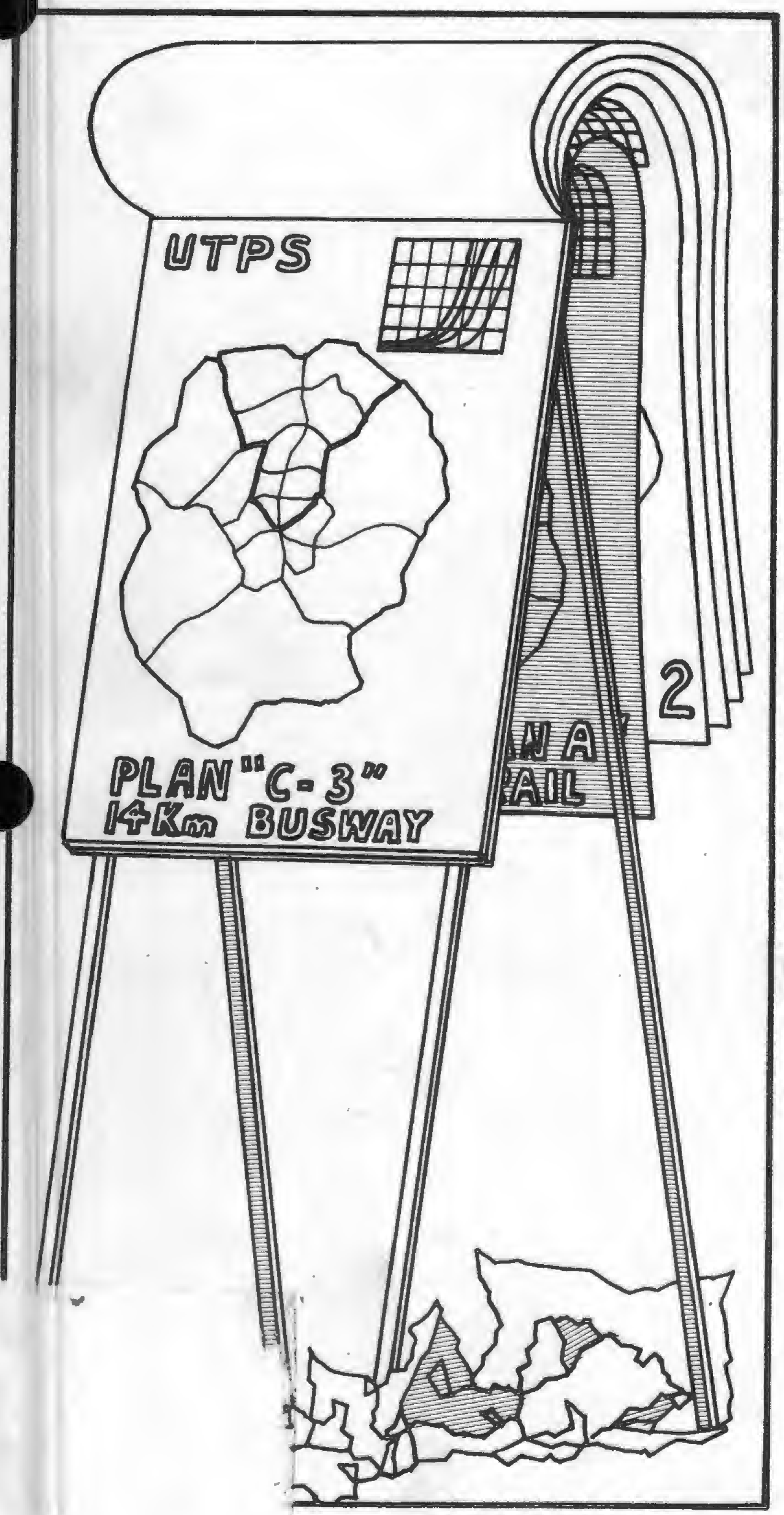
S.C.R.T.D. LIBRARY

S.C.R.T.D. LIBRARY



transit corridor analysis

S.C.R.T.D. LIBRARY

a manual sketch planning technique

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof. The contents of this report do not necessarily reflect the official views or policy of the Department of Transportation, nor do they constitute a standard, specification, or regulation.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTA-MD-06-0046-79-1	--	--

4. Title and Subtitle	5. Report Date
Transit Corridor Analysis - A Manual Sketch Planning Technique -	April 1979
	6. Performing Organization Code: --
7. Author(s) M.M.Carter, R.H.Watkins, J.D.O'Doherty, M.Iwabuchi, G.W.Schultz J.J.Hinkle	8. Performing Organization Report No.: --
9. Performing Organization Name and Address: COMSIS Corp. 11141 Georgia Ave, Wheaton, MD 20902; Alan M. Voorhees & Associates, Inc.; De Leuw, Cather & Co.; R.H.Pratt Assoc., Inc.	10. Work Unit No. (TRAIS): --
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address: Department of Transportation, Urban Mass Transportation Administration, Office of Planning Methods & Support, Washington, D.C. 20590	13. Type of Report and Period Covered: Final Report
	14. Sponsoring Agency Code: DOT-UM-UTP10

15. Supplementary Notes

16. Abstract

The development of the manual sketch planning technique was undertaken for the Urban Mass Transportation Administration (UMTA) as part of its Software Systems Development Program (SSDP). This handbook is a revised version of the May 1976 Draft Final Report. Modifications have been made to the transit impedance nomographs based on experience gained through testing of the procedures. Additionally, the cost calculations have been updated to reflect unit costs as reported in the July, 1977 release of the CUTS manual. The technique, in its final form, will become a module of the Urban Transportation Planning System (UTPS). Thus, it will be a useful addition to the set of planning tools now available.

This is a user's handbook. It describes a sketch planning technique for quick first evaluations of urban transportation planning proposals—a manual technique which does not require computers. It presents the technique's computational steps, which rely heavily on graphic aids, in an orderly manner and minute detail. The technique is useful in the analysis of short and long range plans for urban line-haul transit systems. The manual technique does not provide a single, definitive solution, but it can provide, for each system, alternative measures of demand, performance (cost and travel times), and impact to help local decision making.

The technique has three modular phases: demand estimate, cost analysis, and impact analysis. It is also modular within the phases, since the user is free at many points to substitute his own data or analytical techniques and to substitute local estimates for the default values supplied.

This book has four divisions. The introduction describes the purposes and uses of the technique. The second chapter, an overview, discusses general parameters and assumptions, and identifies those situations in which the technique can be applied. The third chapter describes the method and computation procedures and gives examples of each step of the procedures as applied to a sample problem. The appendices contain nomographs and blank work sheets which can, at the user's option, be used to make some of the calculations.

17. Key Words	18. Distribution Statement
Manual Sketch Planning, Demand Estimation, Impact Analyses, Evaluation	This document is available to the public through the National Technical Information Service, Springfield, Virginia 22151

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	216	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TRANSIT CORRIDOR ANALYSIS
— A Manual Sketch Planning Technique —

Prepared by

COMSIS Corporation

DeLeuw, Cather & Company

Alan M. Voorhees & Associates, Inc.

R.H. Pratt Associates, Inc.

April 1979

Final Report

This Document is Available to the Public
through the
National Technical Information Service
Springfield, Virginia 22151

Prepared for

Department of Transportation

Urban Mass Transportation Administration
Office of Planning Methods and Support
Washington, D.C. 20590

03243

HE
147.5
.T72
1979
c.1

ABSTRACT

The development of the manual sketch planning technique was undertaken for the Urban Mass Transportation Administration (UMTA) as part of its Software Systems Development Program (SSDP). This handbook is a revised version of the May 1976 Draft Final Report. Modifications have been made to the transit impedance nomographs based on experience gained through testing of the procedures. Additionally, the cost calculations have been updated to reflect unit costs as reported in the July, 1977 release of the CUTS manual. The technique, in its final form, will become a module of the Urban Transportation Planning System (UTPS). Thus, it will be a useful addition to the set of planning tools now available.

