings and alightings by stop	planning	route/direction/time period
9.	Transfer rates	planning	route/direction/time period (peak/off-peak)
10.	Passenger characteristics and attitudes	planning	route/time period (peak/off-peak)
11.	Passenger origin-destination pattern along route	planning	route/direction/time period (peak/off-peak)

CHAPTER 3

DATA COLLECTION TECHNIQUES

Data collection techniques used by transit systems can be classified along two dimensions. One dimension, covered in Section 3.1, is the way in which resources (e.g., checkers, special equipment) are deployed to collect the data. The second dimension, covered in Section 3.2, is the types of counts and readings that are taken. The two dimensions overlap because some types of counts can be taken with several different deployment options.

3.1 Deployment Options for Data Collection

There are four major deployment options for positioning personnel and resources in the field for data collection (Table 3.1).

The first is the ride check, in which a checker is stationed on the bus as it travels along the route. This option consumes one checker-hr for every vehicle-hr of service checked.

The second option is the point check, in which a checker is stationed at roadside and observes buses as they pass by. Point checks generally require 1 checker-hr per point per hour of observation in each direction. If both directions can be observed by a single checker, this cost is halved. This can be the case when load is critical in only one direction, and for the other direction the checker needs to note only the time of passage and whether there were standees. The cost can be further reduced if several converging routes can be monitored simultaneously by a single checker.

Four types of point checks can be used in the data collection program. The first is the "peak load point check" or "peak point check", used to observe the "peak load" or "peak

Table 3.1

Major Data Collection Deployment Options

	Option	Description	Resources Consumed
1.	**Ride Check**	Checker rides on board bus	1 checker-hr/ vehicle-hr.
2.	**Point Check**	Checker stands at roadside; may or may not board bus momentarily	1 checker-hr/direction/ point/hr.
	a. Peak Point Check	Checker stationed at peak load point	
	b. Undesignated Point Check	Point at which checker is stationed is flexible within a certain range	
	c. Multiple Point Check	Checkers stationed at selected timepoints	
	d. Endpoint Check	Checkers stationed at endpoints	
3.	**Driver Check**	Driver records data	Very little cost; data reliability may be suspect, however
4.	**Automated Checks**	Buses equipped with automated passenger counters	1 vehicle-hr/vehicle-hr

point load", an important input to scheduling. The peak point is the point on a route at which the average passenger load is the greatest. Since the location of the peak point can change over time, it is necessary to verify the location of the peak point periodically, generally through a ride check.

Multiple point checks can be useful on long routes, crosstown routes, branching routes and routes which serve a number of important activity centers. Such routes may have several points in different areas at which the loads are critical for scheduling purposes, such as selecting the frequency on a branch. Likewise, running time on different segments, such as a short turn portion of a route, may be critical as well.

Endpoint checks, in which checkers are positioned at the route endpoints, are useful for monitoring run time and, if vehicles are equipped with registering fareboxes, revenue per trip. If a checker is stationed at only one endpoint, revenue and running time per round trip can be measured. Endpoint checks can be particularly efficient in bus systems that serve as feeders to rail rapid transit, since in such systems a rapid transit terminal can serve as an endpoint for a large number of routes.

When there is some freedom in the choice of checkpoint, this type of check is called an "undesignated point check." By leaving the checkpoint undesignated, it is often possible to choose a checkpoint at which many routes can be monitored simultaneously. Freedom in the choice of checkpoint arises, for example, when the purpose of the check is to measure schedule adherence, which can be measured at any of a number of points. Another example is when load is to be measured at a point in the vicinity of peak point, and from it either the true maximum load or the peak point load is to be estimated using a conversion factor. If there is a point that many routes pass that is near the peak point of each of these routes, then stationing a checker at that point could be an economical way of monitoring load on these routes.

Point checks typically are taken from the street, but onc variation is to have the checker briefly board the bus. This practice may become more common as more busses with tinted windows are purchased, since such windows greatly reduce the ability of checkers to see into the bus during daylight hours. If point checkers board each bus briefly, they can also take farebox readings.

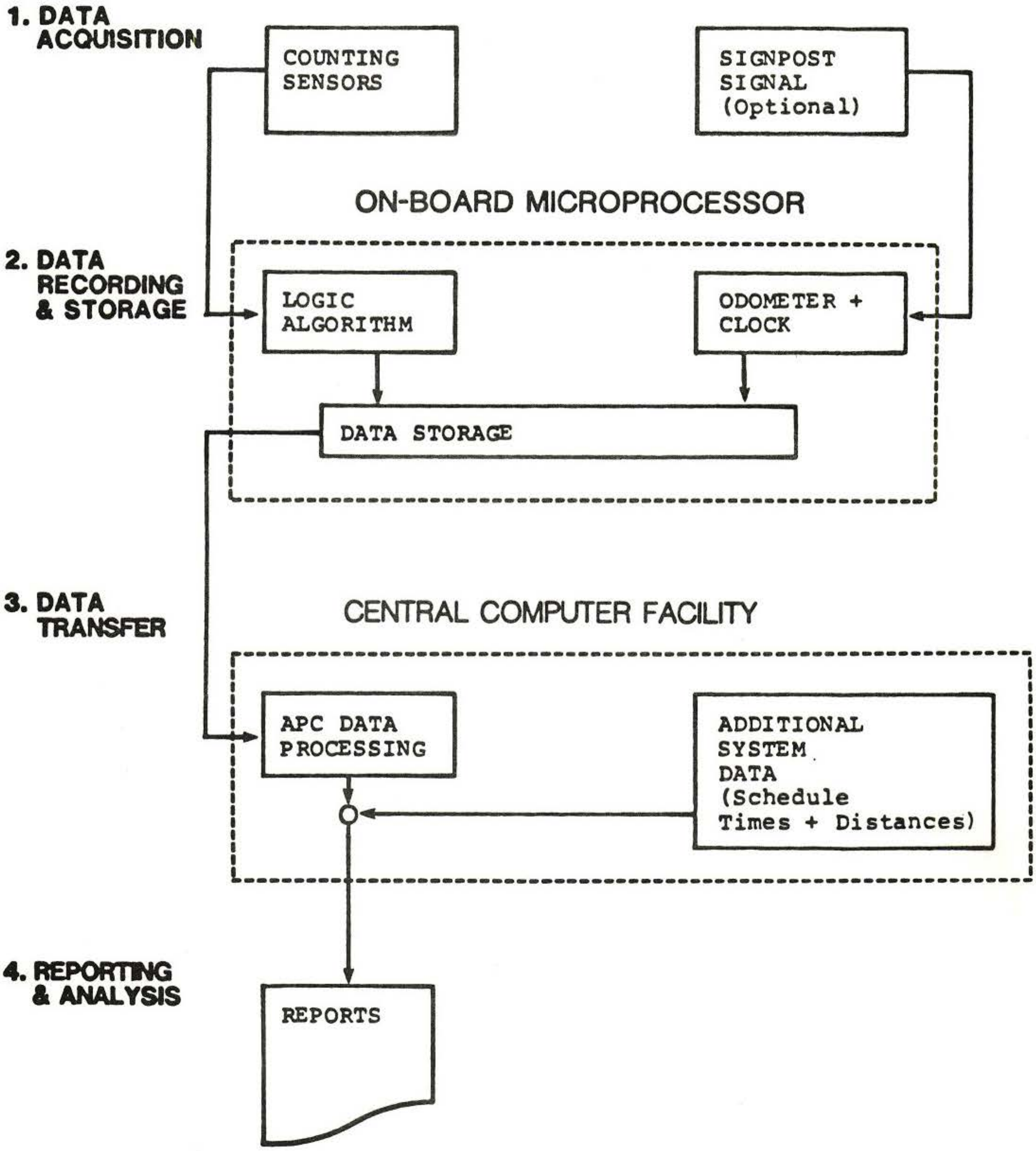
A third deployment option, driver checks, is to use drivers as they perform their regular duty of operating the bus. Demands on drivers and work rules can limit severely the extent to which drivers can be used, and because for them data collection is secondary duty, data thus obtained may be less reliable than data gathered by checkers. Drivers are not generally used to measure running or arrival times.

A fourth deployment option is automated checks, taken by having vehicles equipped with automatic passenger counters (APC's) operate on selected trips. APC's count the number of passengers boarding and alighting at each stop and record related information such as the time, stop number, and/or odometer reading each time the bus stops and the doors are opened. APC's should not be confused with Automatic Vehicle Monitoring (AVM) systems, which provide continuous "real time" information on vehicle locations and emergency status, as well as passenger loads. This information is used by operating personnel to make immediate service changes. Information collected by APC's, on the other hand, is temporarily stored and is retrieved periodically (e.g., weekly) for analysis.

Although several types of APC systems are currently available, all perform the four basic steps of data acquisiton, data recording and storage, data transfer, and data reporting and analysis (Figure 3.1). A number of components are used in the data acquisition step. Sensors are located at each doorway of the bus to detect passenger movements. These sensors are

Figure 3.1

BASIC STEPS AND COMPONENTS OF APC TECHNIQUES



either infrared beams or ultrasonic rays projected across the front and rear stairwells of the bus, or pressure sensitive mats placed on the steps. A data processing unit is located on-board the bus to record and store the data. The counts are stored along with auxiliary information that permits matching with bus stops. This auxiliary information can be time or distance measurements, or coded location signals transmitted to the bus from devices mounted on signposts. After the data have been stored for a period of time (usually several days), it is transferred from the on-board processing unit to a central computing facility where appropriate software packages are used to generate the desired reports.

In addition to these four major deployment options, there are several more specialized ways of collecting data. Some involve little data collection cost, such as counting tickets or revenue at the end of a day, and other can be quite costly, such as passenger interviews.

3.2 Types of Counts and Readings

There are eight types of counts and readings that are commonly taken (Table 3.2).

An on/off count (characteristic count) is a record of passenger boardings and alightings at each stop and the arrival time at selected stops. On/off counts are usally taken using a ride check (see Figure 3.2 for a sample ride check form). At some systems, boarding passengers are counted by fare category and experienced ride checkers may note whether the running speeds on route segments are appropriate. On/off counts can also be gathered by automated checks.

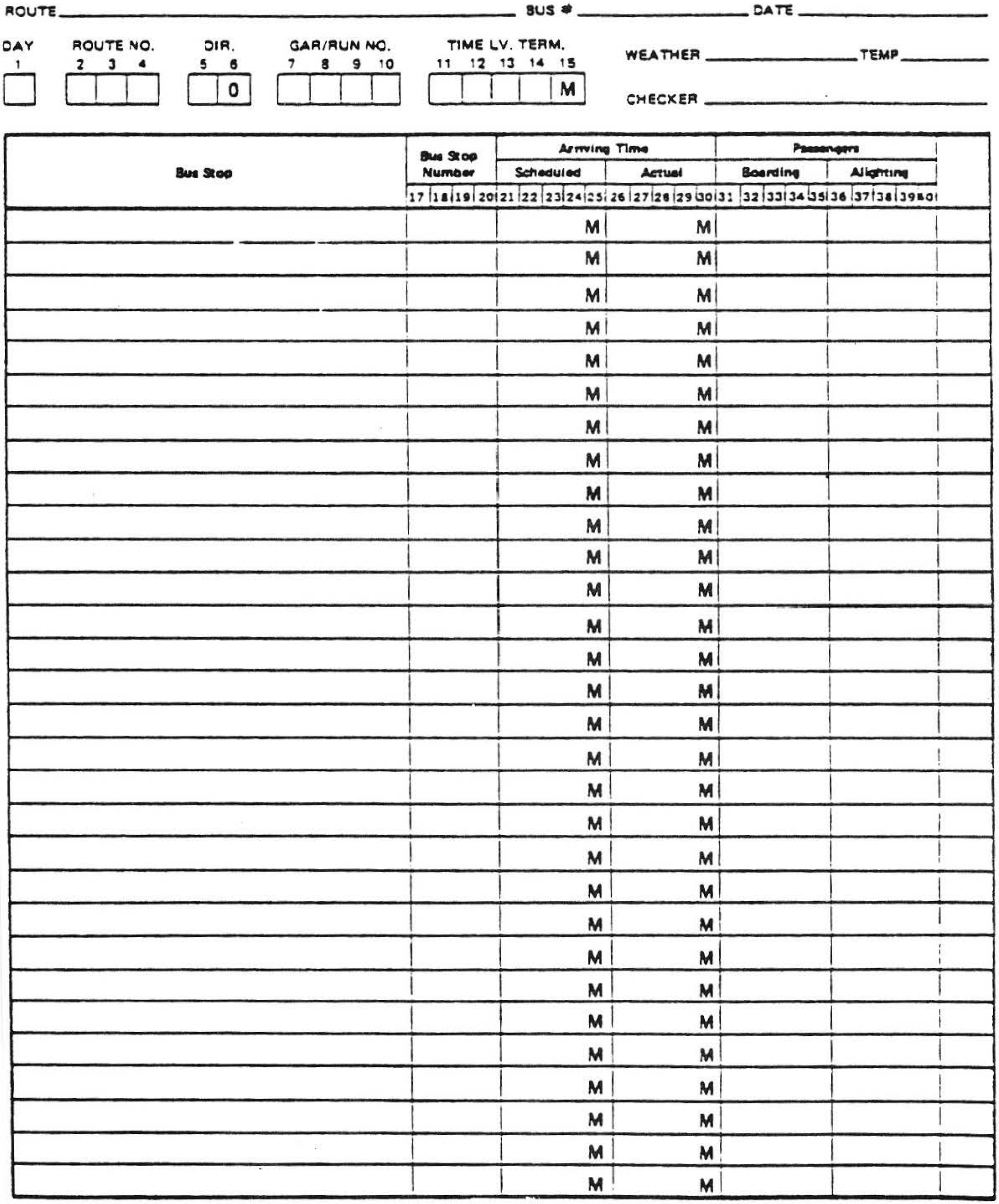
From an on/off count, it is possible to determine the load between each pair of stops. Thus, with on/off counts the true maximum load on each trip can be determined, as well as the location of the peak load point.

Table 3.2

Types of Counts and Readings

Type of Count/ Reading	Description	Corresponding Deployment Options
On/off Count	Ons and Offs at each stop; also time at timepoints. In rare cases, ons may be by fare category.	Ride check; automated count
Boarding counts	Boardings by trip, broken down by fare category; in some case, may be broken down by stop; also time at timepoints if count is done by a checker	ride check driver count
Load Counts	Load on bus as it passes a point; also time at that point	point check
Farebox Reading	Cumulative farebox revenue at checkpoint; also time at checkpoint driver count	point check ride check
Revenue Count	Count of revenue in farebox vault at end of day, by vehicle	None
Transfer Counts	Count of transfer tickets sorted by original and final route	None
Route Origin/ Destination Count	Count of passengers by O/D stop pair	special
Survey	Passengers respond to questions, either written or verbal	Special; often ride checker or driver can distribute questionnaire

Figure 3.2
Sample Form for Ride Check



ROUTE ______________________ BUS # ______________ DATE ______________

DAY	ROUTE NO.	DIR.	GAR/RUN NO.	TIME LV. TERM.
1	2 3 4	5 6	7 8 9 10	11 12 13 14 15
☐	☐☐☐	☐ 0	☐☐☐☐	☐☐☐☐ M

WEATHER ______________ TEMP ______

CHECKER ______________________

Bus Stop	Bus Stop Number	Arriving Time		Passengers		
		Scheduled	Actual	Boarding	Alighting	
	17 18 19 20	21 22 23 24 25	26 27 28 29 30	31 32 33 34 35	36 37 38 39 40	
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			
		M	M			

Given the mileage between successive stops, ride checks can also be used to measure passenger-miles. This Section 15 data item can be simply computed by multiplying the number of passengers on-board leaving each stop by the distance between that stop and the next stop.

Boarding counts are a record of boarding passengers by fare category. These counts are different than on/off counts in that they are usually taken by drivers and that the data are generally recorded by trip and not by stop. Drivers are often in a better position than checkers to determine fare category, because they can more easily see the fare deposited. Counts are generally taken with mechanical counters, which in some systems are attached to the fareboxes. When checkers do the boarding count, the data is usually broken down by step (see Figure 3.3 for a sample boarding count form).

Load counts, taken with point checks, are a measure of the number of passengers on board as a bus either arrives at or leaves a stop. Bus arrival or departure time is usually measured as well (see Figure 3.4 for a sample point check form). Passenger activity (i.e., boardings and alightings) at the stop where the check is being made may also be recorded by the on-street checker.

Farebox readings can be taken when vehicles are equipped with registering fareboxes. Registering fareboxes keep a running total of the amount of money that is collected on a bus. (See Figure 3.5 for a sample farebox reading form.) Register readings are almost always taken at the beginning and end of each day. If a bus remains on the same route all day (i.e., no interlining), its readings can be used to obtain total route revenue. Some systems require drivers to read the boxes at the beginning and end of their shifts. If there is no interlining within shifts, this data can be used to compute route revenue.

If there is interlining (i.e., if buses operate on more than one route between farebox readings), some allocation

Figure 3.3
Sample Form for Boarding Count

ROUTE ______________________ BUS # ____________ DATE ____________

DAY	ROUTE NO.	DIR.	GAR/RUN NO.	TIME LV. TERM
1	2 3 4	5 6	7 8 9 10	11 12 13 14 15
☐	☐☐☐	☐ 0	☐☐☐☐	☐☐☐☐ M

WEATHER ____________ TEMP ________

CHECKER ______________________

Bus Stop	Bus Stop Number	Arriving Time		Passengers Boarding						
		Scheduled	Actual	Full	Full + Transfer	Reduced	Reduced + Transfer	Transfer Received	All Passes	
	17 18 19 20	21 22 23 24 25	26 27 28 29 30	31 32	33 34	35 36	37 38	39 40	41 42	
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							
		M	M							

Figure 3.4
Sample Form for Point Check

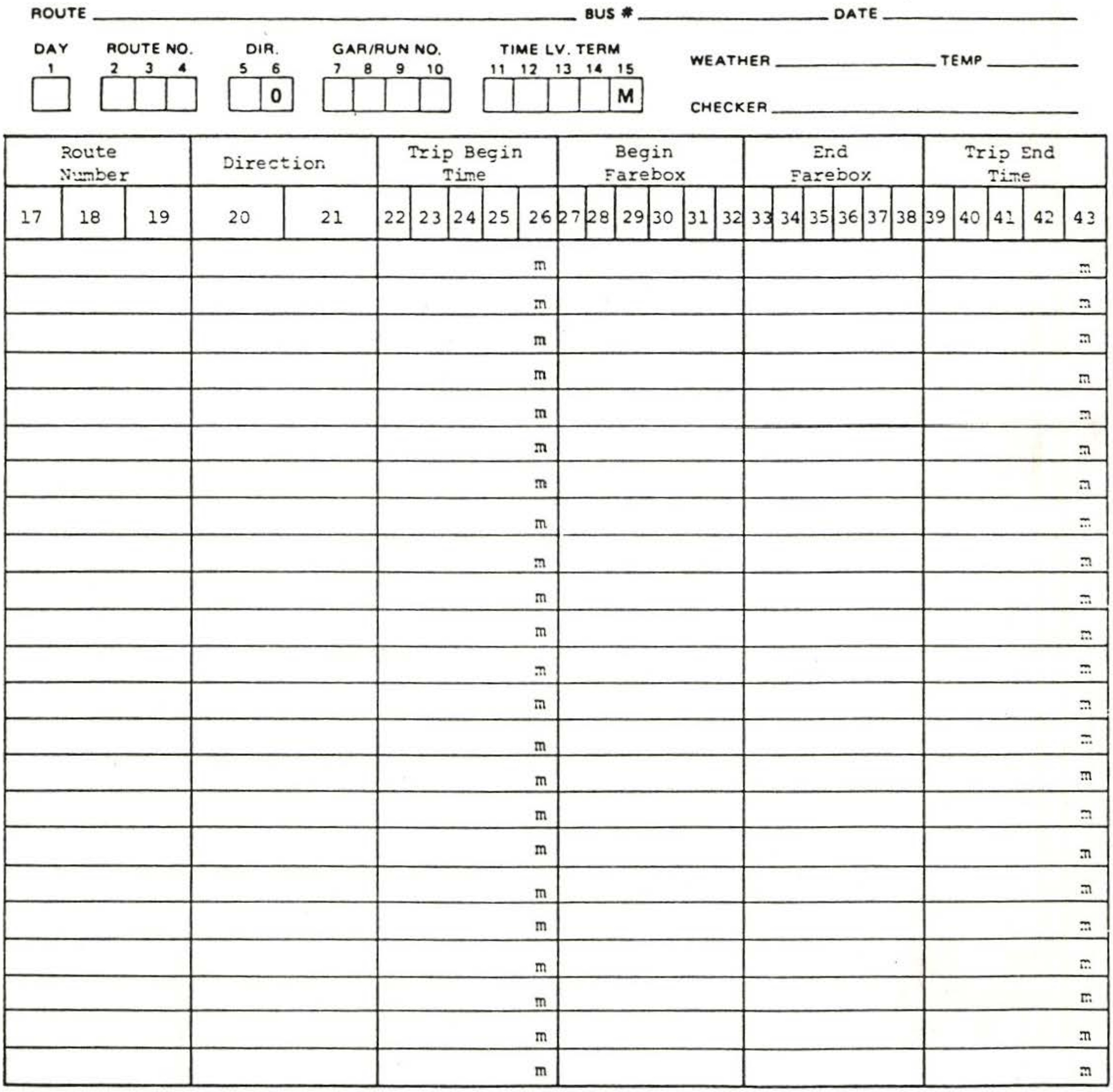
ROUTE(S) ____________________ DAY ____________ DATE ____________

AT ____________ DIRECTION ____________ WEATHER ____________ TEMP ______

MAX LOAD ☐ ARRIVING ☐ LEAVING ☐ CHECKER ____________

Day	Route Number	Direction	Garage/Run Number	Bus Number	Bus Stop Number	Arriving Time		Passengers	
						Scheduled	Actual		
1	2 3 4	5 6	7 8 9 10		17 18 19 20	21 22 23 24 25	26 27 28 29 30	31 32 33 34 35	
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		
						M	M		

Figure 3.5
Sample Form for Farebox Reading



ROUTE ____________________ **BUS #** ____________ **DATE** ____________

DAY 1 ☐ **ROUTE NO.** 2 3 4 ☐☐☐ **DIR.** 5 6 ☐ 0 **GAR/RUN NO.** 7 8 9 10 ☐☐☐☐ **TIME LV. TERM** 11 12 13 14 15 ☐☐☐☐ M

WEATHER ____________ **TEMP** ________

CHECKER ____________________

Route Number			Direction		Trip Begin Time					Begin Farebox						End Farebox						Trip End Time				
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m
									m																	m

between routes must be done. Complex statistical methods can be used to perform this allocation, although it is more common to use simple allocation factors. Either way, some error is introduced by the allocation process. Having drivers record the farebox reading when they switch from one route to another, or, better yet, at the start of each trip, would overcome the allocation problem and yield an accurate measure of revenue by route and, if readings are made with each trip, by trip. However, reliability can be a problem with driver-recorded readings because data collection is not their primary duty.

Checkers can also make farebox readings. During a ride check, a reading can be made at the start and end of each trip and at selected timepoints. With endpoint and multiple point checks, revenue by trip and/or for certain segments can be inferred from farebox readings if checkers board the bus.

In the past few years, a number of systems have installed fareboxes which electronically register boardings by fare category (and hence revenue). These fareboxes require drivers to register each fare as it is deposited. To use these fareboxes, the drivers in effect, must perform boarding counts.

Revenue Counts are a measure of the revenue retrieved from the farebox vaults. All systems measure systemwide revenue on a regular, generally daily, basis. In some systems, revenue is recorded by vehicle every day, or on a sample basis. If buses are not interlined, revenue counts by vehicle will yield revenue by route. If buses are interlined between routes, it is difficult to compute accurate route revenue using revenue counts.

Transfer counts are counts of transfer tickets used to estimate transfer rates between routes. For systems which indicate the originating route on their transfer tickets, this technique requires only the collection of a sample of the transfers received by the drivers. For systems which do not indicate the orginating route on the tickets, a special transfer ticket (perhaps color-coded for a number of intersecting routes) is distributed, collected and counted for several days to obtain this information.

A route origin-destination (O-D) count is a specialized count that measures of the number of passengers going between each pair of stops on a route. It differs from an O-D survey in that all passengers are counted, whereas in a survey only responding passengers are counted. On routes that are not particularly busy, a checker stationed at the rear of the bus notes on a seating chart the origin and destination stop of passengers as they sit and rise. On busier routes, a route-level origin-destination matrix (by stop) can be measured with a minimum of passenger participation by stationing a checker at each door of a bus. Upon boarding, passangers are handed a card that is precoded to indicate the origin stop. Upon alighting, passengers return the cards, which are then filed or coded by destination stop. While it is possible that some passengers will not return their card upon alighting, response rates of over 95% are common. It is also possible to ask passengers to record some information on the card, but the response rate for this information is generally lower, and this technique is better classified as a survey, discussed below.

Passenger surveys are used to obtain information directly from the passengers. Surveys differ from counts in that information about responding passengers only is obtained, necessitating an expansion of the results and subjecting them to biases than can jeopardize their value (see Section 7.3). Transit surveys are generally conducted while passengers are on-board the bus. With longer surveys, passengers may be given the option of returning the surveys, which are printed on postage-free forms, by mail. On-board surveys may be handed out by drivers, by checkers, or by special survey administrators. The person distributing the forms helps answer questions about the survey or may ask some or all of the questions to individuals who may have difficulty with the form (e.g., some elderly and handicapped passengers).

Surveys are the only way to obtain information on passenger travel patterns, characteristics and attitudes. Complete on-board surveys generally include questions of use for general transportation planning as well as those specifically geared to transit management. Typically questions cover the following topics:

- route on which survey is adminstered
- fare paid
- other routes used on trip
- origin and destination
- access mode and distance
- trip purpose
- time-of-day of travel
- frequency of use
- age and sex
- occupation or income level
- auto availability

On-board surveys can also be used to count ridership if sequentially numbered survey forms are handed out to all passengers and forms refused by passengers are discarded.

Some systems periodically conduct special purpose surveys to collect limited data. These should not be substituted for the baseline phase survey described above, but can be used subsequently to acquire accurate data to supplement the baseline data. Examples of special purpose surveys include:

1. Passholder Survey: On systems with significant (and changing) pass usage, it may be desirable to obtain directly ridership patterns of passholders through a survey. This survey can be conducted when passes are issued or through the mail. These data can then be combined with revenue figures at the route level to update ridership estimates. For systems with growing pass usage these data will allow projection of total revenue for budget planning purposes.

2. Transfer Survey: If two routes are being considered for throughrouting, or monitoring indicates a substantial change in the number of transfers, it may be desirable, particularly in systems which do not issue transfer tickets, to conduct a special transfer survey of certain routes. One way this might be accomplished is to station an interviewer at the stop where two routes intersect, where he/she would ask passengers whether they are transferring. (An alternative is to do a transfer count (mentioned earlier) by issuing coded transfer cards to all boarding passengers on the route in question, and then collecting them on the second route.)

3.3 Comparison of Principal Data Collection Techniques

The various deployment options and types of counts and readings provide a range of different data items with different levels of reliability, depending on individual system and route characteristics. As shown in Table 3.3, a number of types of counts, taken using different deployment options, can be used to collect the same data items.

On/off counts provide the most complete set of data, especially if boarding passengers can be recorded by fare category. On/off counts, together with farebox readings when possible, provide reliable and complete data when they are performed by traffic checkers. On/off counts can also be made using APC's, subject to the availability of an accurate stop-referencing capability. Also, subject to this capability, schedule adherence data can be obtained with APC's. The reliability of some of these data may be somewhat less than that collected by experienced checkers; however, the capability for conducting multiple counts inexpensively, and the predictable nature of some forms of error, should offset any inaccuracies associated with this technique.

Counts taken by drivers can be a very inexpensive source of

Table 3.3
Data Items Obtained by Different Techniques

Deployment Option	Counts and Readings	Load			Unlinked Pass.		Revenue					Running Time					
		At Peak Point	At Other Point	Distribution	Total	By Fare Category	By Route	By Trip	By Segment	Ons, Offs by stop	Pass.-Miles	By Trip	By Segment	Schedule Adherence	Linked Passenger Trips	Transfer Rates	Passenger Travel Patterns, characteristics
Ride Check	On/off counts	■	■	■	■					■	■	■	■	(1)	(2)		
	-by fare	■	■	■	■	■				■	■	■	■	(1)			
	Farebox reading						■	■	■			■	■	(1)			
Point Check -peak point	Load count	■												■			
-end point	Load Count		■														
	Farebox reading					■	■				(3)		■				
-multiple point	Load Count	(4)	■	(5)							(5)	(6)	■	■			
	Farebox reading						(6)	(6)	■								
-undesignated point	Load Count		■											■			
Driver Check	Boarding Count				■	■	■	■	■						(2)		
	Farebox reading						■	■	■								
Automated Check	On/off Count	(7)	■	■	■					(7)	■	(7)	(7)	(1,7)			
Special (may combine with above options)	Revenue count						(8)									■	
	Transfer count															■	■
	O-D count	■	■	■	■					■	■	■	■	■	(2)	■	■
	Survey									■	■				■		

KEY: ■ if applicable; blank if not applicable

NOTES:
(1) Cannot be used to check headways unless consecutive trips are checked
(2) May be used if transfer tickets are collected on the terminating route and identifiable by initial and intermediate routes
(3) Round trip only if one endpoint is checked
(4) If peak point is included
(5) Can provide a rough distribution
(6) If enpoints are included
(7) With adequate step-referencing capability
(8) By vehicle; may or may not be useful at route level

data. With increasing level of effort, drivers can take farebox readings, count boardings, count boardings by fare category, and count boardings by fare category and stop. These more advanced levels of detail provide a rich set of data. However, if drivers are used to collect data, experience suggests that the results may be less reliable since data collection is secondary to their primary responsibility of operating the vehicle.

Point checks provide reasonably accurate, but more limited, data. Multiple point and endpoint checks increase the usefulness of this technique by providing information at more than just the peak point, especially on longer routes which serve more than one activity center. The utility of point checks may decrease somewhat, however, as buses with tinted windows become more common, since tinted windows prevent easy estimation of passenger loads without having the checker board the bus.

Passenger surveys provide a wide range of data items; however, some problems exist in ensuring accurate and unbiased results using survey data (see Section 7.3). Surveys generally should not be used to obtain data which can be directly observed using alternative technique because of these potential accuracy problems.

Revenue and transfer counts provide information on a limited number of data items for those systems with operating characteristics allowing the use of these techniques.

3.4 Evaluation of Automatic Passenger Counters

Some heavily patronized properties may find automatic passenger counters to be a cost-effective alternative to ride checks, especially where reliable driver-collected data are unavailable. Although APC's require a substantial initial investment, the incremental cost per count is relatively low thereafter. Manual counts, on the other hand, entail little initial investment, but a higher cost per count. Given these cost structures, systems faced with large on-going monitoring requirements may find the average cost per count to be lower with APC's than with manual counts.

In addition to out of pocket cost, APC's offer several advantages over manual techniques. APC's provide the opportunity to collect additional data at relatively low cost, e.g., to assess seasonal variation in loading profiles, or day-to-day variation within the week. APC's also allow considerable choice in the level of detail of the reports to be generated, depending upon the purpose and types of analyses to be undertaken. Data turnaround is faster because the data are read directly from on-board storage to a central computer facility; the time-consuming functions of coding and keypunching are avoided altogether.

The importance of each of these factors clearly should influence a transit system's choice of collection methods. A few general guidelines are suggested so that a system can determine whether the use of APC's should be seriously considered. Characteristics which favor APC use include:

- more than 300 buses - smaller systems may find acquisiton and software development costs prohibitive.
- preponderance of high volume routes, e.g., with peak hour headways of 10 minutes or less and/or peak period standing loads.
- large on-going data requirements, e.g., due to high day-to-day variances or seasonal variation.
- excessive data collection costs
- inaccurate manually collected data
- no reliable driver-collected data
- use of buses with tinted windows, making point checks difficult
- ready access to computer facilities and associated technical skills

- the availability of capital funds required for APC equipment, as opposed to operating funds

Transit systems with several of these characteristics are most likely to find APC's a cost-effective alternative to manual data collection. A more thorough evaluation of APC's is found in the report "An Assessment of Automatic Passenger Counters", Report No. DOT-I-82-43, prepared for UMTA by Multisystems, Inc.

CHAPTER 4

CONVERSION FACTORS AND OVERALL DATA COLLECTION PROGRAM DESIGN

4.1 Conversion Factors

Conversion factors can play a major role in a data collection program. A conversion factor is simply the ratio of the averages of two related data items, of which one is easy to collect and the other is more difficult to collect. Once a conversion factor has been estimated, the average of the difficult-to-collect item can be inferred in future periods, without measuring it directly, by measuring the easy-to-collect item, and then multiplying the average of the easy-to-collect item by the conversion factor. The easy-to-collect item is called the auxiliary item; the difficult-to-collect item is called the inferred item. The conversion factor is calculated during the baseline phase by measuring both items simultaneously on a sample of trips; it can then be used repeatedly in the monitoring phase as long as the relationship between the items is believed to remain stable.

For example, in a particular system, peak point load is easy to collect, but boardings is difficult to collect. Using a ride check, both boardings and peak point load are measured simultaneously on a sample of trips in the baseline phase. From this sample, average boardings is measured to be 70 and average peak point load is measured to be 50. The conversion factor is the ratio of average boardings to average peak point load, or 70/50 = 1.4. Then, in the monitoring phase, peak point load is measured, while boardings are not, in every quarter. In one quarter, for example, average peak point load was found to be 55 (an increase of 10% from the baseline amount). Average boardings is then inferred to be (55)(1.4) = 77 (also an increase of 10% from the baseline phase).

The use of conversion factors affects the conduct and the costs of both the baseline and monitoring phases. Therefore, careful planning is required in the design of the overall data collection program to ensure that conversion factors are most effectively used to lower the overall cost of the program. This chapter provides an overview of the program design process, and as such provides an introduction to the remainder of Part I of this manual.

4.2 Baseline Phase

The baseline phase is intended to provide a comprehensive "snapshot" of the system. Therefore all the data items that are needed by the transit system (see Chapter 2) should be collected in the baseline phase.

The baseline phase is also intended to estimate conversion factors. To estimate a conversion factor, data must be collected in pairs. Therefore, the need for conversion factors should be anticipated in the design of the baseline phase. Furthermore, one of the items in a conversion pair may not be needed in its own right, but may be needed to serve as an auxiliary item in a conversion strategy in the monitoring phase.

4.3 Monitoring Phase

The monitoring phase serves two purposes: 1) to measure data items that are likely to change and for which updated values are needed as part of the regular scheduling, evaluation, and reporting requirements; and 2), to monitor key data items, called "change indicators", to detect whether a significant change in either ridership or operating patterns have changed, triggering follow-up. Sections 4.3.1 and 4.3.2 deal with data items that must be regularly updated, while Section 4.3.3 deals with change indicators. Section 4.3.4 summarizes the monitoring phase data needs by presenting three low-cost options.

4.3.1 Data Items That Need Regular Updating

For the typical route, the data items that may have to be updated regularly (each season or each year) are:

	Data Item	Level of Detail
o	peak point load or true maximum load	route/direction/time period
o	revenue	route/direction/time period
o	boardings	route/direction/time period/fare category
o	passenger miles	route/time period
o	schedule adherence (proportion early/ on time/late)	route/direction/time period
o	running time	route/direction/time period

Schedule adherence (and/or running time) and peak load are monitored periodically by most systems to ensure efficient scheduling and reliable service. Schedule adherence can be measured at any of a number of points (e.g., peak load point, route endpoints); however, the same point should be used consistently. Load data are most often needed to determine appropriate service frequencies. A point check can often be used to measure both peak load and schedule adherence.

It is appropriate to regularly update running time on routes that exhibit strong seasonal fluctuations in running time, or where growth in traffic activity causes running times to gradually increase. On routes where running times has proven stable, however, it may be sufficient to monitor running time by measuring schedule adherence at a point on the route, using the reasoning that as long as schedule adherence does not change significantly, running time can be assumed to have remained unchanged.

Total boardings, boardings by fare category, revenue, and passenger miles are alternative measures of the utilization of the route. The choice of which one(s) to monitor regularly for this purpose will depend on the feasibility of different data collection techniques for the system, and on particular local needs. Boardings and passenger miles are needed in order to comply with Section 15 requirements.

4.3.2 Updating Using Conversion Factors

As explained in Section 4.1, conversion factors can significantly reduce the cost of the monitoring phase. They make it possible to estimate the average of a difficult-to-collect (inferred) data item by measuring a related easy-to-collect (auxiliary) data item and multiplying its average by the conversion factor. Sometimes two items that are both needed for updating in the monitoring phase can be related by a conversion factor; in such a case, only the easier-to-collect item must be measured in the monitoring phase. In other cases, an item that is not needed in itself during the monitoring phase can serve as the auxiliary item, and be used to infer related items that are needed.

Just which items are difficult/expensive to collect and which are easy/inexpensive depends on individual characteristics of the transit system, such as whether APC's are available, or whether drivers can do boarding counts or farebox readings. Listed below are examples of related data items for which it may be more efficient to use conversion factors than to measure the more expensive item directly in the monitoring phase.

Auxiliary Data Item	Inferred Data Item
load or revenue	boardings
load at inner end of branch or revenue obtained on branch	boardings on branch
boardings, load or revenue	passenger miles
peak point load	true maximum load
load at point near peak point	peak point load, true maximum load
revenue	peak point load, true maximum load

4.3.3 Monitoring Change Indicators

One of the purposes of the monitoring phase is to monitor key data items, called change indicators, with the reasoning that if these key items show no significant change, then all other related data items can be assumed to be unchanged. For most properties, two change indicators will be sufficient, one as an indicator of passenger activity, and one as an indicator of running time.

As mentioned in Section 4.3.1, schedule adherence can be used as a change indicator for running time if running time is not monitored directly. If running time is monitored directly, no change indicator is needed in this area. If neither running time nor schedule adherence was considered (in Section 4.3.1) as needing regular updating, one of them should be added as a change indicator. In nearly all cases, the more efficient one to add is running time.

Passenger related data items such as passenger characteristics, attitudes, origin-destination patterns, and transfer patterns can be monitored indirectly through the measurement of a change indicator such as peak load or revenue. It is highly unlikely that any of these data items will change without a corresponding change in the change indicator.

4.3.4 Frequency of Monitoring

How often the various monitoring data items should be collected and reported depends on the needs of the system. Different items may be desired with different reporting periods. For example, peak load may be desired every quarter while passenger-miles is needed every year. Sample sizes determined for each data item will be with respect to their particular reporting period. However, in scheduling the data collection activities, there will be a standard "monitoring period" which is the smallest reporting period of the data items needed in the monitoring phase. Thus if some items are needed quarterly and others annually, the monitoring period will be the quarter. Sample size requirements of data items with larger reporting period are simply be divided by the ratio of the length of their reporting period to the length of the monitoring period.

4.3.5 Efficient Monitoring Phase Options

Properties that have automatic passenger counters or that can use vehicle operators to collect data may be able to measure directly many or all of these items listed in Section 4.3.1, and perhaps other items as well. For systems that must rely on checkers, however, the use of conversion factors and change indicators may enable a system to restrict direct measurement in the monitoring phase to items that can be obtained by point checks, keeping the cost of the monitoring phase down. Table 4.1 lists 3 possible combinations of data items, each of which can be measured using point checks, and which may be able to fullfil the data needs of the monitoring phase through the use of conversion factors and change indicators.

4.4 Follow-up Phase

Follow-up is necessary when conditions measured in the baseline phase (or in the most recent follow-up phase) have

Table 4.1

Some Monitoring Phase Options

Location of Point Counts	Measure Directly	Data Items Change Indicator	Infer via Conversion
OPTION A			
Peak Point	o peak point load o schedule adherence	o peak point load o schedule adherence	o boardings, pass-miles and revenue from point load. o running time assumed unchanged unless schedule adherence indicates change
OPTION B			
Point near peak point	o point load o schedule adherence	o point load o schedule o adherence	o peak point load from point load o boardings, pass-miles and revenue from point load. o running time assumed unchanged unless schedule adherence indicates change
OPTION C			
Endpoints	o running time o schedule adherence o revenue	o revenue	o peak point load from revenue o boardings, pass-miles from revenue

changed. Indications of change can be both external and internal. An external indication of change would be a change imposed on the users, such as a route restructing, a major schedule change, or a major fare change. With each external change, the operator must decide which related data items are likely to be significantly affected, and then initiate follow-up on those data items.

Changes can also be indicated internally when a data item that is measured in the course of the monitoring phase shows a marked change from baseline conditions. When a monitored data item changes significantly, then, follow-up should be initiated on the related data items for which the monitored item served as a change indicator. Based on the routes analyzed in this study, it is recommended that the baseline phase be redone if the passenger usage indicator changes by 25 percent or more from the initial baseline phase results. When schedule adherence is used as an indicator of running time, it is recommended that running time be rechecked if the proportion of early or late trips changes by 0.15 or more.