This is a user's handbook. It describes a sketch planning technique for quick first evaluations of urban transportation planning proposals--a manual technique which does not require computers. It presents the technique's computational steps, which rely heavily on graphic aids, in an orderly manner and minute detail. The technique is useful in the analysis of short and long range plans for urban line-haul transit systems. The manual technique does not provide a single, definitive solution, but it can provide, for each system, alternative measures of demand, performance (cost and travel times), and impact to help local decision making.

The technique has three modular phases: demand estimate, cost analysis, and impact analysis. It is also modular within the phases, since the user is free at many points to substitute his own data or analytical techniques and to substitute local estimates for the default values supplied.

This book has four divisions. The introduction describes the purposes and uses of the technique. The second chapter, an overview, discusses general parameters and assumptions, and identifies those situations in which the technique can be applied. The third chapter describes the method and computation procedures and gives examples of each step of the procedures as applied to a sample problem. The appendices contain nomographs and blank work sheets which can, at the user's option, be used to make some of the calculations.

ACKNOWLEDGMENTS

COMSIS Corporation has modified the procedures presented herein based on application experience and research performed under the NCHRP 8-12A Project - "Quick Response Urban Travel Estimation Manual Techniques and Transferable Parameters."

De Leuw, Cather & Company is responsible for the development of the procedures. The technique described is based on an earlier version developed by Planning Research Corporation and two subcontractors, R.H. Pratt Associates and Alan M. Voorhees and Associates.

Dr. Robert Dial and Messrs. Tom Hillegass, Granville Paules, and Sam Zimmerman of the Urban Mass Transportation Administration provided guidance and suggested procedures in the development of the demand estimation portion of this Manual Sketch Planning Procedure.

This report does not necessarily reflect the official views or policies of the Department of Transportation. Nothing in this report constitutes a standard, specification, or regulation.

PREFACE

In this time of ever more sophisticated urban transportation planning tools, the development of an analytical technique that calls for no more than pencil, paper, and persistence might not be universally acclaimed as an Advance in the State of the Art. The computer has happily replaced the thousand clerks with a thousand calculators and made it possible to solve problems beyond their imaginations. Less happily, computerized procedures too often tend to replace the use of the back of the envelope. After all, there are many situations in which there is no time to wait for computerized solutions.

There is, in addition, a distinct gap in the spectrum of low-cost, rapid, macro-level planning tools available for the whole size range of urban areas. If the manual sketch planning technique presented in this handbook is used and is usable in the ways we hope it to be, it will be an important contribution towards filling the need within the Urban Transportation Planning System for a non-computerized technique: It is a quick and inexpensive coarse screening tool. Its data requirements are low; but it can absorb large amounts of data. It is responsive to local planning policies. As a tutorial, it cuts through to reach basic planning issues; and it provides real guidance in the planning process, not just hard-number answers.

Certainly this technique will be used in some fairly large urban areas--presumably by large and experienced staffs operating on well prepared data bases; and it should save them time and money. But the acid test of this technique and this user's handbook is how well it can be used in the smaller urban areas: how easily and fruitfully the technique applies in situations frequently quite different from those of large urban areas.

The real contribution of the manual sketch planning technique and the important utility of the user's handbook is that the experience of transportation planners in one situation is made available to planners in another. Experience from studies of problems of many, mainly large, urban areas is distilled to help in smaller urban areas--at least in those applications in which the technical problems can be rendered analogous.

In a way, this user's handbook must be basic; but on the other hand it assumes certain competences on the part of the user. This balance is hard to strike; and technically, it has often been hard to draw the line between the necessity to explain what might be rudimentary and what a harassed planner might need to know: what he knew when he was in school, but what he can easily forget in the process of worrying about zoning and the routing of garbage trucks.

This has presented formal and material difficulties: The handbook must not waste time on the obvious. At the same time it must serve persons who do not deal daily with the terms of its discussions.

It must outline and exemplify basic computational procedures; at the same time it must assume a certain practice in computational work. Explanations must be thorough; and in them, and in such things as sample calculations, a certain redundancy and repetition--normaly undesirable--are appropriate.

Putting aside formal considerations, there is an important material case at hand. Typically, when researchers are writing to themselves and to each other, they must justify what they say. But when a publication is designed for explanation of method, theoretical justifications are only awkwardly accommodated. They blur the focus of both the reader's and writer's attention. They confuse more than they enlighten.

Our experience with this publication suggests that the traditions in the production of such publications are too rigid and confining. The organizational, typographical and documentary apparatus appropriate to reports in which planners speak to themselves and to each other as researchers can get in the way of the clear practical communication of a method.

The problems presented by the present handbook are examples of the difficulties that can arise when we pretend that we may speak of anything to anybody for any purpose, in the same voice and form--with an apparent objectivity and authority whose only real source is the common technical assumptions of professionals in our area. We have attempted to deal with these problems in this first edition of a handbook which has been in a long state of evolution through a number of revisions and has been reviewed and criticized by many experienced professionals within and without the government. Despite this, it must be stressed that the methods described within are still in an experimental stage. The Urban Mass Transportation Administration invites comment from its users about the kinds of problems to which they apply it and the positive or negative results; and UMTA will appreciate all comments or suggestions directed towards the improvement of this technique.

Please address communications to:

Dr. Robert B. Dial, Director
Office of Planning Methods and Support UPM-20
Urban Mass Transportation Administration
U. S. Department of Transportation
400 Seventh Street, S. W.
Washington, D. C. 20590

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

Project Staff

Authors:

Maurice M. Carter	COMSIS Corporation
Jere J. Hinkle	De Leuw, Cather & Company
Robert H. Watkins	De Leuw, Cather & Company
John D. O'Doherty	Alan M. Voorhees and Associates
Mike Iwabuchi	De Leuw, Cather & Company
Gordon W. Schultz	Richard H. Pratt Associates

Other Contributors:

Daniel R. Duggan	COMSIS Corporation
Juergen A. Fehr	Alan M. Voorhees and Associates
Peter S. Loubal	PRC Systems Science Corporation
Morton Schneider	Creighton-Hamburg, Inc.

Associate Consultants:

Paul W. Shuldiner, Professor of Civil Engineering
University of Massachusetts

William R. Wolfe, Associate Professor of English
Middle Tennessee State University

Project Review:

Darwin Stuart	Barton, Aschmann, Inc.
William Steinmetz	Richmond Regional Planning District Commission
Howard Simkowitz	Transportation Systems Center

CHAPTER I

INTRODUCTION

The traditional techniques of urban transportation planning are expensive and time consuming. Typically, their data requirements are so large as to severely limit the number of alternative proposals that can be considered. There is a recognized need for a technique which allows comparisons of many alternatives--rapidly, cheaply, and with a minimum of data. The manual sketch planning technique described herein is an attempt to meet that need.

A. OVERVIEW

In first evaluations of planning alternatives, the manual technique helps generate performance measures and estimates of such things as patronage, costs, levels of service, and impacts. The process starts with the assessment of transit needs and service objectives, the identification of possible corridors, and the gathering of the demographic and economic data. With this information, line-haul volumes for each segment of the line are computed as functions of fare and service levels. When the user knows cost and service characteristics, line-haul volumes, and the fare levels from which these volumes are derived, then the operating and capital costs of each system can be computed and compared with fare revenues. If revenues and costs are in reasonable balance (or if subsidies will meet anticipated deficits), equilibrium is assumed; and the analysis can move on to consider environmental and social impacts and to compare the costs and revenues, service levels, and impacts of the systems. If revenues and costs are in serious imbalance, fare and/or service levels should be revised to re-estimate demands. In cases of extreme imbalance, transit needs and service objectives should themselves be reconsidered.

Since it is a coarse screening tool, the manual technique must use simple estimation procedures. There are limitations inherent in these shortcuts; and the technique's underlying conceptions and assumptions must be clearly identified and thoroughly familiar to the user before it is applied to even the most rudimentary problem.

B. CAPABILITIES

In the analysis of public transportation, sketch planning in general is a set of methods to measure the workability of alternative proposals quickly and inexpensively. Manual sketch planning, in particular, is a coarse screening method to get quick, preliminary answers to such questions as: "Is a system suitable to a certain region or corridor?" And, if so, "What are the controlling features of alternative systems with reference to demand, economic feasibility, and various impacts?" The technique is designed primarily for line-haul transit systems oriented to the Central Business District (CBD). The technique is not so well suited to the analysis of cross-corridor systems--those that do not terminate in the CBD. Applications in these situations should be made cautiously and only after the user is thoroughly familiar with the technique in a line-haul context.

The manual technique's generalized assumptions and technical simplifications make it most useful in preliminary feasibility analyses. It is not designed to give definitive answers to questions of engineering design or final economic evaluations of transit facilities. The technique is, however, adequate for the screening of proposed systems to identify those worth the time and expense of more refined testing techniques.

Although the technique was developed to meet the needs of urban regions of about 100,000 to 3,000,000 population, its local utility is more properly measured by the concentration of travel corridors than by city size. Both short and long range plans can be evaluated. But the kind of information usually available makes the manual technique more suitable to long range planning (15-30 years).

This handbook uses, as much as possible, graphic tools and simple computational procedures. Obviously, electronic desk calculators will make things easier. (Sample calculations programmed for two of the commonly used programmable desk calculators are an appendix to this report.) However, the technique itself, and especially in its demand estimate phase, is adaptable to computer programming. Computerization is especially advantageous if there are very many units of geographical analysis.

C. OBJECTIVES

In its present state of development, manual sketch planning has several objectives:

° The screening of basic transit alternatives
  a. to eliminate clearly unworkable proposals, and
  b. to guard against the premature rejection of possibly workable systems.

° Easy application because of
  a. rapidity,
  b. availability of data, and
  c. use of coarse data bases.

° Use as a tutorial for urban travel forecasting:
  a. Real guidance in the planning process, rather than "hard number" answers.
  b. Influence by local policies and objectives.
  c. Insight into the advantages and disadvantages of transit modes in various situations.
  d. Awareness of service and cost relationships at a given demand level and under given policies.
  e. Awareness of the effectiveness of a transit mode in a given situation with respect to level of service, costs, and impact, as it compares with others.
  f. The determination of the interrelations of different elements of planning analysis (service, patronage, costs, etc.) through sensitivity testing.

° Specification of design information:
  a. Development of detailed data requirements and specification of methodological requirements for further, in-depth analysis.
  b. Provision of system information for subsequent planning in greater detail.

Manual techniques should be applied very early in the overall planning process. After the collection of limited aggregate data for the region and corridors, the technique may be applied to obtain a transit mode's demand estimates, physical and operational characteristics, comparative cost estimates, and impact measures. The manual technique is basically a front-end process that leads into more detailed evaluations of corridor and line-haul technologies. Certain elements of the manual technique, however, can also be applied at more advanced planning stages for quick cost estimates or impact evaluations--before comprehensive and time consuming calculations.

D. RELATIONSHIP WITH UTPS

The manual technique described in this handbook is part of the Urban Transportation Planning System (UTPS). UTPS provides practicing transportation planners with state-of-the-art methods for the analysis of multimodal transportation systems. In addition to a non-computerized analytical tool, UTPS contains computer programs and their attendant documentation and user's guides. The components of UTPS are flexible, user-oriented, and adhere to uniformly high standards. UMTA is committed to maintain, upgrade, and distribute UTPS on a continuing basis.

The general range of planning situations covered by UTPS is illustrated in Figure 1-1. Planning tools cluster in three groups in alternative-detail space:

SKETCH TOOLS: Sketch planning--a manual version of which is contained in this handbook--is the preliminary screening of possible configurations or concepts. It is used to compare a large number of proposed policies in enough analytical detail to support broad policy decisions. Useful in both long- and short-range regional planning and in preliminary corridor analysis, sketch planning, at minimum data costs, yields aggregate estimates of capital and operating costs, patronage, corridor traffic flows, service levels, energy consumption, and air pollution.

The planner usually remains in the sketch planning mode until he completes his comparisons of possibilities or finds a strategic plan worthy of consideration at a finer level of detail.

MESO-LEVEL TOOLS: Meso-level tools treat the kind of detail appropriate to tactical planning; they deal with many fewer alternatives than sketch tools, but in much greater detail. The input and analytical techniques are state-of-the-art. Inputs include the location of principal highway facilities and delineated transit routes. Modal subsystems might be examined separately (but with concern for their interdependency). Disaggregate demand forecasting techniques are applicable. At this level of analysis the outputs are disaggregated estimates of transit fleet size and operating requirements for specific service areas, refined cost and patronage forecasts, and level-of-service measures for specific geographical areas. Household displacements, noise, and aesthetic factors can also be evaluated.

The cost of examining an alternative at the meso level is 10-20 times its cost in sketch planning, although default models, which dispense with many data requirements, can be used for a less expensive first look. Apparently promising plans can be analyzed in detail, and problems uncovered at this stage will suggest a return to sketch planning to accommodate new constraints.

MICRO-ANALYSIS TOOLS: Micro-analysis tools are applicable as the time to implement a project grows near. They are the most detailed of all planning tools. At this level of analysis, one may wish, for example, to make a detailed evaluation of the extension, rescheduling, or re-pricing of existing bus service; to simulate bus priority lanes or signal systems; to analyze passenger and vehicle flows through a transportation terminal or activity center; or to compare possible routing and shuttling strategies for a demand-activated system. Final analysis at this level is prohibitively expensive except for subsystems whose implementation is very likely, and whose design refinements would bring substantial increases in service or significant