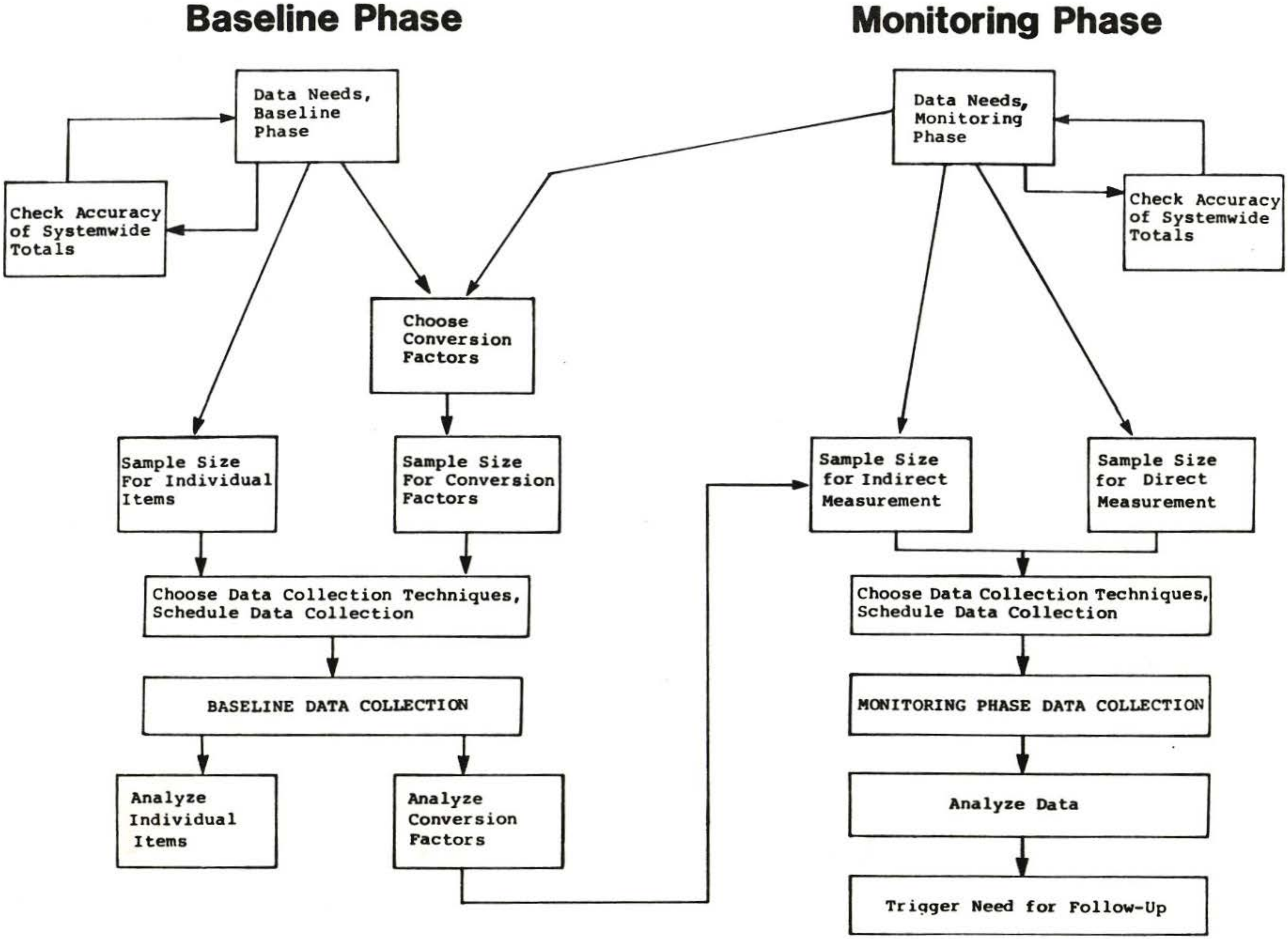
The needs of the follow-up phase are the most unpredictable of the three phases. Immediately after the baseline phase, little follow-up will be needed. With time, however, needs for follow-up will spring up on different routes, in different time periods, and for different data items, and will become a regular part of the data collection program.

4.5 Overview of Data Collection Program Design

Figure 4.1 illustrates the design process for the baseline and monitoring phases of a data collection program. This process is given in detail a step-by-step procedure in Chapter 8. The purpose of this section is merely to present an overview and to relate the remainder of Part I of this manual to the overall design procedure.

Figure 4.1

DESIGNING A DATA COLLECTION PROGRAM



The first step is to define data needs for both phases, as described in Chapter 2 and in Sections 4.2 and 4.3. Part of the definition of data needs is the specification of accuracy level, a topic covered in Section 5.1.1. The chosen accuracy level for route-level items must then be tested to ensure that, when the data are aggregated to yield systemwide totals, the systemwide totals will be accurate enough. This topic is covered in Section 5.1.2.

The next step in the baseline phase is to choose a set of conversion factors. This topic was discussed in Section 4.3.3.

The baseline phase design continues with sample size determination for both individual items and for conversion factors. This topic is covered in Chapter 6. Section 5.2, discussing data variability, also provides important input to sample size determination.

Sample sizes are then translated into a schedule of data collection activities. This topic is covered in Chapter 6.

Once data collection is accomplished, the data are analyzed (to determine the accuracy of the statistics obtained) using procedures found the Chapter 6. (Procedures for determining accuracy and for determining sample size are presented in the same chapter because they are closely related.) Of particular importance are the conversion factors estimated in the baseline phase, whose analysis is discussed in Section 6.4.

Once the baseline phase is completed, design and execution of the monitoring phase follows. Sample size determination for items measured directly (i.e., without use of a conversion factor) follows the same procedure as used in the baseline phase. Sample size determination for auxiliary items meant to be used with conversion factors has its own procedure that is found in Section 6.4. The remainder of the monitoring phase parallels the baseline phase.

In Part II of this manual, Chapter 8 provides a detailed, step-by-step treatment of this design process, including several worksheets. The component of scheduling data collection activities is a rather involved procedure in itself, and has therefore been isolated to form a separate chapter, Chapter 9. Both of these chapters have worked examples that parallel the procedures throughout.

CHAPTER 5

SAMPLING, ACCURACY, AND DATA VARIABILITY

Most data are collected using some type of sampling strategy, since 100 percent coverage of all trips every day is generally too costly. Because only a fraction of all trips is observed, there is uncertainty about how well the sample data represents the total population. Thus, averages computed from a sample are necessarily only estimates of the true averages. The accuracy of these estimates depends on two factors: the size of the sample, and the degree of variability in the data being measured.

This chapter discusses the concepts of sampling, accuracy, and data variability. Section 5.1 introduces the topic of accuracy, and recommends accuracy levels for different data items. Section 5.2 then discusses the causes of data variability, suggests ways to estimate data variability, and offers default values where no other way is feasible.

5.1 Accuracy

Accuracy has two components: a range of uncertainty ("tolerance") and a probability ("confidence") level. The tolerance indicates the range around the observed (measured) value within which the true value of the data item is likely to lie. For averages and totals, a relative tolerance is generally specified. For example, for Section 15, the data must be accurate enough that there is confidence that the true value of the data item is within ±10% of the observed value. The confidence level indicates the probability that the true value is within the tolerance range around the observed value. For Section 15, a confidence level of 95% is specified. Thus, for Section 15 data, there is a 95 percent chance that the true average of the data item is within ±10% of the observed average.

"More accurate", therefore, can mean a smaller tolerance at the same confidence level, or a larger confidence level with the same tolerance. Rather than adjusting both tolerance and confidence level to reflect different levels of accuracy, the approach of this manual is to fix the confidence level and vary the tolerance in response to the need for different accuracy levels. Therefore, this manual recommends that a 90% confidence level be used at all times for both segment- and route-level data, and that a 95% confidence level be used for system-level data.

Sometimes what is desired is not the average of a data item but the proportion of observations that lie in a certain category. For example, schedule adherence is defined in this manual to be the proportion of trips lying in the categories early, on time, and late. Another example is the proportion of passengers who are pass users. For category proportions, relative tolerance is not generally used; instead absolute tolerance (AT) is used. For example, if a proportion is estimated to be 0.7 and its tolerance is 0.1, then the range of uncertainty for the proportion is 0.6 to 0.8.

Another way of specifying tolerance for category proportions is through the absolute equivalent tolerance (AET), defined to be the absolute tolerance that would be achieved if the estimated proportion is 0.5. The rationale behind this form of tolerance is that for many cases, the appropriate desired absolute tolerance (AT) depends on the value of the estimated proportion. Thus, while a ±0.1 AT may be appropriate for an expected proportion of 0.5, a smaller AT would be desired if the proportion were near 0 or 1. However, it turns out that the AT achieved by a given sample size is in fact smaller when the proportion is near 0 or 1 than when it is near 0.5. These two effects balance one another, and suggest that, when convenient, a sample size should be chosen with the assumption that the proportion will be 0.5.

Absolute tolerance and absolute equivalent tolerance are related (at the 90% confidence level) by the formulas

$$d_a = 2\, d_e \sqrt{p(1-p)} \qquad (5.1)$$

$$d_e = \frac{0.5\, d_a}{\sqrt{p(1-p)}} \qquad (5.1a)$$

where d_a = absolute tolerance
d_e = absolute equivalent tolerance
p = proportion lying in category

5.1.1 Need for Accuracy and Recommended Tolerances

Because of the costs of data collection, high accuracy should not be sought for its own sake. Rather, the ways each data item are to be used should be reviewed first to determine the impacts of using more accurate or less accurate data before choosing an appropriate tolerance level.

For example, the accuracy need for the peak load of a busy route in the peak period, peak direction will typically differ considerably from the accuracy need for peak load on a weekend on a route that is operating on a policy headway and never has standees. In the former case, any significant measured change in peak load could result in a change in headway on the route, while in the latter case a drastic change in peak load would be needed to prompt any service change. Thus, in the case of busy peak period route, accurate information is needed because it is quite likely that inaccurate counts will lead to a poor decision, while in the case of a low frequency route, high accuracy is not as necessary since it is unlikely that even a moderately inaccurate count will lead to an incorrect decision. Furthermore, data covering a period of many hours should be more accurate than data covering a short period or a single trip. This is because an error made in scheduling for a long period is more costly than an error made in scheduling a short period.

As a general rule, information that is likely to be used to determine a change in service should be collected at a high degree of accuracy; information that is unlikely to lead to any change is not needed with as great a degree of accuracy. The less accurate information can be used as a screening device; i.e., if a large change is observed, but is suspect due to the low accuracy level, the large change triggers additional data collection until the accuracy of the data is sufficient for making a decision.

Based on these considerations, the following priorities are suggested for the "typical" transit system:

(1) Peak load and running time data are needed at a more accurate level than other route level data since they are the main inputs to the regular scheduling process.

(2) More accuracy in peak load data is needed on long, high-frequency routes than in other cases. As shown in Table 5.1, tolerances ranging from ±5 to ±30 percent are recommended depending on the number of buses operating on the route. (For guidance on determining the number of buses operating on a route, see the explanation following equation (6.14) in Section 6.4.2.)

(3) Route boardings are needed at only a moderate level of accuracy on all routes/all time periods as a general measure of usage. A tolerance of ±30 percent is recommended.

(4) Route segment level data, unless route redesign is anticipated, is not needed with as great accuracy as route level data. A tolerance of ±30 percent or more is recommended.

(5) Less accuracy is needed in short time periods (less than 3 hours) because errors affecting short periods are less serious than errors affecting long periods. Tolerance shown in Table 5.1 should be multiplied by the factors shown in Table 5.2 for periods less than 3 hours long. These factors range from 1.05 for a 2.5-hr period to 2.8 for periods shorter than 15 min.

Table 5.1

Recommended Tolerances

	for time periods lasting 3+ hours(2)
Boardings (by R/D/TP)(1)	
For all routes and time periods	±30%(3)
Peak Load, Peak Direction (by R/TP)*	
Routes operating with 1-3 buses	±30%
Routes operating with 4-7 buses	±20%
Routes operating with 8-15 buses	±10%
Routes operating with 15+ buses	±5%
Peak Load, Reverse Direction (by R/TP)	
For all routes and time periods	±30%
Passenger-miles (by R/D/TP)	
For all routes and time periods	±30%
Run time (by R/D/TP)	
Routes with run time ≤ 20 min	±10%
Routes with run time > 20 min	±5%
Fraction of trips early/on time/late (by R/D/TP)	
For all routes and time periods	±0.1 AET(4)
Segment level boardings, alightings (by R/D/TP) (route segment or market segment)	±30% or more(5)

Note: 90% confidence level assumed.

(1) R/D/TP denotes a combination of Route, Direction and Time Period; R/TP denotes a combination of Route and Time Period.

(2) For shorter time periods or individual trips, multiply by adjustment factors given in Table 5.2.

(3) Provided tolerance for systemwide boardings, given by equation (5.2), (5.2a), or (5.3) (as appropriate) will be below the 10% required by Section 15. If not, decrease tolerance to 20% on highest ridership routes/time periods.

(4) Absolute equivalent tolerance, as defined in text.

(5) In general, segment-level tolerance should exceed route-level tolerance. Also, small segments should have greater tolerances than large segments.

Table 5.2

Tolerance Adjustment Factors for Short Time Periods

Duration of Time Period	Adjustment Factor
2.5 hrs = 150 min	1.05
2.0 hrs = 120 min	1.1
1.5 hrs = 90 min	1.2
1.0 hrs = 60 min	1.35
0.5 hrs = 30 min	1.75
0.33 hrs = 20 min	2.1
0.25 hrs = 15 min	2.4
less than 15 min	2.8

(6) If data items are desired on an individual trip (rather than time period) basis, multiply the tolerances found in Table 5.1 by the factor in Table 5.2 that corresponds to the headway (i.e., set the duration of the time period equal to the headway). For example, with a 15-min headway, use a factor of 2.4; for a 10-min headway, use a factor of 2.8.

An example will illustrate the use of Tables 5.1 and 5.2. A transit system wishes to measure peak load on a route in both directions for two time periods: 6a.m.-7a.m., and 7a.m.-9a.m. During the earlier period, 6 buses are used on the route; during the later period, 10 buses are used. The recommended tolerances for peak load are tabulated below.

	Recommended Tolerance Before Adjustment (Table 4.1)	Adjustment Factor (Table 4.2)	Final Recommended Tolerance
peak load, peak direction, 6-7a.m.	20%	1.35	27%
peak load, reverse direction, 6-7a.m.	30%	1.35	40.5%
peak load, peak direction, 7-9a.m.	10%	1.1	11%
peak load, reverse direction, 7-9a.m.	30%	1.1	33%

The above recommendations are guidelines only and may be modified to reflect local conditions. For example, as explained later in Section 5.2.2, there may be a need in small transit systems to measure boardings more accurately on higher ridership routes in order to comply with the Section 15 requirement of a ±10% tolerance in systemwide boardings.

5.1.2 Relation Between Route-Level and Systemwide Accuracy

All transit systems are required to report systemwide totals of unlinked passenger trips and passenger-miles under

Section 15 of the UMTA Act. The reported totals are to have a tolerance of ±10% at a 95% confidence level.

For a system that collects route-level data, systemwide totals can be estimated by aggregating the totals of all routes, directions, and time periods (R/D/TP's). (Note that R/D/TP totals are obtained by simply expanding R/D/TP averages, and that the expansion procedure does not affect the accuracy level.) The tolerance of the systemwide estimate can be calculated using the following formula:

$$d_{sys} = \frac{t_{sys} \sum_{j=1}^{m} x_j^2 \quad d_j^2}{t_{rt} \sum_{j=1}^{m} x_j} \qquad (5.2)$$

where m = number of route/direction/time period combinations (R/D/TP's) in systemwide total

d_{sys} = systemwide tolerance level (e.g., 0.03 means ±3%)

d_j = route level tolerance for R/D/TP j

x_j = total value of data item for R/D/TP j

t_{sys} = t-value for systemwide confidence level

t_{rt} = t-value for route confidence level

With a 95% confidence level at the systemwide level, t_{sys} is approximately 2.0. With a 90% confidence level at the route level, the value of t_{rt} is approximately 1.8. Then if all routes have data collected at the same tolerance level, equation (5.2) simplifies to

$$d_{sys} = \frac{2.0 \; d_{rt} \sqrt{\sum_{j=1}^{m} x_j^2}}{1.8 \quad \sum_{j=1}^{m} x_j} = \frac{1.11 \; d_{rt} \sqrt{1 + v_{bet}^2}}{\sqrt{m}} \qquad (5.2a)$$

where d_{rt} = R/D/TP-level tolerance

$v_{bet} = s_{bet}/\bar{X}_{bet}$ = between-R/D/TP coefficient of variation of the R/D/TP totals

$\bar{X}_{bet}$ = (unweighted) average total among the m R/D/TP combinations

s_{bet} = between-R/D/TP standard deviation of the R/D/TP totals, given by

$$s_{bet} = \sqrt{\frac{1}{m} \left(\sum_{j=1}^{m} X_j^2 \right) - \bar{X}_{bet}^2}$$

The more the variation in the R/D/TP totals from R/D/TP to R/D/TP, the greater v_{bet} will be. (If all R/D/TP's have identical totals v_{bet} will be zero.) For a sample of routes from Chicago's CTA and SCRTD of Los Angeles, v_{bet} for total boardings was computed to be 0.72 and 1.13, respectively, with the entire weekday constituting a single time period in each case. A reasonable range for v_{bet} for boardings for single time period analyses has been found to be 0.3 to 1.4, with values in the upper range occurring when a substantial fraction of the routes have unusually high total boardings. If there are multiple time periods, v_{bet} will generally be greater, in the range 0.6 to 1.6. For quantities similar to total boardings such as total revenue or total passenger-miles, a similar range in between route coefficient of variation is expected. With this range, the systemwide tolerance achieved by aggregating route level data should lie in the range

$$d_{sys} = \frac{1.16\, d_{rt}}{\sqrt{m}} \text{ to } \frac{1.91\, d_{rt}}{\sqrt{m}} \quad \text{if 1 time period per day is used}$$

$$d_{sys} = \frac{1.29\, d_{rt}}{\sqrt{m}} \text{ to } \frac{2.09\, d_{rt}}{\sqrt{m}} \quad \text{if multiple time periods are used} \qquad (5.3)$$

where m is the number of route/direction/time period combinations (assuming that route-level data is collected by direction to achieve a tolerance d_{rt} at a 90% confidence level, and that the 95% confidence level is used for the systemwide total).

Formula (5.3) suggests that even with a small number of routes, a small systemwide tolerance is achievable. As shown in Table 5.3, collecting data at a route-level tolerance of ±30% will, except for the smallest systems (five routes and smaller), yield a systemwide tolerance of ±10%. However, if for a particular transit system the number of routes and time periods is such that the desired tolerance for systemwide boardings is not achieved by aggregating R/D/TP totals, one of two adjustments can be made. First, route-level tolerance can be reduced on all routes, using equation (5.2a) to determine what the route-level tolerance d_{rt} should be. Second, the tolerance can be reduced on high ridership routes only, and then equation (5.2) can be used to determine systemwide tolerance. With this second approach, route tolerances should be set so that each route has approximately the same absolute (as opposed to relative) tolerance (e.g., ±10% on a route with 500 boardings and a ±1% tolerance on a route with 5,000 boardings both yield an absolute tolerance of ±50 boardings). This latter procedure, while a little more complex computationally, requires less data collection than reducing route-level tolerance across the board.

5.2 Data Variability

Variability in data, which is the reason that estimates obtained by sampling are inevitably inaccurate, arises from two factors, discussed in the following sections: inherent variability in the data, and measurement error. Statistical methods for dealing with variability are discussed in the remaining sections of this chapter.

5.2.1 Inherent Data Variability

Most quantities of interest to the transit operator, including boardings, load, revenue, running time, and schedule deviation, vary from trip to trip, from day to day, from week to week, and so forth. This inherent variability arises from

TABLE 5.3

SYSTEMWIDE TOLERANCES ACHIEVED USING ROUTE-LEVEL DATA *

a. One time period per day (two directions per route assumed)

NUMBER OF ROUTES	ROUTE/** DIRECTION/ TIME PERIODS	ROUTE-LEVEL TOLERANCE		
		+/- 10%	+/- 20%	+/- 30%
2	4	0.058 to 0.096	0.116 to 0.191	0.174 to 0.287
5	10	0.037 to 0.060	0.073 to 0.121	0.110 to 0.181
10	20	0.026 to 0.043	0.052 to 0.085	0.078 to 0.128
25	50	0.016 to 0.027	0.033 to 0.054	0.049 to 0.081
50	100	0.012 to 0.019	0.023 to 0.038	0.035 to 0.057
75	150	0.009 to 0.016	0.019 to 0.031	0.028 to 0.047
100	200	0.008 to 0.014	0.016 to 0.027	0.025 to 0.041
125	250	0.007 to 0.012	0.015 to 0.024	0.022 to 0.036

b. Multiple time periods (two directions per route assumed)

NUMBER OF ROUTES	ROUTE/** DIRECTION/ TIME PERIODS	ROUTE-LEVEL TOLERANCE		
		+/- 10%	+/- 20%	+/- 30%
2	12	0.037 to 0.060	0.074 to 0.121	0.112 to 0.181
5	30	0.024 to 0.038	0.047 to 0.076	0.071 to 0.114
10	60	0.017 to 0.027	0.033 to 0.054	0.050 to 0.081
25	150	0.011 to 0.017	0.021 to 0.034	0.032 to 0.051
50	300	0.007 to 0.012	0.015 to 0.024	0.022 to 0.036
75	450	0.006 to 0.010	0.012 to 0.020	0.018 to 0.030
100	600	0.005 to 0.009	0.011 to 0.017	0.016 to 0.026
125	750	0.005 to 0.008	0.009 to 0.015	0.014 to 0.023

---

* Route confidence level assumed to be 90% and system confidence level assumed to be 95%; route-level boardings measured by direction for a single day-long time period; between-route coefficient of variation of total boardings assumed to range from 0.3 to 1.4.

** Three (3) Time Periods and Two (2) Directions assumed for each route.

the variability in such factors as people's travel needs, traffic conditions, weather, and driver and vehicle performance.

Some of the fluctuations in data items are systematic, in the sense that they can be expected. For example, on rainy days ridership tends to be lower and running times longer in some systems. Another example is that during peak periods, trips in the middle of the period tend to be more heavily patronized than trips at the fringes. Because of these trends, it is important that the chosen sample of trips for a particular R/D/TP be a random or representative sample (see Chapter 7).

5.2.2 Measurement Error

In addition to inherent data variability, there is a measurement error associated with virtually all methods of data collection. For counts taken manually, a variety of factors contribute to the existence and magnitude of measurement error. These factors include the training and experience of the checkers, the number of data items each checker must monitor, the magnitude of the items being counted, and the type of equipment used to register the counts. Point checks are subject to greater error when there are many standees and tinted windows. Ride checks are more difficult if boardings and alightings occur simultaneously and in large numbers, or if fare categories must be counted separately, especially on crowded vehicles. Vehicle operators may have similar problems collecting data on fare categories when there are crush loads or heavy traffic.

Automated passenger counters (APC's) are also subject to measurement error. Experience to date indicates that APC boarding counts tend to be more accurate than alighting counts. In addition, APC's tend to undercount. Overcounting can occur, however, if, for example, large packages get in the way or if people stand in the stairwells. Counters at the front door have been found to be more accurate than those at the rear door of the bus.

In addition to these systematic errors with APC's, equipment reliability problems can include: sensor malfunctions, electrical disconnections, inaccurate odometer readings, and environmental factors. Sensor malfunctions can occur if treadle mats settle over the sensors or if lightheads shift out of alignment. Electrical disconnections can affect either the counts themselves or storage of the counts in the microprocessor. Inaccurate odometer readings can throw off the location of bus stops. Finally, environmental factors such as water penetration, cold or heat can also throw off the sensors.

In the case of manual counts, measurements errors are generally random with little directional bias, i.e., no consistent under- or over-counting. Consequently, it can be assumed that these errors will balance out over time, and become even less important as the level of aggregation of the data increases.

If, however, there is reason to believe that a directional bias is occurring, and that it cannot be eliminated by additional training (in the case of manual counts) or mechanical adjustment (in the case of automatic counts), this bias should be corrected by factoring the counts up or down as appropriate. For example, some systems routinely factor up their APC counts to correct for systematic under-counting. To determine the proper correction factor, counts are simultaneously taken using: 1) the method that is suspected of bias and 2) a better trusted method. The ratio of the sum of the trusted counts to the sum of the suspect counts becomes the correction factor.

Other than correcting for directional bias, the existence of measurement error requires no special treatment. In the course of data collection, variability caused by measurement error is indistinguishable from inherent variability, and together these two sources produce the observed variability in data around which the data collection program is designed.

5.2.3 Estimating Data Variability

Transit systems typically have information available on the variability of different data items. Three related measures of variability commonly used in statistical analysis, and necessary for the design of a systematic data collection program, are:

Variance $$s_X^2 = \frac{1}{n-1} (\sum_{i=1}^{n} X_i^2) - \frac{n}{n-1} \bar{X}^2 \qquad (5.4)$$

Standard deviation $$s_X = \sqrt{s_X^2} \qquad (5.5)$$

Coefficient of variation $$v_X = \frac{s_X}{\bar{X}} \qquad (5.6)$$

where n = number of observations in sample

$X_1, X_2, \ldots, X_n$ = individual observations

$\bar{X}$ = average for the sample

Collecting data expressly for the purpose of estimating these variability measures can be expensive. For this reason, guidance is offered in Section 5.2.4 on how to estimate these measures using existing data. In the absence of such data, values derived from the experience of other systems may be used. To this end, default values for key items have been prepared for different classes of routes. This route classification scheme and the corresponding default values are presented in Section 5.2.5.

5.2.4 Estimating Variability From Existing Data

If recent counts are available, they can be used to estimate the variability measures using equations (5.4) - (5.6) above. It is important that the data points used be "raw" data, not an average of a number of data points. Adequate variability estimates can be obtained with a sample of 12 data points, although larger samples, of course, provide better estimates. It is also preferable that the data points be for different trips on a few different days rather than all on the same day.

If the most recent set of counts is not large enough, it can be supplemented by one or more older sets of counts (or, for that matter, a new set) such that the total number of counts is at least 12. Then the formula for estimating the variance from the two datasets is

$$s_X^2 = \frac{(n_1 - 1)\ s_1^2 \quad + \quad (n_2 - 1)\ s_2^2}{(n_1 - 1) + (n_2 - 1)} \qquad (5.4a)$$

where s_1^2, s_2^2 = variance of X from the first dataset, from the second dataset

n_1, n_2 = size of first dataset, second dataset

(To incorporate additional datasets, add corresponding terms for each dataset to both numerator and denominator of (5.4a).)

When using (5.4a) to estimate the variance, standard deviation is still computed using (5.5). When using (5.6) to compute the coefficient of variation, the most recently available value of $\bar{X}$ should be used.

5.2.5 Default Values

Using data from four large systems*, coefficients of variation for three key data items for different routes and time periods were compared to see whether there were systematic differences in coefficient of variation between the time periods and between classes of routes (e.g., long vs. short

---

* San Francisco (MUNI), Chicago (CTA and RTA) and Pittsburgh (PAT).

routes, etc.). The three data items, which are all measured at the route and trip level, are peak load, boardings, and running time. Where significant differences were found between time periods/route classes, a default value for each time period/route class was computed. These default values were conservatively estimated to be slightly higher than the average C.O.V. for their particular classification. The default values, with the corresponding classification scheme, are summarized in Table 5.4.

For load at points other than the peak point, the same set of default C.O.V.'s as used for peak load can be used, provided the average load at that point is at least 12 passengers or 33% of the average peak load, whichever is smaller. For example, if average load on a route in an off-peak period is 50 passengers at one peak (the peak point) and 15 passengers at another, the default C.O.V.'s for load are 0.45 at the peak point and 0.60 at the other point. The default running time C.O.V.'s can be used for entire routes as well as route segments that are at least 10 min long.

For segment-level boardings, the segment-level C.O.V. will generally be greater than the route-level C.O.V. How much greater it is depends on the size of the segment. A formula for estimating a default C.O.V. for segment-level boardings is

$$v_S = \sqrt{v_{RT}^2 + \frac{1 - f}{f\bar{X}_{RT}}} \qquad (5.7)$$

where v_S = C.O.V. of segment-level boardings

v_{RT} = C.O.V. of route-level boardings

f = ratio of segment-level to route-level boardings

$\bar{X}_{RT}$ = average route-level boardings

To be conservative, it is important that the estimate of f used in this equation be at the lower end of its expected range.

Table 5.4

DEFAULT VALUES FOR COEFFICIENT OF VARIATION OF KEY DATA ITEMS

Data Item	Time Period	Route Classification	Default Value
Load	Peak	Load < 35 pass./trip	.50
	Peak	≥ 35 pass./trip	.35
	Off-Peak	< 35 pass./trip	.60
	Off-Peak	35-55 pass./trip	.45
	Off-Peak	> 55 pass./trip	.35
	Evening	All	.75
	Owl*	All	1.00
	Sat., 7a.m.-6p.m.	All	.60
	Sat., 6p.m.-1a.m.	All	.75
	Sun., 7a.m.-1a.m.	All	.75
Boardings, Passenger-miles	Peak	Peak Load < 35 pass./trip	.42
	Peak	≥ 35 pass./trip	.35
	Off-Peak	< 35 pass./trip	.45
	Off-Peak	35-55 pass./trip	.40
	Off-Peak	> 55 pass./trip	.35
	Evening	All	.73
	Owl*	All	.80
	Sat., 7a.m.-6p.m.	All	.45
	Sat., 6p.m.-1a.m.	All	.73
	Sun., 7a.m.-1a.m.	All	.73
Running Time	All	short (≤ 20 min.)	.16
	All	long (> 20 min.)	.10

---

*Owl default values are the same for weekdays and weekends.

For example, on a route in the peak period with an average peak load of 40 and an estimated average boardings per trip of 100, the default C.O.V. (from Table 5.4) is 0.35. It is estimated that a certain segment has 20 to 25 boardings per trip, so that the estimated range for f is between 0.2 and 0.25.

Known data

$v_{RT} = 0.35$

$\bar{x}_{RT} = 100$

$f = 20/100 = 0.2$ (estimate at lower end of range)

From equation (5.7),

$$v_S = \sqrt{(.35)^2 + \frac{1 - .2}{.2(100)}} = 0.40$$

For category proportions, such as proportion of trips early/on time/late, a coefficient of variation estimate is not needed because the C.O.V. of a category proportion can be determined directly from the magnitude of the proportion. Therefore, sample size and accuracy formulas for category proportions (in Section 6.3) do not explicitly use C.O.V.'s.

5.2.6 Route Classification for System-Specific Default Values

In between the approaches of estimating variability directly for each route, direction and time period combination and using the default values given in Table 5.4 is the approach of developing a system-specific set of default values based on data from a large cross-section of routes. While few systems may have such data available now, such an approach may become possible as more data is collected.

In developing system-specific default values, a route classification scheme such as the one used in Table 5.4 must be employed. The dimensions along which routes can be classified include: time of day, direction, demand level, route length, and route type. By computing C.O.V.'s for a large number of routes, different categorizations along the above dimensions can be examined in search of a categorization scheme in which the within-group variability is small.

Whatever the classification scheme chosen, the default value of C.O.V. for a particular category should be conservatively chosen to be above the average C.O.V. for routes in that category. This is to correct for the fact that using average C.O.V.'s will systematically underestimate sample size (because the sample size formulas depend on the square of the C.O.V.). In most cases, using the 70-percentile C.O.V. for the category as a default value will be adequate. (This is the value for which 30% of the routes in the category have greater C.O.V.'s, and 70% have smaller C.O.V.'s.) Another (nearly equivalent) approach is to set the default C.O.V. equal to the average C.O.V. for the category plus half a standard deviation.

CHAPTER 6

SAMPLE SIZE DETERMINATION

The concepts of sampling, accuracy, and variability are combined in this chapter in the form of tables and formulas to show the relationship between sample size and accuracy level. All of the formulas and tables assume a confidence interval of 90%, except where noted. For ease in reference, all of the tables presented in this chapter are also collected in Appendix A.

This chapter is divided into five sections, each dealing with either a different type of quantity being estimated, or a different approach to estimating a quantity. Sections 6.1 and 6.2 deal with the direct estimation of averages. Section 6.3 deals with the estimation of category proportions. Section 6.4 deals with indirect estimation of averages using conversion factors, as discussed in Chapter 4. Section 6.5 deals with the product of two estimated quantities, one an average and the other a proportion, as when average boardings is multiplied by the proportion of pass users to estimate average number of pass users. The remainder of this introduction to the chapter clarifies the distinction among these five approaches.

In Section 6.1, an approach is presented for determining sample size for an average measured directly. This approach can be applied to averages of all items that can be observed directly at the route level such as boardings, load, and run time. This approach is also appropriate for data items at time segment-level such as running time. It can also be appropriate for other segment-level items, subject to two conditions: 1), the item can be observed directly (i.e. without a survey); and 2), the segment-level coefficient of variation for the item can be estimated.

Two quantities commonly desired at the segment level, boardings and alightings, are considered in Section 6.2.

"Segment", in this context, can mean a physical route segment. It can also mean a market segment within the route, such as the number of riders on a route that use a pass, provided that a person's belonging to the market segment of interest can be observed without a passenger survey. While segment-level boardings and alightings can be estimated directly, determining their sample size using the approach of Section 6.1 can be difficult because that approach requires a segment-level estimate of the coefficient of variation (C.O.V.). Segment-level C.O.V.'s are difficult to estimate because the data are usually lacking, and it is difficult to give default values because segments can differ so much in size. The approach of Section 6.2 has the advantage that it depends instead on estimates of the route-level C.O.V. and of the fraction of the route-level boardings (alightings) that belong to the segment.

Sample sizes for estimating category proportions are covered in Section 6.3. Category proportions are the estimates of the fractions of a whole such as the proportion of riders on a route that own a car, or the proportion of trips that are on time.

Sample size determination for both estimating conversion factors in the baseline phase and for using conversion factors in the monitoring phase are covered in Section 6.4. Conversion factors are the ratio between two averages, such as average boardings on a route divided by average load, that can be used to estimate the average of one of the items from a measured average of the other.

There are situations in which the quantity ultimately desired is the average number of passengers on a route that belong to a particular category. This type of quantity can either be estimated directly as an average using Section 6.2 (if the market segment is readily observable), or indirectly using both an average and a proportion. This latter approach is covered in Section 6.5. For example, to estimate the average number of boardings in fare category Y, the direct approach is to sample a number of trips, count the number of boardings in that fare category on each trip, compute the average number of passengers in the category per trip and then multiply by the number of trips to estimate the total number of passengers in the category. The indirect approach is to sample individual passengers, determine either by inquiry or by observation whether they belong to fare category Y, and then to estimate the proportion of boardings that are in fare category Y (a proportion). This proportion is then multiplied by the average number of boardings on the route (another estimate) to estimate the total number of passengers in the category. The approach of Section 6.2 is recommended over the approach of Section 6.5, since in the second approach the quantity desired is a product of two estimated quantities, making its accuracy harder to control. However, if the item of interest cannot be observed without a survey, then the second approach must be taken.

6.1 Averages

If a data item is measured directly on a sample of trips and the mean (average) of that sample is used as an estimate of the true mean for that data item, the sample size necessary to attain a desired accuracy level is:

$$n = \frac{3.24\ v^2}{d^2} \quad \text{(round up to next whole number)} \qquad (6.1)$$

where n = sample size (number of trips)

d = tolerance (e.g., $d = .03$ means ± 3% tolerance)

v = coefficient of variation

90% confidence level assumed

A reference table for this relationship is provided in Appendix A and is shown in Table 6.1. In the table, the values of n are listed for particular values of v and d for an assumed confidence level of 90%.

Table 6.1

Required Sample Size for Estimating Averages

v	d = tolerance									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
0.10	13	4	2	1	1	1	1	1	1	1
0.20	52	13	6	4	3	2	2	1	1	1
0.30	117	30	13	8	5	4	3	2	2	2
0.40	208	52	24	13	9	6	5	4	3	3
0.50	324	82	36	21	13	10	7	6	5	4
0.60	467	117	52	30	19	13	10	8	6	5
0.70	636	159	71	40	26	18	13	10	8	7
0.80	830	208	93	52	34	24	17	13	11	9
0.90	1050	263	117	66	42	30	22	17	13	11
1.00	1296	325	144	82	52	37	27	21	17	13
1.25	2025	507	225	127	82	57	42	32	25	21
1.50	2917	730	324	183	117	82	60	46	37	30

Notes. assuming 90% confidence level
v = coefficient of variation

The use of the reference table may require interpolation. For example, suppose average boardings per trip is desired for a particular route/direction/time period combination (R/D/TP) with a ±30% tolerance at the 90% confidence level. The coefficient of variation of boardings for this R/D/TP is estimated to be 0.35. Interpolating on Table 6.1 between v=.30 (4 trips) and v=.40 (6 trips), 5 trips are calculated to be needed. This answer is the same as applying equation (6.1) directly, where $n = (3.24)(.35)^2/(.3)^2 = 4.41$, which rounds up to 5.

After data has been collected, it is possible to estimate the tolerance achieved by the sample. The coefficient of variation (v) is an important input to determining the tolerance achieved. If the size of the sample collected for a particular data item is at least 12, its coefficient of variation can be estimated from the baseline sample (equations 5.4 - 5.6). Otherwise, a default coefficient of variation should be used, as it was in determining sample size.

If a default coefficient of variation is used to estimate the tolerance achieved by a sample, the tolerance achieved is given by

$$d = \frac{1.8\ v}{\sqrt{n}} \tag{6.2a}$$

where n = size of the sample
v = default coefficient of variation
d = tolerance achieved (e.g. d=0.2 means a tolerance of ±20%) (at 90% confidence level)

A reference table for this relationship is provided in Appendix A and is shown in Table 6.2a. In the table, the values of d are listed for particular values of n and v for an assumed confidence level of 90%.

If the sample size is at least 12 and a fresh coefficient of variation is computed from the sample, then the tolerance

Table 6.2

Tolerance Achieved for Estimates of Averages

a. Using a default coefficient of variation

v	n = sample size									
	1	3	6	10	20	40	60	80	100	200
0.10	0.18	0.10	0.07	0.06	0.04	0.03	0.02	0.02	0.02	0.01
0.20	0.36	0.21	0.15	0.11	0.08	0.06	0.05	0.04	0.04	0.03
0.30	0.54	0.31	0.22	0.17	0.12	0.09	0.07	0.06	0.05	0.04
0.40	0.72	0.42	0.29	0.23	0.16	0.11	0.09	0.08	0.07	0.05
0.50	0.90	0.52	0.37	0.28	0.20	0.14	0.12	0.10	0.09	0.06
0.60	1.08	0.62	0.44	0.34	0.24	0.17	0.14	0.12	0.11	0.08
0.70	1.26	0.73	0.51	0.40	0.28	0.20	0.16	0.14	0.13	0.09
0.80	1.44	0.83	0.59	0.46	0.32	0.23	0.19	0.16	0.14	0.10
0.90	1.62	0.94	0.66	0.51	0.36	0.26	0.21	0.18	0.16	0.11
1.00	1.80	1.04	0.73	0.57	0.40	0.28	0.23	0.20	0.18	0.13
1.25	2.25	1.30	0.92	0.71	0.50	0.36	0.29	0.25	0.23	0.16
1.50	2.70	1.56	1.10	0.85	0.60	0.43	0.35	0.30	0.27	0.19

b Using a coefficient of variation estimate computed from the sample

v	n = sample size									
	6	8	10	12	20	40	60	80	100	200
0.10	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.01
0.20	0.16	0.13	0.11	0.10	0.08	0.05	0.04	0.04	0.03	0.02
0.30	0.23	0.20	0.17	0.15	0.12	0.08	0.07	0.06	0.05	0.04
0.40	0.31	0.27	0.23	0.21	0.16	0.11	0.09	0.08	0.07	0.05
0.50	0.39	0.34	0.28	0.26	0.19	0.13	0.11	0.09	0.08	0.06
0.60	0.47	0.40	0.34	0.31	0.23	0.16	0.13	0.11	0.10	0.07
0.70	0.54	0.47	0.40	0.36	0.27	0.19	0.15	0.13	0.12	0.08
0.80	0.62	0.54	0.46	0.41	0.31	0.22	0.17	0.15	0.13	0.09
0.90	0.70	0.60	0.51	0.46	0.35	0.24	0.20	0.17	0.15	0.11
1.00	0.78	0.67	0.57	0.51	0.39	0.27	0.22	0.19	0.17	0.12
1.25	0.97	0.84	0.71	0.64	0.49	0.34	0.27	0.23	0.21	0.15
1.50	1.16	1.01	0.85	0.77	0.58	0.40	0.33	0.28	0.25	0.18

Notes: assuming 90% confidence level
v = coefficient of variation

achieved is

$$d = \frac{tv}{\sqrt{n}} \qquad (6.2b)$$

where n = size of the sample (n should be at least 12)
v = coefficient of variation computed from sample
t = t-value corresponding to n (from Table 6.3)
d = tolerance achieved (e.g. $d=0.2$ means a tolerance of ±20%) (at 90% confidence level)

A reference table for this relationship is provided in Appendix A and is shown in Table 6.2b. In the table, the values of d are listed for particular values of n and v for an assumed confidence level of 90%.

The use of the reference tables in Table 6.2 may require interpolation. Suppose, for the example cited above, boardings were measured on 25 trips. If the default C.O.V. estimate of 0.35 is still used to estimate achieved tolerance, then from Table 6.2a, interpolating for values of v and of n, the tolerance achieved lies between $d=0.09$ and $d=0.16$, and looks to be around ±13%. Alternatively, if equation (6.2a) is used, $d = (1.8)(.35)/\sqrt{25} = .126$, for a tolerance of ±12.6%. (Answers may differ slightly between the equations and the tables due to approximations and rounding off. In general, the tables are more accurate when there is no interpolation, and the formulas are more accurate otherwise.)

Suppose, for the same example, that a new C.O.V. is estimated from the baseline sample (since the baseline sample size was greater than 12), and that this new C.O.V. estimate is $v=0.35$. Although this value is the same as the default value just used, the tolerance achieved will be narrower because the C.O.V. estimate used in this case is more reliable than the C.O.V. used in the previous case (a default value). From Table 6.2b, d lies between .09 and .14, with the tolerance lying around ±12.5%. Alternatively, equation (6.2b) can be used. With a t-value of 1.7 for $n=25$ (from Table 6.3), $d = (1.7)(.35)/\sqrt{25} = 0.119$, for a tolerance of ±11.9%.