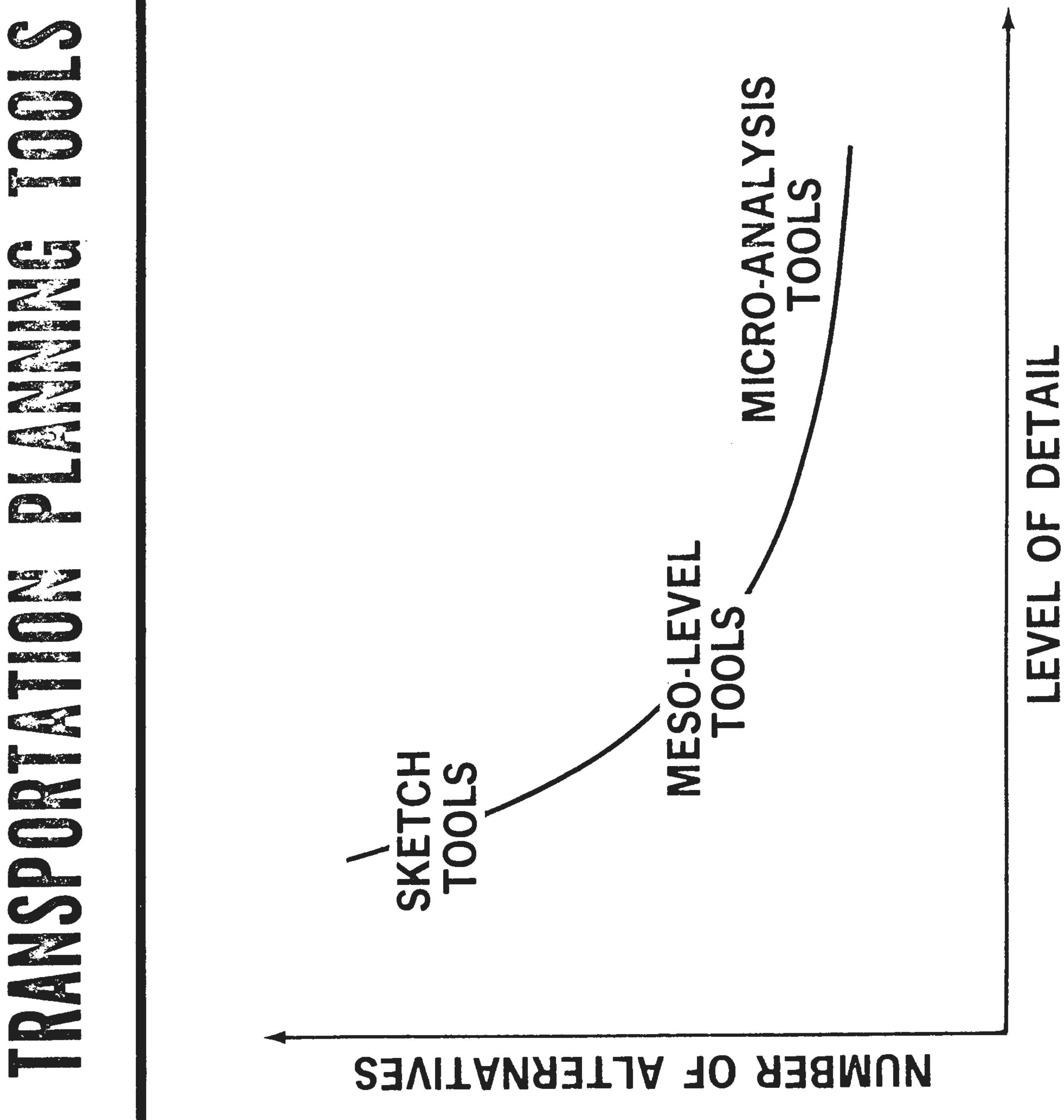


Figure 1-1. Urban Transportation Planning System (UTPS)

reductions of cost. It is most effective in near-term planning when a great many outside variables can be accurately observed or estimated. It is sometimes necessary, however, to use micro-analysis tools to supplement the output of traditional longer-range planning.

An evolving system, UTPS is continually being expanded and improved to help solve planning problems. To obtain a copy of UTPS, the requestor should furnish a 2400-foot tape (and, if a private agency, a check for $40.00 made out to the Urban Mass Transportation Administration) to the address on Page iv. The tape contains an introduction to UTPS and user's guides and documentation of all the modules.

CHAPTER II

GENERAL PARAMETERS

This chapter summarizes the major parameters of the technique in terms of levels of data aggregation, applicable transit modes, and the general flow of the analytical procedures. It also explains some of the important assumptions built into the technique and discusses the reliability of the default values provided. Finally, the chapter explores some of the ranges of application and the limitations of the manual sketch planning technique.

A. DATA REQUIREMENTS

The amount and accuracy of available data naturally affect the accuracy and reliability of any analysis. The manual technique is designed to be useful with easily available and inexpensive information. To mitigate the difficulties of limited data, it is necessary to distinguish their quality, at four levels:*

° District (the basic analysis unit recommended for the sketch planning technique)

° Super District (a group of two or more districts)

° Corridor (a group of superdistricts radiating from the CBD)

° Region (several corridors form a region)

The demand estimate module involves all four. It starts at the areawide, regional level and ultimately produces a transit trip table at the lowest, or district, level. District-to-district trip data are then aggregated and assigned to individual transit facilities to obtain patronage volumes for each transit line.

On the supply side, both the economic and impact evaluations are made of various systems at either the corridor or the line level, depending on the number of facilities envisaged for the corridor.

The procedure estimates corridor transit trips only. If inter-corridor transit trips are a large portion of total regional travel,

---

*These levels are explained in more detail in Chapter III.

the trip distribution procedure will require special attention to the geographical relationships of corridors and travel impedances between them. This is discussed in Chapter III.

Although the technique has been developed primarily to analyze mass transit systems which focus upon a Central Business District, it can, with judicious application, analyze systems which do not. It is important that the user become thoroughly familiar with the technique in line-haul/CBD applications before analyzing cross-corridor systems.

B. APPLICATION TO TRANSIT MODES

The manual technique deals with abstract modes. That is to say, in the classification of transit modes and submodes operational and service level norms are used--not hardware specifications. This is done to allow the description of a wide variety of systems of the same generic class within the parameters of the technique. Another advantage of this system of classification is that it accommodates the description of new modes insofar as they can be adequately represented by a particular set of parameter values.

Generic classes range from high capital cost, high capacity, fixed guideway systems to low capital cost, low capacity, unfixed systems. Manual sketch planning deals with line-haul modes, not coverage modes--such as dial-a-ride, jitney, or taxi--with routes and schedules that vary with demand. Important functional and operational differences between line-haul and coverage modes make it impractical to develop a single planning technique for both modes. Also, coverage modes require a network orientation impossible to analyze with the traditional thoroughness without computers.

The manual technique can be used to analyze the following line-haul modes:*

° Local or Express Bus - Conventional buses operating in mixed traffic with or without preferential treatment. In its wider sense, this mode constitutes a transition to the coverage type transit modes. (The term "local" here refers to local line-haul bus service rather than to local coverage-type transit service.)

° Bus Rapid Transit - Conventional or larger-than-standard buses operating on exclusive rights-of-way, characterized by medium capital cost,

---

*A more detailed description of the characteristics of transit modes is provided in "Urban Mass Transit Planning," Institute of Transportation and Traffic Engineering, Wolfgang S. Homburger, ed., University of California, Berkeley, 1967, p. 23. The terms <u>coverage</u> and <u>line-haul</u> are further discussed in Section D of this chapter.

low to medium capacities, and great operational flexibility ranging from exclusive trunk line service to combined trunk line and feeder mode offering door-to-door service.

- Light Rail Transit - Modern, lightweight vehicles operating predominantly on private rights-of-way, at surface level or fully grade separated. This mode is in extensive use in Europe, primarily as articulated trains. Combines low investment and good collection and distribution capability of buses with high level of service, high capacity, and potential for conversion to rapid transit.

- Rail Rapid Transit - High capacity, varying degrees of automated operation, fare collection at stations, and relatively high speed. (The new San Francisco Bay Area and Washington, D.C., systems are examples.)

- Commuter Railroad* - Suburban orientation, typically both passenger and freight, diesel powered, low-platform loading, on-board fare collection, large station, and (usually) limited downtown distribution.

The manual technique, however, because of its use of parametric service and cost measures, is not limited to the specific modes listed above. Since the technique requires the identification of service levels and operational characteristics rather than hardware requirement, it is especially useful in studying innovative line-haul modes, because such conditions as their speed, capacity, and operating cost can vary greatly from those of existing modes. Without the general specifications of the manual technique, the analysis of each new mode would require separate procedures and nomographs. Nomograph development is discussed in Chapter III and Appendix A.

C. PROCEDURES

Figure 2-1 outlines the steps of the planning technique, which is a sequence of logical steps.

After the identification of the transportation issues and objectives, the first task for the user is to subdivide the region of interest into appropriate travel corridors and districts reflecting homogeneous land uses and predominant travel desire lines. At this point, the user relies largely on his own experience and his knowledge of the area; but he may get some help from guidelines presented later in this handbook.

---

*Although the handbook does not treat this mode specifically, the mode could be analyzed, given an appropriate description of its level of service and operating characteristics.

The number of districts (about 50-100 regionally) to be used will depend on the level of aggregation of existing data, the number and configuration of travel corridors, and the constraints imposed by the computational effort required. Data assembly, to proceed concurrently with corridor and district delineation, should be relatively simple, taking no longer than a few days.

Following the first two tasks is the estimate of travel demand for the region as a whole and for each district. Subsequently, mode choice and travel allocation procedures will produce comparative estimates of peak ridership volumes by transit facility.

Having obtained approximate line volumes for each transit line, the user then proceeds to the physical and annualized cost analysis and environmental impact phases. These parts of the analysis are performed on a facility-by-facility basis, considering simultaneously, however, the interaction between each facility and the entire transit system.

At several points in the analysis, a check of intermediate results will help the user decide whether to proceed with the alternative under consideration or to revise certain previous assumptions. For example, as discussed under Section A, Overview, major changes in fare or service levels might require re-estimation of demand, or, even, respecification of objectives.

After the initial estimate of physical parameters and costs of the proposed system, the graphic techniques employed in this handbook permit simple use in a backward-seeking mode. This will supply design guidance in dealing with such questions as the impact of changes in operational costs or the adjustment of fleet-size requirements. In addition the nomographs facilitate the performance of rough sensitivity analyses.

Finally, the modular design of the technique is meant to allow the user flexibility in the evaluation of his alternatives. This flexibility is reflected in the user's freedom to substitute his own data and techniques at various steps. The user might already have reliable demand estimates, in which case he can proceed directly to the physical and cost analysis and the evaluation phases. Or, at a level of finer detail, the user might use his own values for certain parameters rather than the default values of the technique. Sensitivity tests, as for the effects of increased fares or travel speeds on transit patronage, can easily be made through the modular structure of this technique. Additional testing can explore the impact of uncertainties in assumed performance or cost estimates.

D. ASSUMPTIONS AND DEFAULT VALUES

The manual technique makes certain assumptions about the type of system being investigated, the degree of detail needed, and the transportation planning experience of the user. The assumptions do not necessarily preclude the analysis of new or otherwise unconventional modes--if the user

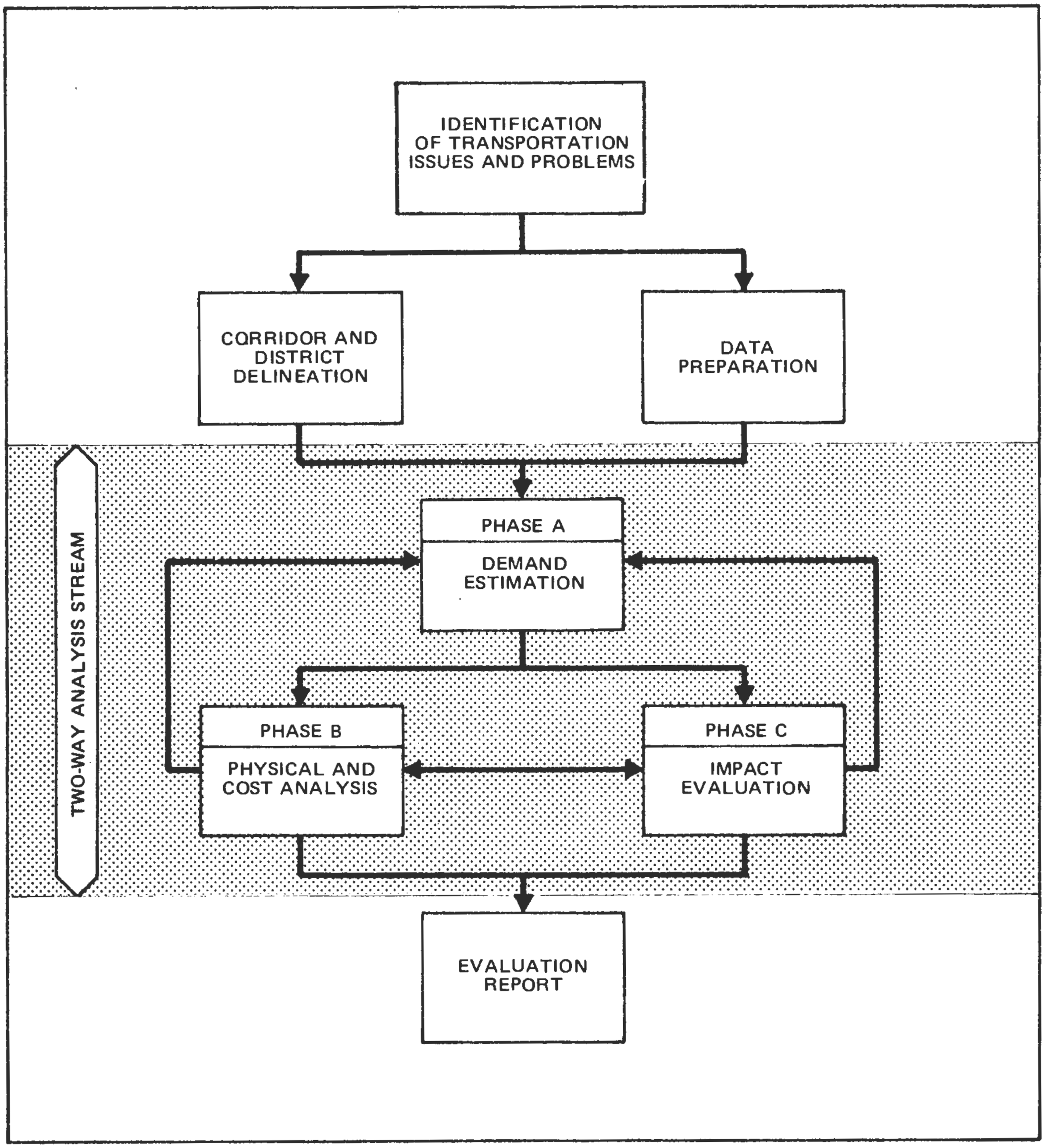


Figure 2-1. Manual Sketch Planning Steps

can specify costs, capacities, and service levels in such a way that the new mode is adequately represented.

Transit modes are assumed to be line-haul. By line-haul is meant the transit facility or the portion of the transit facility on which vehicles operate in a wholly or partially exclusive manner. Examples of line-haul facilities are exclusive guideways such as railroad or busways and restricted or semi-restricted operations such as bus lanes on expressways or arterial streets. The mode of operation opposed to line-haul is coverage. Major coverage systems require refined planning techniques beyond the scope of those presented in this manual; however, the treatment of ancillary coverage components (i.e. feeder and distributor adjuncts to the line-haul facility) is discussed.

It is assumed that the transit systems will be sized to accommodate peak period demands. Such an assumption obviously enlarges estimates of capital costs and of a system's productivity and operating costs. However, since the comparative advantage of most line-haul transit systems is their ability to carry peak-period loads to major activity centers, such an enlargement should be expected.

As to amount of detail, the principal assumption is that all results are preliminary and approximate and that preferred alternatives will be further investigated. Although the manual technique uses the limited base of commonly available data, certain special data must be acquired for analysis at the regional, district, or transit facility level.

Analysis districts are derived from planning data typically organized at the Traffic Analysis Zone (TAZ) level. Of course, any local demographic data base which provides appropriately stratified inputs may be used.

Future projections are required, as in any transportation planning process. Again, locally available land use projections, trends (or hopes) may support the manual sketch planning analysis.