Table 6.3

Approximate t-Values

A. For Route- and Segment-Level Data (90% Confidence Level)

Number of Observations	t-Value
2	6.3
3	2.9
4	2.35
5	2.1
6	2.0
7-9	1.9
10-19	1.8
20-99	1.7
100	1.66

B. For Systemwide Data (95% Confidence Level)

Number of Observations Systemwide	t-Value
10-14	2.2
15-29	2.1
30+	2.0

6.2 Segment-Level Boardings and Alightings

For segment-level boardings and alightings, the same procedure as for route-level boardings and alightings is used, except that the segment-level C.O.V. is used instead of the route level C.O.V. The segment-level C.O.V., v_S, is calculated using equation (5.7). The sample size required to estimate segment-level boardings and alightings is given by:

$$n = \frac{3.24\ v_S^2}{d_S^2} \qquad \text{(round up to next whole number)} \qquad (6.3)$$

where n = sample size (number of trips) (90% confidence level)

d_S = the segment-level tolerance (e.g., d = .03 means ± 3% tolerance)

v_S = coefficient of variation of segment-level boardings (alightings)

90% confidence level assumed

Sample size can also be determined using a combination of Tables 6.1 and 6.4 and the formula:

$$n = n_a + n_b \qquad (6.4)$$

where: n_a = sample size from Table 6.1 corresponding to the route-level coefficient of variation v_{RT} and and the segment-level desired tolerance d_S

n_b = additional sample size from Table 6.4

For example, suppose that, for the same route described in Section 6.1, average boardings within a certain segment is desired with a ±30% tolerance (90% confidence level assumed). The average boardings on the route is estimated to be 60, and the fraction of these boardings originating on the segment is estimated to be 0.1. As in Section 6.1, the estimated coefficient of variation of route-level boardings is estimated to be 0.35. For clarity, these figures are summarized as follows:

$$d_S = 0.3 \qquad \bar{X}_{RT} = 60$$
$$v_{RT} = 0.35 \qquad f = 0.1$$

Reading n_a from Table 6.1 with v = 0.35 and d = 0.3, it is found (as in Section 6.1) that n_a=5. Reading n_b from Table 6.4b (since tolerance = ±30%) with f=0.1 and X_{RT}=60, it is found that n_b=6. Thus, the sample size is $n_a + n_b = 5 + 6 = 11$.

Alternatively, equation (5.7) is used to compute

$$v_S = \sqrt{(.35^2) + \frac{1-0.1}{0.1(60)}} = .52$$

Then equation (6.3) is used to compute

$$n = \frac{3.24\ (.52)^2}{0.3^2} = 9.7$$

which rounds up to 10. The difference between the answers (one trip) is due to approximations and rounding off built into the tables.

After the data are collected, the segment-level coefficient of variation can be estimated directly from the sample, provided the sample contains at least 6 observations. The tolerance achieved is

$$d_S = \frac{t_S\ v_S}{\sqrt{n}} \tag{6.5}$$

where n = size of the sample of segment-level observations n should be at least 6

v_S = coefficient of variation of segment-level boardings (alightings)

t_S = t-value corresponding to the segment-level sample size (from Table 6.3)

d_S = tolerance achieved (at 90% confidence level)

Table 6.4

Additional Required Sample Size for Segment-Level Boardings and Alightings

a. Tolerance = ± 20%

f	$\bar{X}_{RT}$= average of route-level item						
	20	40	60	80	100	150	200
0.01	401	201	134	101	81	54	41
0.05	77	39	26	20	16	11	8
0.10	37	19	13	10	8	5	4
0.20	17	9	6	5	4	3	2
0.30	10	5	4	3	2	2	1
0.40	7	4	3	2	2	1	1
0.50	5	3	2	2	1	1	1
0.60	3	2	1	1	1	1	1
0.70	2	1	1	1	1	1	1
0.80	2	1	1	1	1	1	1

b. Tolerance = ± 30%

f	$\bar{X}_{RT}$= average of route-level item						
	20	40	60	80	100	150	200
0.01	179	90	60	45	36	24	18
0.05	35	18	12	9	7	5	4
0.10	17	9	6	5	4	3	2
0.20	8	4	3	2	2	1	1
0.30	5	3	2	2	1	1	1
0.40	3	2	1	1	1	1	1
0.50	2	1	1	1	1	1	1
0.60	2	1	1	1	1	1	1
0.70	1	1	1	1	1	1	1
0.80	1	1	1	1	1	1	1

Notes: assuming 90% confidence level
f = estimated fraction of route-level it belonging to segment

Table 6.4 continued

c Tolerance = ± 40%

f	$\bar{X}_{RT}$= average of route-level item						
	20	40	60	80	100	150	200
0.01	101	51	34	26	21	14	11
0.05	20	10	7	5	4	3	2
0.10	10	5	4	3	2	2	1
0.20	5	3	2	2	1	1	1
0.30	3	2	1	1	1	1	1
0.40	2	1	1	1	1	1	1
0.50	2	1	1	1	1	1	1
0.60	1	1	1	1	1	1	1
0.70	1	1	1	1	1	1	1
0.80	1	1	1	1	1	1	1

d Tolerance = ± 50%

f	$\bar{X}_{RT}$= average of route-level item						
	20	40	60	80	100	150	200
0.01	65	33	22	17	13	9	7
0.05	13	7	5	4	3	2	2
0.10	6	3	2	2	2	1	1
0.20	3	2	1	1	1	1	1
0.30	2	1	1	1	1	1	1
0.40	1	1	1	1	1	1	1
0.50	1	1	1	1	1	1	1
0.60	1	1	1	1	1	1	1
0.70	1	1	1	1	1	1	1
0.80	1	1	1	1	1	1	1

Notes: assuming 90% confidence level
f = estimated fraction of route-level it
belonging to segment

This is the same formula as equation (6.2b). Therefore, Table 6.2b can also be used to give d in terms of v_S and n.

Suppose that, for the example above, 25 trips are monitored. The segment-level C.O.V. is calculated from the data (using equations (5.4) - (5.6)) to be 0.45. From Table 6.3, the t-value for n=25 is 1.7. Summarizing these figures,

$$n = 25 \qquad v_S = 0.45 \qquad t_S = 1.7$$

Using Table 6.2b, it is necessary to interpolate twice: first for v = 0.45 (between v = 0.4 and v = 0.5), and then for n = 25 (between n = 20 and n = 40). Interpolating for v = 0.45, tolerance is estimated to be 0.175 for n = 20, and 0.12 for n = 40. Then interpolating between these values, the tolerance for n = 25 is one quarter of the way from the first value to the second, or 0.175 - (.055)/4 = 0.161, or $\pm$16.1%. Alternatively, equation (6.5) is used, yielding $d = (1.7)(.45)/\sqrt{25} = 0.15$, for a tolerance of $\pm$15%. The difference in answers between the table and the equation is due to roundoff errors and approximations.

6.3 Category Proportions

Often the purpose of a sample is to determine the proportion of observations lying in various categories. For example, trip arrival times are often sampled to determine the proportion that are early, on time, and late. Another example is that passenger surveys are used to determine the proportion of respondents belonging to categories such as age under 16, passholder, and making a transfer.

Tolerances for proportions are expressed either as absolute tolerance (AT) or absolute equivalent tolerance (AET) (described in Section 5.1), as opposed to the relative tolerance used heretofore for averages. To use absolute tolerance to estimate sample size, it is necessary to make a prior estimate of the value of the proportion. The absolute tolerance desired should correspond to this estimate. Absolute equivalent tolerance is not based on a prior estimate of the proportion, and thus is a more general measure of accuracy.

Using absolute equivalent tolerance (AET), sample size can be determined using the following formula:

$$n = \frac{0.75}{d_e^2} \quad \text{(round up to next whole number)} \qquad (6.6a)$$

where n = sample size (number of observations)

d_e = absolute equivalent tolerance specified

(The coefficient 0.75 applies for the 90% confidence level. For a 95% confidence level, the coefficient is 1.0.)

A reference table for this relationship is provided in Appendix A and is shown in Table 6.5a. In the table, the values of n are listed for different values of d_e.

For example, the recommended tolerance for route schedule adherence (proportion of trips early/on time/late) given in Table 5.1 is an absolute equivalent tolerance. Using the recommended absolute equivalent tolerance of ±0.1 and the recommended 90% confidence level, the necessary sample size is seen from Table 6.5a to be 71 trips. In essence, then, the accuracy level recommended in Table 5.1 for schedule adherence is to collect data on 71 trips. Using equation (6.6a) instead of Table 6.5a, necesssary sample size is computed to be $0.75/(.1^2) = 75$, which is slightly higher than the value given in the table because of an approximation in the equation.

If accuracy level is specified with an absolute tolerance (AT) in conjunction with a prior estimate of the proportion p instead of with an absolute equivalent tolerance, the sample size formula is:

$$n = \frac{3p(1-p)}{d_a^2} \quad \text{(round up to next whole number)} \qquad (6.6b)$$

where n = sample size

p = estimated proportion

d_a = absolute tolerance specified for the assumed proportion p (e.g., d = 0.1 means a range of uncertainty of p ± 0.1)

(The coefficient 3 applies for the 90% confidence level. For a 95% confidence level, the coefficient is 4.)

A reference table for this relationship is provided in Appendix A and is shown in Table 6.5b. In the table, the values of n are listed for different values of d_a and p.

A special interpretation is needed for combinations of p and d_a for which

$$d_a > 0.577\, p(1-p) \tag{6.7}$$

These combinations most commonly occur when p is near 0 or 1. Because the value of a proportion is limited to the range 0 to 1, tolerance ranges will be significantly asymmetrical when d_a is large in comparison with either p or (1-p). For example, consider the case of p = 0.03. Suppose a broad tolerance range is desired, a range with a width of 0.08. Normally, this would simply mean an absolute tolerance of half this width, or $d_a = \pm 0.04$. But in this case, the range of 0.03 ± 0.04 is not realistic, because it goes below 0. Instead, the appropriate tolerance range with a width of 0.08 is asymmetric, such as 0.005 to 0.085.

Table 6.5b indicates, for different values of p, the smallest possible value of d_a that may be considered a "true" absolute tolerance. Larger values of d_a should be considered as "nominal absolute tolerance". However, the procedure for sample size determination is essentially the same whether d_a is nominal or not. The general procedure is as follows. First, the estimated value of the proportion p and the desired width of the tolerance range should be determined. Then set

Table 6.5

Required Sample Size for Estimating Category Proportions

a. Using Absolute Equivalent Tolerance

d_e	n
.025	1102
.05	276
.075	122
.1	71
.125	45
.15	32
.2	19

b. Using Absolute Tolerance with Proportion Estimate p

p	maximum "real" d_a^*	d_a = absolute tolerance						
		.01	.02	.04	.06	.08	0.10	0.15
0.01 or .99	.005	273	70	19	10	6	6	3
0.03 or .97	.017	802	200	51	24	14	10	6
0.05 or .95	.027	1309	327	84	38	22	15	8
0.10 or .90	.052	2480	620	155	71	41	26	13
0.20 or .80	.092	4409	1102	276	122	71	45	21
0.30 or .70	.121	5787	1447	362	161	93	59	27
0.40 or .60	.138	6613	1653	413	184	103	68	31
0.50	.144	6889	1722	431	191	108	71	32

Note: Assuming 90% confidence level

* Larger values of a d_a may be used, but they are only approximate (nominal) absolute tolerances. When p is near 0 or 1, actual tolerance range is asymmetric.

d_a equal half this width. If d_a is smaller than the limit for d_a (for the given value of p) given by either Table 6.5b or equation (6.7), d_a should be considered the nominal absolute tolerance. Then d_a may be used (whether it is nominal or not) with either Table 6.5b or equation (6.7) to determine the sample size.

For example, suppose it is estimated that $p = 0.03$ and a tolerance width of 0.04 is desired. Then, taking $d_a = 0.02$, Table 6.5b indicates that this is a nominal absolute tolerance. Then n is read from Table 6.5b to be 200.

Accurately estimating proportions that are near 0 or 1 requires a particularly large sample. For example, suppose an estimate is desired for the proportion of riders on a route who are aware of a certain marketing promotion, and that a prior estimate of this proportion is 0.03 and that a tolerance range of ±0.01 is specified at the 95% confidence level. Then, from equation (6.6b), $n = 4(0.03)(0.97)/(.01^2) = 1164$.

Once a sample is collected and processed, the absolute tolerance achieved can be estimated from the sample. The absolute tolerance achieved for the proportion of observations lying in a particular category is

$$d_a = t\sqrt{\frac{p(1-p)}{n}} \qquad (6.8)$$

where d_a = absolute tolerance achieved

t = t-value corresponding to specified confidence level and to n (from Table 6.3)

p = proportion of observations in sample actually lying in category

n = actual sample size

A reference table for this relationship is provided in Appendix A and is shown in Table 6.6. In the table, the values

Table 6.6

Tolerance Attained for Category Proportions

Number of Observations	*	40	70	160	640	2,560	10,000
	**	55	100	230	920	3,680	14,700
Proportion	n_{min}***						
0.5	36	±0.134	±0.100	±0.066	±0.033	±0.0164	±0.0082
0.4 or 0.6	38	±0.132	±0.098	±0.064	±0.032	±0.0161	±0.0080
0.3 or 0.7	43	±0.123	±0.092	±0.060	±0.030	±0.0150	±0.0075
0.2 or 0.8	56	±0.108	±0.080	±0.052	±0.026	±0.0131	±0.0066
0.1 or 0.9	100	±0.081	±0.060	±0.039	±0.020	±0.0098	±0.0049
0.05 or 0.95	190	±0.059	±0.044	±0.029	±0.014	±0.0072	±0.0036
0.03 or 0.97	309	±0.046	±0.034	±0.022	±0.011	±0.0056	±0.0028
0.01 or 0.99	909	---	±0.020	±0.013	±0.007	±0.0033	±0.0016

---

* With 90% confidence level

** With 95% confidence level

*** Minimum number of observations in keeping with the "rule of 9". If the number of observations is below n_{min}, the tolerance range may be asymmetrical, although the value given in the table can serve as a guide.

of d_a are listed for different values of n, p, and confidence level.

Thus, for example, suppose the recommended accuracy level for schedule adherence were followed and 71 trips were observed. Suppose the proportion of trips that were early, on time, and late were 0.1, 0.6, and 0.3 respectively. To find the absolute tolerance ranges attained at the 90% confidence level, either Table 6.6 or equation (6.8) can be used. From Table 6.6 the resulting ranges of uncertainty are seen to be 0.1 ± 0.060, 0.6 ± 0.098, and 0.3 ± 0.092.

The value of d_a obtained from Table 6.6 or equation (6.8) should be interpreted with caution when the condition of equation (6.6c) is not met, since in such a case the tolerance range will usually be asymettrical. Formula (6.7) is equivalent to the so-called "rule of 9", which states that $np(1-p)$ should be at least 9. Therefore, n_{min}, minimum value of n that satisfies the rule of 9 for a given value of p, is $n_{min} = 9/(p(1-p))$. Values of n_{min} for different values of p are shown in Table 6.6. When n is below the corresponding n_{min}, the value of d_a obtained from Table 6.6 or equation (6.8) should be interpreted as a nominal absolute tolerance, and the actual tolerance range will be asymmetrical, slanted away from the extremes of 0 and 1, and with a width just slightly smaller than $2d_a$.

For a second example, suppose that for the marketing promotion example cited above only 160 completed questionnaires are returned. The proportion of those sampled who are aware of the promotion is found to be 3%. From Table 6.6, when $p = 0.03$, $n_{min} = 309$, and so the sample size of 160 is below n_{min}. Therefore, the value of d_a read from Table 6.6, $d_a = \pm 0.022$, should be taken as a nominal absolute tolerance. The actual tolerance range is asymmetrical with a width slightly below 0.044. While procedures for determining the tolerance range exactly are too advanced for this manual, the tolerance range for this example is approximately (0.03 - 0.019) to (0.03 + 0.024), or 0.011 to 0.054.

6.4 Conversion Factors

The costs of data collection can often be reduced in the monitoring phase by using a conversion factor to estimate the mean of one data item (the "inferred" data item) from the mean of another (the "auxiliary") data item. This type of conversion factor is a simple ratio of averages. For example, to convert load at a point to boardings, the conversion factor "average boardings/average load" is used. More complex relationships, such as linear regression estimates, can also be used and are appropriate when there is reason to believe that the relationship between the two data items does not pass through the origin or is non-linear. However, since these cases are uncommon for the types of applications expected in a transit data collection program, only ratio factors are discussed in this section.

To use a conversion factor in the monitoring phase, information on the two related data items must be collected during the baseline phase. Information on the two related data items must be measured directly in pairs in the baseline phase for each particular route/direction/time period combination (R/D/TP). The ratio of the means, as computed from that paired sample, is then used as a conversion factor in the monitoring phase.

The process for computing and using conversion factors is discussed in the following sections. The necessary formulas for computing the conversion factor and its coefficient of variation are presented in Section 6.4.1. Recommendations on the number of paired observations that should be taken in the baseline phase are offered in Section 6.4.2. Screening prior to data collection is discussed in Section 6.4.3. How the baseline paired sample should be checked and analyzed in preparation for the monitoring phase is described in Section

6.4.4. The necessary sample size of the auxiliary item during the monitoring phase is given in Section 6.4.5. The formula for the tolerance attained using the monitoring sample with a conversion factor is provided in Section 6.4.6. To facilitate the discussion, the example of boardings as the inferred data item and load at a particular point as the auxiliary item is followed through these sections.

6.4.1 Computation of the Conversion Factor and Its Coefficient of Variation

The conversion factor is computed from a paired sample in which the two items are jointly observed on a set of n trips. The conversion factor (conversion ratio) is

$$R = \bar{Y}/\bar{X} \qquad (6.9)$$

where R = conversion factor

$\bar{Y}$ = average of the inferred data item (e.g. boardings) in paired sample

$\bar{X}$ = average of the auxiliary data items (e.g. load) in paired sample

Since the conversion factor is computed from a limited sample, it is only an estimate of the true ratio between the data items. The square of the coefficient of variation of an estimated conversion factor is:

$$v_R^2 = \frac{1}{n-1.7}(v_X^2 + v_Y^2 - 2\, v_X v_Y r_{XY}) \qquad (6.10)$$

where v_R = coefficient of variation (C.O.V.) of the conversion factor as measured from the paired sample

v_X = C.O.V. of the auxiliary item (e.g. load) as measured from the paired sample

v_Y = C.O.V. of the inferred item (e.g. boardings) as measured from the paired sample

r_{XY} = correlation coefficient between the inferred and auxiliary items as measured from the paired sample

n = number of paired observations in the sample

The correlation coefficient between the inferred and auxiliary items, r_{XY}, is a measure of the strength of the relationship between the two items. If the correlation coefficient is near 1, indicating a strong relationship, then the conversion is likely to be an efficient one. To compute the correlation coefficient, the standard deviation s_X and s_Y of both the auxiliary and inferred items, and their covariance, s_{XY}, are needed. The formula for the covariance is:

$$s_{XY} = \mathrm{Cov}(X,Y) = \frac{(\sum X_i Y_i) - n \bar{X} \bar{Y}}{n - 1} \qquad (6.11)$$

The formula for the correlation coefficient is

$$r_{XY} = \frac{s_{XY}}{s_X \, s_Y} \qquad (6.12)$$

It is helpful to have prior estimates of v_X, v_Y, and r_{XY} when determining the baseline sample size needed for estimating a conversion factor. Default C.O.V.'s of X and Y are given in Section 5.2.5. At the writing of this manual, there has not been sufficient empirical analysis to recommend default values of the correlation coefficient r_{XY}. Limited experience with correlation coefficients between peak point load and boardings suggests that r_{XY} is in the range of 0.88 to 0.98 for this pair of data items on most routes. There has been no experience with correlation coefficients for other pairs of data items.

6.4.2 Determining Sample Size of Paired Observations for the Baseline Phase

The accuracy attainable when using a conversion factor depends in part on how large a paired sample was used to estimate the factor. To avoid bias, the sample should include at least 10 observations. Using prior estimates of v_X, v_Y, and r_{XY}, the dummy variable, L, should be computed as:

$$L = \frac{3.24}{d_m^2} (v_X^2 + v_Y^2 - 2\, v_X v_Y r_{XY}) \qquad (6.13)$$

where d_m = specified tolerance for the inferred item in the monitoring phase

Then the recommended sample size of paired observations for the baseline phase is

$$n_1 = L + 1.7 + 7.6 \frac{v_X}{d_m} \sqrt{\frac{L}{B}} \quad \text{(round up to at least 10)} \qquad (6.14)$$

where n_1 = size of paired sample in the baseline phase (90% confidence level)

B = number of buses operating full-time on route during the relevant time period

As equation (6.14) indicates, n_1 should be at least 10.

There are two ways to determine B (the number of buses operating on a route) to an adequate level of precision. If the average headway during the time period is known and if all trips have the same cycle time (round trip time), then B = (cycle time)/(avg. headway.). Otherwise, determine the number of vehicle-hrs of operation in the period by summing the cycle time of every trip on that route in that period, and then divide this sum by the duration of period.

In the absence of any prior estimate of the correlation coefficient or either of the C.O.V.'s, a baseline sample size of n_1 = 15 paired observations is recommended.

The use of equations (6.13) and (6.14) can be shown through an example which involves peak point load and boardings. A sample in which both peak point load and boardings are measured must be taken in order to estimate a conversion from load to boardings. Desired tolerance for boardings is ±30%. The following data is known:

B = 7 = number of buses operating on the route

v_X = .410 = C.O.V. of peak point load

v_Y = .369 = C.O.V. of boardings

r_{XY} = 0.95 = Correlation coefficient between peak point load and boardings

d_m = 0.30 = desired tolerance of the inferred item (boardings) in the monitoring phase

From equation (6.13), the dummy variable, L, is computed:

$$L = \frac{3.24}{(.3)^2} \left[(.410)^2 + (.369)^2 - 2\,(.410)(.369)(.95) \right] = .605$$

Then n_1 is obtained from equation (6.14):

$$n_1 = .605 + 1.7 + 7.6\,(.410/.3)\sqrt{.605/7} = 5.3$$

which, as equation (6.13) indicates, is rounded up to 10. Thus, a baseline sampling of n_1 = 10 paired observations should be undertaken. If, on the other hand, r_{XY} had not been known, n_1 = 15 paired observations would have been recommended.

Since applying the above procedure to every route/direction/time period (R/D/TP) combination can be tedious or difficult due to limited data availability, an efficient way of determining the baseline sample size is to apply this procedure to a few representative R/D/TP's, and then use the resulting sample sizes for corresponding R/D/TP's.

6.4.3 Screening Conversions

In the process of designing a data collection program, as summarized in Figure 3.1, several potential conversion options for estimating the same item may have been proposed. For example, it may be possible to infer boardings on a route by conversion using peak point load, load at some other point, or revenue as the auxiliary item. In the end, only the most efficient conversion will be used in the monitoring phase. Doing baseline data collection and analysis for all of the proposed conversions when only one will ultimately be used can involve significant effort, effort which can be reduced if less efficient conversion options can be screened out prior to data collection. While there are no rules for determining with certainty how efficient a conversion may be, some guidance is given below with which it may be possible to confidently eliminate one or more proposed conversions after estimating the baseline sample size. Listed below are four attributes of a conversion by which it may be judged.

1. Is direct measurement of the auxiliary item already needed in the monitoring phase, either because the item is needed in its own right or for another conversion? If yes, using this item should entail little or no data collection costs in the monitoring phase.

2. Is the auxiliary item inexpensive to collect? If the answer to the first question is no, then auxiliary items that are inexpensive to collect suggest smaller monitoring phase data collection costs.

3. How large a baseline sample does the use of the auxiliary item entail, and how expensive are the paired baseline samples? If the auxiliary item is to be used for more than one conversion, the largest sample size required by any conversion should be the basis for judgement. The smaller the baseline cost,

the better. Also, a larger required baseline sample size usually implies a large required monitoring sample size.

4. <u>How large is the auxiliary item's C.O.V.?</u> If it is large, implying a lot of variability, the monitoring sample will have to be larger to get a reliable estimate of the auxiliary item's average, implying more cost.

6.4.4 Analysis of Baseline Data

Once the baseline paired sample is collected, preparation for the monitoring phase requires four steps of analysis. These steps should be applied to every conversion factor separately (typically there will be separate conversion factors for each route/direction/time period combination).

1. <u>Compute statistics</u>. Compute the means and C.O.V.'s of both the auxiliary and inferred data items, and compute their correlation coefficient r_{XY}.
2. <u>Test the conversion</u> to see whether additional paired samples of the two items (i.e., additional baseline data) are warranted. The baseline sample size n_1, computed using equations (6.13) and (6.14), was based on prior estimates of v_X, v_Y, and r_{XY}. If Step 1 above indicates that the measured values of these statistics materially differs from those prior estimates, n_1 should be recalculated using the measured statistics.
   a. If the resulting value of n_1 is greater than the actual size of the baseline paired sample, additional paired samples should be taken to supplement the baseline data to attain the newly calculated required sample size n_1. Then return to Step 1 using the supplemented sample.

b. If the newly calculated n_1 is smaller than the actual baseline paired sample size, no corrective action is necessary.

3. Determine the conversion factor. Compute R as the ratio of the mean of the inferred item to the mean of the auxiliary item (equation 6.9).

4. Estimate the square of the C.O.V. of the conversion factor. Compute v_R^2 using equation (6.10).

To continue the example from Section 6.4.2, supposed 10 paired observations of peak point load and boardings were taken in the baseline phase in order to estimate a conversion from load to boardings. The desired tolerance for boardings is ±30%. The following data was obtained:

n_1 = 10 = number of paired observations (trips)

$\bar{X}$ = 14.93 = average peak point load

v_X = .45 = C.O.V. of peak point load

v_Y = .35 = C.O.V. of boardings

s_X = 6.12 = standard deviation of peak point load

s_Y = 7.57 = standard deviation of boardings

r_{XY} = 0.89 = correlation coefficient between peak point load and boardings

Because the calculated correlation coefficient (0.89) is significantly smaller than the correlation coefficient assumed in determining n_1 originally (0.95), the conversion should be tested by recalculating n_1 using the statistics listed above. First the dummy variable L is recomputed using equation (6.13):

$$L = \frac{3.24}{(.3)^2}\left[(.450)^2 + (.350)^2 - 2\,(.450)(.350)(.89)\right] = 1.61$$

Then n_1 is obtained from equation (6.14):

$$n_1 = 1.61 + 1.7 + 7.6\,(.450/.3)\sqrt{1.61/7} = 8.8$$

which again rounds up to 10. Because the newly recommended value of n_1 is the same as the sample size that was taken, no supplementary paired samples are necessary.

The conversion factor is calculated using equation (6.9):

R = 1.38 = conversion factor
= average boardings / average peak point load

From equation (6.10), v_R^2, the square of the C.O.V. of the conversion factor, is

$$v_R^2 = \frac{1}{10-1.7} \left[(.450)^2 + (.350)^2 - 2(.450)(.350)(0.89)\right] = .00538$$

6.4.5 Determining Sample Size in the Monitoring Phase

Once a conversion factor R has been analyzed and the square of its C.O.V., v_R^2, is calculated, the number of observations of the auxiliary data item needed in the monitoring phase can be determined:

$$n_2 = \frac{v_X^2 (1 + v_R^2)}{0.31\ d_m^2 - v_R^2} \quad \text{(round up to next whole number)} \qquad (6.15)$$

where n_2 = sample size of the auxiliary item in the monitoring phase (90% confidence level)

v_X = estimated coefficient of variation of the auxiliary data item (e.g. load)

d_m = desired tolerance of the inferred data item

A reference table for this relationship is provided in Appendix A and is shown in Table 6.7. In the table, the values of n_2 are listed for different values of v_X, v_R^2, and d_m.

Continuing the example from Section 6.4.4, the necessary number of observations of the auxiliary data item in the monitoring phase, n_2, can then be read from Table 6.7e using

Table 6.7

Required Sample Size of Auxiliary Item

a. Desired Tolerance of Inferred Item = ± 5%

v_X	v_R^2				
	.0001	.0002	.0003	.0004	0005
0.10	15	18	22	27	37
0.20	60	70	85	107	146
0.30	134	157	190	241	328
0.40	238	279	337	427	583
0.50	371	435	527	667	910
0.60	534	627	759	961	1310
0.70	726	853	1032	1308	1783
0.80	949	1114	1348	1708	2329

b. Desired Tolerance of Inferred Item = ±10%

v_X	v_R^2							
	.0001	.0005	.001	.0015	.002	.00225	.0025	00275
0.10	4	4	5	7	10	12	17	29
0.20	14	16	20	26	37	48	67	115
0.30	31	35	43	57	82	107	151	258
0.40	54	62	77	101	146	189	268	459
0.50	84	97	120	157	228	295	418	717
0.60	121	139	172	226	328	425	602	1032
0.70	164	189	234	307	447	578	819	1404
0.80	214	247	306	401	583	755	1070	1834

Notes: assuming 90% confidence level

v_X = coefficient of variation of auxiliary item

v_R^2 = square of coefficient of variation of conversion factor

Table 6.7 (continued)

c. Desired Tolerance of Inferred Item = ±15%

v_x	v_R^2						
	.001	.002	.003	.004	.005	.006	.0065
0.10	2	3	3	4	6	11	22
0.20	7	9	11	14	21	42	85
0.30	16	19	23	31	46	93	191
0.40	27	33	41	54	82	166	340
0.50	42	51	64	85	128	258	530
0.60	61	73	91	122	184	372	763
0.70	83	99	124	166	250	506	1039
0.80	108	129	162	216	326	661	1357

d. Desired Tolerance of Inferred Item = ±20%

v_x	v_R^2							
	.001	.002	.004	.006	.008	.01	.011	.012
0.10	1	1	2	2	3	5	8	26
0.20	4	4	5	7	10	17	29	102
0.30	8	9	11	15	21	38	65	228
0.40	15	16	20	26	37	68	116	405
0.50	22	25	30	40	58	106	181	633
0.60	32	35	44	57	83	152	260	911
0.70	44	48	59	78	113	207	354	1240
0.80	57	62	77	101	147	270	463	1620

e. Desired Tolerance of Inferred Item = ±30%

v_x	v_R^2								
	.001	.005	.01	.015	.02	.025	.026	.027	.0275
0.10	1	1	1	1	2	4	6	12	26
0.20	2	2	3	4	6	15	22	46	103
0.30	4	4	6	8	12	32	49	103	232
0.40	6	8	10	13	21	57	87	183	412
0.50	10	11	15	20	33	89	136	286	643
0.60	14	16	21	29	47	128	195	411	925
0.70	19	22	28	39	64	174	265	560	1259
0.80	24	29	37	51	83	227	346	731	1645

Notes: assuming 90% confidence level

v_x = coefficient of variation of auxiliary item

v_R^2 = square of coefficient of variation of conversion factor

v_X = .450 and v_R^2 = .00538. Interpolating first for v_X = 0.45, it is estimated that n_2 = 9.5 for v_R^2 = .005 and n_2 = 12.5 for v_R^2 = 0.01. Then since v_R^2 is quite close to .005, the appropriate value of n_2 is 10. Alternatively, equation (6.15) can be used, yielding:

$$n_2 = \frac{(.450)^2 \quad (1 + .00538)}{.31 \ (.3)^2 - .00538} = 9.04$$

which rounds up to n_2 = 10, in agreement with the answer found using the table. Therefore, 10 observations of peak load are needed in the monitoring phase to estimate boardings to the desired level of accuracy using a conversion factor.

6.4.6 Tolerance Attained by a Given Monitoring Sample

Depending on the actual number of observations made in the monitoring phase, the tolerance level attained is:

$$d = 1.8 \sqrt{\frac{v_X^2(1 + v_R^2)}{n_2} + v_R^2} \tag{6.16}$$

(at the 90% confidence level)

For example, suppose that, for the same example cited in the previous sections, peak point load is sampled on 15 trips during the monitoring phase, and the average load is multiplied by R (=1.38) to yield an estimate for average boardings. Then the tolerance attained is

$$d = 1.8 \sqrt{\frac{(0.410)^2 \ (1 + \ 0.00202)}{15} \quad + (0.00202)} = 0.207$$

or ± 20.7%.

6.5 Products of Averages and Proportions

There are times when the only way to estimate the average number of boardings per trip lying in a category is to multiply an estimate of the average number of boardings per trip by the an estimate of the proportion of passengers on the route that belong to that category. For example, average number of reduced fare passengers on a route could be determined by multiplying average boardings by the proportion of boardings who pay reduced fare. Because the resulting average is the product of two estimates, each contributes to the variability of the product. Consequently, the relative tolerance of the product will always exceed the relative tolerance of both the route average and the proportion. (The relative tolerance of a proportion is the absolute tolerance divided by the tolerance.) If the same confidence level is used for all estimates, the tolerance of the product can be approximated using the following formula:

$$d_Z = \sqrt{d_X^2 + d_a^2/p^{\,2}} \qquad (6.17)$$

where d_Z = tolerance of the product of a route average and a proportion

d_X = tolerance of the route average

d_a = absolute tolerance of the proportion

p = proportion

To use the example just cited, suppose average boardings per trip on a route was estimated to be 66 with a tolerance of ±22%, and that the proportion of boardings in the reduced fare category was estimated to be 0.21, with an absolute tolerance of 0.06. Then the estimated number of reduced fare boardings per trip is (66)(.21) = 13.9, and the relative tolerance of this estimate is

$$\sqrt{(.22)^2 + (.06)^2/(.21)^2} = 0.36, \text{ or } \pm 36\%$$

Caution must be exercised if p is near 0 or 1, for then d_a may be only a nominal absolute tolerance because the tolerance range is asymmetrical (see Section 6.3). In these cases, the same equation (6.17) can still be applied using d_a, but the resulting tolerance should be taken as only a guide to the actual tolerance range which will exhibit the same kind of asymettry as the range for the proportion, as discussed in Section 6.3.

It is hard to determine optimal sample sizes for estimating such a product, since the accuracy of the product is affected by the sample sizes used to estimate both the route average and the proportion composing the product. However, if the desired tolerance for the route average is considerably narrower than the tolerance desired for the product, then the sample size for the route average (usually average boardings per trip) may be set by the need to know that average for its own sake. Then only the sample size for estimating the proportion needs to be determined. When this is the case, the necessary tolerance for the proportion is:

$$d_a = p\sqrt{d_Z^2 - d_X^2} \tag{6.18}$$

Then, given the value of d_a, the sample size required to estimate the proportion p can be determined using Table 6.5b or equation (6.5), as explained in Section 6.3.

It should be emphasized that d_X, the tolerance of the route level average, must be smaller than d_Z, the desired tolerance of the product, or d_Z will be unattainable. If this situation occurs, the tolerance of the route level average must be lowered (through additional data collection) to below the desired tolerance of the product. Furthermore, if d_X is only slightly smaller than the desired d_Z, then the estimate of p will have to be extremely accurate (i.e., d_a will be very small), and the cost of achieving this accuracy may be inordinately high. Therefore, it is suggested that d_X, the tolerance of the route-level item, be set at approximately 70% of d_Z or lower.

For example, suppose average boardings (the route-level average) is desired with a tolerance of ±30% tolerance, and average reduced fare boardings (the product) is desired at a ±30% tolerance as well. Economically achieving the desired tolerance of the product implies that the tolerance of route-level boardings should be lowered to abount 70% of the product's tolerance, which is (0.7)(0.30) = 0.21 or ±21%. Therefore, in determining the sample size for route-level boardings, the tolerance of ±21% supplants the pereviously desired tolerance of ±30%. Then the computation of desired tolerance and sample size for the proportion of boardings in the reduced fare category proceeds as follows. First, a prior estimate of this proportion must be made; suppose this estimate is 0.20. These facts are summarized below:

d_Z = 0.30 = desired tolerance of the product

d_X = 0.21 = desired tolerance of route-level average boardings

p = 0.20 = estimate of the proportion

Then the absolute tolerance needed for the proportion is, from equation (6.19),

$$d_a = 0.20 \sqrt{.3^2 - .21^2} = 0.043.$$

The tolerances desired for the proportion and for route-level boardings must then be translated into sample sizes using the procedures described in Section 6.3 and 6.1. The determination of sample size for the proportion will be illustrated in this example. Using Table 6.5b with p=0.2 and d_a=0.043, the number of boarding passengers that must be sampled to determine their fare category is between 276 to 122, and is interpolated to be 253. Alternatively, using equation (6.6b), the sample size is calculated to be

$$n = \frac{3(.2)(.8)}{.043^2} = 260$$

CHAPTER 7

DESIGN OF SAMPLING PLANS

From a statistician's viewpoint, once the proper sample sizes have been computed, the data collection design process is essentially done. From the transit operator point of view, however, the process has only begun. The operator has only a limited number of checkers and other data collection resources available, and is now faced with the task of scheduling and otherwise deploying these resources in the most cost-effective way. To a large extent, the solution to the problem is highly system-specific, and must be reached by trial-and-error seasoned with experience and common sense. There are, however, some generally applicable guidelines presented in this chapter that can help simplify this scheduling task.

The guidelines of this chapter are organized around the four major deployment options for data collection activities presented in Chapter 3. These options, listed in Table 3.1, are :

1. Ride check = data collected by an on-board checker
2. Point check = data collected by a wayside checker
3. Driver check = data collected by the driver
4. Automated check = data collected by automatic passenger counters (APC's)

The particular types of counts and readings that can be made with each of these options are discussed in Chapter 3 and are summarized in Tables 3.2 and 3.3.

Three topics are covered in this chapter. In Section 7.1, the selection of the appropriate deployment option is discussed. A priority scheme is described by which the most efficient choice can be made by coordinating the data collection plan with respect to all data items, routes, and time periods. In Section 7.2, scheduling principles for the major deployment options are presented. The information presented in these two sections is summarized in a step by step scheduling procedure found in Chapter 9, which is accompanied by an example. Finally, in Section 7.3, guidance is offered on the scheduling and conduct of passenger surveys.

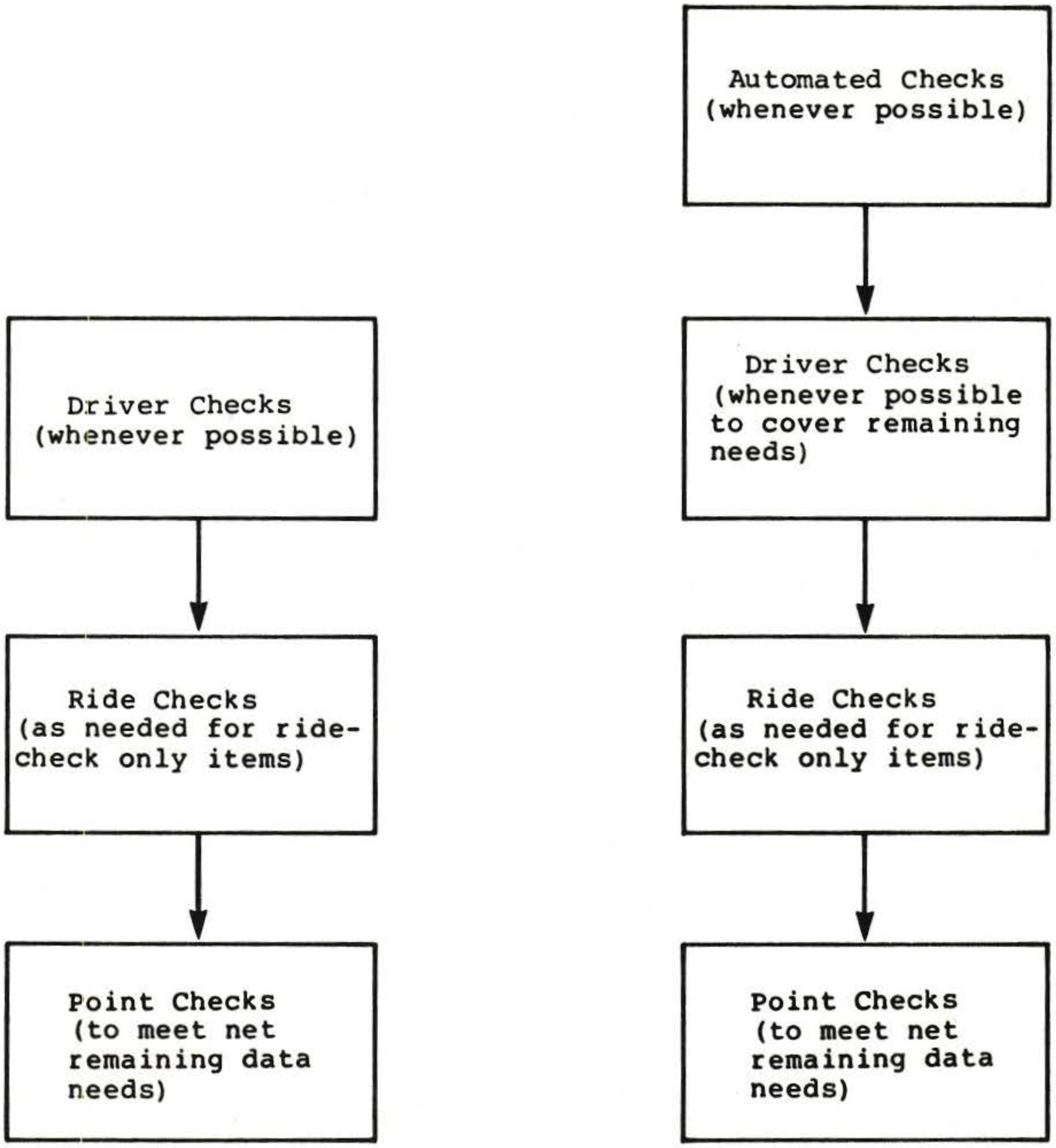
7.1 Coordinated Choice of Appropriate Data Collection Techniques

A data collection plan can entail the use of many data collection techniques, some of which are less costly that others. An important determinant of the efficiency of such a plan is which technique(s) are used for which data items. Practically every data item, save those that require a passenger survey, can be measured with a variety of techniques. It is important to choose the technique(s) that yield the least overall cost.

A separate priority scheme is presented for those systems using APC's and those that rely exclusively on manual counts. For non-APC systems, the priority scheme is illustrated in Figure 7.1(a). The first priority is driver checks, which can be made at a very small cost. Any data item that can be reliably measured by drivers should be. The second priority is to use ride checks, generally the most expensive technique, for only those items that cannot be gathered in any other way, such as passenger-miles or (if drivers cannot collect it) boardings; these items are called RCO (ride check only) data items. The remaining data items are measured using point checks. Since most data items monitored with point checks can also be measured with ride checks, point checks should be used to supplement the information derived from the point checks where necessary. Thus point checks are scheduled to meet net sample size requirements (sample size requirement minus number of

Figure 7.1

COORDINATED CHOICE OF DATA COLLECTION TECHNIQUES



a. Non-APC Systems

b. APC Systems

samples obtained via ride checks). For example, if boardings, measured using ride checks, requires a sample size of 9 trips while load at the peak point requires 20 trips, 9 ride checks are scheduled, and are supplemented by 11 point checks at the peak point.

An exception to the rule that ride checks are more expensive than point checks can occur when dealing with a data item that can be measured using either a ride check or multiple point checks, such as segment-level running time or load at various points along a route. For a route in isolation, ride checks require fewer checker-hours than multiple point checks when the number of points requiring checks is greater than the number of buses operating on the route. However, if other routes also require point checks at some of those points, those points should not be counted in assessing the relative cost of a multiple point count. If it is determined that a ride check is less expensive than multiple point checks for a particular application, the data item should be treated as a RCO item.

For example, in order to measure segment running times on a particular route with ride checks, 6 points must be checked. One of these points is a terminal shared by other routes that can all be monitored by a single checker. But because the route operates partly on a one-way couplet, one of the points actually needs two checkers, one for each direction. Then the net number of points attributed to this route is 6 - 1 + 1 = 6. Consequently, during time periods in which the route operates with more than 6 buses, point checks are more economical; during time periods in which it operates with fewer than 6 buses, ride checks are more economical.

For systems that have APC's, the priority scheme, illustrated in Figure 7.1(b), is to first use APC's for all data items that APC's can measure, and then to use manual counts to meet remaining sample size requirements in the same priority as presented for non-APC systems. For example, a particular system wants to measure only peak load, boardings, and the fraction of boardings in each fare category. First, APC's are used to measure peak load and boardings. Then if drivers can record fare category, driver checks should be used to determine the fraction of boardings in each fare category. If drivers cannot reliably record fare category information, it is collected with ride checks. Point checks are unnecessary in this example.

7.2 Framework for Scheduling Major Data Collection Techniques

In this section, the framework for scheduling data collection activities (deciding which trips to sample, and on which dates) is presented for the four major deployment options. The framework for each deployment option has two major components. The first is the "scheduling unit", which is the basic piece of work from which work assignments are built; they differ for the four options. The second is the "scheduling group", the group of route/direction/ time period combinations (R/D/TP's) that should be scheduled as a group in order to achieve efficient coordination without undue complexity. These two items are summarized in Table 7.1.

7.2.1 Ride Checks

A checker making ride checks on a given route will usually follow one run (one sequence of trips performed by the same driver) for a period of a few hours. Thus the run will usually be the basic checker scheduling unit. If a run is particularly long, or if it consists of two or more pieces that are separated by a substantial break, it is convenient to split the run into pieces and use these pieces as scheduling units. Another possiblility, applicable to low headway routes where the layover is considerably longer than the headway, is for the checker to skip ahead to the next earlier bus at one or both termini instead of waiting for the full layover with the same driver. This "leapfrogging" modification makes it possible for

Table 7.1

Basic Units and Groups in Scheduling Data Collection Activities

Data Collection Technique	Scheduling Unit	Scheduling Group
Ride Check	driver run (or piece of a run)	By route or route group and day type: all trips in both directions on a route for all time periods in the day type. Use route groups if routes are interlined.
Point Check	time period (or piece of a time period)	By point, direction, & time period: all trips that pass the poin in the time period (may include numerous routes). Combine directions if one checker can monitor both directions.
Driver Check	entire day	all trips on all routes for a day type (weekday, Saturay, Sunday).
Automated Check	vehicle block (or piece of a block)	By route or route group & day type: all trips in both directions on a route for all time periods in the day type. Use route groups if routes are interlined.

a checker to cover more trips than he would if he stayed with the same driver, and eliminates the (minor) problem of having an unrepresentative sample because of the particular characteristics of the driver or run.

Of course, every scheduling unit does not include the same number of trips in a given direction in a given period. Furthermore, runs can include trips in more than one period. Thus, there is room for discretion in deciding how many times to sample each run or piece of a run in order to make the total number of trips covered in each period match or slightly exceed the required sample size. Once it is determined how often each run or piece is to be sampled, dates must be selected. Guidelines have been developed to aid in the selection of runs and dates and are incorporated in the Chapter 9 scheduling procedure.

For a sample to be unbiased, there should not be over-sampling of some groups of trips and under-sampling of others. Ideally, each trip should be sampled the same number of times. While this ideal can rarely be met perfectly, it should not be grossly violated. For example, if at least 23 trips are needed, and there are 5 runs in a day, each including two trips in each direction, then covering two of those runs three times and covering the other three runs twice is a "good" solution. Covering four of those runs three times and leaving the fifth unmonitored is not as good a solution, but could be considered acceptable if that fifth run were particularly difficult to cover and if there was no prior reason to believe that the trips belonging to that run were significantly different from the other trips. However, covering two of those runs six times and leaving the other three uncovered is not an adequately representative sampling plan. Likewise, making all the counts on Mondays is not a good idea; spreading them over the days of the week provides a more representative sample.

Another ideal is to <u>avoid positive correlaton</u> and <u>take advantage of negative correlation</u>. <u>Positive correlation</u> occurs between a pair trips when a random factor that affects the item being measured is especially likely to be the same on both trips. The major instance of positive correlation is that trips occurring on the same day will usually be subject to the same traffic and weather conditions, so that if a long running time or a particularly high load is measured on one trip, it is likely to happen on the other trip as well. Therefore it is recommended that, when practical, ride checks be spread out over a number of different days, and that these days be, as much as possible, a cross-section of days of the week and the weeks of the season the sample is meant to represent. Separating these days by a week or more is a good idea since weather conditions often persist for a few days.

Negative correlation between two trips means that a high value of, say, boardings on one trip is likely to be compensated by a low value on the other trip. With both boardings and running times, negative correlation between successive trips can be particularly strong on routes where buses tend to bunch. By monitoring pairs of successive runs in such cases, a more balanced sample will be obtained.

In summary, then, the above guidelines suggest that counts be taken:

- on as near a uniform cross-section of runs as possible;
- on a number of different days, spread widely over the season being monitored, and distributed as uniformly as possible over the days of the week;
- by pairs of successive runs on routes where buses tend to bunch.

7.2.2 Point Checks

The obvious sampling unit for point checks is a block of time a few hours in length, since moving checkers frequently is costly. The block of time should correspond to a time period to ensure that time periods are covered evenly. If a time period is particularly long, as on a weekend day, the scheduling unit could be a portion of a time period.

Because point checks can often monitor a number of routes at once, all the routes being monitored at a given point should be scheduled as a group. Since in most situations a checker can monitor trips in only one direction, the directions can be scheduled separately. (If both directions can be monitored by the same checker, the directions should not be separated.) Time periods can also be scheduled separately. Of course, when selecting dates, all time periods and directions must be considered together to avoid exceeding staffing levels.

The number of days that point checks must be taken is determined by first calculating the net sample requirement for each of the data items being monitored with point checks. The net sample requirement for a data item in a particular R/D/TP (route/direction/time period combination) is its sample requirement minus the number of ride checks scheduled for that R/D/TP. The net sample requirement is then used to calculate the net day requirement. The net day requirement is the net sample requirement divided by the number of trips per day operated in that R/D/TP, rounded up to the next whole number. The net day requirement is calculated for each data item being monitored by point checks. Finally, the number of days of counts needed at a point is the maximum number of days needed by any data item on any of the routes being monitored at that point.

After the number of days of counts needed in each R/D/TP is determined, the scheduling units (time periods or pieces of time periods) are assembled into daily work assignments. The work assignments should be prepared to minimize travel between points and slack time and to conform to work rules.

The selection of representative days in important in assembling work assignments. Dates must of course be well distributed in order to stay within staffing levels on each day. When two or more days of checks are called for, they should be spaced widely over the season and be on different days of the week in order to maximize representativeness. Consideration must also be given to the occurrence of inclement weather, adverse traffic conditions, many missed trips, or other factors causing "extraordinary" patterns of operations and patronage. From a systemwide point of view, including counts taken on such days is important since it would be incorrect to under-represent extraordinary days. From a route-level point of view, however, counts taken on such days cannot be trusted as representative for making route-level decisions, and should be repeated. These substitute counts should not be included in making systemwide estimates, however.

7.2.3 Driver Checks

The day is the recommended sampling unit for driver checks. This is recommended because of the low cost of operator-made counts and the operational difficulties of having operators count selected, rather than all, trips during a day.

All R/D/TP's of the same day type (weekday, Saturday, Sunday) should be scheduled together as a group. The day requirement of any R/D/TP is simply the number of trips needed for that R/D/TP divided by the number of trips operated per day on that R/D/TP. Then the number of days of counts for a particular day type is the largest number of days required by any R/D/TP in the scheduling group.

7.2.4 Automated Checks

For automated checks, the basic sampling unit is the vehicle block, since the counting units are installed in the vehicles. If a block is particularly long, it can be split into pieces. Otherwise the scheduling of automated checks is the same as scheduling for ride checks.

7.3 Sampling Plans for Passenger Surveys

There are a large number of issues which must be addressed in the design and conduct of an on-board survey. Many of these issues, such as questionnaire design, are covered in textbooks on survey design. Some references related to transportation surveys are listed at the end of this chapter. The focus of this section is on statistical issues in survey design and on other basic issues.

One issue is the selection of the data items to be collected. It is recommended that surveys be used only for measuring data items that cannot be measured by any other means, because of the low response rate that typically occurs in surveys. For example, surveys should not be used to measure passenger-miles, boardings at stops, or boardings by fare category, all of which can be measured directly using ride checks.

Surveys are generally used to measure a large number of data items, some of which are averages and some category proportions. The number of completed questionnaires needed to attain the desired accuracy level for each item can be computed using the tables and formulas of Chapter 6. With category proportions, the approach of using absolute equivalent tolerance (i.e., the tolerance that would be desired if the value of the proportion were 0.5) can be used through the application of either Table 6.5a or equation (6.6a). Alternatively, the survey designer may want to specify absolute tolerances for each proportion, each corresponding to a prior estimate of the proportion. In this instance, either Table 6.5b or equation (6.6b) would be used. In either case, required sample size is computed for each item. The number of completed questionaires is then set at the largest sample size that is required for a data item.

For example, a survey on a certain route/direction/ time period is to be designed to determine the following characteristics at a 90% confidence level.

Characteristic	Expected Proportion (Range)	Desired Tolerance
A. Passholder	15 - 20%	±4.0%
B. Age under 16	20 - 25%	±5.0%
C. Age greater than 65	3 - 4%	±1.5%

To determine the sample size for each of these three category proportions, the upper limit of the expected proportion range is taken as a conservative estimate of the proportion p. Interpolating very roughly on Table 6.5b, it is found that characteristic A requires about 276 completed surveys; characteristic B, about 230; and characteristic C, about 660. Since the required sample size for Characteristic C is the largest, equation (6.6b) is used to evaluate it precisely, with the result that $3(.04)(.96)/(0.015)^2 = 512$ completed questionnaires are needed. Then, if the minimum response rate is estimated to be 0.3, the number of surveys that should be distributed is 512/0.3 = 1707.

Passenger surveys are also used to estimate values for averages. For example, the average number of trips taken in the last month per passholder may be desired with a ±5% tolerance at the 90% confidence level. This is a simple average that can be estimated directly using the approach of Section 6.1, where each responding passenger is considered an observation. The prior estimate is 24 trips per passholder, with a standard deviation estimate of 4. Using these estimates and equation (5.6), the coefficient of variation, is calculated as $v = 4/24 = 1/6$. From equation (6.1), the required sample size is then:

$$n = \frac{3.24\ (1/6)^2}{(.05)^2} = 36$$

A low estimate that only 12% of the survey respondents will be passholders is used to calculate the number of completed questionnaires desired, since in any particular survey the sample proportion of passholders could vary. Using this value, it is calculated that 36/0.12 = 300 completed questionnaires are required. Since this is less than the 512 required for the categorical data, the total required sample size remains unchanged.

Once the number of questionnaires needed is computed, trips must be selected on which to distribute them. Questionnaires are generally distributed to every passenger on selected trips. With an estimate of boardings per trip, the number of trips needed is determined.

A survey can be either conducted all in one day, in which case it is necessary only to select trips for surveying; or the survey can be administered over a period of time by sampling trips on different days. This second approach has the advantage of being less subject to abnormal conditions on the day of the survey, but has the disadvantage that it makes it more likely to survey a person more than once. If this approach is taken, runs for survey distribution can be selected in accordance with the guidelines given for ride checks in Section 7.2.1 and in the scheduling procedure of Chapter 9, step S4.

The accuracy of a completed survey is the final statistical issue which must be addressed. Once the questionnaires have been distributed, collected, and processed, the actual number of responses is known, as are the actual values of each category proportion and average.

The accuracy of values of averages can be determined by using either Table 6.2(b) or equation (6.2b). For example, it was found in the example cited above that of the 400 responses, 18% (72) were passholders. For this sample of passholders, the mean and standard deviation of trips taken per passholder were

25 and 5, yielding a coefficient of variation of 5/25 = 0.2. The tolerance obtained from the sample of 72 passholders (t=1.7, from Table 6.3) was calculated using equation (6.2b) to be

$$d = \frac{(1.7)\ (0.2)}{\sqrt{72}} = 0.04$$

or ±4%.

Either equation (6.8) or Table 6.6 can be used to determine the absolute tolerance achieved for category proportions. For the example just cited, 1,600 surveys were distributed and, due to a low response rate, only 400 surveys were completed (25% response rate). From these responses, the actual proportions were computed as shown below.

Characteristic	Actual Proportion	Tolerance
A. Passholder	18%	±3.2%
B. Age under 16	30%	±3.8%
C. Age greater than 65	3%	±1.4%

The tolerances were computed from equation (6.8), assuming a 90% confidence level (t=1.66, from Table 6.3). For example, the tolerance for proportion passholders was computed as

$$d_a = 1.66 \sqrt{\frac{.18(1-0.18)}{400}} = 0.032$$

or ±3.2%.

In addition to the statistical accuracy issues, there are a number of other operational issues which must be addressed. These include the following issues.

1. Should the questionnaire be hand-in or mail-back?

   In order to maximize the response rate and to avoid bias, it is suggested that both options be provided to the passenger. Response rates are usually higher on hand-in surveys; however, on crowded buses, it is difficult for passengers to complete a long questionnaire en route. Without a mail-back option response, the survey may be more biased towards those boarding early enough to get a seat.

2. Should the survey be conducted inbound (or outbound) only?

   Surveying in one direction only is a common method for avoiding asking the same person to fill in the questionnaire twice; however, it fails to provide information on the timing and even the routing of the return trip. If this approach is adopted, it is advisable to request limited information on other transit trips made that day. Whether conducted in one or both directions, passengers should be instructed whether or not to fill out a second questionnaire if they completed one previously. There should also be a place on the survey to indicate if the passenger has previously completed a survey.

3. What is the expected response rate?

   Not every passenger fills out a survey form. The response rate depends on such factors as crowding, route length, and survey length. Transit properties around the country have experienced response rates ranging from 15 to 90 percent. It is always best to be conservative in projecting response rate (i.e., project a low level of response), since the cost of handing out more surveys than necessary is not likely to be great, and it is not necessary to process all surveys returned if the response rate exceeds expectations.

5. How can bias be dealt with?

The problem of bias is always present in surveying. It exists when the survey responses are not representative. Any device to reduce the probability of differential response rates should be used, including:

1. Offering questionnaires to all passengers on a bus, to avoid bias introduced through the selection of passengers by the survey administrators.
2. Providing a mail-back option to avoid higher response rates from those obtaining seats.
3. Keeping the questionnaire simple so that everyone can understand it.
4. Making foreign language versions available in heavily ethnic neighborhoods.
5. Selecting buses on which to survey either randomly or uniformly from the time period of interest.
6. Obtaining control totals at fine enough levels of disaggregation to allow use of expansion factors as described below.

Once the survey has been completed, control totals for different segments of the population can be used to determine each segment's response rate. Based on these response rates, expansion factors are computed for each population segment. For example, suppose that the survey results for a route, when compared with control totals, show two distinct response rates for different segments of the route. Expansion factors should then be estimated for each segment separately, rather than for the route as a whole. Expansion by population segment can reduce bias substantially. The population can be segmented into other kinds of categories as well (e.g., fare category), if control totals and response rates can be measured on this basis.

References on Passenger Surveys

P. Box and J.C. Oppenhander, "Public Transportation Usage", Chapter II, in Manual of Traffic Engineering Studies, Institute of Transportation Engineers, 1976.

J. Shortreed and E. Miller, "Surveys", Chapter 5 in Canadian Transit Handbook, R.M. Soberman and H.A. Hazard, eds., University of Toronto - York University Joint Program in Transportation, 1980.

J.W. Billhermer and R.R. Trexler, Evaluation Handbook for Transportation Impact Assessment, Chapters 4-6, UMTA report UMTA-IT-06-0203-81-1, prepared by Systan, Inc., 1981.

Urban Transportation Systems Associates, Inc., Urban Mass Transportation Travel Surveys, U.S. Government Printing Office , 1972.

PART II

STEP-BY-STEP PROCEDURES

CHAPTER 8

PROCEDURE FOR OVERALL DESIGN OF DATA COLLECTION PROGRAM

A step-by-step procedure for designing a data collection program is presented in this chapter. The steps in the procedures are presented on the left pages of this chapter. For each step, the reader is referred to a specific section of the manual to which contains further information about the step. On the facing right pages, an example is provided which shows how the steps are applied.

SETTING FOR EXAMPLE

The transit system which is used has 20 routes. Automatic passenger counters are not available, but drivers are able to collect trip revenue data on a limited basis since the system has registering fareboxes. In addition, there is now a budgeted line item for hiring checkers and processing data.

In this example, only one route in one direction for one time period (inbound a.m. peak) will be fully examined at the route level. This route, Route 1, uses 7 buses in the a.m. peak and carries les than 30 passengers per trip both inbound and outbound. Running time for Route 1 in the a.m. peak is approximately 35 minutes in each direction. Part of Route 1 lies within an adjacent town, which contracts with the transit system to provide partial service. Boarding counts for the route segment within this jurisdiction are needed to fairly allocate subsidy requirements.

At some points in the procedure, it will be helpful for the sake of illustration to examine more than a single route/direction/time period. Thus, at different points in the procedure additional routes are included in the analysis.

1. DETERMINE DATA NEEDS

1.1 Inventory Data Needs (Section 2.1)

A system-wide survey should be conducted to determine what data items are used by each department, how they are used and how often they are used. Of special importance are the data items required by UMTA Section 15, which are systemwide boardings and passenger-miles. The data items needed by a typical large American system are listed in Table 2.1. Suggested level of detail for key data items is shown in Table 2.2.

1.2 Baseline Phase Data Needs - Route Level (Sections 2.1, 2.3, 4.2, 5.1)

Based on the inventory of Step 1.1, specify the route-level data needs of the baseline phase. To this end, specify:

- data items needed
- time periods for which item is needed
- when segment-level data are needed, and what constitutes a segment

Also determine:

- whether all data items will be measured by direction
- the confidence level.

Then, following the guidelines of Section 5.1.1, specify for each item, by direction and time period,

- tolerance desired

Recommended tolerances are given in Table 5.1. For time periods shorter than 3 hours long,

EXAMPLE FOR OVERALL DESIGN PROCEDURE

1. DETERMINE DATA NEEDS

1.1 Inventory Data Needs

A questionnaire was prepared for the different managers in the system, asking them to report the data items that they now use or would like to have, the level of detail needed, how they use the data, and how accurate and current the data should be. The questionnaire was distributed to all relevant managers, including service planning, scheduling, transportation, finance, and general manager. The reported needs were clarified through follow-up conversations. The results are listed in the following sections.

1.2 Baseline Phase Data Needs--Route Level

Route-level data items needed (from needs inventory):

peak point load	(average)
boardings - entire route	(average)
boardings in adjacent town	(seg't-level average)
passenger miles	(average)
running time	(average)
% passengers using pass	(category proportion)
% riders owning car	(category proportion)
% trips on time	(category proportion)

Time periods: The system has 4 analysis periods on weekdays: morning peak (6 a.m. - 9 a.m.); base (9 a.m. - 3 p.m.); evening peak (3 p.m. - 5:30 p.m.); and night (5:30 p.m. to closing). Saturday and Sunday are not broken down into analysis periods. The five averages listed above and schedule adherence are desired for every time multiply these tolerances by the adjustment factors in Table 5.2. For averages, relative tolerance (±X%) is used. For category proportions, using absolute equivalent tolerance (AET, as explained in Section 5.1) is the easiest way to specify tolerance. The other way to deal with category proportions is to specify an absolute tolerance (AT); it should be specified in reference to an estimate of the proportion.

1.3 Baseline Phase Data Needs - Systemwide (Sections 1.6, 5.1)

Specify:

- data items needed
- time periods for which each item is needed
- confidence level (95% specified for Section 15 data, and recommended for all other systemwide data)
- tolerance (±10% specified for Section 15 data; follow guidelines of Step 1.2 and Section 5.1.1 for other items)

Be sure that the same items requested for the system level were also specified at the route level in Step 1.2 (if not, add them to the route-level specification).

period; the other two items (pass use and auto ownership) are desired for the three weekday daytime periods only. However, for this example, only the weekday a.m. peak will be examined.

Segment definition: the only segment-level item is boardings, for which the segment is the adjacent town contracting for service.

By direction?: yes (all items).

Confidence level: 90% (all items).

Tolerance: Taken from Table 5.1 when applicable. Otherwise, chosen in accordance with the need for accuracy, as discussed in Section 5.1.1. Because the a.m. peak period is 3 hours long, no adjustment to the tolerances in Table 5.1 are needed. The chosen tolerances are:

Item	Tolerance
peak point load	±20%
boardings (route-level)	±30%
boardings (segment-level)	±30%
passenger miles	±30%
running time	±10%
% passengers using pass	±.1 AET
% trips on time	±.1 AET
% riders owning car	±.07 AT, with an estimate of 30% of riders owning a car.

1.3 Baseline Phase Data Needs--Systemwide

Data items: Only the required Section 15 data items, boardings and passenger-miles, are needed. Because both of these items have already been specified for the route level, no modifications to the route-level needs are necessary.

1.4 Monitoring Phase Data Needs - Route Level

(Sections 4.3.1, 4.3.3, 4.3.5, 5.1)

a. Items needed in the monitoring phase are: items that need regular updating; a change indicator for passenger use; and running time (unless either running time or schedule adherence is on the list for regular updating). Where possible, make the change indicator be one of the items needing regular updating. In addition, specify for each item:

   - reporting period (i.e., how often it is needed - each quarter, each year, etc.).

b. Then determine

   - the monitoring period (i.e., the basic scheduling period for the monitoring phase). It is the reporting period of the data item with the smallest reporting period.

1.5 Monitoring Phase Data Needs - Systemwide

This step is the same as Step 1.3, except applied to the monitoring phase. In addition, specify for each item:

- reporting period (i.e., how often it is needed - each quarter, each year, etc.)

Time periods: The only breakdown by time period is into day type (weekday, Saturday, Sunday).

Confidence level: 95% for all items.

Tolerance: ±10% for all items.

1.4 Monitoring Phase Data Needs--Route Level

a. Route-level data items that need regular updating (from needs inventory):

Item	Reporting Period
peak point load	quarterly
boardings (route-level)	quarterly
boardings (segment-level)	quarterly
passenger-miles	annually
running time	quarterly
% trips on time	quarterly

Level of detail (time periods, segments, directions), confidence, and tolerance are all the same as in the baseline phase. Either boardings or peak point load can be used as a change indicator for passenger-use related measures such as pass use and auto ownership.

b. Monitoring period: quarterly

1.5 Monitoring Phase Data Needs--Systemwide

As in the baseline phase, only boardings and passenger-miles will be collected at the systemwide level, using the same time periods, confidence level and tolerance as the route level. Reporting period for both items is a year.

2. CHECK ROUTE-LEVEL TO SYSTEMWIDE AGGREGATION (Section 5.1.2)

2.1 Baseline Phase

a. Systemwide averages can usually be obtained at the desired tolerance by simply aggregating route-level data at the tolerance specified in Step 1.2. Table 5.3 indicates what the systemwide tolerance will be depending on the number of routes and the specified route-level tolerance. These tables indicate that it will be the exception rather than the rule that the desired systemwide tolerance is not achieved. Check these tables for each average required systemwide for each time period into which the systemwide data is segregated.

b. If for any data item/time period Table 5.3 does not give a clear indication that systemwide accuracy will be achieved, equation (5.2) (or equation (5.2a) if all routes have the same tolerance) can be used to compute the systemwide tolerance that will result from aggregating route-level data at the tolerances specified in Step 1.2.

   If this resulting systemwide tolerance exceeds the desired tolerance specified in Step 1.3, route-level tolerances must be narrowed until the systemwide tolerance (as computed from equation (5.2)) is in compliance. Guidance for narrowing route-level tolerances is offered at the end of Section 5.1.2.

2. CHECK ROUTE-LEVEL TO SYSTEMWIDE AGGREGATION

2.1 Baseline Phase

a. For both boardings and passenger-miles, the route-level tolerance was chosen to be ±30%, and the required systemwide tolerance is ±10%. The system has 20 routes, each having boardings and passenger-miles measured in two directions in 4 periods on weekdays and in 2 periods on Saturdays and Sundays. Thus, there are 160 route/direction/time period combinations on weekdays, and 80 on Saturday and Sunday. Table 5.3 indicates that the resulting systemwide tolerance will be in the neighborhood of 0.01 (±1%) to 0.03 (±3%), well within the required level of ±10%.

b. If the results of part (a) are not convincing, equation (5.2a) is used to compute the resulting systemwide tolerance (equation (5.2a) can be used rather than (5.2) since every route uses the ±30% tolerance). To demonstrate the use of (5.2a) applied to boardings, v_{bet}, the between-route coefficient of variation of boardings, is needed.

Previous data on average weekday boardings for 40 route/direction combinations is available. (The data are not broken down by period.) These data are:

	Boardings	
Route	in	out
1	300	150
2	500	300
3	350	150
4	400	300
5	200	100
6	200	200
7	200	200
8	200	100
9	150	100
10	150	100
11	150	100
12	150	100
13	100	50
14	100	50
15	100	80
16	100	80
17	100	80
18	50	40
19	50	30
20	50	30

(summary statistics shown on next page)

2.2 Monitoring Phase

This step is the same as Step 2.1, except applied to the monitoring phase. Exception: if the reporting period for a systemwide item is greater then the standard monitoring period (determined in Step 1.4), then multiply the number of routes contributing to the systemwide total by the number of monitoring periods in the systemwide reporting period.

$\bar{x}_{bet}$ = between-route average boardings = 147.3
s_{bet} = between-route standard deviation of boardings = 105.2
$v_{bet} = s_{bet}/\bar{x}_{bet}$ = 105.2/147.3 = 0.71

Because the available data are not broken down by time period, one of two approaches can be taken. One is to guess what v_{bet} would be if it were based on 80 or 160 R/D/TP's (it will undoubtedly be greater; a reasonable guess is 1.0). Instead, the chosen approach is to see if the required systemwide tolerance would be achieved with only 40 R/D/TP's. (If so, the required tolerance will certainly be achieved with 80 or 160 R/D/TP's, even though v_{bet} will be greater.) Using equation (5.2a), the resulting tolerance for systemwide boardings is computed to be:

$$d_{sys} = \frac{1.11\ d_{rt}\sqrt{1 + v_{bet}^2}}{m} = \frac{1.11\ (.3)\ \sqrt{1 + .7^2}}{40} = 0.064$$

which is still well within the required ±10% limit.

2.2 Monitoring Phase

Since the same tolerances apply to the monitoring phase as to the baseline phase, the results of Step 2.1 apply to the monitoring phase. Further- more, since the reporting period for route-level boardings is quarterly in the monitoring phase while systemwide it is annual, systemwide boardings can be considered as an aggregation of 160 routes (20 routes, 2 directions, 4 reporting periods), and so will clearly meet the requirements of a ±10% tolerance.

3. DETERMINE BASELINE PHASE SAMPLE SIZES (EXCEPT FOR CONVERSION FACTOR DATA)

Use a "Baseline Phase Worksheet", shown in Appendix B, for each route/direction/time period to determine sample sizes.

3.1 Averages (Except Segment-Level Boardings and Alightings)

(Section 6.1)

This step applies to all route-level items and all segment-level data items except boardings and alightings, which are covered in Steps 3.2 and 3.3. For each item, fill in rows B1-B4 of the Baseline Phase Worksheet according to the instructions below.

Row B1: Describe the item precisely, e.g. "load at point X", or "running time on segment Y."

Row B2: Enter d, the tolerance desired, according to the specifications of Step 1.2. Enter d as a decimal (e.g. for ±20%, enter 0.2).

Row B3: Enter v, the coefficient of variation (C.O.V.) estimate. If existing data are available, C.O.V. estimates can be computed using equations (5.4)-(5.6). If data from two different datasets are being combined, equation (5.4a) should be used instead of (5.4).

If there is not enough data to compute C.O.V. estimates, default values can be used. A set of default values for different categories of routes and time periods is shown in Table 5.4. A system may also develop its own set of default

3. DETERMINE BASELINE PHASE SAMPLE SIZES (EXCEPT FOR CONVERSION FACTOR DATA)

Since this example deals with only one route/direction/time period, only one "Baseline Phase Worksheet" is used.

3.1 Averages (Except Segment-Level Boardings and Alightings)

This step is performed on the top part of the worksheet.

Row B1: Fill in items from Step 1.2. (See partially filled in worksheet at the end of this step.)

Row B2: Fill in tolerance from Step 1.2.

Row B3: With existing data (shown below) for Route 1, weekday a.m. peak, inbound, the coefficient of variation of route-level boardings and peak point load can be calculated. As explained in Section 5.2.4, there should be at least 12 datapoints (more is better), and these should be a random or representative sample. The existing data are:

Trip	Boardings	Load at Peak Point	Trip	Boardings	Load at Peak Point
1	40	32	9	18	14
2	32	24	10	16	15
3	25	15	11	15	12
4	25	18	12	15	10
5	22	15	13	15	9
6	20	16	14	13	9
7	20	13	15	12	10
8	20	12			

Summary statistics	Boardings	Load at Peak Point
$\bar{X}$ (Average):	20.5	14.93
s (std dev):	7.57	6.12
$v = s/\bar{X}$:	.369	.410

values using its own data and route classification scheme.

-EXAMPLE-

For running time there are data on only 10 recent trips. However, this data can be augmented (see Section 5.2.4) with data from a previous year:

Running Time (recent data)		Running Time (previous data)	
34	40	35	35
36	38	35	38
35	36	42	37
42	40	39	42
41	39	40	35

Average: $\bar{X}_1 = 38.1$ $\bar{X}_2 = 37.8$

Std dev: $s_1 = 2.72$ $s_2 = 2.85$

sample size: $n_1 = 10$ $n_2 = 10$

Then from equation (5.4a):

$$s^2 = \frac{s_1^2 (n_1 - 1) + s_2^2 (n_2 - 1)}{(n_1 - 1) + (n_2 - 1)}$$

$$= \frac{(2.72)^2 (9) + (2.85)^2 (9)}{9 + 9} = 7.76$$

So $s = \sqrt{7.66} = 2.77$

and $v = \frac{s}{\text{recent mean}} = \frac{2.77}{38.1} = 0.073.$

Since no data on passenger-miles is available, the default C.O.V. from Table 5.4 is issued. It is 0.42.

Row B4: From either Table 6.1 or equation (6.1), determine n, the sample size required, based on d (Row B2) and v (Row B3).

Row B4:

For peak point load, with v = 0.410 and d = 0.2, n (from Table 6.1) is approximately 13. (Note: v was approximated as 0.40 for reading the table.) Alternatively, using equation (6.1):

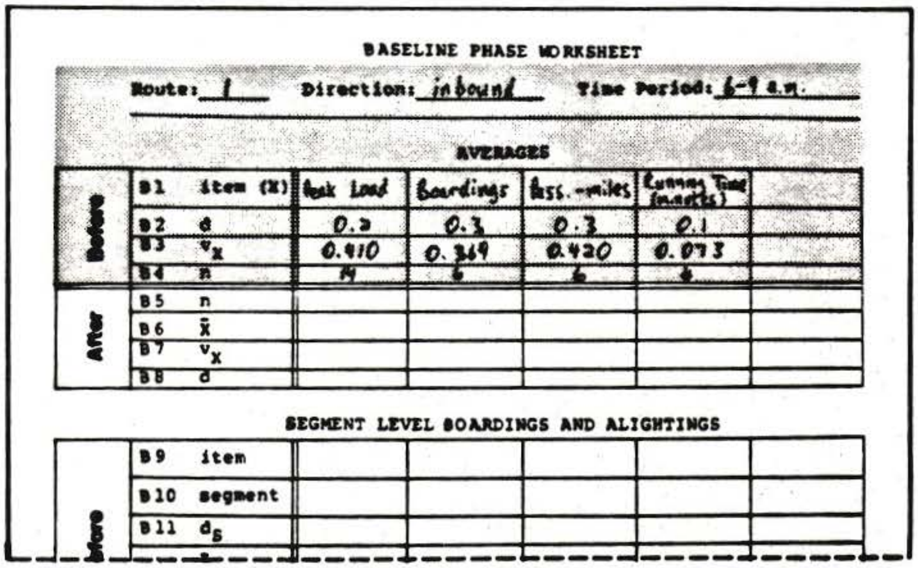
$$n = \frac{3.24 \quad v^2}{d^2} = \frac{3.24 \quad (.41)^2}{(0.2)^2} = 13.6$$

which rounds up to 14.

For boardings, with v = 0.369 (approximate as 0.40) and d = 0.3, n = 6 (from Table 6.1).

For running time, with v = 0.073 and d = 0.1, Table 6.1 indicates that n is no more than 4; therefore n is set at 4.

For passenger-miles, with v = 0.42 (approximate as 0.40) and d = 0.3, n = 6 (from Table 6.1).



BASELINE PHASE WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

AVERAGES

Before	B1	item (X)	Peak Load	Boardings	Pass.-miles	Running Time (minutes)	
	B2	d	0.2	0.3	0.3	0.1	
	B3	v_x	0.410	0.369	0.420	0.073	
	B4	n	14	6	6	4	
After	B5	n					
	B6	$\bar{x}$					
	B7	v_x					
	B8	d					

SEGMENT LEVEL BOARDINGS AND ALIGHTINGS

Before	B9	item					
	B10	segment					
	B11	d_s					

3.2 Segment-Level Average Boardings and Alightings (Section 6.2)

This step applies to segment-level boardings and alightings. This step also applies to total boardings and alightings by category of passengers, provided the category is readily observable. Fare type and sex are examples of such categories. This step applies when the number of passengers, as opposed to the proportion of such passengers, is desired. Step 3.3 is used when the proportion of passengers in a category is desired.

For each item, fill in rows B9-B15 following the instructions below.

Rows B9 and B10: Describe precisely the item and the segment to which it applies.

Row B11: Enter d, the tolerance desired, according to the specifications of Step 1.2. Enter d as a decimal (e.g. for ±20%, enter 0.2).

Row B12: Enter $\overline{X}$, the estimated average of the route-level item.

Row B13: Enter v_X, the coefficient of variation (C.O.V.) of the route-level item. It was already entered in Row B3 of the same worksheet.

3.2 Segment-Level Average Boarding and Alightings

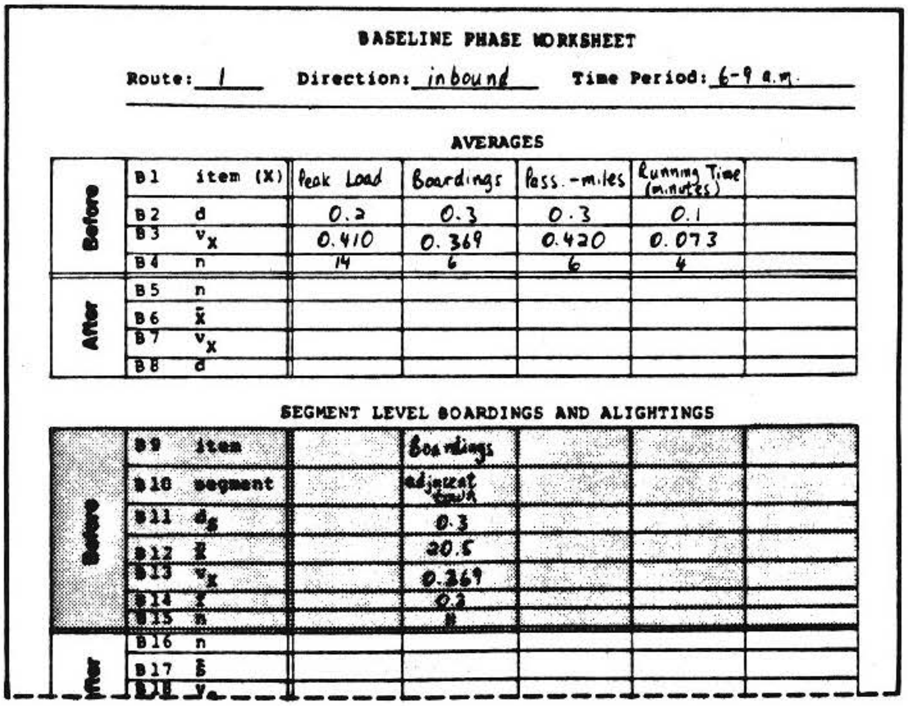
This step is performed on the middle part of the Baseline Phase Worksheet. The only data item to which it applies is boardings on the segment in the adjacent town.

Rows B9, B10: Fill in item and segment description (boardings in adjacent town) from Step 1.2.

Row B11: From Step 1.2, enter the segment-level tolerance, d_S = .3.

Row B12: Enter the estimated average route-level boardings, $\bar{X}_{RT}$ = 20.5 (from Step 3.1).

Row B13: Copy the route-level C.O.V., v_{RT}=.369 from row B3.



BASELINE PHASE WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

AVERAGES

Before	B1	item (X)	Peak Load	Boardings	Pass.-miles	Running Time (minutes)	
	B2	d	0.2	0.3	0.3	0.1	
	B3	v_X	0.410	0.369	0.420	0.073	
	B4	n	14	6	6	4	
After	B5	n					
	B6	$\bar{x}$					
	B7	v_X					
	B8	d					

SEGMENT LEVEL BOARDINGS AND ALIGHTINGS

Before	B9	item		Boardings			
	B10	segment		adjacent town			
	B11	d_S		0.3			
	B12	$\bar{X}$		20.5			
	B13	v_X		0.369			
	B14	[illegible]		0.3			
	B15	n		8			
After	B16	n					
	B17	$\bar{s}$					
	B18	v_s					

Row B14: Enter f, the estimated fraction of the route-level item that belongs to this segment. (Thus the estimated segment-level average is $f\bar{X}$.)

Row B15: From either equations (5.7) and (6.3) or equation (6.4) with Tables 6.1 and 6.4, determine and enter n, the sample size needed.

3.3 Category Proportions (Section 6.3)

This step applies for finding the proportion of observations (trips, passengers, etc.) that lie in a category, e.g. fraction of trips on time, fraction of passengers transferring to Route X. For each item, fill in Rows B20-B24 of the Baseline Phase Worksheet according to the instructions given below.

Row B20: Describe the item and category, e.g., "trips on time", "passengers transferring to Route Y."

Row B21 -
Row B23: Either row B21 or rows B22-B23 must be completed. Row B21 applies when an absolute equivalent tolerance (AET) is specified; rows B22-B23 apply when an absolute tolerance (AT) is specified.

Row B21: Enter d_e, the absolute equivalent tolerance, as specified in Step 1.2.

Row B22: Enter p, the estimated proportion lying in the category.

Row B23: Enter d_a, the desired absolute tolerance appropriate to the proportion specified in row B22.

Row B14: Since there are no hard data on the ratio of segment ridership to route ridership, it is estimated (perhaps from talking with drivers on the route) as 30%, so f=0.3. (See Section 6.2.)

Row B15: From Table 6.1, $n_a=6$ for the segment-level tolerance $d_S=.3$ and the route-level coefficient of variation $v_{RT}=.369$. Next, from Table 6.4b, $n_b=5$ is found for $f=.3$ and $\bar{X}_{RT}=20$. The required sample size for the segment-level boardings is then $n = n_a+n_b = 6+5 = 11$.

3.3 Category Proportions

This step is performed on the bottom part of the Baseline Phase Worksheet, shown at the end of the chapter.

Row B20: Enter the three categorical items of Step 1.2, which are fraction of riders using a pass, fraction of riders owning a car, and fraction of trips on time.

Rows B21 - B23: For the first and third items, AET is used, so Row B23 is filled in. For the second item, AT is used, so Rows B24 - B25 are filled in.

Row B21: For "% riders using pass" and "% trips on time", the absolute equivalent tolerance was specified in Step 1.2 as $d_e = 0.1$.

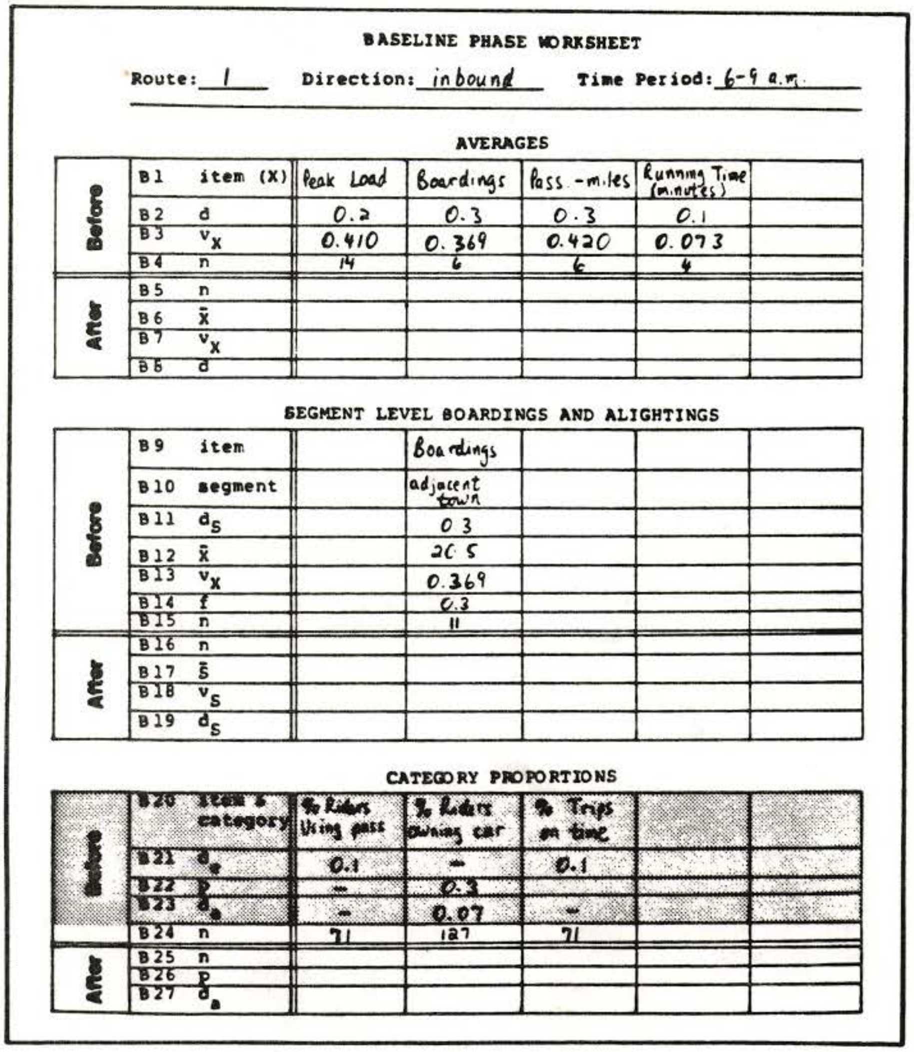
Row B22: For "% riders owning a car", 0.3 was the educated guess of the fraction of riders owning cars made in Step 1.2.