Certain information which the use of the technique requires must be provided by the user. Examples of such information are transit vehicle load factor and operating cost per mile.

The user of the manual technique is assumed to be familiar with the area under study and the major steps in transportation planning.

In certain cases the user has the option of using the default input values provided. These operational values come from a variety of sources, and there is a certain unavoidable arbitrariness in their representation as "typical" values. (Many of these values which relate the operating characteristics of alternative mass transportation systems have been compiled and summarized in "Characteristics of Urban Transportation Systems: A Handbook for Transportation Planners."*) In most cases values

---

*Developed under the auspices of the Planning Methods and Support Division of the Urban Mass Transportation Administration. Available from U.S. DOT, UMTA, UPM-20, Washington, D.C. 20590.

developed by the local planner provide more reliable results than default values. Nevertheless, the optional values are useful guidelines when there is little information available locally.

It cannot be stressed too much that the refinement of data and technique should be kept commensurate with the presumably general nature of the manual technique's results. Elaborate and extensive efforts to attain extreme precision in one area are a waste of time in the presence of coarse procedures and short cuts in another.

E. LIMITATIONS OF THE MANUAL TECHNIQUE

The manual technique is only <u>one</u> of a number of sketch planning techniques. The special opportunities it presents and the limitations peculiar to it are discussed in the handbook.

The user could carefully consider the appropriateness of this technique to his planning situation--before, during, and after his use of it. Much is made above of the relatively low data requirements and of the inexpensiveness and speed of this coarse technique. This is not meant to suggest that every situation in which the data are few, people are in a hurry, and money is short is a situation to which this technique can be fruitfully applied. It is conceivable that in certain situations there are not enough data to support the operation even of this technique. Only the user can make that judgment.

Moreover, this technique advertises itself as an analytical tool that can be used without computers; and it is important that the significance of that fact does not mislead. The technique does call for certain computational competences, and at certain points considerable computational labor. The user must be certain that, without computers, he can in fact provide the computational services required. And, for all the advantages and economies of the manual technique, it is obviously not applicable in all cases. Only the man on the spot can decide.

It should also be made clear that the planning experience on which the assumptions of this technique are based is mostly experience in large urban areas. At least in certain functional ways (from the point of view of transportation planning), large urban areas might be said to have more in common than a casually selected group of smaller urban areas. It is not certainly predictable that the results of the application of this technique in a small urban situation will fit that situation well. Since it is easy to become preoccupied with such results in terms of their abstract merits (how well the data fit the models and how successfully and smoothly the computations go, for instance), the user needs to keep his common-sense eye out for apparently neat conclusions that are in fact out of line with local practicalities of economy, policy, or geography. And here again, the user is the only authority.

The primary focus of this handbook, in terms of demand analysis, is the work trip type. Assumptions are made with regard to the relationship of work transit trips and non-work transit trips but the non-work person travel is not directly addressed. If the user so chooses, these techniques can be extended to the home based non-work and non-home based trip purposes. Chapter III contains discussion on this extension.

CHAPTER III

COMPUTATION PROCEDURES

This chapter explains in detail how to apply the procedures of the manual sketch planning technique and includes sample calculations. These procedures are in three phases, each a coherent but separate module:

Phase A - Demand Estimate
Phase B - Physical and Cost Analysis
Phase C - Impact Evaluation

At the end of this chapter, discussion is presented to permit the development of locally calibrated demand models and to extend the demand analysis to the non-work trip types specifically.

PHASE A. DEMAND ESTIMATE

In this phase the user will first sketch out the major travel corridors and the proposed facilities and systems. Next, he will define analysis districts to organize the economic and demographic inputs and will develop trip generation estimates. Then he will compare the service measures of the transportation alternatives. Finally, he will compute the peak-hour line volumes and maximum load point volumes. These flow data will be input for Phase B, Physical and Cost Analysis.

The procedures of Phase A and their relationships are shown in Figure 3-1. Hereafter the procedures will be referred to as they are identified in parentheses in Figure 3-1.

The sequence of the demand estimate process described here is (1) trip generation, (2) trip distribution and mode choice, and (3) assignment to transit. Since the process is modular, the user may insert local data at certain points.

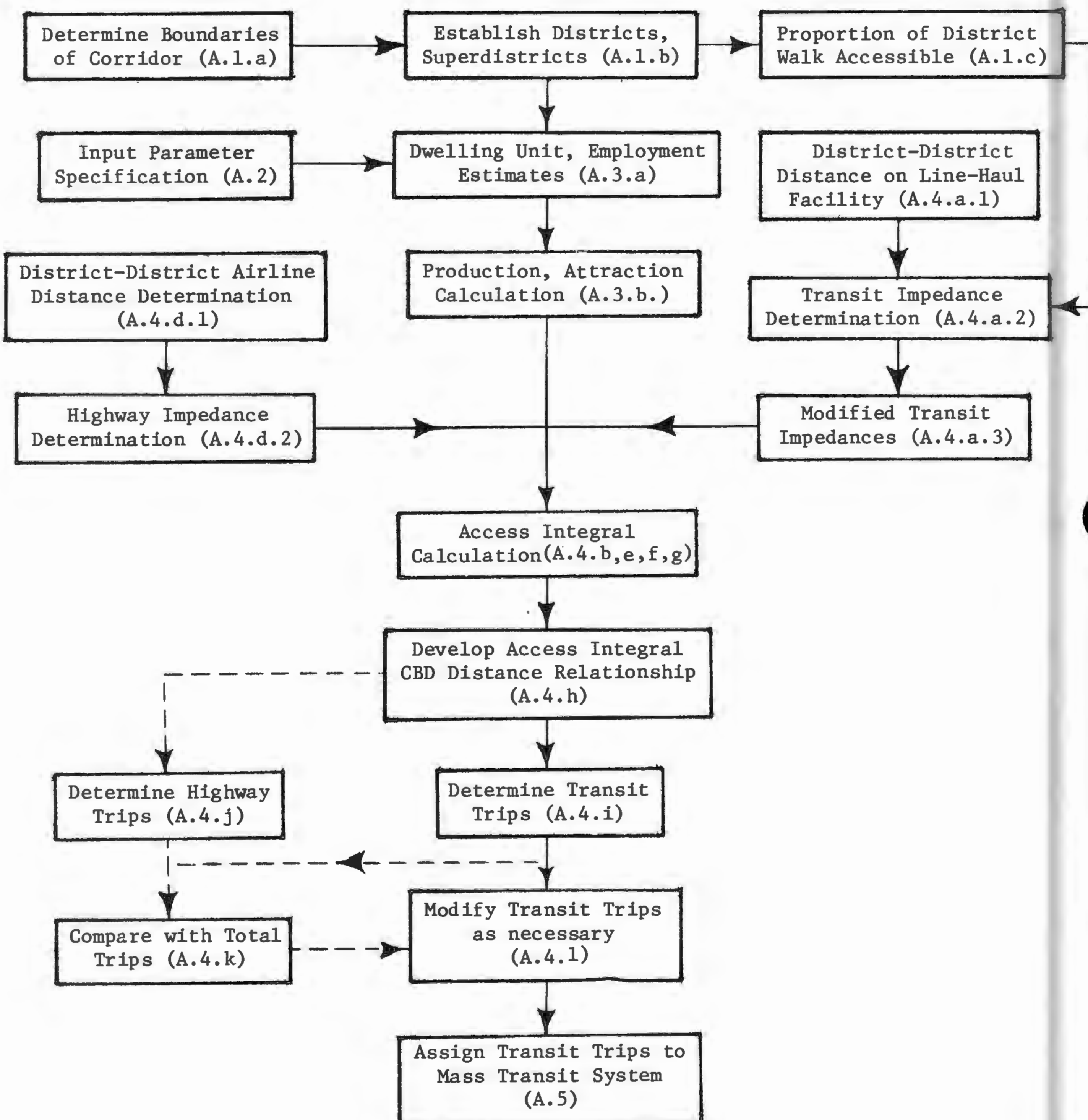
Three facts about the computation procedures must be clear to the user at the outset.