Row B23: Assuming that 30% of the riders own a car, an absolute tolerance of 7% or 0.07 was specified in Step 1.2, implying a range of uncertainty of 23% to 37%.

Row B24: Determine n, the number of observations needed, using the instructions below. Note that the units for n can differ according to the data item; e.g. for fraction of trips on time, a trip is an observation, while for fraction of passengers transferring to Route Y, a passenger is an observation.

- o If absolute equivalent tolerance (Row B23) was used: Determine n from Table 6.5a or equation (6.6a).
- o If absolute tolerance (Rows B24, B25) was used: Determine n from Table 6.5b or equation (6.6b).

Row B24: For both "% riders using a pass" and "% trips on time", the sample size is n=71 from Table 6.5a. Thus, samples of 71 passengers for the first item and 71 trips for the second item are needed. Interpolating from Table 6.5b, it is found that a sample of 127 passengers is needed to estimate the "% riders owning a car" (for p = 0.3 and d_a = 0.07).



BASELINE PHASE WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

AVERAGES

Before	B1	item (X)	Peak Load	Boardings	Pass.-miles	Running Time (minutes)	
	B2	d	0.2	0.3	0.3	0.1	
	B3	v_X	0.410	0.369	0.420	0.073	
	B4	n	14	6	6	4	
After	B5	n					
	B6	$\bar{X}$					
	B7	v_X					
	B8	d					

SEGMENT LEVEL BOARDINGS AND ALIGHTINGS

Before	B9	item		Boardings			
	B10	segment		adjacent town			
	B11	d_S		0.3			
	B12	$\bar{X}$		20.5			
	B13	v_X		0.369			
	B14	f		0.3			
	B15	n		11			
After	B16	n					
	B17	$\bar{S}$					
	B18	v_S					
	B19	d_S					

CATEGORY PROPORTIONS

Before	B20	item & category	% Riders Using pass	% Riders owning car	% Trips on time		
	B21	d_r	0.1	–	0.1		
	B22	p	–	0.3			
	B23	d_a	–	0.07	–		
	B24	n	71	127	71		
After	B25	n					
	B26	p					
	B27	d_a					

4. DETERMINE BASELINE SAMPLE SIZES FOR CONVERSION FACTORS

The ratio between the average of an easy-to-collect "auxiliary" item X and the average of a difficult-to-collect "inferred" item Y can serve as a conversion factor in the monitoring phase. To estimate a conversion factor, a sample of paired observations (observing both X and Y on the same trip) must be made in the baseline phase. A separate conversion factor for each route/direction/time period (R/D/TP) should be computed. Use a "Conversion Factors Worksheet", illustrated in Appendix B, for each R/D/TP.

4.1 List Potential Conversions (Sections 4.3.2, 4.3.5)

On each worksheet, list all the potential conversions contemplated.

Row C1: describe precisely the auxiliary item. It is called "X".

Row C2: describe precisely the inferred item. It is called "Y".

Row C3: enter d_m, the desired tolerance of the inferred item in the monitoring phase, as specified in Step 1.4. Enter d_m as a decimal (e.g., for ±20%, enter 0.2).

4. DETERMINE BASELINE SAMPLE SIZES FOR CONVERSION FACTORS

Only one route/direction/time period (Route 1 inbound, weekday a.m.) is examined in this example, so only one Conversion Factors Worksheet is used.

4.1 List Potential Conversions

Data items which are more difficult to collect in the monitoring phase are boardings and passenger-miles. Hopefully, these can be estimated from the peak load figures. Furthermore, Route 2's peak load point, henceforth called PP2, is passed by Route 1 as well as Route 2. Route 1's peak load point (PP1) is only half a mile away. Therefore, it would be nice to be able to measure load on both routes at Route 2's peak load point and infer the other items from the resulting loads. An alternate auxiliary item is revenue, since the driver can collect this data by trip on an occasional basis. Possible conversions are thus:

	Row C1: auxiliary item	Row C2: inferred item
(a)	point load at PP2	point load at PP1
(b)	point load at PP2	boardings
(c)	point load at PP2	passenger-miles
(d)	revenue	point load at PP1
(e)	revenue	boardings
(f)	revenue	passenger-miles

Rows C1, C2: Information is entered as above.

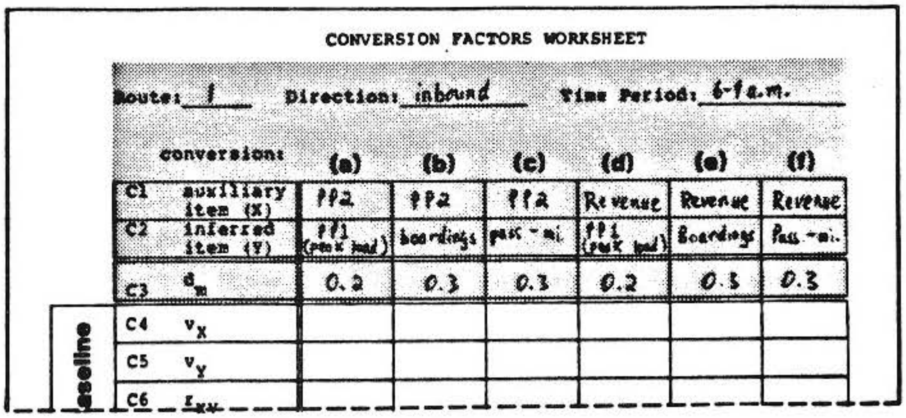
Row C3: In Step 1.4, it was specified that the tolerances used in the baseline phase should also be used in the monitoring phase. These tolerances were already entered in row B2 of the Baseline Phase Worksheet. They are 0.2 for conversions (a) and (d) and 0.3 for all other conversions.

4.2 Determine Sample Size for Representative Routes

(Sections 6.4.1, 6.4.2)

Apply this step to either every R/D/TP or to a number of representative R/D/TP's whose results can be extended to the entire system. It requires prior estimates of coefficients of variation and correlation coefficients. Default values for the C.O.V.'s of some items may be taken from Table 5.4. If any of these prior estimates are not available, skip to Step. 4.3.

For each representative R/D/TP chosen, fill in Rows C4-C9 of that R/D/TP's Conversion Factor Worksheet for each conversion .



CONVERSION FACTORS WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

	conversion:	(a)	(b)	(c)	(d)	(e)	(f)
	C1 auxiliary item (X)	PP2	PP2	PP2	Revenue	Revenue	Revenue
	C2 inferred item (Y)	PP1 (peak load)	boardings	pass - mi.	PP1 (peak load)	Boardings	Pass - mi.
	C3 d_m	0.2	0.3	0.3	0.2	0.3	0.3
aseline	C4 v_X						
	C5 v_Y						
	C6 r_{XY}						

4.2 Determine Sample Size for Representative Routes

The only data available with which to test the conversions is an old set of on-off counts and trip revenue conducted on Route 1. Fifteen a.m. peak period trips were observed. These were done in conjunction with peak load counts at PP1. No load counts were taken at PP2. The relevant data from these counts are tabulated below. With these data, conversions (d) and (e) can be directly analyzed.

Test Dataset for Route 1, Inbound

Trip	Boardings	Load at PP1	Revenue
1	40	32	24.10
2	32	24	18.45
3	25	15	13.75
4	25	18	14.90
5	22	15	12.10
6	20	16	11.65
7	20	13	10.15
8	20	12	9.65
9	18	14	9.50
10	16	15	8.95
11	15	12	8.25
12	15	10	9.30
13	15	9	8.40
14	13	9	7.15
15	12	10	6.50

Row C4: Enter v_X, the prior estimate of the coefficient of variation (C.O.V.) of X.

Row C5: Enter v_Y, the prior estimate of the C.O.V. of Y.

Averages, standard deviations, coefficients of variation, and correlation coefficients are computed using either a statistical package or equations (5.4)-(5.6) and (6.11)-(6.12). The results are:

	Boardings	Load at PP1	Revenue
Average:	20.53	14.93	11.53
Std. Dev.:	7.57	6.12	4.70
Coef. of Variation	.369	.410	.408

Correlation Coeff's	Rev-Brd	Rev-PP1	Brd-PP1
	0.98	0.95	0.95

Row C4: For conversions (a) and (b) (involving load at PP2), information about load at PP2 is not directly available. However, since PP2 is very close to PP1, it is assumed that the loads at the two points have very similar characteristics. Therefore, the prior estimate of the C.O.V. for the load at PP1 (.410) is used as an estimate of the C.O.V. for the load at PP2.

For conversions (d) and (e) (involving revenue), the prior estimate of the C.O.V. of revenue is 0.408 (from the dataset above).

For conversions (c) and (f), no information is available on passenger-miles, so Step 4.2 is skipped for these columns.

Row C5: From the dataset above, the prior estimates of the C.O.V. are entered for both load at PP1 (.410, columns (a) and (d)) and boardings (.369, columns (b) and (e)).

<u>Row C6</u>: Enter r_{xy}, the prior estimate of the correlation coefficient between X and Y.

Row C6: The correlation coefficients were estimated using the old set of on-off counts and trip revenue. However, for the sake of example, their calculation is illustrated here using the following equations:

$$\text{Covariance} = \text{Cov}(X,Y) = s_{XY} = \frac{(\sum x_i y_i) - n\bar{X}\bar{Y}}{n-1}$$

$$\begin{array}{l}\text{correlation}\\ \text{coefficient}\end{array} = r_{XY} = \frac{s_{XY}}{s_X\ s_Y}$$

For conversion (a) (X = load at PP2, Y = load at PP1)

No information is available on load at PP2. However, since PP2 is very close to PP1, the loads at the two points are assumed to be highly correlated. An estimate for the correlation coefficient of $r_{PP2,\ PP1} = 0.96$ is used.

For conversion (b) (X = load at PP2, Y = boardings):

The correlation coefficient load at PP2 to boardings cannot be determined directly but, due to the close proximity of PP1 to PP2, it is estimated to be very close to the correlation coefficient of load at PP1 to boardings. Therefore, for the conversion of PP1 to boardings (with X = load at PP1, Y = boardings):

$$\text{Cov(PP1, Brd)} = \frac{5217 - 15(14.93)(20.53)}{14} = 44.2$$

$$r_{\text{PP1, Brd}} = \frac{44.2}{(6.12)(7.57)} = 0.95$$

A lower value of 0.93 was used for $r_{\text{PP2, Brd}}$ to reflect the uncertainty about the relationship between PP1 and PP2.

(this page intentionally left blank)

For conversion (d) (X = revenue, Y = load at PP1):

$$\mathrm{Cov(Rev,\ PP1)} = \frac{3007 - 15(11.53)(14.93)}{14} = 27.3$$

$$r_{\mathrm{Rev,\ PP1}} = \frac{27.3}{(4.70)(6.12)} = 0.95$$

For conversion (e) (X = revenue, Y = boardings):

$$\mathrm{Cov(Rev,\ Brd)} = \frac{4040 - 15(11.53)(20.53)}{14} = 35.0$$

$$r_{\mathrm{Rev,\ Brd}} = \frac{35.0}{(4.70)(7.57)} = 0.98$$

Row C7: Enter B, the number of buses used on the route during the time period in question.

Row C8: Compute the dummy variable L using equation (6.12).

Row C7: B, the number of buses operating on Route 1 during the a.m. peak is 7.

Row C8: From equation (6.12):

$$L = \frac{3.24}{d_m^2} (v_X^2 + v_Y^2 - 2v_X v_Y r_{XY})$$

For conversion (a):

$$L = \frac{3.24}{(.2)^2} ((.410)^2 + (.410)^2 - 2\ (.410)(.410)(0.96)) = 1.089$$

For conversion (b):

$$L = \frac{3.24}{(.3)^2} ((.410)^2 + (.369)^2 - 2\ (.410)(.369)(0.93)) = 0.823$$

For conversion (d):

$$L = \frac{3.24}{(.2)^2} ((.410)^2 + (.408)^2 - 2\ (.408)(.410)(0.95)) = 1.355$$

For conversion (e):

$$L = \frac{3.24}{(.3)^2} ((.408)^2 + (.369)^2 - 2\ (.408)(.369)(0.98)) = 0.272$$

Row C9: Compute n_1, the sample size required in the baseline phase, from equation (6.13), unless the computed n_1 is below 10, in which case set n_1 equal to 10.

4.3 Determine Sample Size on Other Routes (Section 6.4.2)

This step is for R/D/TP's which were not covered in Step 4.2, for which no entries were made in rows C4-C8.

Row C9: Enter n_1, the sample size required in the baseline phase. Take n_1 from Row C9 of a similar R/D/TP analyzed in Step 4.2, or if there was none, set $n_1 = 15$.

Row C9: Equation (6.13) is

$$n_1 = L + 1.7 + 7.6 \frac{v_X}{d_m} \sqrt{\frac{L}{B}} \quad \text{(round up to at least 10)}$$

Using figures from rows C3, C4, C7, and C8, n_1 is computed as follows.

Conversion (a):

$$1.089 + 1.7 + 7.6\ (.410/.2)\ \sqrt{1.089/7} = 8.9$$

Conversion (b):

$$0.823 + 1.7 + 7.6\ (.410/.3)\ \sqrt{0.823/7} = 6.1$$

Conversion (d):

$$1.355 + 1.7 + 7.6\ (.408/.2)\ \sqrt{1.355/7} = 9.9$$

Conversion (e):

$$0.272 + 1.7 + 7.6\ (.408/.3)\ \sqrt{0.272/7} = 4.0$$

In all these cases the computed figure is below 10, so n_1 is rounded up to 10.

4.3 Determine Sample Size on Other Routes

On Conversion Factors Worksheets for R/D/TP's similar to Route 1/inbound/a.m. peak, the same sample sizes calculated in Section 5.2 can be entered in row C9 for conversions (a), (b), (d), and (e) (see next page).

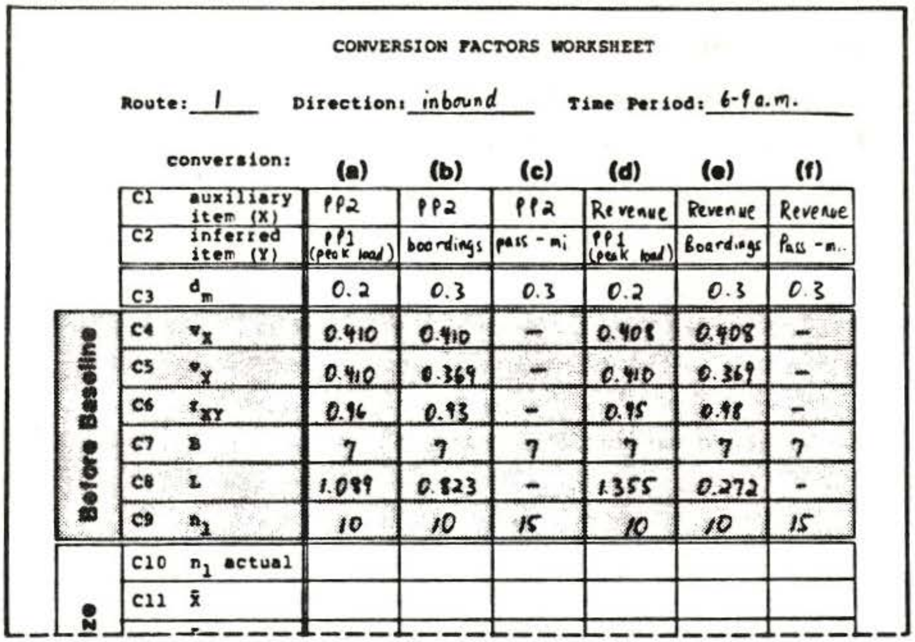
For conversions (c) and (f) which involve passenger-miles, there is no existing dataset on Route 1 or any other route. The default recommended value of 15 is used for n_1 (see next page).

4.4 Narrow Set of Conversions (Section 5.4.3)

If two or more conversions for the same inferred data item are listed on worksheets in Step 4.1, eliminate those that are clearly less efficient. Factors that make a conversion efficient are:

1. Its required baseline sample size is small.
2. The auxiliary item is already needed for the monitoring phase.
3. The auxiliary item is easy and inexpensive to collect.
4. The auxiliary item has a small coefficient of variation v_X.

-EXAMPLE-



CONVERSION FACTORS WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

		conversion:	(a)	(b)	(c)	(d)	(e)	(f)
	C1	auxiliary item (X)	PP2	PP2	PP2	Revenue	Revenue	Revenue
	C2	inferred item (Y)	PP1 (peak load)	boardings	pass - mi	PP1 (peak load)	Boardings	Pass - m..
	C3	d_m	0.2	0.3	0.3	0.2	0.3	0.3
Before Baseline	C4	v_X	0.410	0.410	–	0.408	0.408	–
	C5	v_Y	0.410	0.369	–	0.410	0.369	–
	C6	r_{XY}	0.96	0.93	–	0.95	0.98	–
	C7	B	7	7	7	7	7	7
	C8	L	1.089	0.823	–	1.355	0.272	–
	C9	n_1	10	10	15	10	10	15
ze	C10	n_1 actual						
	C11	$\bar{x}$						

4.4 Narrow Set of Conversions

Since the minimum figure of 10 was found for conversions using both the load at PP2 and the revenue as auxiliary items, and since both items can be measured in the course of the baseline phase ride checks (required for taking the paired sample), neither set of conversions could be eliminated. If the baseline data indicate that either item will give an acceptable tolerance, revenue will be chosen as the auxiliary item to use in the monitoring phase since it can be collected at no additional cost. (Drivers can collect this item on our system).

5. SCHEDULE AND EXECUTE BASELINE DATA COLLECTION

5.1 Schedule Data Collection (Chapters 7, 9)

The step-by-step procedure for scheduling data collection activities is covered in Chapter 9. Follow this procedure to schedule non-survey data collection for the baseline phase. Survey data collection should also be scheduled at this time; however, it is not covered in this manual because of the complexities involved in administering surveys. Some guidelines for surveys, as well as for non-survey data collection, are in Chapter 7.

5. SCHEDULE AND EXECUTE BASELINE DATA COLLECTION

5.1 Schedule Data Collection

The scheduling of data collection activities for this example is illustrated alongside the procedure itself in Chapter 9. It involves the scheduling of checkers and driver counts to meet the data needs of the non-survey items. For this case, both "% riders using a pass" and "% riders owning a car" must be measured using a survey, since the marketing staff would like to know the correlation of these two items and they must therefore be monitored jointly.

The scheduling example of Chapter 9 demonstrates the coordinated scheduling of checkers and driver counts for the a.m. peak for Route 1 inbound along with Route 1 outbound and Route 2.

For the survey items, which will be gathered separately from the non-survey items, one item requires a sample size of 71 riders and the other a sample size of 127 riders (from row B26 of the Baseline Phase Worksheet). The controlling sample size, therefore, is 127 passengers. Conservatively estimating 18 passengers per trip and a response rate of 30%, the number of trips needed is 127/18/0.3 = 24. If drivers were distributing and collecting surveys, we would repeat this procedure for every R/D/TP, and then find the day requirement of each R/D/TP by dividing the trip requirement by the number of trips per day. Then surveys would be distributed on all routes on enough days to meet the day requirement of every R/D/TP. If instead checkers distribute and collect the surveys, survey distribution would be scheduled as a ride check using the procedure of Chapter 9.

5.2 Execute Baseline Data Collection

Baseline data collection can now be done.

6. ANALYZE BASELINE DATA (EXCEPT FOR CONVERSION FACTOR ANALYSIS)

This step uses all the baseline data, whether observed singly or in pairs. It is executed on the Baseline Phase Worksheets used in Step 3.

6.1 Averages (Section 6.1)

For each item in the top part of the Baseline Phase Worksheet, fill in Rows B5-B8 according to the instructions below.

Row B5: Enter n, the actual size of the sample (number of trips).

Row B6: Enter $\bar{X}$, the average of the data item from the sample.

Row B7: If the size of the sample (n) was at least 12, recompute and enter the coefficient of variation (C.O.V.) estimate v_X (as in Row B3, Step 3.1). Otherwise, copy v_X from Row B3. (Exception: if a route classification scheme is used to assign default values of v_X, and the baseline data either have been processed to yield new default values or have changed the classification of a R/D/TP, enter the new appropriate default value.)

5.2 Execute Baseline Data Collection

Using the results of the Chapter 9 scheduling procedure, we can carry out and compile the data.

6. ANALYZE BASELINE DATA (EXCEPT FOR CONVERSION FACTOR ANALYSIS)

6.1 Averages

This step is performed on the top part of the same Baseline Phase Worksheet used in Step 3.

Row B5: For route 1/inbound/a.m. peak, all the items in the top part of the Baseline Phase Worksheet were measured on 20 trips.

Row B6: Item averages from the survey are entered here, which were: for peak load, 17.1; for boardings, 23.6; for passenger-miles, 118.5; and for running time, 36.1.

Row B7: Since the sample size was more than 15, we recompute the coefficient of variation (C.O.V.).

$$v_X = s_X / \bar{X}$$

For peak load, $v_X = 7.06/17.1 = 0.413$

C.O.V.'s for other data items were computed similarly and entered.

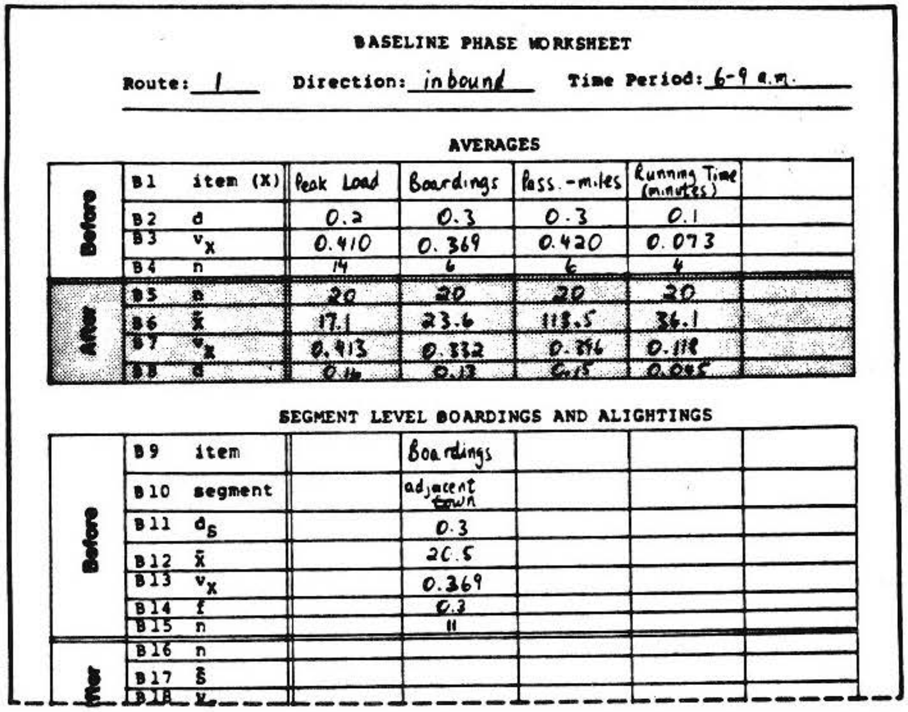
Row B8: Determine d, the tolerance attained, using either Table 6.2 or equation (6.2b).

Row B8:

$$d = \frac{tv}{\sqrt{n}} \qquad \text{(equation (6.2b))}$$

$$\text{For peak load, } d = \frac{1.7(.413)}{\sqrt{20}} = 0.16$$

Tolerances for other data items were computed similarly.



BASELINE PHASE WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

AVERAGES

Before	B1	item (X)	Peak Load	Boardings	Pass.-miles	Running Time (minutes)	
	B2	d	0.2	0.3	0.3	0.1	
	B3	v_X	0.410	0.369	0.420	0.073	
	B4	n	14	6	6	4	
After	B5	n	20	20	20	20	
	B6	$\bar{X}$	17.1	23.6	118.5	36.1	
	B7	v_X	0.413	0.332	0.396	0.118	
	B8	d	0.16	0.13	0.15	0.045	

SEGMENT LEVEL BOARDINGS AND ALIGHTINGS

Before	B9	item		Boardings			
	B10	segment		adjacent town			
	B11	d_S		0.3			
	B12	$\bar{X}$		20.5			
	B13	v_X		0.369			
	B14	f		0.3			
	B15	n		11			
After	B16	n					
	B17	$\bar{S}$					
	B18	v_X					

6.2 Segment-Level Average Boardings and Alightings

(Section 6.2)

For each item in the middle part of the Baseline Phase Worksheet, fill in Rows B16-B21 according to the instructions below.

Row B16: Enter n, the actual size of the sample (number of trips).

Row B17: Enter $\bar{S}$, the average of the segment-level item from the sample.

Row B18: Enter v_S, the coefficient of variation of the segment-level item, calculated from the sample.

Row B19: Compute and enter d, the tolerance attained, using equation (6.5) or Table 6.2b.

6.2 Segment-Level Average Boardings and Alightings

There is one item in this section of the worksheet: boardings in the adjacent town.

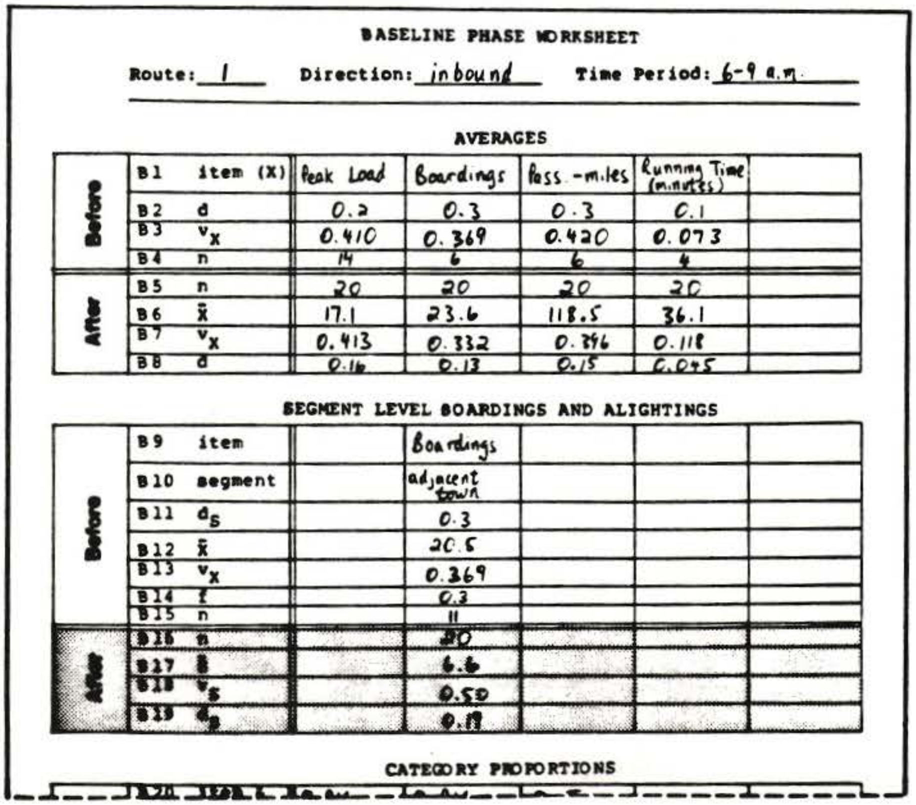
Row B16: The segment level sample size was the same as the route-level, 20.

Row B17: From the baseline sample, the average value was measured to be 6.6.

Row B18: The C.O.V. for segment-level boardings was found to be 0.50.

Row B19: Using equation (6.5),

$$d = \frac{t_s \; v_s}{\sqrt{n}} = \frac{1.7 \; (.50)}{\sqrt{20}} = .19$$



BASELINE PHASE WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

AVERAGES

Before	B1	item (X)	Peak Load	Boardings	Pass.-miles	Running Time (minutes)	
	B2	d	0.2	0.3	0.3	0.1	
	B3	v_x	0.410	0.369	0.420	0.073	
	B4	n	14	6	6	4	
After	B5	n	20	20	20	20	
	B6	$\bar{x}$	17.1	23.6	118.5	36.1	
	B7	v_x	0.413	0.332	0.346	0.118	
	B8	d	0.16	0.13	0.15	0.045	

SEGMENT LEVEL BOARDINGS AND ALIGHTINGS

Before	B9	item		Boardings			
	B10	segment		adjacent town			
	B11	d_s		0.3			
	B12	$\bar{x}$		20.5			
	B13	v_x		0.369			
	B14	f		0.3			
	B15	n		11			
After	B16	n		20			
	B17	$\bar{x}$		6.6			
	B18	v_s		0.50			
	B19	d_s		0.19			

CATEGORY PROPORTIONS

6.3 Category Proportions (Section 6.3)

For each item and category listed in the lower part of the Baseline Phase Worksheet, fill in rows B27-B30 according to the instructions below.

Row B25: Enter n, the number of observations actually made.

Row B26: Enter p, the proportion of those observations lying in the category.

Row B27: Determine d_a, the absolute tolerance attained, from either Table 6.6 or equation (6.7).

6.3 Category Proportions

Three category proportions are listed in the bottom section of the Baseline Phase Worksheet.

Row B25: For % riders owning a car and % riders using a pass, each completed survey is an observaton. The surveys were handed out on all trips, and 165 usable surveys were returned. For schedule adherence, for which each trip is an observation, 20 trips were observed.

Row B26: It was found that 9.3 percent of the riders used a pass; 41.2% of the riders owned a car; and of the 20 trips observed, 17, or 85%, were on time.

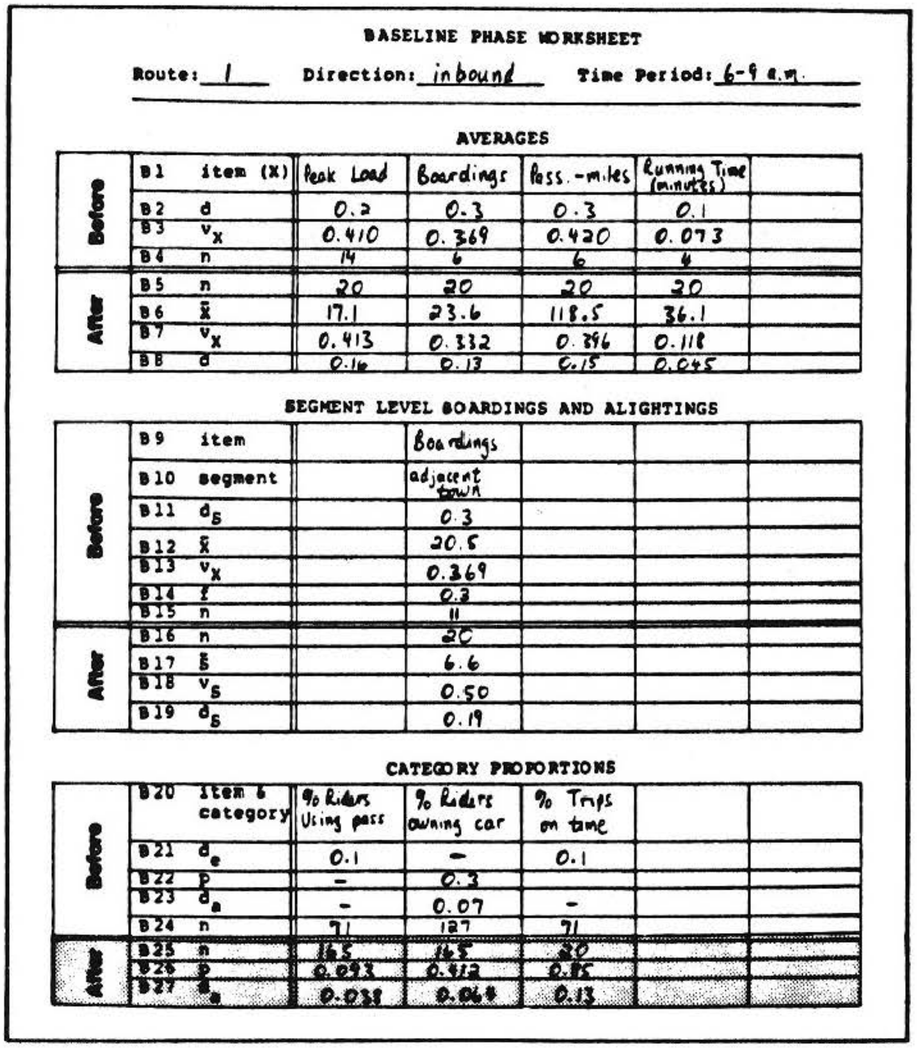
Row B27: Equation (6.8) was used to calculate % riders owning a car:

$$d_a = t \sqrt{\frac{p(1-p)}{n}} = 1.66 \sqrt{\frac{.412(.588)}{165}} = 0.064$$

Calculations for the other items were made in a similar fashion.

(this page intentionally left blank)

-EXAMPLE-



BASELINE PHASE WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

AVERAGES

Before	B1	item (X)	Peak Load	Boardings	Pass.-miles	Running Time (minutes)	
	B2	d	0.2	0.3	0.3	0.1	
	B3	v_x	0.410	0.369	0.420	0.073	
	B4	n	14	6	6	4	
After	B5	n	20	20	20	20	
	B6	$\bar{x}$	17.1	23.6	118.5	36.1	
	B7	v_x	0.413	0.332	0.396	0.118	
	B8	d	0.16	0.13	0.15	0.045	

SEGMENT LEVEL BOARDINGS AND ALIGHTINGS

Before	B9	item		Boardings			
	B10	segment		adjacent town			
	B11	d_s		0.3			
	B12	$\bar{x}$		20.5			
	B13	v_x		0.369			
	B14	f		0.3			
	B15	n		11			
After	B16	n		20			
	B17	$\bar{s}$		6.6			
	B18	v_s		0.50			
	B19	d_s		0.19			

CATEGORY PROPORTIONS

Before	B20	item & category	% Riders Using pass	% Riders owning car	% Trips on time		
	B21	d_e	0.1	–	0.1		
	B22	p	–	0.3			
	B23	d_a	–	0.07	–		
	B24	n	71	127	71		
After	B25	n	165	165	20		
	B26	p	0.093	0.412	0.85		
	B27	d_a	0.038	0.064	0.13		

7. CONVERSION FACTOR ANALYSIS (Section 6.4)

This step analyzes the paired baseline data only. It is executed for each R/D/TP using the Conversions Factor Worksheet(s) used in Step 4. In each conversion the auxiliary item is called X and the inferred item Y. For each potential conversion listed, fill in rows C10-C21 using the instructions given below.

(Note: If an item is listed on both the Conversion Factors Worksheet and the Baseline Phase Worksheet, its average and its C.O.V. may not be the same on both worksheets. On the Conversion Factors Worksheet, these statistics must be calculated from the paired data only, regardless of sample size. (Default C.O.V.'s should not be used, even if the sample size is below 12.) On the Baseline Phase Worksheet, these statistics are based on data observed individually as well as in pairs, and default C.O.V.'s may be used, particularly if the sample size is below 12.)

Row C10: Enter n_1, the number of trips on which paired observations were made.

Row C11: Enter $\bar{X}$, the average of the auxiliary item from the paired sample.

Row C12: Enter $\bar{Y}$, the average of the inferred item from the paired sample.

Row C13: Enter v_X, the coefficient of variation (C.O.V.) of the auxiliary item from the paired sample, using equations (5.4) and (5.5).

7. CONVERSION FACTOR ANALYSIS

The Conversion Factors Worksheet used in Step 4 is used in this step as well.

Note: Because all the baseline data (except the survey) came from ride checks, all of the data is used in the conversion factor analysis. Thus, averages entered on theis worksheet are the same as those reported on the Baseline Phase Worksheet for the same items. And because the number of ride checks (20) is above 12, so that calculated (rather than default) C.O.V.'s were used in Row B7 of the Baseline Phase Worksheet, C.O.V.'s are the same as well.

Row C10: The size of the sample taken in the baseline phase was 20 for each pair of data items.

Row C11: The auxiliary items are load at PP2 (for conversions (a)-(c)) and revenue (conversions (d)-(e)). Their averages are calculated from the sample to be 13.2 for load at PP2 and 11.88 for revenue.

Row C12: The inferred items are peak load (conversions (a) and (d)), boardings (conversions (b) and (e)), and passenger-miles (conversions (c) and (f)). They were analyzed for the same set of 20 trips on the Baseline Phase Worksheet. Their averages are copied from Row B6: 17.1 for peak load, 23.6 for boardings and 118.5 for passenger-miles.

Row C13: The C.O.V.'s for the two auxiliary items were computed from the sample: 0.408 for load at PP2 (conversions (a)-(c)), and 0.498 for revenue (conversions (d)-(f)).

Row C14: Enter v_Y, the C.O.V. of the inferred item from the paired sample, using equations (5.4) and (5.5).

Row C15: Enter r_{XY}, the correlation coefficient between X and Y from the paired sample, computed using equations (6.11) and (6.12).

Row C16: Recompute the dummy variable L using equation (6.13), as done in row C7, Step 4.2, but using v_X, v_Y, and r_{XY} from rows C13-C15.

Row C17: Recompute n_1, the necessary baseline paired sample size, using equation (6.14), as in row C9, Step 4.2, but using L and v_X from rows C16-C17.

Row C14: The C.O.V.'s for the three inferred items were already computed from the 20-trip sample on the Baseline Phase Worksheet. They are copied from Row B7: 0.413 for peak load (conversions (a) and (d)); 0.332 for boardings (conversions (b) and (c)); and 0.396 for passenger-miles (conversions (c) and (f)).

Row C15: An example computation of the correlation coefficient was shown in Step 4.2 for row C6. Values for the six conversions are computed as for row C6 but using the baseline data, and are entered on the worksheet.

Row C16: L was recomputed for each conversion as in Step 4.2, Row C7. The calculation for Conversion (c) is presented here as an example. The formula is:

$$L = \frac{3.24}{d_m^2} (v_X^2 + v_Y^2 - 2v_X v_Y r_{XY})$$

For conversion (c):

$$L = \frac{3.24}{(.3)^2} ((.408)^2 + (.396)^2 - 2 (.408)(.396)(.91)) = 1.05$$

Likewise L was computed to be 0.55 for conversion (a); 0.21 for conversion (b); 2.92 for conversion (d); 1.35 for conversion (e); and 1.93 for conversion (f).

Row C17: n_1 was recomputed for the six conversions as in Step 4.2, Row C9. The calculation for conversion (c) is presented here as an example.

Row C18: If, for any conversion, n_1 computed in row C17 is equal to or smaller than the actual sample size n_1 found in row C10, enter a 0 (zero) and continue to row C19.

However, if row C17 is greater that row C10, enter the difference. It is the required additional number of paired observations that must be taken to supplement the baseline data before the conversion factor can be used. There are two options in this case. One is to simply eliminate the conversion from consideration. Otherwise, the additional paired observations must be made. After they are done, repeat rows C10-C15 using the supplemented sample (use a clean worksheet if necessary), and then continue with row C19.

The formula is:

$$n_1 = L + 1.7 + 7.6 \frac{v_X}{d_m} \sqrt{\frac{L}{B}} \qquad \text{(round up to at least 10)}$$

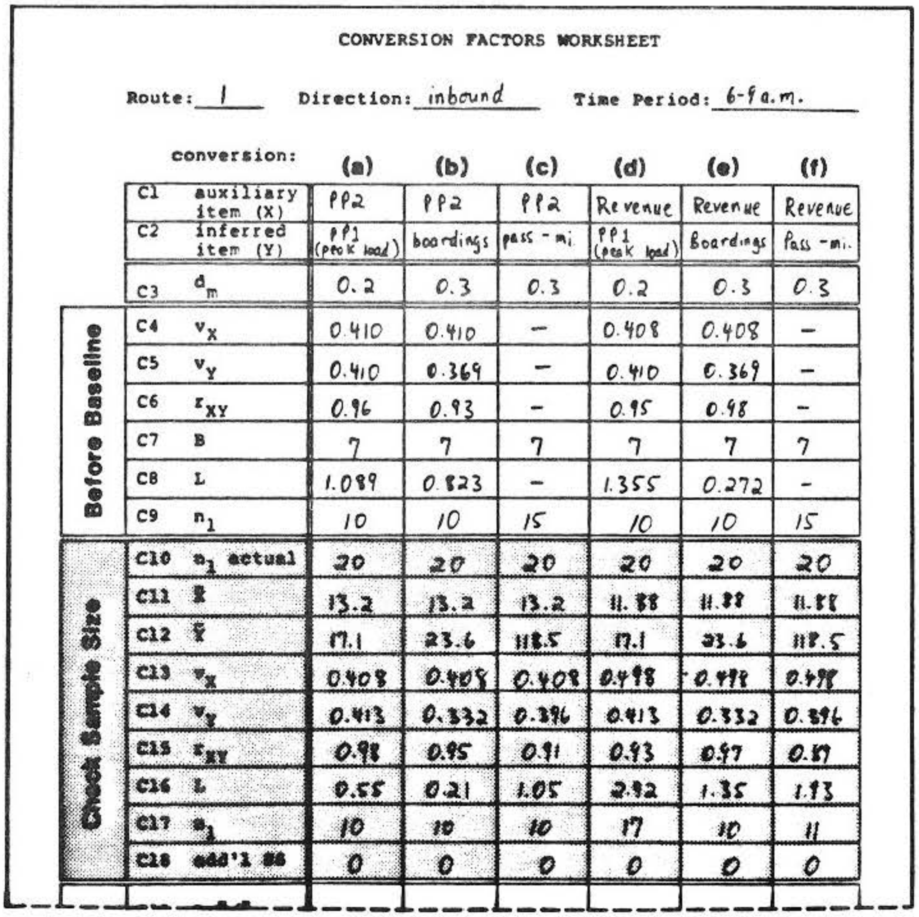
For conversion (a):

$$n_1 = 1.089 + 1.7 + 7.6 (.410/.2) \sqrt{1.089/7} = 8.9$$

which rounds up to 10.

Likewise, n_1 was calculated to be 10 for conversions (a), (b), and (e); 17 for conversion (d); and 11 for conversion (f).

Row C18: For all six conversions, n_1 as calculated for Row C17 is smaller than the actual sample size of 20 (row C10). Thus, no additional samples are needed for any of the conversions. None of the conversions are eliminated at this stage.



CONVERSION FACTORS WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

		conversion:	(a)	(b)	(c)	(d)	(e)	(f)
	C1	auxiliary item (X)	PP2	PP2	PP2	Revenue	Revenue	Revenue
	C2	inferred item (Y)	PP1 (peak load)	boardings	pass - mi	PP1 (peak load)	Boardings	Pass - mi.
	C3	d_m	0.2	0.3	0.3	0.2	0.3	0.3
Before Baseline	C4	v_X	0.410	0.410	–	0.408	0.408	–
	C5	v_Y	0.410	0.369	–	0.410	0.369	–
	C6	r_{XY}	0.96	0.93	–	0.95	0.98	–
	C7	B	7	7	7	7	7	7
	C8	L	1.089	0.823	–	1.355	0.272	–
	C9	n_1	10	10	15	10	10	15
Check Sample Size	C10	n_1 actual	20	20	20	20	20	20
	C11	$\bar{X}$	13.2	13.2	13.2	11.88	11.88	11.88
	C12	$\bar{Y}$	17.1	23.6	118.5	17.1	23.6	118.5
	C13	v_X	0.408	0.408	0.408	0.498	0.498	0.498
	C14	v_Y	0.413	0.332	0.396	0.413	0.332	0.396
	C15	r_{XY}	0.98	0.95	0.91	0.93	0.97	0.87
	C16	L	0.55	0.21	1.05	2.92	1.35	1.93
	C17	n_1	10	10	10	17	10	11
	C18	add'l #s	0	0	0	0	0	0

Row C19: Compute the conversion factor $R = \bar{Y}/\bar{X}$. $\bar{Y}$ is from row C12, and $\bar{X}$ from row C11.

Row C20: Compute v_R^2, the square of the C.O.V. of the conversion factor, from equation (6.10).

Row C19: The conversion factors for conversions (a)-(f) are:

(a) $R = Y/X = 17.1/13.2 = 1.30$

(b) $R = Y/X = 23.6/13.2 = 1.79$

(c) $R = Y/X = 118.5/13.2 = 8.98$

(d) $R = Y/X = 17.1/11.88 = 1.44$

(e) $R = Y/X = 23.6/11.88 = 1.99$

(f) $R = Y/X = 118.5/11.88 = 9.98$

Row C20: Using equation (6.10):

$$v_R^2 = \frac{1}{n-1.7}\,(v_X^2 + v_Y^2 - 2v_X v_Y v_{XY})$$

Conversion

(a) $$v^2_{PP2,PP1} = \frac{(.408)^2 + (.413)^2 - 2(.408)(.413)(.98)}{20 - 1.7} = .00037$$

(b) $$v^2_{PP3,Brd} = \frac{(.408)^2 + (.332)^2 - 2(.408)(.332)(.95)}{20 - 1.7} = .00106$$

(c) $$v^2_{PP2,PM} = \frac{(.408)^2 + (.396)^2 - 2(.408)(.396)(.91)}{20 - 1.7} = .00160$$

(d) $$v^2_{Rev,PP1} = \frac{(.498)^2 + (.413)^2 - 2(.498)(.413)(.93)}{20 - 1.7} = .00197$$

(e) $$v^2_{Rev,Brd} = \frac{(.498)^2 + (.332)^2 - 2(.498)(.332)(.97)}{20 - 1.7} = .00205$$

(f) $$v^2_{Rev,PM} = \frac{(.498)^2 + (.396)^2 - 2(.498)(.396)(.89)}{20 - 1.7} = .00294$$

Row C21: From either Table 6.7 or equation (5.15), determine n_2, the sample size of the auxiliary item required in the monitoring phase.

Row C21: Using equation (6.15),

$$n_2 = \frac{v_X^2 \quad (1 + v_R^2\ )}{0.31\ d^2_m - v_R^2}$$ (round up to next whole number)

Conversion

(a) $$n_2 = \frac{(.408)^2\ (1 + .00037)}{(.31)(.2)^2 - .00037} = 13.9$$ (round up to 14)

(b) $$n_2 = \frac{(.408)^2\ (1 + .00106)}{(.31)(.3)^2 - .00106} = 6.2$$ (round up to 7)

(c) $$n_2 = \frac{(.408)^2\ (1 + .00160)}{(.31)(3)^2 - .00160} = 6.3$$ (round up to 7)

(d) $$n_2 = \frac{(.498)^2\ (1 + .00197)}{(.31)(.2)^2 - .00197} = 23.9$$ (round up to 24)

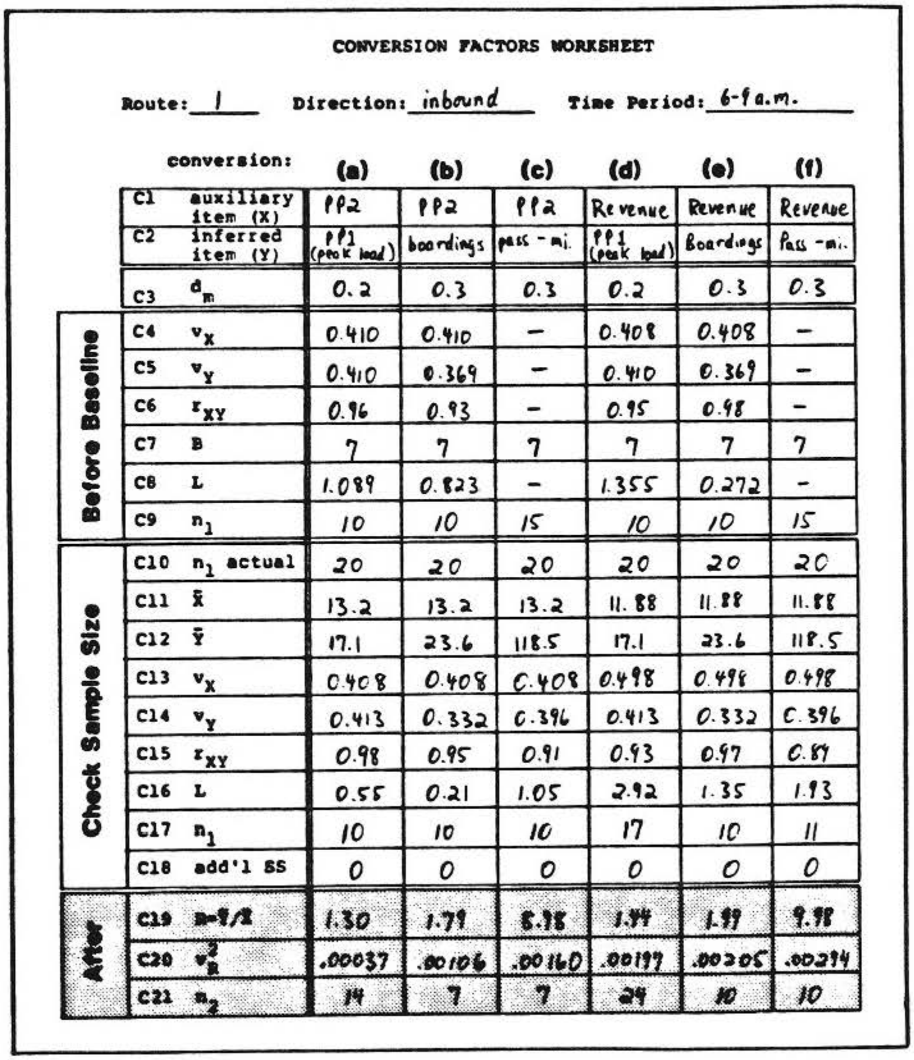
(e) $$n_2 = \frac{(.498)^2\ (1 + .00205^2)}{(.31)(.3)^2 - .00205} = 9.6$$ (round up to 10)

(f) $$n_2 = \frac{(.498)^2\ (1 + .00294^2)}{(.31)(.3)^2 - .00294} = 9.9$$ (round up to 10)

(see completely filled in worksheet on next page)

(this page intentionally left blank)

-EXAMPLE-



CONVERSION FACTORS WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

		conversion:	(a)	(b)	(c)	(d)	(e)	(f)
	C1	auxiliary item (X)	PP2	PP2	PP2	Revenue	Revenue	Revenue
	C2	inferred item (Y)	PP1 (peak load)	boardings	pass - mi.	PP1 (peak load)	Boardings	Pass - mi.
	C3	d_m	0.2	0.3	0.3	0.2	0.3	0.3
Before Baseline	C4	v_X	0.410	0.410	–	0.408	0.408	–
	C5	v_Y	0.410	0.369	–	0.410	0.369	–
	C6	r_{XY}	0.96	0.93	–	0.95	0.98	–
	C7	B	7	7	7	7	7	7
	C8	L	1.089	0.823	–	1.355	0.272	–
	C9	n_1	10	10	15	10	10	15
Check Sample Size	C10	n_1 actual	20	20	20	20	20	20
	C11	$\bar{X}$	13.2	13.2	13.2	11.88	11.88	11.88
	C12	$\bar{Y}$	17.1	23.6	118.5	17.1	23.6	118.5
	C13	v_X	0.408	0.408	0.408	0.498	0.498	0.498
	C14	v_Y	0.413	0.332	0.396	0.413	0.332	0.396
	C15	r_{XY}	0.98	0.95	0.91	0.93	0.97	0.89
	C16	L	0.55	0.21	1.05	2.92	1.35	1.93
	C17	n_1	10	10	10	17	10	11
	C18	add'l SS	0	0	0	0	0	0
After	C19	$m=\bar{Y}/\bar{X}$	1.30	1.79	8.98	1.44	1.99	9.98
	C20	v_R^2	.00037	.00106	.00160	.00197	.00205	.00294
	C21	n_2	14	7	7	24	10	10

8. DETERMINE MONITORING PHASE SAMPLE SIZES

Monitoring phase sample sizes are determined using a Monitoring Phase Worksheet for each R/D/TP. A filled in worksheet for the example is found at the end of this chapter. Only two types of data items are considered: averages and proportions. Segment-level averages are treated simply as other averages in the monitoring phase.

8.1 List Averages Desired

For each item whose average is desired, fill in Rows M1 and M2 according to the following instructions. If an item is the inferred item of more than one potential conversion, repeat the item according to the number of conversions so that the item occupies as many columns as there are potential conversions.

Row M1: Precisely define the item, e.g., "Boardings in fare category X", "boardings on segment W", "load at point Z".

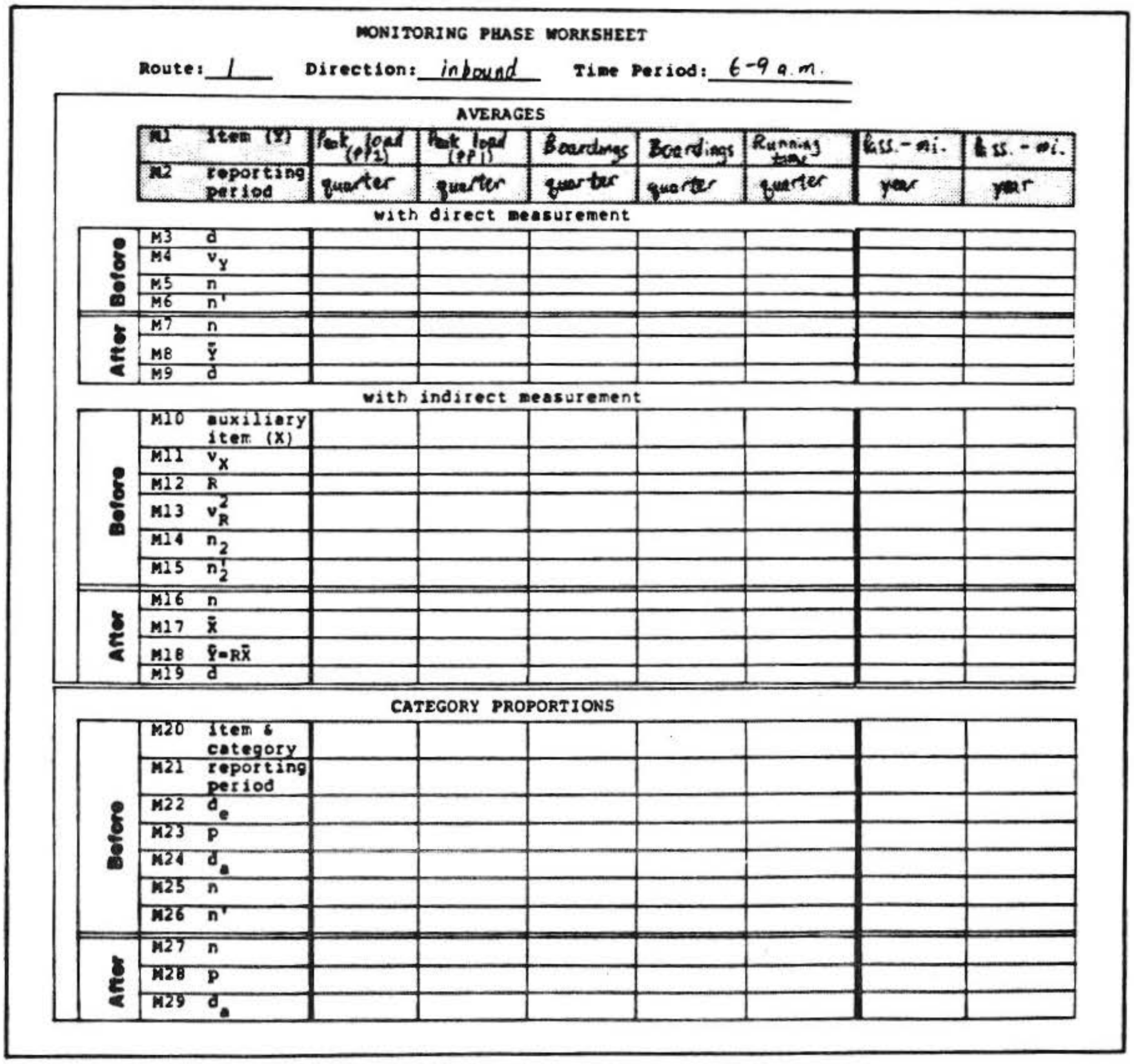
Row M2: Enter the reporting period for this item.

8. DETERMINE MONITORING PHASE SAMPLE SIZES

8.1 List Averages

Row M1: The items are specified in Step 1.4. All items except running time are given two columns to allow for the two potential conversions.

Row M2: The reporting period is given in Step 1.4 for each item.



MONITORING PHASE WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

AVERAGES

	M1	item (Y)	Peak load (PP2)	Peak load (PP1)	Boardings	Boardings	Running time	Pass.-mi.	Pass.-mi.
	M2	reporting period	quarter	quarter	quarter	quarter	quarter	year	year
		with direct measurement							
Before	M3	d							
	M4	v_Y							
	M5	n							
	M6	n'							
After	M7	n							
	M8	$\bar{y}$							
	M9	d							
		with indirect measurement							
Before	M10	auxiliary item (X)							
	M11	v_X							
	M12	R							
	M13	v_R^2							
	M14	n_2							
	M15	n_2'							
After	M16	n							
	M17	$\bar{x}$							
	M18	$\hat{y}=R\bar{x}$							
	M19	d							
		CATEGORY PROPORTIONS							
Before	M20	item & category							
	M21	reporting period							
	M22	d_e							
	M23	p							
	M24	d_a							
	M25	n							
	M26	n'							
After	M27	n							
	M28	p							
	M29	d_a							

8.2 Averages - Direct Measurement (Section 6.1)

If it has already been determined for practical reasons that an item will be measured indirectly using a conversion factor, skip this step. If direct measurement is a possibility, however, then fill in row M3-M5 according to the instructions given below.

Row M3: Enter d, the tolerance desired, according to specifications of Step 1.4. Enter d as a decimal (e.g., enter ±20% as 0.2).

Row M4: Enter v_Y, the coefficient of variation of the item from row B7 of the Baseline Phase Worksheet.

Row M5: From either Table 6.1 or equation (6.1), determine n, the sample size required.

Row M6: If the reporting period for this item (row M2) is different from the standard monitoring period (determined in Step 1.4b), divide n by the number of monitoring periods per reporting period, and round up. (e.g., if the monitoring period is a quarter, and the reporting period a year, divide n by 4). The result, n', is the number of trips needed per monitoring period.

8.2 Averages -- Direct Measurement

Because of the low monitoring phase sample sizes required by all of the conversions (see row C26 of the Conversion Factors Worksheet), it has been decided that all the averages except running time will be monitored indirectly using conversions. Thus this step is skipped for these items.

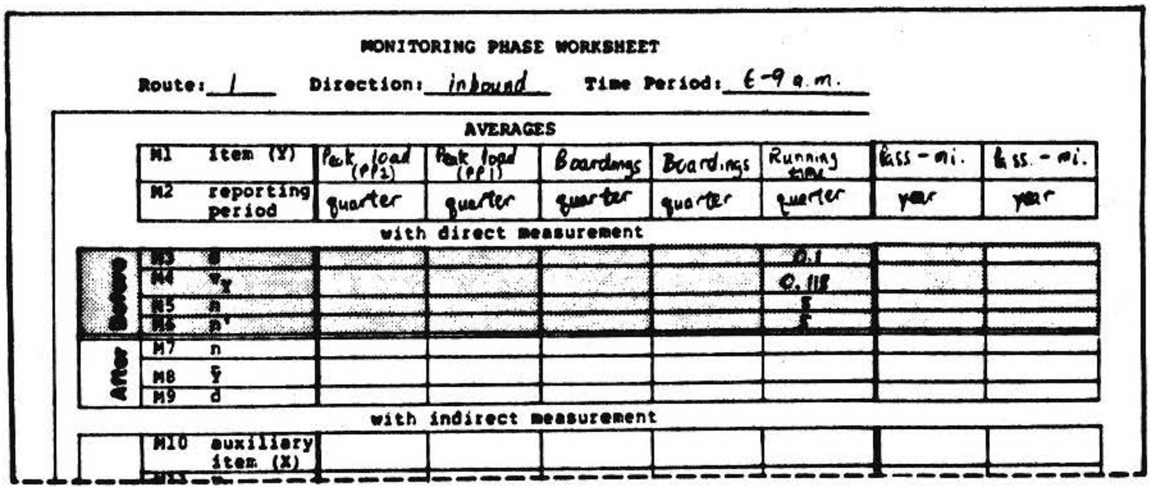
For running time, however, this part of the worksheet is completed as follows:

Row M3: From Step 1.2, the route-level tolerance of 0.1 is entered.

Row M4: The coefficient of variation for running time, v, is 0.118 from row B7 of the baseline data.

Row M5: From Table 6.1, for d = 0.1 and v = 0.118, n is a little above 4. Applying equation (6.1), n = (3.24)(.118)^2/(.1)^2 = 4.5, or (rounded up) 5.

Row M6: Since the reporting period for running time is the same as the monitoring period row M6 equals M5.



MONITORING PHASE WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

AVERAGES

	M1	item (Y)	Peak load (PP2)	Peak load (PP1)	Boardings	Boardings	Running time	Pass-mi.	Pass.-mi.
	M2	reporting period	quarter	quarter	quarter	quarter	quarter	year	year
		with direct measurement							
Before	M3	d					0.1		
	M4	v_Y					0.118		
	M5	n					5		
	M6	n'					5		
After	M7	n							
	M8	$\bar{Y}$							
	M9	d							
		with indirect measurement							
	M10	auxiliary item (X)							

8.3 Averages - Indirect Measurement Using Conversion Factors (Section 6.4.5)

For every item whose average can be inferred using a conversion (as listed on the Conversion Factor Worksheet for that item), fill out rows M11-M16 according to the instructions below. If there is more than one potential conversion for an inferred item (so that, in accordance with Step 9.1, the item occupies a column for conversion), fill in rows M10-M15 for each conversion.

Row M3: If not done in Step 9.2, enter d, the desired monitoring phase tolerance.

Row M10: Describe the auxiliary item (from the Conversion Factors Worksheet, row C1).

Row M11: Enter v_X from either row C13 of the Conversion Factors Worksheet or row B3 of the Baseline Phase Worksheet.

Row M12: Enter R, the conversion factor, from row C19 of the Conversion Factors Worksheet.

Row M13: Enter v_R^2, the square of the coefficient of variation of R, from row C20 of the Conversion Factors Worksheet.

Row M14: Enter n_2, the sample size of the auxiliary item needed per reporting period in the monitoring phase, from row C21 of the Conversion Factors Worksheet.

8.3 Averages -- Indirect Measurement Using Conversion Factors

Six columns are filled in for this middle part of the worksheet (one for each conversion). There are two conversions for each of the three inferred item. The inferred items are peak load (i.e., load at PP1), boardings, and passenger-miles.

Row M3: Since Step 1.2 specified the same tolerances in the monitoring phase as in the baseline phase, tolerances can be copied from the Baseline Phase Worksheet, row B2. For peak load, the tolerance is 0.2 (i.e., ±20%); for boardings, 0.3; for passenger-miles, 0.3; and for running time, 0.1.

Row M10: The auxiliary items are copied from the Conversion Factors Worksheet, row C1. Peak load, boardings, and passenger-miles each has two potential auxiliary items: load at PP2, and revenue.

Row M11: The C.O.V.'s are copied from row C13 of the Conversion Factors worksheet: 0.408 for load at PP2, and 0.498 for revenue.

Row M12: The six conversion factors are copied from row C19 of the Conversion Factors Worksheet.

Row M13: For each of the six conversions, v_R^2 is copied from row C20 of the Conversion Factors Worksheet.

Row M14: From row C21 of the Conversion Factors Worksheet, values of n_2 = are copied.

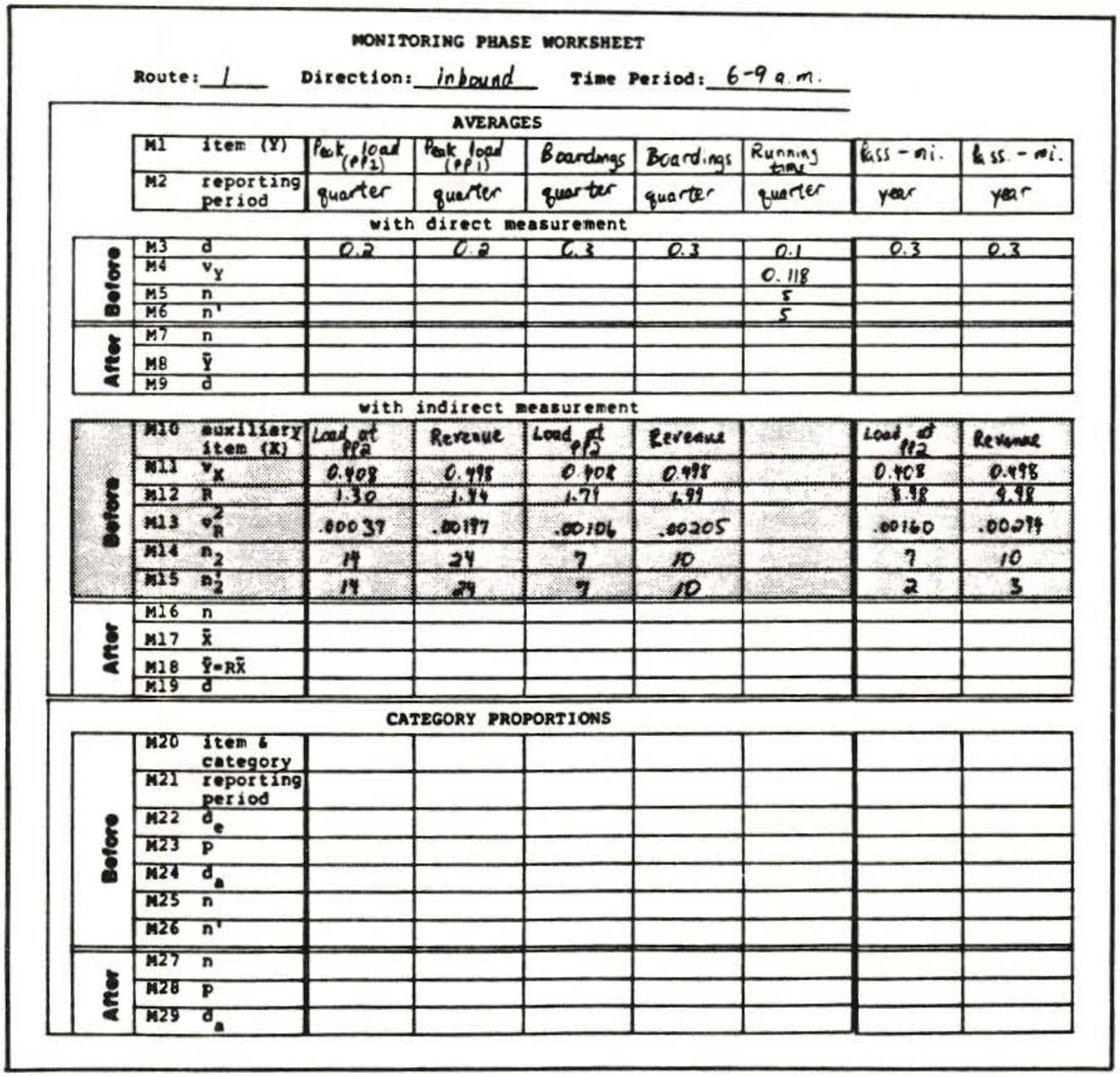
Row M15: If the reporting period for this item (row M2) is different from the standard monitoring period (determined in Step 1.4b), divide n_2 by the number of monitoring periods per reporting period, and round up. (e.g., if the monitoring period is a quarter, and the reporting period a year, divide n_2 by 4). The result, n_2, is the number of trips needed per monitoring period.

<u>Row M15</u>: From row M2, passenger-miles is the only item with a longer reporting period (annual) than the monitoring period (quarter). In both passenger-miles columns, row M14 is divided by 4 and rounded up:

7/4 = 1.75 or 2 in the first pass.-mi column;

10/4 = 2.5 or 3 in the second pass.-mi column.

In the other columns, row M14 is copied into row M15.



MONITORING PHASE WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

AVERAGES

	M1	item (Y)	Peak load (PP2)	Peak load (PP1)	Boardings	Boardings	Running time	Pass-mi.	Pass.-mi.
	M2	reporting period	quarter	quarter	quarter	quarter	quarter	year	year
		with direct measurement							
Before	M3	d	0.2	0.2	0.3	0.3	0.1	0.3	0.3
	M4	v_Y					0.118		
	M5	n					5		
	M6	n'					5		
After	M7	n							
	M8	$\bar{Y}$							
	M9	d							
		with indirect measurement							
Before	M10	auxiliary item (X)	Load at PP2	Revenue	Load at PP2	Revenue		Load at PP2	Revenue
	M11	v_X	0.408	0.498	0.408	0.498		0.408	0.498
	M12	R	1.30	1.44	1.74	1.99		3.98	9.98
	M13	v_R^2	.00037	.00197	.00106	.00205		.00160	.00279
	M14	n_2	14	24	7	10		7	10
	M15	n_2'	14	24	7	10		2	3
After	M16	n							
	M17	$\bar{X}$							
	M18	$\bar{Y}=R\bar{X}$							
	M19	d							

CATEGORY PROPORTIONS

Before	M20	item & category							
	M21	reporting period							
	M22	d_e							
	M23	p							
	M24	d_a							
	M25	n							
	M26	n'							
After	M27	n							
	M28	p							
	M29	d_a							

8.4 Choose Final Set of Conversions

For any item for which both direct and indirect measurement are contemplated, or for which more than one conversion is contemplated, compare the sample sizes in rows M6 and M15 of the Monitoring Phase Worksheet. Accounting for the cost of a direct vs. an indirect sample, decide which approach will be the most cost-effective. If direct measurement is chosen, eliminate the indirect measurement entries for this item from the Monitoring Phase Worksheet. If one of the conversions is chosen, eliminate the direct measurement entry and any other indirect measurement entries for this item.

8.5 Category Proportions (Section 6.3)

For each category proportion needed in the monitoring phase, fill out rows M20-M26 of the Monitoring Phase Worksheet (use a separate worksheet for each R/D/TP).

Row M20: Describe the item and category, (e.g. "trips on time.")

Row M21: Enter the reporting period.

Rows M22-M24: Either Row M22 or rows M23-M24 must be completed. Row M22 applies when an absolute equivalent tolerance (AET) is specified; rows M23-M24 apply when an absolute tolerance (AT) is specified.

Row M22: Enter d_e, the absolute equivalent tolerance, as specified in Step 1.4.

8.4 Choose Final Set of Conversions

Even though the conversions using load at PP2 as an auxiliary item require fewer sampled trips, the conversions using revenue are chosen, since the sample size is reasonable and can be obtained at minimal cost by drivers. Analysis of conversions using load at PP2 is discontinued.

8.5 Category Proportions

Row M20: From Step 1.4, the category proportions desired are "% trips on time" and "% riders using a pass."

Row M21: Quarterly data is required for % trips on time, and annual data for % pass use.

Rows M22-M24: In Step 1.4, the same tolerance for both "% trips on time" and "% pass use" were specified as absolute equivalent tolerances of 0.1. Since AET is used, rows M23-M24 are skipped.

Row M22: The specified tolerance is entered, 0.1 for both items.

Row M23: Enter p, the estimated proportion lying in the category, from the Baseline Phase Worksheet, row B28.

Row M24: Enter d_a, the desired absolute tolerance appropriate to the proportion specified in row M23.

Row M25: Determine n, the number of observations needed, using the instructions below. Note that the units for n can differ according to the data item; e.g. for fraction of trips on time, a trip is an observation, while for fraction of passengers transferring to Route Y, a passenger is an observation.

If absolute equivalent tolerance (Row M23) was used: Determine n from Table 6.5a or equation (6.6a).

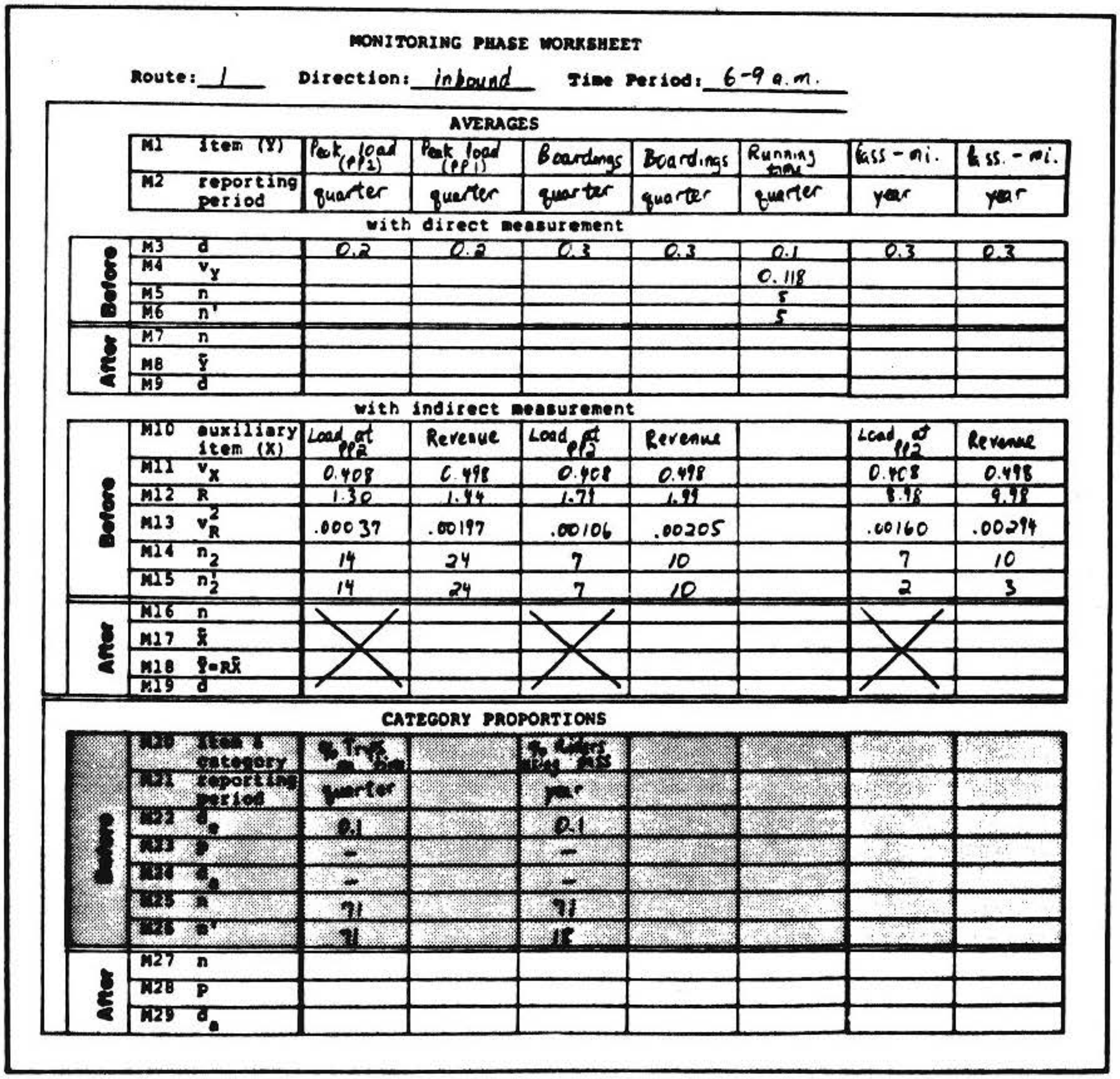
If absolute tolerance (Rows M23, M24) was used: Determine n from Table 6.5b or equation (6.6b).

Row M26: If the reporting period for this item (row M2) is different from the standard monitoring period (determined in Step 1.4b), divide n by the number of monitoring periods per reporting period, and round up. (E.g., if the monitoring period is a quarter, and the reporting period a year, divide n by 4 and round up). The result, n', is the number of observations needed per monitoring period. If not, copy the value in Row M25.

<u>Rows M23-M25</u>: skipped (see above)

<u>Row M25</u>: From Table 6.5a, the sample size n is 71 for both "% riders using a pass" and "% trips on time".

<u>Row M26</u>: From Step 1.4b, the standard monitoring period is the quarter. For "% trips on time", the reporting period is also a quarter, so 71 is copied from Row M25. For "% pass use", the reporting period is a year, which is 4 quarters, so the sample size per monitoring period is 71/4 (round up) = 18.



MONITORING PHASE WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

AVERAGES

	M1	item (Y)	Peak load (PP2)	Peak load (PP1)	Boardings	Boardings	Running time	Pass-mi.	Pass.-mi.
	M2	reporting period	quarter	quarter	quarter	quarter	quarter	year	year
		with direct measurement							
Before	M3	d	0.2	0.2	0.3	0.3	0.1	0.3	0.3
	M4	v_Y					0.118		
	M5	n					5		
	M6	n'					5		
After	M7	n							
	M8	$\tilde{y}$							
	M9	d							
		with indirect measurement							
Before	M10	auxiliary item (X)	Load at PP2	Revenue	Load at PP2	Revenue		Load at PP2	Revenue
	M11	v_X	0.408	0.498	0.408	0.498		0.408	0.498
	M12	R	1.30	1.44	1.71	1.99		8.98	9.98
	M13	v_R^2	.00037	.00197	.00106	.00205		.00160	.00294
	M14	n_2	14	24	7	10		7	10
	M15	n_2'	14	24	7	10		2	3
After	M16	n	☒		☒			☒	
	M17	$\tilde{x}$	☒		☒			☒	
	M18	$\tilde{y}=R\tilde{x}$	☒		☒			☒	
	M19	d	☒		☒			☒	

CATEGORY PROPORTIONS

Before	M20	item & category	% trips on time		% riders using pass				
	M21	reporting period	quarter		year				
	M22	d_a	0.1		0.1				
	M23	p	–		–				
	M24	d_a	–		–				
	M25	n	71		71				
	M26	n'	71		18				
After	M27	n							
	M28	p							
	M29	d_a							

9. SCHEDULE AND EXECUTE MONITORING PHASE DATA COLLECTION

9.1 Schedule Data Collection (Chapters 7, 9)

As in Step 5.1, follow the scheduling procedure of Chapter 9 and the guidelines of Chapter 7 to schedule data collection activity for the monitoring phase. The schedule should be for a single monitoring period (as determined in Step 1.4b), and should take as required sample sizes the per reporting period sample sizes n' from rows M16 and M28 of the Monitoring Phase Worksheet.

9.2 Execute Monitoring Phase Data Collection

Monitoring phase data collection can now begin. It should be repeated each monitoring period.

10. ANALYZE MONITORING PHASE DATA

This step should be performed after data collection for each reporting period. Thus, items whose reporting period is the standard monitoring period should be analyzed every monitoring period, while items whose reporting period is, for example, four monitoring periods long should be analyzed only after every four monitoring periods.

9. SCHEDULE AND EXECUTE MONITORING PHASE DATA COLLECTION

Again, use the Chapter 9 procedure is used to schedule non-survey data collection and the Chapter 7 guidelines to schedule surveys. This second scheduling process is not shown for this example.

10. ANALYZE MONITORING PHASE DATA

In order to demonstrate this step for all data items (including those with an annual reporting period), the analysis is shown for end of the first year of monitoring. For items reported quarterly, data from the fourth quarter is used; for items reported annually, data from the entire year is used.

10.1 Averages Measured Directly (Section 6.1)

For items listed on the top part of a Monitoring Phase Worksheet, fill in rows M7-M9.

Row M7: Enter n, the actual number of observations made in the reporting period. Note that if the reporting period is longer than the monitoring periods, data from all the monitoring periods within the reporting period should be included.

Row M8: Enter $\overline{Y}$, the average of the data item from the reporting period sample.

Row M9: Enter d, the tolerance attained, from either Table 6.2a or equation (6.2a). For v, use v_Y (row M4).

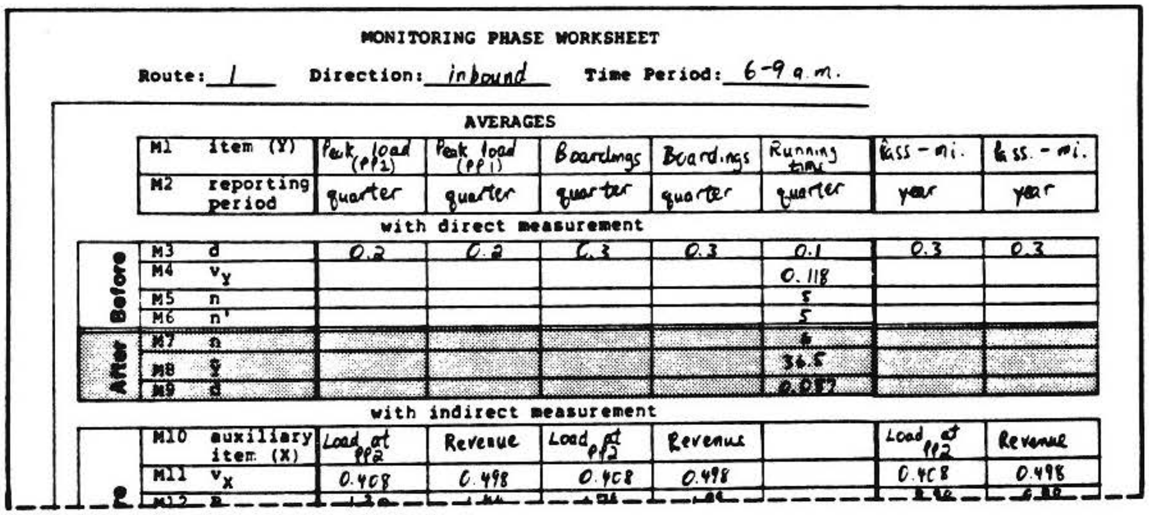
10.1 Averages Measured Directly

Only running time was measured directly. Its reporting period is a quarter, so only fourth quarter data is examined.

Row M7: Six trips were sampled directly for Route 1/ inbound/a.m. peak for running time.

Row M8: The average running time was calculated from the monitoring data to be 36.5 min.

Row M9: From Table 6.2a, d is a little above 0.07 for $v_Y = 0.118$ and $n = 6$. For a more accurate estimate, equation (6.2a) was used to compute $d = (1.8)(.118)/\sqrt{6} = .087$.



MONITORING PHASE WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

AVERAGES

	M1	item (Y)	Peak load (PP2)	Peak load (PP1)	Boardings	Boardings	Running time	Pass - mi.	Pass. - mi.
	M2	reporting period	quarter	quarter	quarter	quarter	quarter	year	year
		with direct measurement							
Before	M3	d	0.2	0.2	0.3	0.3	0.1	0.3	0.3
	M4	v_Y					0.118		
	M5	n					5		
	M6	n'					5		
After	M7	n					6		
	M8	$\bar{Y}$					36.5		
	M9	d					0.087		
		with indirect measurement							
	M10	auxiliary item (X)	Load at PP2	Revenue	Load at PP2	Revenue		Load at PP2	Revenue
	M11	v_X	0.408	0.498	0.408	0.498		0.408	0.498

10.2 Averages Measured Indirectly (Section 6.4.6)

For items measured indirectly via conversion, where rows M1-M2 and M10-M15 were filled out on a Monitoring Phase Worksheet, fill in rows M16-M19.