First, the analysis directly estimates only the work-oriented transit travel The work travel, after the assignment phase, is factored to derive estimates of total peak-hour and daily travel on the transportation system under investigation. The derived peak-hour values are used to size the system, i.e. to determine the number of vehicles needed to satisfy the demand. The twenty-four hour values are used to determine the feasibility of the system, e.g. to estimate the daily revenues and costs.

Second, the gravity-type distribution/mode choice model used is based on aggregated values of travel time components (in-vehicle time, wait time, transfer time) and on costs (out-of-pocket, parking, tolls) measured between areas in the metropolitan region for alternative systems. These penalties of cost or time which must be paid to travel are referred to collectively

Figure 3-1

Phase A. Demand Estimation Process



as impedances. In order to have a single value of impedance, the cost will be converted to an equivalent time by a relation giving the value of time. As a result of this conversion, the unit of all impedances is minutes. These are also called disutility minutes to remind the user that he is not dealing with clock minutes but rather with abstract minutes which are used as a common basis to measure the obstacles to travel.

Third, nomographs are given to simplify the calculation of impedances. Additional graphs are available to aid the trip distribution and mode allocation. For those who wish greater accuracy than the nomographs will provide, the mathematical relations on which they are based are contained in Appendix F.

At the end of this chapter (following Phase C) users will find instruction on developing combined distribution/mode choice models specifically for their area. Additionally, information is provided to allow the analyst to extend these procedures to address the non-work trip purposes. A decision to extend these procedures to address the non-work trip purposes should be carefully evaluated, in terms of benefits for the time investment, since the objective here is to perform comparative sketch planning.

A1. Geographic Structuring of Urban Area

This section explains how to establish appropriate analysis units and how to make preliminary estimates of the number of people who can walk to the system.

Step A1a. Identification of Corridor Boundaries. The first task is to divide a region into travel corridors according to the uniformity of land use and dominant travel desires. To a great extent, the orientation of existing transportation facilities controls the selection of corridors. In some instances, as in the case of an obstacle such as an unbridged river, a natural corridor boundary will be indicated.

Most corridors are oriented to the city center. But attention should be paid to the possibility of corridors between outlying activity centers. The following factors should be considered in choosing the defining travel corridors:

- Barriers such as rivers, airports, viaducts, and rail freight yards.
- Existing facilities, such as rail lines and highways.
- Land use, such as residential, industrial, commercial and recreational.
- Population densities. High densities could indicate the need for some form of high capacity line-haul system.
- Jurisdictional boundaries, where legal considerations may bear on corridor analysis.
- Availability of data, such as population and employment figures and their degree of disaggregation.

In summary, corridor spines will tend to be defined by the routes of major transportation systems, either existent or proposed. The corridor area should in general consist of those points more accessible to the spine of a given corridor than to that of any other. Specific corridor boundaries are to be determined by natural and jurisdictional boundaries, and the boundaries of predetermined units of data aggregation (e.g. census blocks). Where possible, considerations of homogeneity of socio-economic and land use characteristics can be brought to bear--locating boundaries at points of sharp changes in these characteristics.

Step A1b. Establish Districts and Superdistricts. To estimate travel demand, the urban region must first be divided into a number of uniform analysis units. These areas are organized into corridors and become the basis to generate, distribute, and assign transit trips. It is important that these areas be specified carefully.

For most metropolitan areas where the manual sketch planning technique might be applied, a set of analysis units will have already been developed in previous studies. An entire urban area might be divided into relatively small units called traffic analysis zones (TAZ), a number of these might be grouped into districts, and a number of these might in turn be grouped into superdistricts.

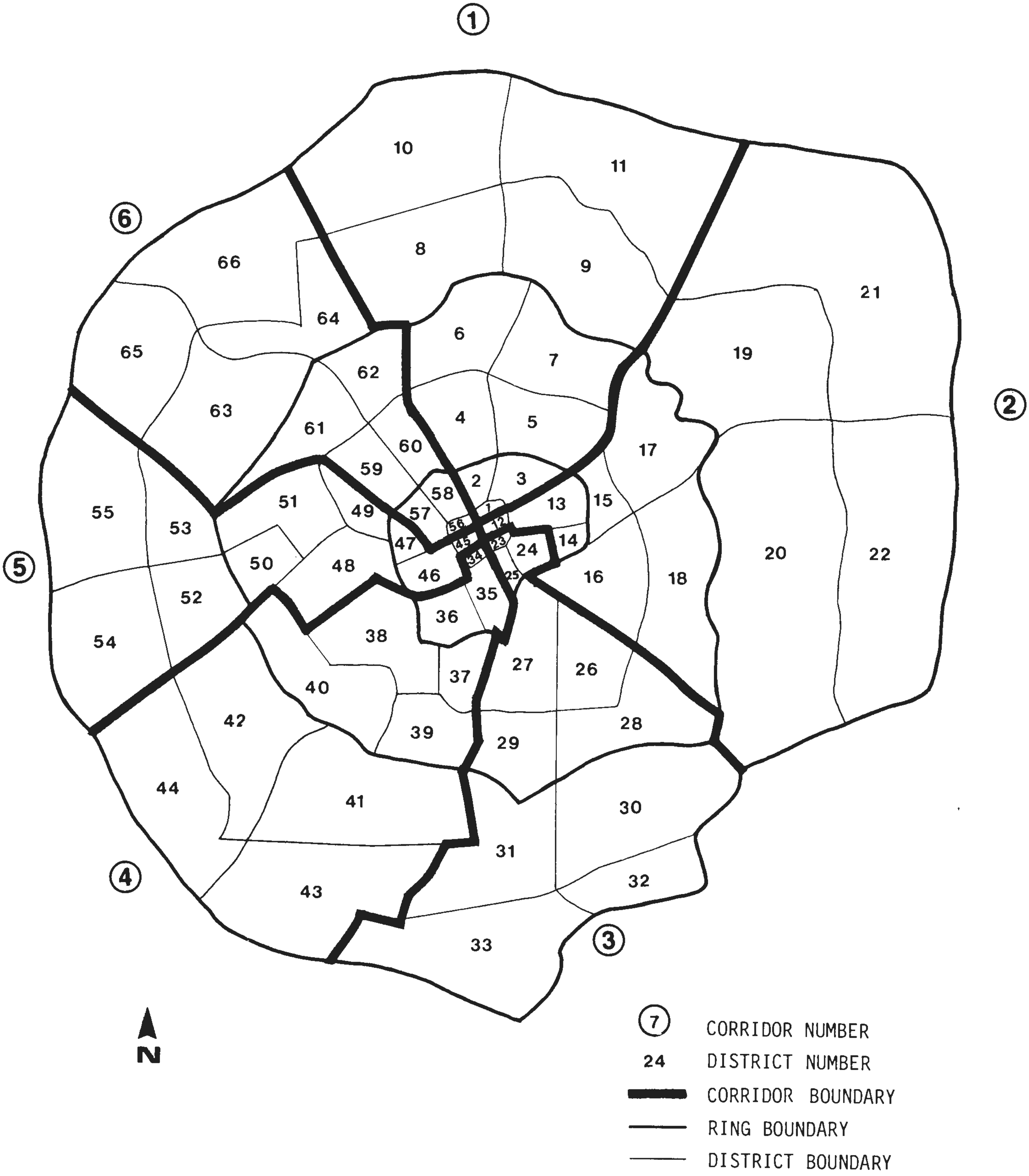
Over one of these levels of aggregation there may be imposed a separate classification into rings (concentric areas usually centered on the CBD) and sectors (wedges extending out from the CBD). The basic analysis unit recommended for the manual technique is the district, which is typically a grouping of TAZ's. The number of districts for a metropolitan area normally ranges from 50 to 100. If no district structure has been specified for the area, the procedure described below may be used.