Row M16: Enter n, the actual number of observations of the auxiliary item made in the reporting period.

Row M17: Enter $\bar{X}$, the average of the auxiliary item from the reporting period sample.

Row M18: Compute and enter $\bar{Y}$, the estimated average of the inferred item, by multiplying $\bar{X}$ (row M17) by the conversion factor R (row M12).

10.2 Averages Measured Indirectly

This step applies to the three items covered in the middle part of the worksheet: peak load, boardings, and passenger-miles. Each item has two columns, but only the column for the chosen conversion (see Step 8.4), whose auxiliary item is revenue, is filled in in this step.

The data collected on revenue on Route 1/inbound/a.m. peak is as follows:

Fourth Quarter		Entire Year	
Number of observations	Avg revenue	Number of observations	Avg revenue
15	$12.06	57	$12.01

Row M16: For peak load and boardings, which are reported quarterly, n = 15. For passenger-miles, n = 57 since the reporting period is a year.

Row M17: For peak load and boardings, the average revenue for the fourth quarter, $12.06, was entered. For passenger-miles, average annual revenue, $12.01, was entered.

Row M18: In column 2, average peak load for the quarter was estimated by multiplying average revenue for the quarter, 12.06, by the revenue-to-peak load conversion factor, 1.44 (row M12), yielding 17.4. Likewise, average boardings for the quarter is estimated to be (12.06)(1.99) = 24.0, and average passenger-miles for the year is estimated to be (12.01)(9.98) = 119.9.

Row M19: Compute d, the tolerance attained for the item for the reporting period, from equation (6.16). Note that v_X is found in row M11.

Row M19: Equation (6.16) is:

$$d = 1.8 \sqrt{\frac{v_X^2 \, (1 + v_R^2)}{n_2} + v_R^2}$$

peak load

$$d = 1.8 \sqrt{\frac{(0.498)^2 \, (1 + (.00197))}{(15)} + (.00197)} = .25$$

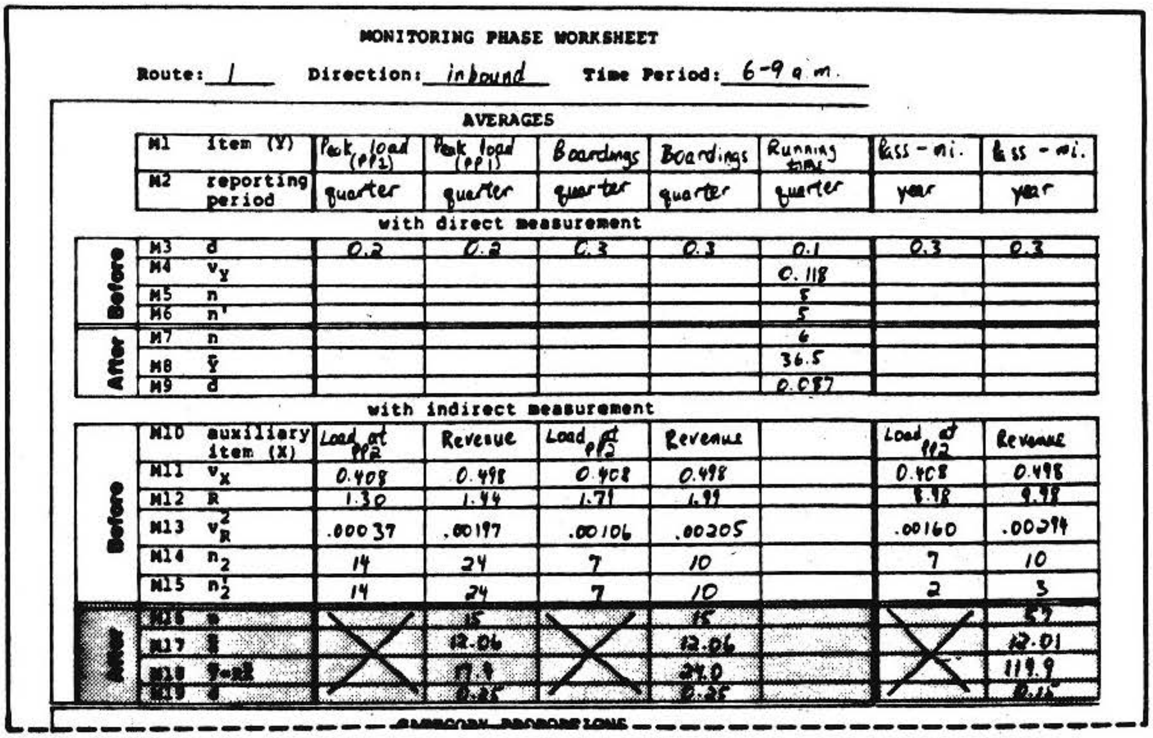
boardings

$$d = 1.8 \sqrt{\frac{(0.498)^2 \, (1 + (.00205))}{(15)} + (.00205)} = .25$$

pass.-miles

$$d = 1.8 \sqrt{\frac{(0.498)^2 \, (1 + (.00294))}{(57)} + (.00294)} = 0.15$$

The achieved tolerance is better than the desired tolerance for boardings (0.3) and passenger-miles (0.3), because the actual sample size exceeded the required sample size. However, for peak load the required sample size was 24, while the actual sample size was only 15, and as a result the desired tolerance (.2) was not met.



MONITORING PHASE WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

AVERAGES

	M1	item (Y)	Peak load (PP2)	Peak load (PP1)	Boardings	Boardings	Running time	Pass-mi.	Pass-mi.
	M2	reporting period	quarter	quarter	quarter	quarter	quarter	year	year
		with direct measurement							
Before	M3	d	0.2	0.2	0.3	0.3	0.1	0.3	0.3
	M4	v_y					0.118		
	M5	n					5		
	M6	n'					5		
After	M7	n					6		
	M8	$\bar{y}$					36.5		
	M9	d					0.087		
		with indirect measurement							
Before	M10	auxiliary item (X)	Load at PP2	Revenue	Load at PP2	Revenue		Load at PP2	Revenue
	M11	v_X	0.408	0.498	0.408	0.498		0.408	0.498
	M12	R	1.30	1.44	1.71	1.99		9.98	9.98
	M13	v_R^2	.00037	.00197	.00106	.00205		.00160	.00294
	M14	n_2	14	24	7	10		7	10
	M15	n_2'	14	24	7	10		2	3
After	M16	n		15		15			57
	M17	$\bar{x}$		12.06		12.06			12.01
	M18	$\bar{y}=\bar{x}R$		17.4		24.0			119.9
	M19	d		0.25		0.25			0.15

CATEGORY PROPORTIONS

10.3 Category Proportions (Section 6.3)

For each category listed in the lower part of a Monitoring Phase Worksheet, fill in rows M27-M29 according to the instructions below.

Row M27: Enter n, the number of observations actually made in the reporting period.

Row M28: Enter p, the proportion of those observations lying in the category.

Row M29: Determine d_a, the absolute tolerance tolerance attained, from either Table 6.6 or equation (6.8).

10.3 Category Proportions

The two items covered in this step are "% riders using a pass" and "% trips on time" (shown in the bottom part of the Monitoring Phase Worksheet). "% riders using a pass" was monitored with a survey done on 5 trips (one day) each quarter. A total of 120 good surveys were returned, of which 10 reported pass use. Schedule adherence (% trips on time) was monitored on one day this quarter by checkers, allowing 15 trips to be observed. Of the 15, 12 were on time.

Row M27: For pass use, the sample size was 120. For trips on time, it was 15.

Row M28: For pass use, p = 10/120 = .083. For trips on time, p = 12/15 = 0.80.

Row M29: For pass use, from Table 6.6, with n = 120 and p = 0.083, d_a is approximately $\pm$0.045. For trips on time, equation (6.7) is used:

$$d_a = t\sqrt{\frac{p(1-p)}{n}} = 1.8\sqrt{\frac{.8(.2)}{15}} = 0.19$$

The calculated tolerance attained for trips on time is far worse than the tolerance desired. This is because, as in the baseline phase, it was decided before scheduling the monitoring phase that the specified accuracy (0.1 AET) was not worth the cost of observing 71 trips per quarter (the amount indicated in row M26). Therefore, care must be used in drawing conclusions about schedule adherence from this monitoring data. As data are aggregated over more quarters or time

(This page intentionally left blank)

periods or routes, the tolerance for this item becomes more acceptable. For example, aggregating over 4 quarters, resulting in 60 observations, yields an AET of 0.11.

MONITORING PHASE WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

AVERAGES

M1	item (Y)	Peak load (PP2)	Peak load (PP1)	Boardings	Boardings	Running time	Pass - mi.	Pass. - mi.
M2	reporting period	quarter	quarter	quarter	quarter	quarter	year	year

with direct measurement

Before	M3	d	0.2	0.2	0.3	0.3	0.1	0.3	0.3
	M4	v_Y					0.118		
	M5	n					5		
	M6	n'					5		
After	M7	n					6		
	M8	$\bar{Y}$					36.5		
	M9	$\bar{d}$					0.087		

with indirect measurement

Before	M10	auxiliary item (X)	Load at PP2	Revenue	Load at PP2	Revenue		Load at PP2	Revenue
	M11	v_X	0.408	0.498	0.408	0.498		0.408	0.498
	M12	R	1.30	1.44	1.79	1.99		8.98	9.98
	M13	v_R^2	.00037	.00197	.00106	.00205		.00160	.00294
	M14	n_2	14	24	7	10		7	10
	M15	n_2'	14	24	7	10		2	3
After	M16	n	✗	15	✗	15		✗	57
	M17	$\bar{X}$		12.06		12.06			12.01
	M18	$\bar{Y}=R\bar{X}$		17.4		24.0			119.9
	M19	$\bar{d}$		0.25		0.25			0.15

CATEGORY PROPORTIONS

Before	M20	item & category	% Trips on time		% Riders using pass				
	M21	reporting period	quarter		year				
	M22	d_e	0.1		0.1				
	M23	p	–		–				
	M24	d_a	–		–				
	M25	n	71		71				
	M26	n'	71		18				
After	M27	n	15		120				
	M28	p	0.50		0.083				
	M29	d_a	0.19		0.045				

10.4 Determine the Need for Follow-Up (Section 4.4)

If any average serving as a change indicator (as described in Section 4.3.3) changes by more than 25%, or if the proportion of late trips changes by 0.1 and schedule adherence is serving as a change indicator, initiate follow-up for all items related to the items displaying the change.

10.4 Determine the Need for Follow-Up

Averages have changed from the baseline phase as follows:

	peak load	boardings	pass-mi	running time
baseline	17.1	23.6	118.5	36.1
monitoring	17.4	24.0	119.9	36.5
% change	2%	2%	1%	1%

In addition, percent trips on time changed from 85% to 80%, and percent pass use from 9.3% to 8.3%. These small changes from the baseline values do not warrant follow-up for this R/D/TP.

BASELINE PHASE WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

AVERAGES

Before	B1	item (X)	Peak Load	Boardings	Pass.-miles	Running Time (minutes)	
	B2	d	0.2	0.3	0.3	0.1	
	B3	v_X	0.410	0.369	0.420	0.073	
	B4	n	14	6	6	4	
After	B5	n	20	20	20	20	
	B6	$\bar{X}$	17.1	23.6	118.5	36.1	
	B7	v_X	0.413	0.332	0.396	0.118	
	B8	d	0.16	0.13	0.15	0.045	

SEGMENT LEVEL BOARDINGS AND ALIGHTINGS

Before	B9	item		Boardings			
	B10	segment		adjacent town			
	B11	d_S		0.3			
	B12	$\bar{X}$		20.5			
	B13	v_X		0.369			
	B14	f		0.3			
	B15	n		11			
After	B16	n		20			
	B17	$\bar{S}$		6.6			
	B18	v_S		0.50			
	B19	d_S		0.19			

CATEGORY PROPORTIONS

Before	B20	item & category	% Riders Using pass	% Riders owning car	% Trips on time		
	B21	d_e	0.1	–	0.1		
	B22	p	–	0.3			
	B23	d_a	–	0.07	–		
	B24	n	71	127	71		
After	B25	n	165	165	20		
	B26	p	0.093	0.412	0.85		
	B27	d_a	0.038	0.064	0.13		

CONVERSION FACTORS WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

		conversion:	(a)	(b)	(c)	(d)	(e)	(f)
	C1	auxiliary item (X)	PP2	PP2	PP2	Revenue	Revenue	Revenue
	C2	inferred item (Y)	PP1 (peak load)	boardings	pass.-mi.	PP1 (peak load)	Boardings	Pass.-mi.
	C3	d_m	0.2	0.3	0.3	0.2	0.3	0.3
Before Baseline	C4	v_X	0.410	0.410	—	0.408	0.408	—
	C5	v_Y	0.410	0.369	—	0.410	0.369	—
	C6	r_{XY}	0.96	0.93	—	0.95	0.98	—
	C7	B	7	7	7	7	7	7
	C8	L	1.089	0.823	—	1.355	0.272	—
	C9	n_1	10	10	15	10	10	15
Check Sample Size	C10	n_1 actual	20	20	20	20	20	20
	C11	$\bar{X}$	13.2	13.2	13.2	11.88	11.88	11.88
	C12	$\bar{Y}$	17.1	23.6	118.5	17.1	23.6	118.5
	C13	v_X	0.408	0.408	0.408	0.498	0.498	0.498
	C14	v_Y	0.413	0.332	0.396	0.413	0.332	0.396
	C15	r_{XY}	0.98	0.95	0.91	0.93	0.97	0.89
	C16	L	0.55	0.21	1.05	2.92	1.35	1.93
	C17	n_1	10	10	10	17	10	11
	C18	add'l SS	0	0	0	0	0	0
After	C19	$R=\bar{Y}/\bar{X}$	1.30	1.79	8.98	1.44	1.99	9.98
	C20	v_R^2	.00037	.00106	.00160	.00197	.00205	.00294
	C21	n_2	14	7	7	24	10	10

MONITORING PHASE WORKSHEET

Route: 1 Direction: inbound Time Period: 6-9 a.m.

AVERAGES

M1	item (Y)	Peak load (PP1)	Peak load (PP1)	Boardings	Boardings	Running time
M2	reporting period	quarter	quarter	quarter	quarter	quarter

with direct measurement

Before	M3	d	0.2	0.2	0.3	0.3	0.1
	M4	v_Y					0.118
	M5	n					5
	M6	n'					5
After	M7	n					6
	M8	$\bar{Y}$					36.5
	M9	d					0.087

with indirect measurement

Before	M10	auxiliary item (X)	Load at PP2	Revenue	Load at PP2	Revenue	
	M11	v_X	0.408	0.498	0.408	0.498	
	M12	R	1.30	1.44	1.79	1.99	
	M13	v_R^2	.00037	.00197	.00106	.00205	
	M14	n_2	14	24	7	10	
	M15	n_2'	14	24	7	10	
After	M16	n		15		15	
	M17	$\bar{X}$		12.06		12.06	
	M18	$\bar{Y}=R\bar{X}$		17.4		24.0	
	M19	d		0.25		0.25	

CATEGORY PROPORTIONS

Before	M20	item & category	% Trips on time		% Riders using pass		
	M21	reporting period	quarter		year		
	M22	d_e	0.1		0.1		
	M23	p	–		–		
	M24	d_a	–		–		
	M25	n	71		71		
	M26	n'	71		18		
After	M27	n	15		120		
	M28	p	0.80		0.083		
	M29	d_a	0.19		0.045		

MONITORING PHASE WORKSHEET (cont'd)

Route: 1 Direction: inbound Time Period: 6-9a.m.

AVERAGES

M1	item (Y)	Pass.-mi.	Pass.-mi.			
M2	reporting period	year	year			

with direct measurement

Before	M3	d	0.3	0.3			
	M4	v_Y					
	M5	n					
	M6	n'					
After	M7	n					
	M8	$\bar{Y}$					
	M9	d					

with indirect measurement

Before	M10	auxiliary item (X)	Load at PP2	Revenue			
	M11	v_X	0.408	0.498			
	M12	R	8.98	9.98			
	M13	v_R^2	.00160	.00294			
	M14	n_2	7	10			
	M15	n_2'	2	3			
After	M16	n		57			
	M17	$\bar{X}$		12.01			
	M18	$\bar{Y}=R\bar{X}$		119.9			
	M19	d		0.15			

CATEGORY PROPORTIONS

Before	M20	item & category					
	M21	reporting period					
	M22	d_e					
	M23	p					
	M24	d_a					
	M25	n					
	M26	n'					
After	M27	n					
	M28	p					
	M29	d_a					

Chapter 9

PROCEDURE FOR SCHEDULING DATA COLLECTION ACTIVITIES

This chapter is a procedure for scheduling data collection activities to meet the sample size requirements of a monitoring program. It deals only with data that can be collected without a survey. Principles upon which the procedure is based are explained in Chapter 7. The data collection techniques are grouped into four "deployment options," driver checks, automated checks, ride checks, and point checks, all of which are described in Chapter 3. Through each of these options, various types of counts and readings can be made by which specific data items are measured, as described in Chapter 3.

Step numbers for the scheduling procedure have the letter S as their first character to distinguish steps of the scheduling procedure from steps of the overall data collection program design procedure (Chapter 8).

An example follows along with the procedure on the facing pages.

Setting for Example

This example is limited to scheduling data collection activites on two routes for the a.m. peak only for the baseline phase. Available information on Route 1 inbound is taken from the example of Chapter 8. Other information is introduced as needed.

Filled in worksheets used in this example are found at the end of this chapter.

S1. LIST SAMPLE SIZE FOR EACH DATA ITEM

Sample size determination is a part of the overall procedure of Chapter 8, where it is executed as a part of Steps 3 and 4. Results of these steps are displayed on the Baseline Phase Worksheet, rows B4, B15, and B26, and on the Conversion Factors Worksheet, row C9.

From these results, compile a list of the sample size requirements of each data item for each route/direction/time period. For data items that must be observed in pairs for the purpose of computing conversion factors, list the size of the paired sample required. In the remainder of the procedure, consider such pairs of data items as a unit (i.e., as a single data item).

S1. DETERMINE SAMPLE SIZE FOR EACH DATA ITEM

Sample sizes for Route 1 inbound were determined in the example of Chapter 8. They are shown on the Baseline Phase Worksheet, rows B4, B15, and B26, and on the Conversion Factors Worksheet, row C9. Similar analysis on Route 1 outbound and on Route 2 yield the following sample sizes.

TRIP SAMPLE SIZES, A.M. PEAK

Data Items or Pair	Route 1/inbound	Route 1/outbound	Route 2/inbound	Route 2/outbound
peak load	14	8	24	22
boardings (route-level)	6	5	8	7
boardings (segment-level)	11	9		
running time	4	4	4	4
passenger-miles	7	6	9	8
% trips on time	71	71	71	71
PP2*, peak load	10	10	-	10
PP2, boardings	10	10	10	10
PP2, passenger-miles	15	15	15	15
Revenue, peak load	10	10	10	10
Revenue, boardings	10	10	10	10
Revenue, passenger-miles	15	15	15	15

* "PP2" means load taken at the inbound peak point of Route 2.

S2. SCHEDULE AUTOMATED CHECKS

If APC's are available, they should be used for every data item that can be monitored with an APC.

To schedule automated checks, follow the same procedure as found in Step S4 (scheduling ride checks), with the following exception: substitute "(vehicle) block" for "(driver) run."

S2. SCHEDULE AUTOMATED CHECKS

Since APC's are not available in our system, we skip this step.

S3. SCHEDULE DRIVER CHECKS

S3.1 Determine Number of Days of Driver Checks Needed

a. Identify the items on the list compiled in Step 1 that can be measured by drivers, and were not scheduled for automated checks (Step S2). (If there are no such items, skip to Step S4.)

b. Find the required sample size for each item identified in step (a). Convert each sample size into a "day requirement" by dividing the required sample size by the number of trips per day for the corresponding day type, route, direction, and time period. Round the result up to the next whole number.

c. For each day type (weekday, Saturday, Sunday), find the greatest day requirement. Add two to four days to each of these three figures to allow for errors. The results are the number of days on which all trips (of all routes and time periods) will be checked by day type.

S3. SCHEDULE DRIVER CHECKS

The only information that drivers can collect is revenue, by recording the farebox reading at the end of each trip. However, revenue alone is not needed in the baseline phase; rather, revenue is needed as one element of a number of pairs of data items (e.g., revenue and boardings). Since none of these pairs can be monitored with driver checks, no driver counts are scheduled for the baseline phase.

For the sake of illustration, however, suppose revenue alone was needed on 20 trips in each R/D/TP, and so driver counts could be used.

S3.1 Determine Number of Days of Driver Checks Needed

a. The only item that drivers can measure is revenue, in every R/D/TP.

b. As mentioned above, it is assumed that the sample size requirement for every R/D/TP is 20. (Normally, this figure would be taken from the table in step S1). There are 17 trips in each direction during the weekday a.m. peak on Route 1 and 23 trips on Route 2. The "day requirement" (required number of trips divided by the number of daily trips, rounded up to the next whole number) is thus 2 for Route 1 and 1 for Route 2. The table on the next page lists the day requirement for the other R/D/TP's.

c. The greatest day required for a weekday is 10; for a Saturday, it is 3, and for a Sunday, 4. Adding a few extra days for a margin of error, the desired number of days of driver checks is 13 weekdays, 5 Saturdays, and 6 Sundays.

S3.2 Select Dates

Select dates that yield a representative cross-section of the season/year under study. Plan to check every trip on every route on each of those dates.

-EXAMPLE-

SAMPLE DAY REQUIREMENTS

Route	Weekday A.M.		Weekday Off-Peak		Weekday P.M.		Weekday Evening		Saturday		Sunday	
	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT
1	2	2	3	3	2	1	4	5	1	2	-	-
2	1	1	2	2	2	2	7	6	2	2	3	4
3	1	1	2	3	1	1	3	3	3	2	-	-
.												
.												
.												
18	1	2	2	1	2	1	4	4	1	1	3	3
19	3	4	4	6	4	4	8	10	2	2	-	-
20	1	1	2	2	2	1	4	5	1	1	-	-

S3.2 Select Dates

It is desired that the baseline phase be carried out between August and November. Because ridership in 3 summer months is significantly different from ridership the remaining 9 months (which do not show significant systematic differences between them), it was decided to gather one quarter of the data in the summer and the remainder in the fall. The weekdays are scheduled in groups of 2 or 3 days to reduce training requirements. The dates chosen for weekdays are (days and weeks are given rather than dates):

Mid Aug. - Sat, Sun, Mon, Tue, Wed
Late Sept. - Sat, Sun, Mon, Tue, Wed
Mid Oct. - Thurs, Fri, Sat, Sun
Early Nov. - Sat, Sun, Mon, Tues, Wed, Sun
Late Nov. - Thurs, Fri, Sat, Sun

S4. SCHEDULE RIDE CHECKS

Schedule ride checks to meet only the requirements of those data items that can be collected in no other way. These data items are called RCO (ride check only) items.

S4.1 List Given Information

A separate worksheet W-1 is needed for each route/day type (where "day type" means either weekday, Saturday, or Sunday). Circle the appropriate day type in the upper right corner of the worksheet. For each separate worksheet, execute the following substeps.

S4. SCHEDULE RIDE CHECKS

Ride checks are needed to meet the requirements of the following RCO (ride check only) data items and pairs listed in Step S1:

TRIP SAMPLE SIZES, A.M. PEAK: RCO* ITEMS

Data Items or Pair	Route 1/inbound	Route 1/outbound	Route 2/inbound	Route 2/outbound
boardings (route-level)	6	5	8	7
boardings (segment-level)	11	9		
passenger-miles	7	6	9	8
PP2**, boardings	10	10	10	10
PP2, passenger-miles	15	15	15	15
Revenue, boardings	10	10	10	10
Revenue, passenger-miles	15	15	15	15

* RCO means "ride check only".

** "PP2" means load taken at the inbound peak point of Route 2.

S4.1 List Given Information

In this example, ride checks will be scheduled for Route 1 on weekdays only. Thus, only one worksheet W-1 is used. At the top of the worksheet, the route number is entered and "weekday" is circled.

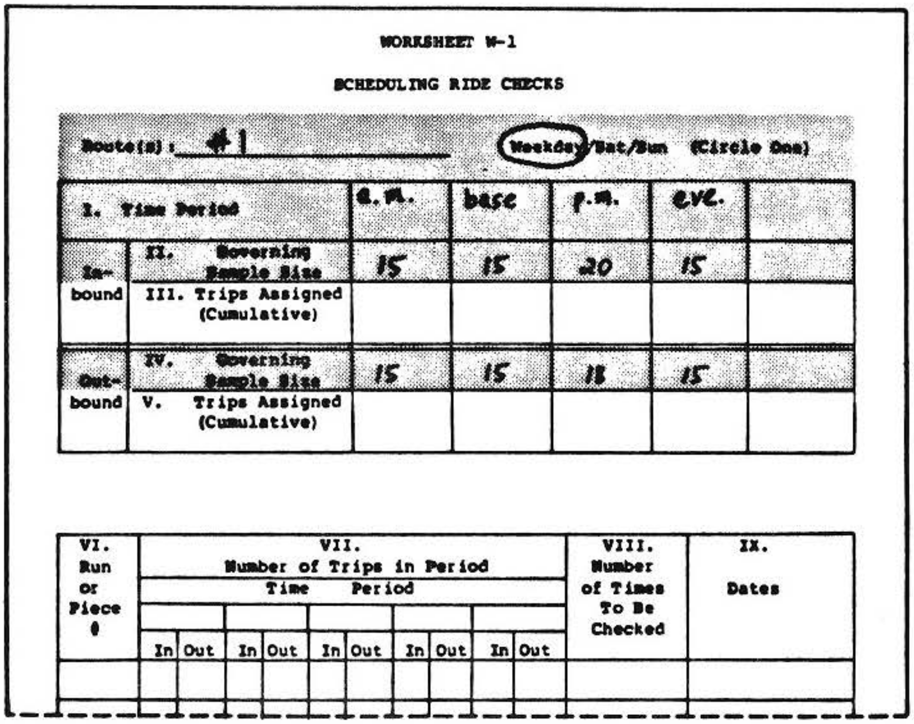
a. Enter Governing Sample Sizes

In Section I of the worksheet, list the time periods belonging to the day type being analyzed. Then, in rows II and IV, enter the governing sample size for each period for the two directions. The governing sample size is the largest sample size among all the RCO items needed for that route/direction/ time period (sample sizes were listed in Step S1).

-EXAMPLE-

a. Enter Governing Sample Sizes

The four weekday time periods are entered in row I. Governing sample sizes for the two directions are taken from the RCO list shown earlier. For example, in the inbound direction in the a.m. peak period., the sample sizes are found in the first column in the RCO list. The greatest or governing sample size is 15; this figure is entered on worksheet W-1, row II, first column. Likewise, the governing sample size for the outbound direction of Route 1, a.m. peak, is found, by scanning the second column of the RCO list, to be 15; this figure is entered in row IV, first column of worksheet W-1. The other figures entered in rows II and IV of worksheet W-1 are derived from RCO lists for the corresponding time periods.



WORKSHEET W-1

SCHEDULING RIDE CHECKS

Route(s): #1 [✓ Weekday]/Sat/Sun (Circle One)

I. Time Period		a.m.	base	p.m.	eve.	
In-bound	II. Governing Sample Size	15	15	20	15	
	III. Trips Assigned (Cumulative)					
Out-bound	IV. Governing Sample Size	15	15	18	15	
	V. Trips Assigned (Cumulative)					

VI. Run or Piece #	VII. Number of Trips in Period										VIII. Number of Times To Be Checked	IX. Dates
	Time Period											
	In	Out	In	Out	In	Out	In	Out	In	Out		

b. Enter Schedule Information

Enter the time period designations in the column headings of Section VII (there is room for up to five time periods).

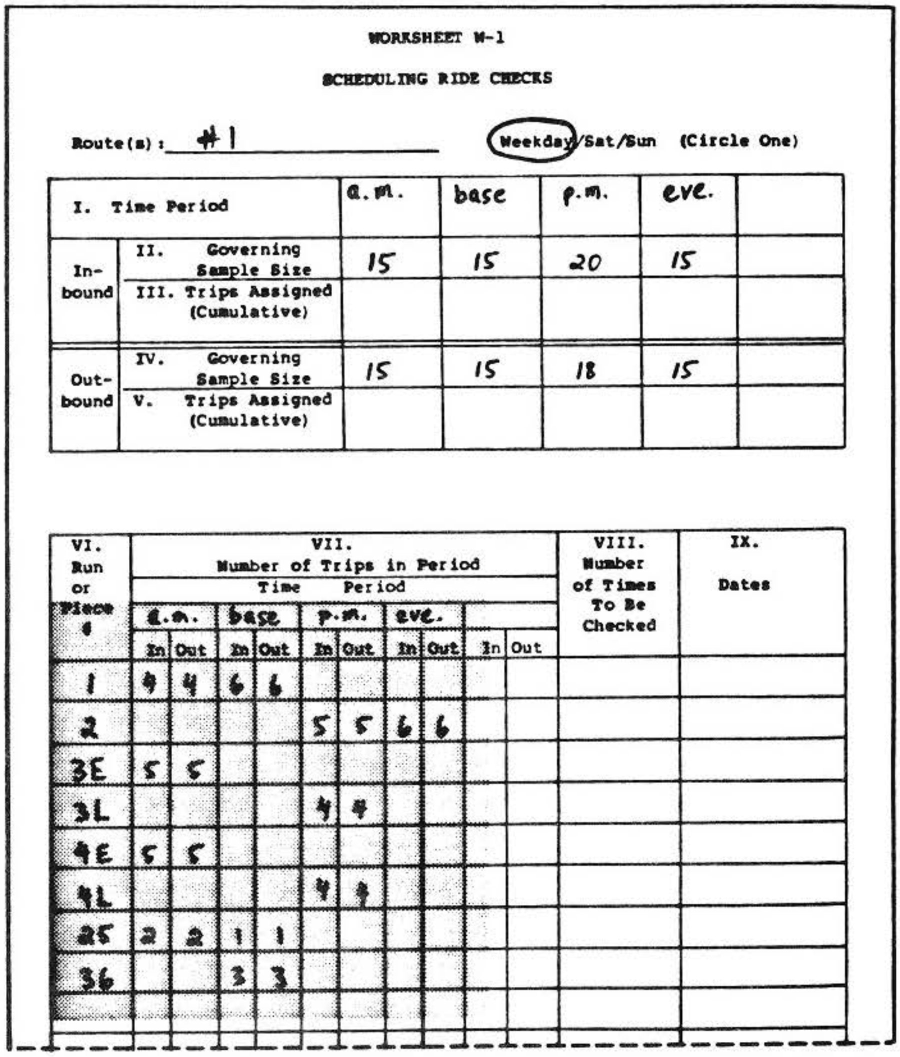
In Column VI, list all the runs or run pieces that include a trip on this route on this day type. In Section VII, enter, for each run or run piece, the number of trips on this route in each direction (inbound, outbound) during each time period.

Runs that include trips on more than one route will appear on more than one W-1 worksheet.

b. Enter Schedule Information

Time period headings are entered in Section VII of worksheet W-1.

The system has 6 runs (runs 1, 2, 3, 4, 25, and 36) that operate on Route 1 on weekdays. Runs 25 and 36 are shared runs; i.e., they operate on other routes as well as Route 1. Since runs 3 and 4 include a long midday break, they are each considered as two runs: 3E (early) and 3L (late), and 4E and 4L. The eight run numbers are thus entered in Section VI of the worksheet. From schedule information, the number of inbound and outbound trips for each run by time period are entered in Section VII.



WORKSHEET W-1

SCHEDULING RIDE CHECKS

Route(s): #1 [✓ Weekday]/Sat/Sun (Circle One)

I. Time Period		a.m.	base	p.m.	eve.	
In-bound	II. Governing Sample Size	15	15	20	15	
	III. Trips Assigned (Cumulative)					
Out-bound	IV. Governing Sample Size	15	15	18	15	
	V. Trips Assigned (Cumulative)					

VI. Run or Piece #	VII. Number of Trips in Period										VIII. Number of Times To Be Checked	IX. Dates
	Time Period											
	a.m.		base		p.m.		eve.					
	In	Out	In	Out	In	Out	In	Out	In	Out		
1	4	4	6	6								
2					5	5	6	6				
3E	5	5										
3L					4	4						
4E	5	5										
4L					4	4						
25	2	2	1	1								
36			3	3								

S4.2 Run Selection

For this step, route/day type combinations that share runs in common should be processed as a group.

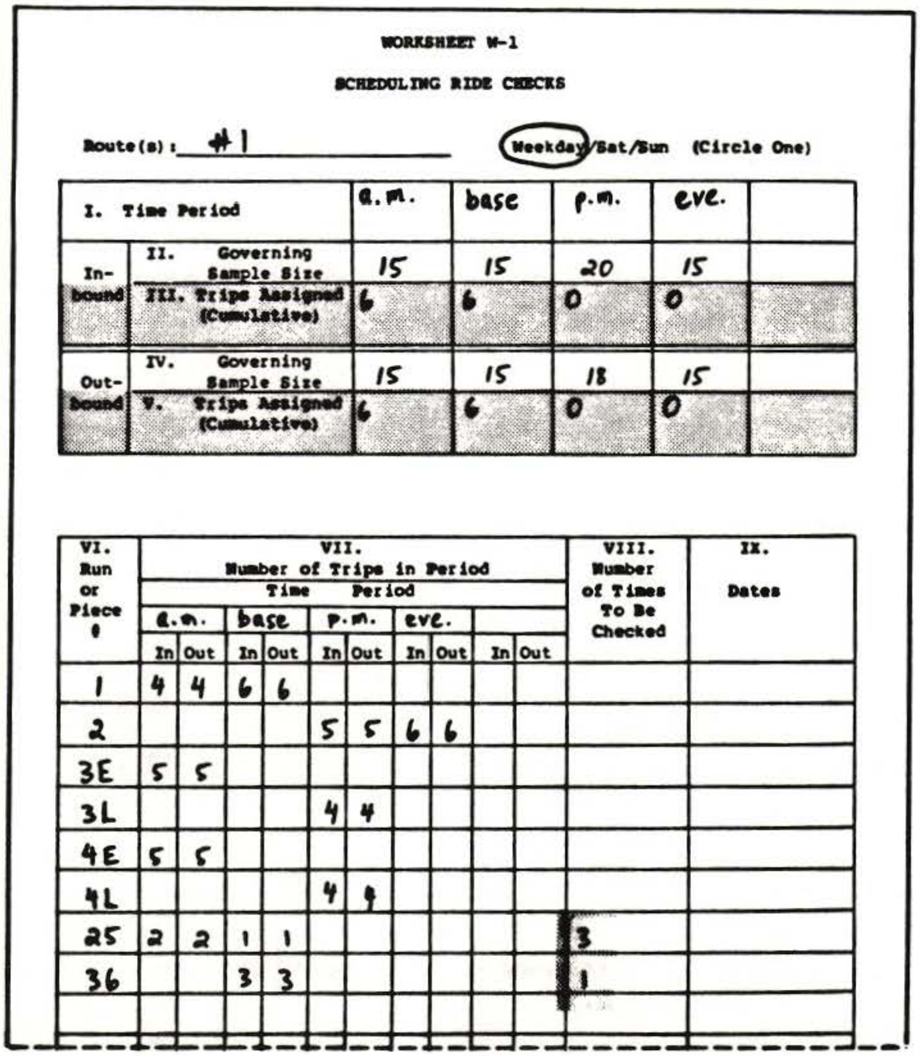
Determine (by trial and error) how many times each run is to be monitored in order to meet the governing sample size requirement of each route/direction/time period. For maximum representativeness, every run should be checked once before any run is checked twice, and every run should be checked twoce before any run is checked three times, and so forth. Deviations from this procedure can be made when a run is particularly costly or difficult to collect (see guidelines in Section 7.2.1 of this manual).

In column VIII of Worksheet W-1, enter the number of times each run is to be checked. "Shared runs", i.e. runs that operate on more than one route, need special attention. They will appear on the worksheet of each route on which they operate. It is assumed that a checker assigned to a shared run will check every trip made, and thus will colect data on more than one route. Therefore, whatever number is entered for a shared run in column VIII of the worksheet for a particular route, the same number should be entered for that run in column VIII of the worksheet of the other routes on which that run operates. If a shared run on the worksheet being executed has already been treated on the worksheet of another route, there should already be an entry for that run in column VIII. Any changes made to this entry must also be made on the worksheets of the other routes that share this run.

Sections III and V of Worksheet W-1 are provided as a place to keep a running total of number of trips scheduled in each direction. As each run is picked, add to the cumulative total for each time period and

S4.2 Run Selection

In filling out Worksheet W-1 for the routes that share runs 25 and 36, it was decided to perform 3 checks on run 25 and 1 check on run 36. Therefore, before scheduling begins for Route 1, these figures for Routes 25 and 36 are entered in Column VIII. According to the schedule information listed in Section VII of the worksheet, sampling run 25 three times and run 36 once will yield 6 a.m. peak trips in each direction and 6 base period trips in each direction. These figures are entered in rows III and V of the worksheet.



WORKSHEET W-1

SCHEDULING RIDE CHECKS

Route(s): #1

[✓ Weekday]/Sat/Sun (Circle One)

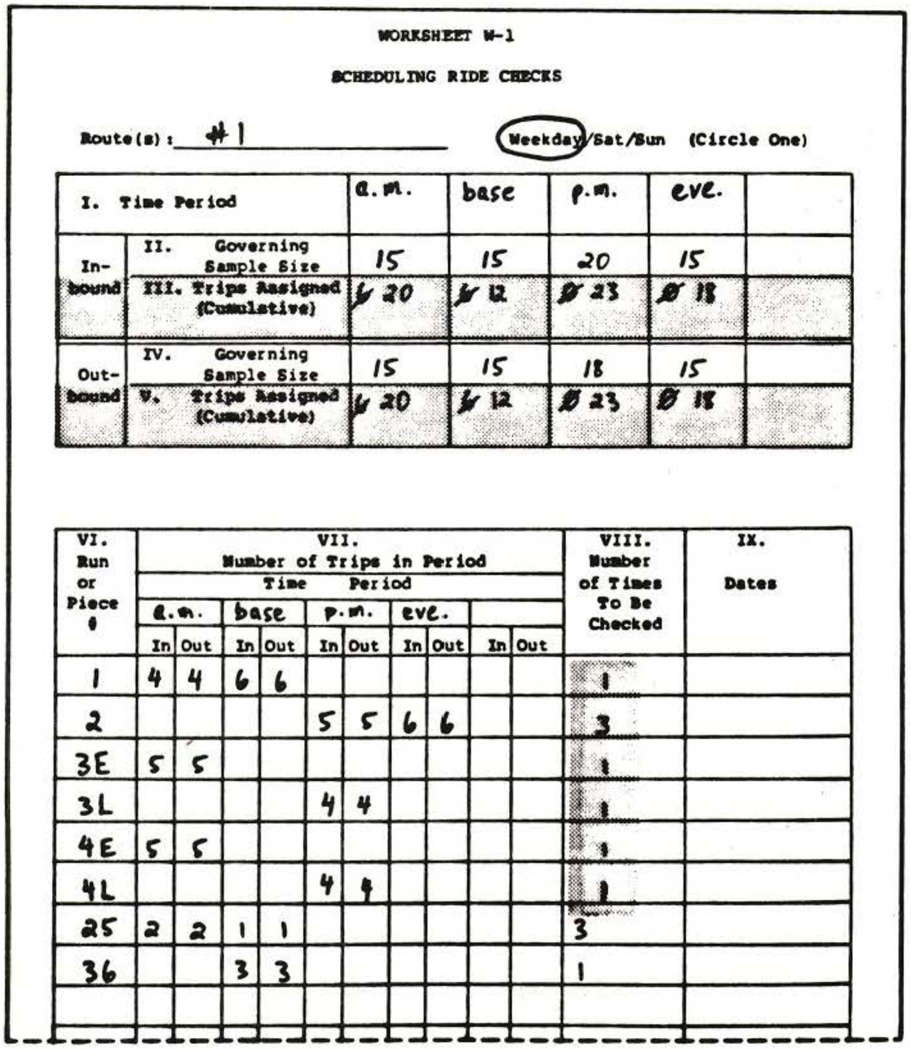
I. Time Period		a.m.	base	p.m.	eve.	
In-bound	II. Governing Sample Size	15	15	20	15	
	III. Trips Assigned (Cumulative)	6	6	0	0	
Out-bound	IV. Governing Sample Size	15	15	18	15	
	V. Trips Assigned (Cumulative)	6	6	0	0	

VI. Run or Piece #	VII. Number of Trips in Period — Time Period										VIII. Number of Times To Be Checked	IX. Dates
	a.m.		base		p.m.		eve.					
	In	Out	In	Out	In	Out	In	Out	In	Out		
1	4	4	6	6								
2					5	5	6	6				
3E	5	5										
3L					4	4						
4E	5	5										
4L					4	4						
25	2	2	1	1							3	
36			3	3							1	

direction the number of trips included in that run multiplied by the number of times the run is to be checked. The final totals in this section should be equal or exceed the governing sample sizes listed in Sections II and IV of the worksheet.

-EXAMPLE-

Run selection to meet Route 1's weekday RCO requirements proceeds as follows. To maximize representativeness, a first guess is to sample each run once. However,. because run 2 is the only run operating in the night period, it is clear than this run must be sampled 3 times (since the sampling requirement for that period is 15 trips in each direction, and run 2 has 6 trips in each direction in that period). This "first guess" is shown in the partially filled in worksheet below. Updated figures for "cumulative trips assigned" appear in rows III and V.



WORKSHEET W-1

SCHEDULING RIDE CHECKS

Route(s): #1 [✓ Weekday]/Sat/Sun (Circle One)

I. Time Period		a.m.	base	p.m.	eve.	
In-bound	II. Governing Sample Size	15	15	20	15	
	III. Trips Assigned (Cumulative)	~~6~~ 20	~~6~~ 12	~~0~~ 23	~~0~~ 18	
Out-bound	IV. Governing Sample Size	15	15	18	15	
	V. Trips Assigned (Cumulative)	~~6~~ 20	~~6~~ 12	~~0~~ 23	~~0~~ 18	

VI. Run or Piece #	VII. Number of Trips in Period										VIII. Number of Times To Be Checked	IX. Dates
	Time Period											
	a.m.		base		p.m.		eve.					
	In	Out	In	Out	In	Out	In	Out	In	Out		
1	4	4	6	6							1	
2					5	5	6	6			3	
3E	5	5									1	
3L					4	4					1	
4E	5	5									1	
4L					4	4					1	
25	2	2	1	1							3	
36			3	3							1	

(this page intentionally left blank)

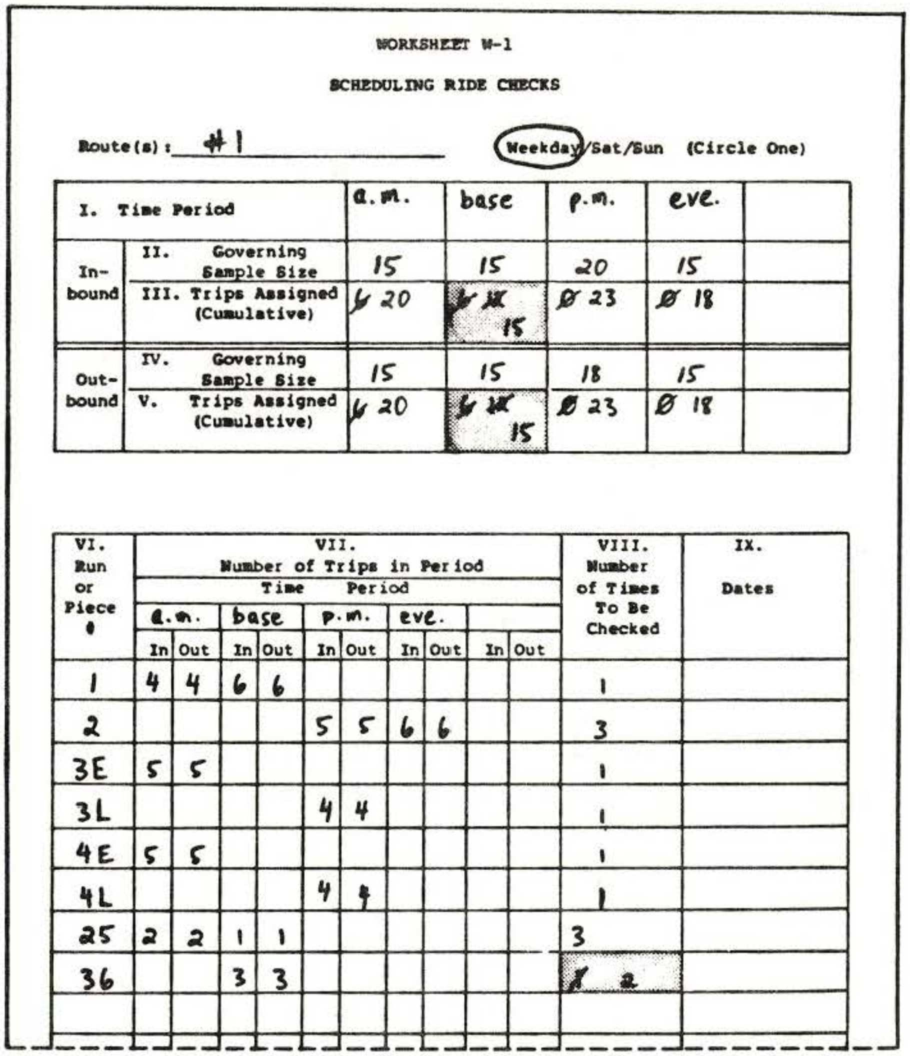
Looking at the worksheet just shown, sample size requirements are met as closely as can be expected in the p.m. peak and night periods. However, more trips are needed in the base period, and there are some excess trips in the a.m. peak period. The deficiency in the base period can be corrected by adding one to either run 1 or run 36. Run 36 is judged less costly because it is shorter, and so a run is added to run 36. (This requires a correction in column VIII and in rows III and V of both the worksheet shown in the example and the worksheet of the other route that shares run 36.) The excess in the a.m. period can be corrected by cutting out a sample of run 3E or run 4E (run 1 is left alone because it is needed for the base period's requirement, and run 25 is left alone because it is needed for another route). However, cutting out one of these runs makes the a.m. peak sample quite uneven, with some trips sampled 3 times and others not at all. The choice between lower cost (through cutting a sample) and statistical integrity is not cleancut; in this case, it is decided not to cut a sample from either run. The final entries in sections VIII, III, and V are shown on the completed worksheet that follows.

S4.3 Date Selection

If point checks are also being scheduled, then it is best to delay the date selection process until point check requirements are finalized, and then coordinate the date selection of ride checks and point checks at Step S6.c.

Otherwise, after all the routes have been processed, compile a master list of runs for each day type (weekday, Saturday, Sunday) indicating the number of times each run is to be checked. Then, conforming to the guidelines of Section 7.2.1, choose dates for the ride checks. This process is done by trial-and-error, attempting to achieve an efficient schedule that conforms with work rules and checker availability.

-EXAMPLE-



WORKSHEET W-1

SCHEDULING RIDE CHECKS

Route(s): #1

[✓ Weekday]/Sat/Sun (Circle One)

I. Time Period		a.m.	base	p.m.	eve.	
In-bound	II. Governing Sample Size	15	15	20	15	
	III. Trips Assigned (Cumulative)	~~6~~ 20	~~6~~ ~~11~~ 15	~~0~~ 23	~~0~~ 18	
Out-bound	IV. Governing Sample Size	15	15	18	15	
	V. Trips Assigned (Cumulative)	~~6~~ 20	~~6~~ ~~11~~ 15	~~0~~ 23	~~0~~ 18	

VI. Run or Piece #	VII. Number of Trips in Period										VIII. Number of Times To Be Checked	IX. Dates
	Time Period											
	a.m.		base		p.m.		eve.					
	In	Out	In	Out	In	Out	In	Out	In	Out		
1	4	4	6	6							1	
2					5	5	6	6			3	
3E	5	5									1	
3L					4	4					1	
4E	5	5									1	
4L					4	4					1	
25	2	2	1	1							3	
36			3	3							~~1~~ 2	

S4.3 Date Selection

This step is deferred until step 6.c.

S5. COMPUTE REQUIREMENTS FOR POINT CHECKS

Non-RCO data items that cannot be monitored with driver checks or automated checks are monitored with point checks, whose scheduling unit is a point, direction, and day. Some of these items are collected incidentally on the ride checks scheduled in Step S4, however, and so before scheduling point checks, it is necessary to compute net requirements for point checks. Worksheet W-2 is used in this step. A separate W-2 worksheet is used for each point at which counts are to be made, for each time period, and for each direction (unless a single checker can monitor more than one direction at a time, in which case include both directions).

S5.1 Compute Net Day Requirements

On Worksheet W-2, list in Column I the routes that need counts at this point in this time period. If more than one direction is covered by the worksheet, treat each direction as a separate route.

Enter in Column II the number of trips operated in this time period and direction on a single day for each route.

Then in Column III list, for each route, the non-RCO data items to be monitored in this time period and direction.

For each data item, enter in Column IV the sample size required (as listed in Step S1).

S5. COMPUTE REQUIREMENTS FOR POINT CHECKS

Individual non-RCO items for Route 1 are: peak load, running time, and % trips on time. "PP1" is used as an abbreviation Route 1's peak point, and (where appropriate) for load at that point; "PP2" is used similarly for Route 2. There are also two non-RCO pairs of data items: PP1 (i.e., the load at PP1) with PP2, and PP1 with revenue. Route 2 has the same set of non-RCO items, with two exceptions: the PP1-PP2 pair is not needed, and the PP1-revenue pair is replaced with the PP2-revenue pair.

These individual items and item pairs involve counts at several points. Each point, direction (unless both directions can be checked by one checker), and time period needs its own Worksheet W-2. For this example, only one worksheet, the one for point PP2, inbound direction, a.m. peak time period is completed.

S5.1 Compute Net Day Requirements

Two routes, 1 and 2, need checks at point PP2 in the a.m. peak period inbound, and so they are both entered in Column I.

In Column II, Route 1 has 16 inbound trips in the a.m. peak (from schedule information); Route 2 has 23.

In Column III, the non-RCO items mentioned above are entered.

Sample size requirements are entered in Column IV. The figures are taken from the table constructed in Step S1; for example, the requirement for peak load on Route 1 (inbound, a.m. peak) is 14.

In Column V enter the number of samples of this data item obtained by ride check. This will be either zero (if this item cannot be measured via ride check) or the number of ride checks scheduled for this route/direction/time period (from the appropriate Worksheet W-1).

Enter the net sample size requirement (Column IV minus Column V) in Column VI (enter a 0 (zero) if the difference is negative).

For Column VII, divide this net sample requirement by the number of trips in a day (Column II) and round up to the next whole number to obtain the net required number of days of point counts for this data item.

Take the maximum net day requirement in Column VII and enter it at the bottom of the worksheet. This is the governing net day requirement or the number of days point checks are required at the given checkpoint.

Number of ride check samples (Column V) is taken from worksheet W-1. The worksheet for Route 1 is shown at the end of Step S4.2; it resulted with 20 a.m. peak inbound trips on Route 1 (see row III, first column). Thus, 20 is entered in Column V of Worksheet W-2 for every Route 1 item that can be monitored with a ride check (all five items). Likewise, execution of worksheet W-2 for Route 2 (not shown in this example) resulted in 16 ride checks; thus 16 is entered in Column V for all the Route 2 items (since they, too, are all measureable using a ride check).

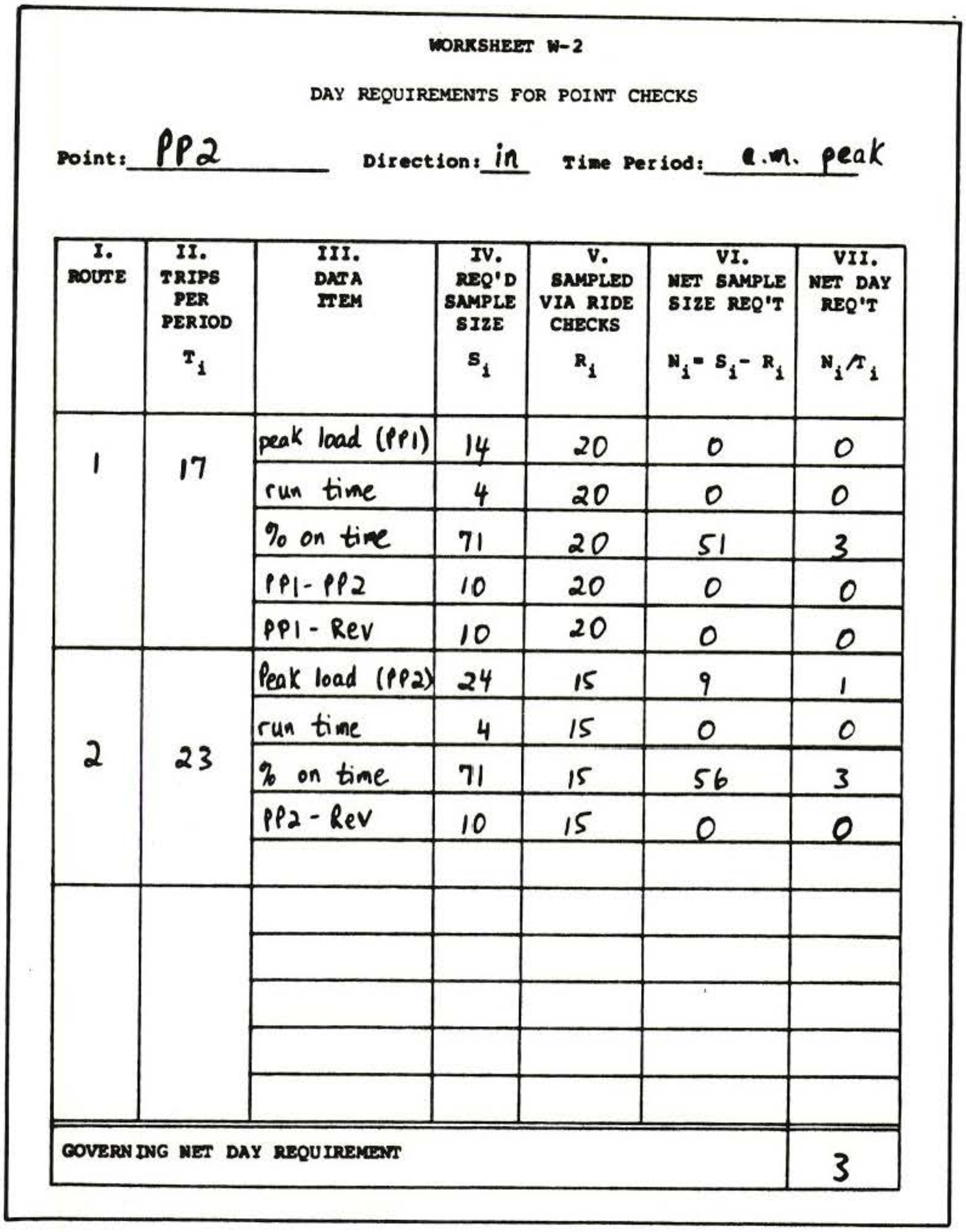
Column VI, the net sample size requirement, is Column IV minus Column V (or zero, if this difference is negative). For example, the net requirement for peak load on Route 1 is 0 because 14 samples are needed, and 20 will be obtained with ride checks. However, the net requirement for "% on time" is 51 because 68 samples are needed and 20 will be obtained from ride checks.

Column VII, the net day requirement, is column VI divided by Column II, rounded up to the next whole number. For example, the net day requirement for "% on time" for Route 1 is 51/17 = 3 (no rounding needed), and for "% on time" for Route 2 it is 53/23 = 2.3, which rounds up to 3.

The largest entry in Column VII is 3 (the number of days at point PP2 in the a.m. peak period, inbound direction). Thus, the governing sample size, 3, is entered at the bottom of Column VII.

(this page intentionally left blank)

-EXAMPLE-



WORKSHEET W-2

DAY REQUIREMENTS FOR POINT CHECKS

Point: PP2 Direction: in Time Period: a.m. peak

I. ROUTE	II. TRIPS PER PERIOD T_i	III. DATA ITEM	IV. REQ'D SAMPLE SIZE S_i	V. SAMPLED VIA RIDE CHECKS R_i	VI. NET SAMPLE SIZE REQ'T $N_i = S_i - R_i$	VII. NET DAY REQ'T N_i/T_i
1	17	peak load (PP1)	14	20	0	0
		run time	4	20	0	0
		% on time	71	20	51	3
		PP1-PP2	10	20	0	0
		PP1-Rev	10	20	0	0
2	23	Peak load (PP2)	24	15	9	1
		run time	4	15	0	0
		% on time	71	15	56	3
		PP2-Rev	10	15	0	0
GOVERNING NET DAY REQUIREMENT						3

S6. SCHEDULE POINT CHECKS

In scheduling point checks, scheduling must be done by point (not by route), by day type (weekday), Sat., Sun.), and by direction (unless a single checker can monitor more than one direction). With a separate Worksheet W-3 for each point, direction, and day type, execute the folling substeps.

a. List Route Requirements

On Worksheet W-3, list in Column I each time period for which counts are to be taken at this point in this direction on this day type. For each time period, enter the governing net day requirement (from the bottom of Column VII or Worksheet W-2) for that point.

b. List Checker Work Pieces

List in Column III the work pieces that checkers can be assigned to; e.g. a work piece might be 6 a.m. - 9 a.m. Work pieces should be either an entire period or a part of a time period. If a large time period is split into two or more work pieces, the pieces should completely cover the time period with no overlap.

c. Assign Dates

The dates on which the counts are scheduled to occur should be selected in conformity with the guidelines of Section 7.2.2 of this manual. Each work piece within a period should be done the same number of times; that number is the governing net day requirement shown in Column II. If date selection for ride checks was not done in Step S4.3, it should be done at this step in coordination with date selection for point checks

S6. SCHEDULE POINT CHECKS

A worksheet W-3 is needed for each point, day type, and direction requiring point checks. In this example, only point PP2 inbound on weekdays is considered.

a. List Route Requirements

The four weekday time periods are entered in column I. In column II is entered the governing net day requirement. For the a.m. peak period, this requirement is 3, read from the bottom of Worksheet W-2 (for point PP2, a.m. peak inbound on Route 1), shown in Step S5. The requirement for the other three periods is taken from W-2 worksheets for the other periods (not shown).

b. List Checker Work Pieces

In this transit system, work pieces cannot exceed four hours in length. Therefore, each peak period is one work piece, and the base and evening periods are divided into two pieces each. These pieces are entered in column III.

c. Assign Dates

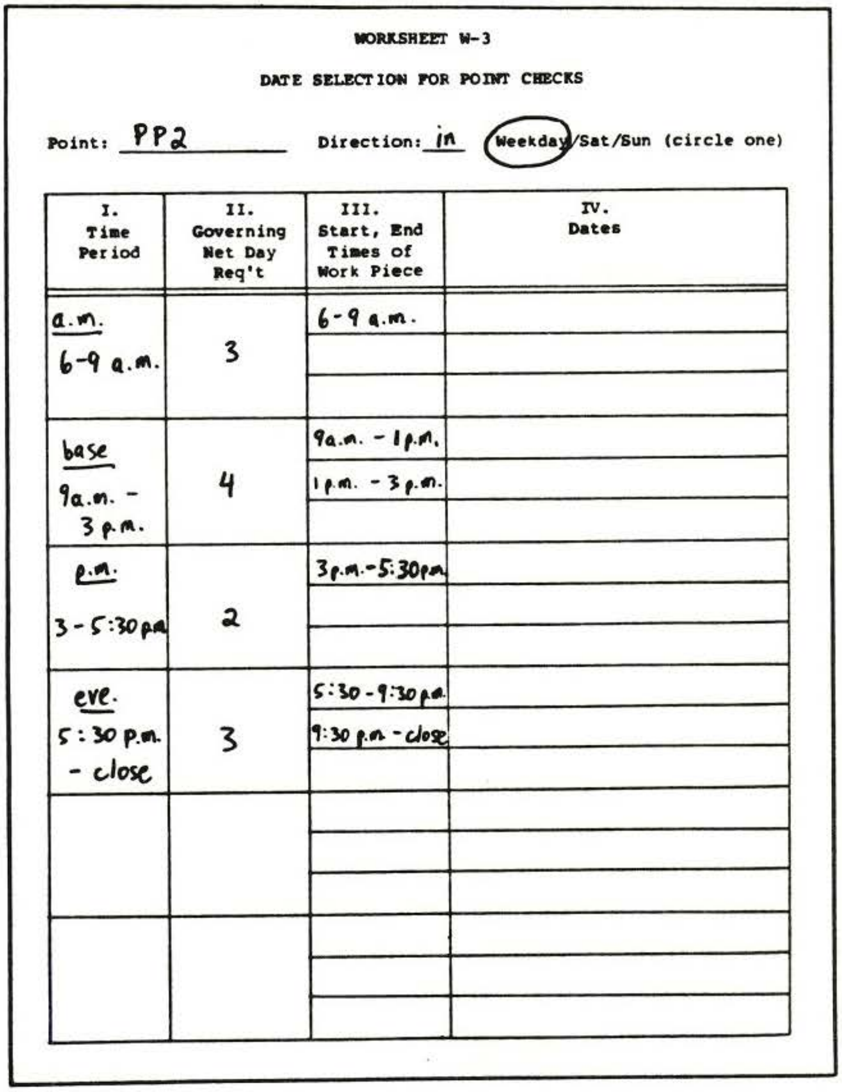
Dates for both point checks and ride checks (see S4.3) are selected in this step.

Worksheet W-3 indicates (in column II) the number of days that each of the listed work pieces must be performed. Collecting the W-3 worksheets for all the checkpoints/directions/day types in the system yields the complete set of point check requirements. Collecting the W-1 worksheets for all of the routes/day types in the system yields the complete set of ride check requirements. The final choice of dates for the ride checks needed and point checks needed depends on the sampling requirements of the entire system, the number of checkers available, and the to yield balanced staffing levels and work assignments that conform to work rules.

ability to efficiently schedule checkers to cover,where possible, a number of assignments in one day. This exercise is beyond the scope of this manual. The following guidelines apply in this case:

1. Choose the dates for each run/check point and time period to be as representative a sample as possible.

2. Avoid making point checks on the same day as ride checks where the same route is involved, lest a trip be counted twice.



WORKSHEET W-3

DATE SELECTION FOR POINT CHECKS

Point: PP2 Direction: in [✓ Weekday]/Sat/Sun (circle one)

I. Time Period	II. Governing Net Day Req't	III. Start, End Times of Work Piece	IV. Dates
a.m. 6-9 a.m.	3	6-9 a.m.	
base 9a.m. - 3 p.m.	4	9a.m. - 1p.m.	
		1p.m. - 3p.m.	
p.m. 3-5:30pm	2	3p.m.-5:30pm	
eve. 5:30 p.m. - close	3	5:30-9:30pm	
		9:30 p.m - close	

APPENDIX A

SAMPLE SIZE AND TOLERANCE TABLES

Table 5.1

Recommended Tolerances

	for time periods lasting 3+ hours (2)
Boardings (by R/D/TP) (1)	
For all routes and time periods	±30% (3)
Peak Load, Peak Direction (by R/TP)*	
Routes operating with 1-3 buses	±30%
Routes operating with 4-7 buses	±20%
Routes operating with 8-15 buses	±10%
Routes operating with 15+ buses	±5%
Peak Load, Reverse Direction (by R/TP)	
For all routes and time periods	±30%
Passenger-miles (by R/D/TP)	
For all routes and time periods	±30%
Run time (by R/D/TP)	
Routes with run time ≤ 20 min	±10%
Routes with run time > 20 min	±5%
Fraction of trips early/on time/late (by R/D/TP)	
For all routes and time periods	±0.1 AET (4)
Segment level boardings, alightings (by R/D/TP) (route segment or market segment)	±30% or more (5)

Note: 90% confidence level assumed.

(1) R/D/TP denotes a combination of Route, Direction and Time Period; R/TP denotes a combination of Route and Time Period.

(2) For shorter time periods or individual trips, multiply by adjustment factors given in Table 5.2.

(3) Provided tolerance for systemwide boardings, given by equation (5.2), (5.2a), or (5.3) (as appropriate) will be below the 10% required by Section 15. If not, decrease tolerance to 20% on highest ridership routes/time periods.

(4) Absolute equivalent tolerance, as defined in text.

(5) In general, segment-level tolerance should exceed route-level tolerance. Also, small segments should have greater tolerances than large segments.

Table 5.2

Tolerance Adjustment Factors for Short Time Periods

Duration of Time Period	Adjustment Factor
2.5 hrs = 150 min	1.05
2.0 hrs = 120 min	1.1
1.5 hrs = 90 min	1.2
1.0 hrs = 60 min	1.35
0.5 hrs = 30 min	1.75
0.33 hrs = 20 min	2.1
0.25 hrs = 15 min	2.4
less than 15 min	2.8

TABLE 5.3

SYSTEMWIDE TOLERANCES ACHIEVED USING ROUTE-LEVEL DATA *

a. One time period per day (two directions per route assumed)

NUMBER OF ROUTES	ROUTE/** DIRECTION/ TIME PERIODS	ROUTE-LEVEL TOLERANCE		
		+/- 10%	+/- 20%	+/- 30%
2	4	0.058 to 0.096	0.116 to 0.191	0.174 to 0.287
5	10	0.037 to 0.060	0.073 to 0.121	0.110 to 0.181
10	20	0.026 to 0.043	0.052 to 0.085	0.078 to 0.128
25	50	0.016 to 0.027	0.033 to 0.054	0.049 to 0.081
50	100	0.012 to 0.019	0.023 to 0.038	0.035 to 0.057
75	150	0.009 to 0.016	0.019 to 0.031	0.028 to 0.047
100	200	0.008 to 0.014	0.016 to 0.027	0.025 to 0.041
125	250	0.007 to 0.012	0.015 to 0.024	0.022 to 0.036

b. Multiple time periods (two directions per route assumed)

NUMBER OF ROUTES	ROUTE/** DIRECTION/ TIME PERIODS	ROUTE-LEVEL TOLERANCE		
		+/- 10%	+/- 20%	+/- 30%
2	12	0.037 to 0.060	0.074 to 0.121	0.112 to 0.181
5	30	0.024 to 0.038	0.047 to 0.076	0.071 to 0.114
10	60	0.017 to 0.027	0.033 to 0.054	0.050 to 0.081
25	150	0.011 to 0.017	0.021 to 0.034	0.032 to 0.051
50	300	0.007 to 0.012	0.015 to 0.024	0.022 to 0.036
75	450	0.006 to 0.010	0.012 to 0.020	0.018 to 0.030
100	600	0.005 to 0.009	0.011 to 0.017	0.016 to 0.026
125	750	0.005 to 0.008	0.009 to 0.015	0.014 to 0.023

---

* Route confidence level assumed to be 90% and system confidence level assumed to be 95%; route-level boardings measured by direction for a single day-long time period; between-route coefficient of variation of total boardings assumed to range from 0.3 to 1.4.

** Three (3) Time Periods and Two (2) Directions assumed for each route.

Table 5.4

DEFAULT VALUES FOR COEFFICIENT OF VARIATION OF KEY DATA ITEMS

Data Item	Time Period	Route Classification	Default Value
Load	Peak	Load < 35 pass./trip	.50
	Peak	≥ 35 pass./trip	.35
	Off-Peak	< 35 pass./trip	.60
	Off-Peak	35-55 pass./trip	.45
	Off-Peak	> 55 pass./trip	.35
	Evening	All	.75
	Owl*	All	1.00
	Sat., 7a.m.-6p.m.	All	.60
	Sat., 6p.m.-1a.m.	All	.75
	Sun., 7a.m.-1a.m.	All	.75
Boardings, Passenger-miles	Peak	Peak Load < 35 pass./trip	.42
	Peak	≥ 35 pass./trip	.35
	Off-Peak	< 35 pass./trip	.45
	Off-Peak	35-55 pass./trip	.40
	Off-Peak	> 55 pass./trip	.35
	Evening	All	.73
	Owl*	All	.80
	Sat., 7a.m.-6p.m.	All	.45
	Sat., 6p.m.-1a.m.	All	.73
	Sun., 7a.m.-1a.m.	All	.73
Running Time	All	short (≤ 20 min.)	.16
	All	long (> 20 min.)	.10

---

*Owl default values are the same for weekdays and weekends.

Table 6.1

Required Sample Size for Estimating Averages

v	d = tolerance									
	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
0.10	13	4	2	1	1	1	1	1	1	1
0.20	52	13	6	4	3	2	2	1	1	1
0.30	117	30	13	8	5	4	3	2	2	2
0.40	208	52	24	13	9	6	5	4	3	3
0.50	324	82	36	21	13	10	7	6	5	4
0.60	467	117	52	30	19	13	10	8	6	5
0.70	636	159	71	40	26	18	13	10	8	7
0.80	830	208	93	52	34	24	17	13	11	9
0.90	1050	263	117	66	42	30	22	17	13	11
1.00	1296	325	144	82	52	37	27	21	17	13
1.25	2025	507	225	127	82	57	42	32	25	21
1.50	2917	730	324	183	117	82	60	46	37	30

Notes: assuming 90% confidence level
v = coefficient of variation

Table 6.2

Tolerance Achieved for Estimates of Averages

a. Using a default coefficient of variation

v	n = sample size									
	1	3	6	10	20	40	60	80	100	200
0.10	0.18	0.10	0.07	0.06	0.04	0.03	0.02	0.02	0.02	0.01
0.20	0.36	0.21	0.15	0.11	0.08	0.06	0.05	0.04	0.04	0.03
0.30	0.54	0.31	0.22	0.17	0.12	0.09	0.07	0.06	0.05	0.04
0.40	0.72	0.42	0.29	0.23	0.16	0.11	0.09	0.08	0.07	0.05
0.50	0.90	0.52	0.37	0.28	0.20	0.14	0.12	0.10	0.09	0.06
0.60	1.08	0.62	0.44	0.34	0.24	0.17	0.14	0.12	0.11	0.08
0.70	1.26	0.73	0.51	0.40	0.28	0.20	0.16	0.14	0.13	0.09
0.80	1.44	0.83	0.59	0.46	0.32	0.23	0.19	0.16	0.14	0.10
0.90	1.62	0.94	0.66	0.51	0.36	0.26	0.21	0.18	0.16	0.11
1.00	1.80	1.04	0.73	0.57	0.40	0.28	0.23	0.20	0.18	0.13
1.25	2.25	1.30	0.92	0.71	0.50	0.36	0.29	0.25	0.23	0.16
1.50	2.70	1.56	1.10	0.85	0.60	0.43	0.35	0.30	0.27	0.19

b. Using a coefficient of variation estimate computed from the sample

v	n = sample size									
	6	8	10	12	20	40	60	80	100	200
0.10	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.02	0.02	0.01
0.20	0.16	0.13	0.11	0.10	0.08	0.05	0.04	0.04	0.03	0.02
0.30	0.23	0.20	0.17	0.15	0.12	0.08	0.07	0.06	0.05	0.04
0.40	0.31	0.27	0.23	0.21	0.16	0.11	0.09	0.08	0.07	0.05
0.50	0.39	0.34	0.28	0.26	0.19	0.13	0.11	0.09	0.08	0.06
0.60	0.47	0.40	0.34	0.31	0.23	0.16	0.13	0.11	0.10	0.07
0.70	0.54	0.47	0.40	0.36	0.27	0.19	0.15	0.13	0.12	0.08
0.80	0.62	0.54	0.46	0.41	0.31	0.22	0.17	0.15	0.13	0.09
0.90	0.70	0.60	0.51	0.46	0.35	0.24	0.20	0.17	0.15	0.11
1.00	0.78	0.67	0.57	0.51	0.39	0.27	0.22	0.19	0.17	0.12
1.25	0.97	0.84	0.71	0.64	0.49	0.34	0.27	0.23	0.21	0.15
1.50	1.16	1.01	0.85	0.77	0.58	0.40	0.33	0.28	0.25	0.18

Notes: assuming 90% confidence level
v = coefficient of variation

Table 6.3

Approximate t-Values

A. For Route- and Segment-Level Data (90% Confidence Level)

Number of Observations	t-Value
2	6.3
3	2.9
4	2.35
5	2.1
6	2.0
7-9	1.9
10-19	1.8
20-99	1.7
100	1.66

B. For Systemwide Data (95% Confidence Level)

Number of Observations Systemwide	t-Value
10-14	2.2
15-29	2.1
30+	2.0

(this page intentionally left blank)

Table 6.4

Additional Required Sample Size for Segment-Level Boardings and Alightings

a. Tolerance = ± 20%

f	$\bar{X}_{RT}$= average of route-level item						
	20	40	60	80	100	150	200
0.01	401	201	134	101	81	54	41
0.05	77	39	26	20	16	11	8
0.10	37	19	13	10	8	5	4
0 20	17	9	6	5	4	3	2
0.30	10	5	4	3	2	2	1
0.40	7	4	3	2	2	1	1
0.50	5	3	2	2	1	1	1
0.60	3	2	1	1	1	1	1
0.70	2	1	1	1	1	1	1
0.80	2	1	1	1	1	1	1

b. Tolerance = ± 30%

f	$\bar{X}_{RT}$= average of route-level item						
	20	40	60	80	100	150	200
0.01	179	90	60	45	36	24	18
0.05	35	18	12	9	7	5	4
0.10	17	9	6	5	4	3	2
0.20	8	4	3	2	2	1	1
0.30	5	3	2	2	1	1	1
0.40	3	2	1	1	1	1	1
0.50	2	1	1	1	1	1	1
0.60	2	1	1	1	1	1	1
0.70	1	1	1	1	1	1	1
0.80	1	1	1	1	1	1	1

Notes: assuming 90% confidence level
f = estimated fraction of route-level it
belonging to segment

Table 6.4 continued

c. Tolerance = ± 40%

f	$\bar{X}_{RT}$ = average of route-level item						
	20	40	60	80	100	150	200
0.01	101	51	34	26	21	14	11
0.05	20	10	7	5	4	3	2
0.10	10	5	4	3	2	2	1
0.20	5	3	2	2	1	1	1
0.30	3	2	1	1	1	1	1
0.40	2	1	1	1	1	1	1
0.50	2	1	1	1	1	1	1
0.60	1	1	1	1	1	1	1
0.70	1	1	1	1	1	1	1
0.80	1	1	1	1	1	1	1

d. Tolerance = ± 50%

f	$\bar{X}_{RT}$ = average of route-level item						
	20	40	60	80	100	150	200
0.01	65	33	22	17	13	9	7
0.05	13	7	5	4	3	2	2
0.10	6	3	2	2	2	1	1
0.20	3	2	1	1	1	1	1
0.30	2	1	1	1	1	1	1
0.40	1	1	1	1	1	1	1
0.50	1	1	1	1	1	1	1
0.60	1	1	1	1	1	1	1
0.70	1	1	1	1	1	1	1
0.80	1	1	1	1	1	1	1

Notes: assuming 90% confidence level
f = estimated fraction of route-level it
belonging to segment

Table 6.5

Required Sample Size for Estimating Category Proportions

a. Using Absolute Equivalent Tolerance

d_e	n
.025	1102
.05	276
.075	122
.1	71
.125	45
.15	32
.2	19

b. Using Absolute Tolerance with Proportion Estimate p

p	maximum "real" d_a*	d_a = absolute tolerance						
		.01	.02	.04	.06	.08	0.10	0.15
0.01 or .99	.005	273	70	19	10	6	6	3
0.03 or .97	.017	802	200	51	24	14	10	6
0.05 or .95	.027	1309	327	84	38	22	15	8
0.10 or .90	.052	2480	620	155	71	41	26	13
0.20 or .80	.092	4409	1102	276	122	71	45	21
0.30 or .70	.121	5787	1447	362	161	93	59	27
0.40 or .60	.138	6613	1653	413	184	103	68	31
0.50	.144	6889	1722	431	191	108	71	32

Note: Assuming 90% confidence level

* Larger values of a d_a may be used, but they are only approximate (nominal) absolute tolerances. When p is near 0 or 1, actual tolerance range is asymmetric.

Table 6.6

Tolerance Attained for Category Proportions

Number of Observations	*	40	70	160	640	2,560	10,000
	**	55	100	230	920	3,680	14,700
Proportion	n_{min}***						
0.5	36	±0.134	±0.100	±0.066	±0.033	±0.0164	±0.0082
0.4 or 0.6	38	±0.132	±0.098	±0.064	±0.032	±0.0161	±0.0080
0.3 or 0.7	43	±0.123	±0.092	±0.060	±0.030	±0.0150	±0.0075
0.2 or 0.8	56	±0.108	±0.080	±0.052	±0.026	±0.0131	±0.0066
0.1 or 0.9	100	±0.081	±0.060	±0.039	±0.020	±0.0098	±0.0049
0.05 or 0.95	190	±0.059	±0.044	±0.029	±0.014	±0.0072	±0.0036
0.03 or 0.97	309	±0.046	±0.034	±0.022	±0.011	±0.0056	±0.0028
0.01 or 0.99	909	---	±0.020	±0.013	±0.007	±0.0033	±0.0016

---

* With 90% confidence level

** With 95% confidence level

*** Minimum number of observations in keeping with the "rule of 9". If the number of observations is below n_{min}, the tolerance range may be asymmetrical, although the value given in the table can serve as a guide.

Table 6.7

Required Sample Size of Auxiliary Item

a. Desired Tolerance of Inferred Item = ± 5%

v_x	v_R^2				
	.0001	.0002	.0003	.0004	.0005
0.10	15	18	22	27	37
0.20	60	70	85	107	146
0.30	134	157	190	241	328
0.40	238	279	337	427	583
0.50	371	435	527	667	910
0.60	534	627	759	961	1310
0.70	726	853	1032	1308	1783
0.80	949	1114	1348	1708	2329

b. Desired Tolerance of Inferred Item = ±10%

v_x	v_R^2							
	.0001	.0005	.001	.0015	.002	.00225	.0025	.00275
0.10	4	4	5	7	10	12	17	29
0.20	14	16	20	26	37	48	67	115
0.30	31	35	43	57	82	107	151	258
0.40	54	62	77	101	146	189	268	459
0.50	84	97	120	157	228	295	418	717
0.60	121	139	172	226	328	425	602	1032
0.70	164	189	234	307	447	578	819	1404
0.80	214	247	306	401	583	755	1070	1834

Notes: assuming 90% confidence level

v_x = coefficient of variation of auxiliary item

v_R^2 = square of coefficient of variation of conversion factor

Table 6.7 (continued)

c. Desired Tolerance of Inferred Item = ±15%

v_x	v_R^2						
	.001	.002	.003	.004	.005	.006	.0065
0.10	2	3	3	4	6	11	22
0.20	7	9	11	14	21	42	85
0.30	16	19	23	31	46	93	191
0.40	27	33	41	54	82	166	340
0.50	42	51	64	85	128	258	530
0.60	61	73	91	122	184	372	763
0.70	83	99	124	166	250	506	1039
0.80	108	129	162	216	326	661	1357

d. Desired Tolerance of Inferred Item = ±20%

v_x	v_R^2							
	.001	.002	.004	.006	.008	.01	.011	.012
0.10	1	1	2	2	3	5	8	26
0.20	4	4	5	7	10	17	29	102
0.30	8	9	11	15	21	38	65	228
0.40	15	16	20	26	37	68	116	405
0.50	22	25	30	40	58	106	181	633
0.60	32	35	44	57	83	152	260	911
0.70	44	48	59	78	113	207	354	1240
0.80	57	62	77	101	147	270	463	1620

e. Desired Tolerance of Inferred Item = ±30%

v_x	v_R^2								
	.001	.005	.01	.015	.02	.025	.026	.027	.0275
0.10	1	1	1	1	2	4	6	12	26
0.20	2	2	3	4	6	15	22	46	103
0.30	4	4	6	8	12	32	49	103	232
0.40	6	8	10	13	21	57	87	183	412
0.50	10	11	15	20	33	89	136	286	643
0.60	14	16	21	29	47	128	195	411	925
0.70	19	22	28	39	64	174	265	560	1259
0.80	24	29	37	51	83	227	346	731	1645

Notes: assuming 90% confidence level

v_x = coefficient of variation of auxiliary item

v_R^2 = square of coefficient of variation of conversion factor

U.S. GOVERNMENT PRINTING OFFICE 1985 491 81[illegible]

APPENDIX B

BLANK WORKSHEETS

BASELINE PHASE WORKSHEET

Route:______ Direction:__________ Time Period:____________

AVERAGES

Before	B1	item (X)					
	B2	d					
	B3	v_X					
	B4	n					
After	B5	n					
	B6	$\bar{X}$					
	B7	v_X					
	B8	d					

SEGMENT LEVEL BOARDINGS AND ALIGHTINGS

Before	B9	item					
	B10	segment					
	B11	d_S					
	B12	$\bar{X}$					
	B13	v_X					
	B14	f					
	B15	n					
After	B16	n					
	B17	$\bar{S}$					
	B18	v_S					
	B19	d_S					

CATEGORY PROPORTIONS

Before	B20	item & category					
	B21	d_e					
	B22	p					
	B23	d_a					
	B24	n					
After	B25	n					
	B26	p					
	B27	d_a					

CONVERSION FACTORS WORKSHEET

Route:______ **Direction:**___________ **Time Period:**_____________

		conversion:	**(a)**	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**
	C1	auxiliary item (X)						
	C2	inferred item (Y)						
	C3	d_m						
Before Baseline	C4	v_X						
	C5	v_Y						
	C6	r_{XY}						
	C7	B						
	C8	L						
	C9	n_1						
Check Sample Size	C10	n_1 actual						
	C11	$\bar{X}$						
	C12	$\bar{Y}$						
	C13	v_X						
	C14	v_Y						
	C15	r_{XY}						
	C16	L						
	C17	n_1						
	C18	add'l SS						
After	C19	$R=\bar{Y}/\bar{X}$						
	C20	v_R^2						
	C21	n_2						

MONITORING PHASE WORKSHEET

Route:______ Direction:___________ Time Period:_____________

AVERAGES

M1	item (Y)					
M2	reporting period					

with direct measurement

Before	M3	d					
	M4	v_Y					
	M5	n					
	M6	n'					
After	M7	n					
	M8	$\bar{Y}$					
	M9	d					

with indirect measurement

Before	M10	auxiliary item (X)					
	M11	v_X					
	M12	R					
	M13	v_R^2					
	M14	n_2					
	M15	n'_2					
After	M16	n					
	M17	$\bar{X}$					
	M18	$\bar{Y}=R\bar{X}$					
	M19	d					

CATEGORY PROPORTIONS

Before	M20	item & category					
	M21	reporting period					
	M22	d_e					
	M23	p					
	M24	d_a					
	M25	n					
	M26	n'					
After	M27	n					
	M28	p					
	M29	d_a					

WORKSHEET W-1

SCHEDULING RIDE CHECKS

Route(s): ______________________________ Weekday/Sat/Sun (Circle One)

I. Time Period						
In-bound	II. Governing Sample Size					
	III. Trips Assigned (Cumulative)					
Out-bound	IV. Governing Sample Size					
	V. Trips Assigned (Cumulative)					

VI. Run or Piece #	VII. Number of Trips in Period										VIII. Number of Times To Be Checked	IX. Dates
	Time Period											
	In	Out	In	Out	In	Out	In	Out	In	Out		

WORKSHEET W-2

DAY REQUIREMENTS FOR POINT CHECKS

Point:________________ **Direction:**____ **Time Period:**____________

I. ROUTE	II. TRIPS PER PERIOD T_i	III. DATA ITEM	IV. REQ'D SAMPLE SIZE S_i	V. SAMPLED VIA RIDE CHECKS R_i	VI. NET SAMPLE SIZE REQ'T $N_i = S_i - R_i$	VII. NET DAY REQ'T N_i/T_i
GOVERNING NET DAY REQUIREMENT						

WORKSHEET W-3

DATE SELECTION FOR POINT CHECKS

Point: ________________ Direction:____ Weekday/Sat/Sun (circle one)

I. Time Period	II. Governing Net Day Req't	III. Start, End Times of Work Piece	IV. Dates