The number of districts used will depend on the level of aggregation of existing data, the number and configuration of travel corridors, and the computation effort required. Land uses and the kinds of transit systems to be tested should be the determinants both of the TAZ's and of their aggregation into districts. The land uses in each district should be as homogeneous as possible, but the number of districts must be within the capacity of manual analysis. The primary reason for preserving uniformity is to avoid conflict with that uniformity of land use which is a premise of the urban-travel gravity model. Aggregations of TAZ's comprising the central business district, the center city, and the suburbs are examples of creating districts from similar land use groupings. The districts should also be identified by the trip-shed of each line-haul transit facility to be investigated. Each trip-shed should include the entire area from which travelers can reasonably be expected to use the line. In estimating the trip-shed, all reasonably possible modes of access to the line should be considered, e.g. walk, feeder bus, and automobile.

Once the district system is established for the metropolitan area, it is the basis for all subsequent analysis. Figure 3-2 illustrates a set of districts established for a hypothetical urban area.

Since the manual technique is primarily designed for major transportation corridors which are oriented to the CBD, many districts established will provide too few trips to be of interest or use in some applications of

Figure 3-2. Example Layout of Alternative Analysis Units



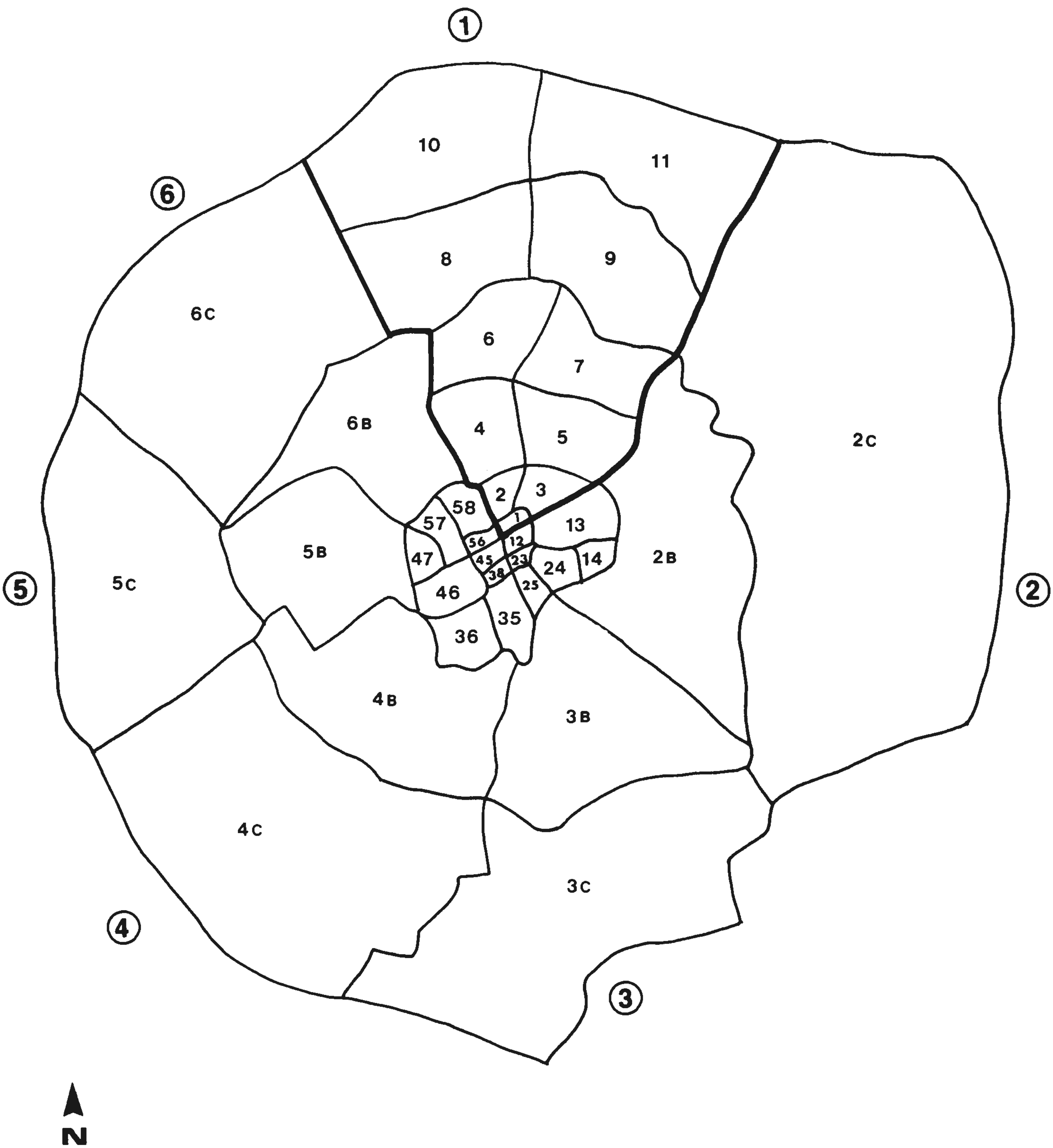
this technique. These districts will be those outside the corridor, where the probability of trips between them and districts within the corridor is small. For example (see Figure 3-2), if transit alternatives are being considered and analyzed for Corridor 1, a corridor running due north from the CBD, considerably more detail is desired in Districts 1-11 than in Districts 55 and 65 (which lie on the western urban fringe). If the corridor under analysis runs west from the city center, the greatest geographic detail is required for districts in this corridor, and the least in Districts 10 and 11. The manual technique is structured to employ geographic detail in the area of interest (the corridor) and to aggregate information outside the corridor. Thus, in a given corridor analysis, the district should be the analysis unit. Outside-the-corridor districts should be aggregated into superdistricts, which are used as analysis units in those parts of the metropolitan area neither in the central activity area nor in the corridor under investigation.

A ring/sector method is suggested to establish the superdistricts. The sector relates directly to travel corridors, seen as geographical "wedges" of the metropolitan area as traced along district boundaries. For sketch planning purposes, three separate rings should be established. The innermost ring, A, includes the area of the highest employment in the metropolitan area. This is the central activity area, i.e. the Central Business District and the central city "fringe" of the CBD. The second ring, B, contains those areas so densely developed that a significant portion (defined later) of the population might walk to a proposed rapid transit facility. Such an area might be characterized by multi-family residential units. The outer ring, C, contains the rest of the metropolitan area, in which walking to any proposed rapid transit facility would be unlikely. (Much of this area would contain single-family residences.) Each area defined by sector and ring boundaries is a superdistrict. To simplify the analysis, superdistricts should be made up of a number of whole districts.

Figure 3-3 shows an example of a superdistrict created from the districts shown in Figure 3-2. If Corridor 1 is the corridor under consideration, districts in all other corridors are aggregated into superdistricts; e.g., Districts 19, 20, 21, and 22 are a single superdistrict, 2C. The central area districts--those in Ring A--are allowed to retain their individual identities, because there could be some kind of central area distribution system in them.

Step A1c. <u>Determination of Population with Walk Access.</u> Special attention should be paid to densely populated districts, in which a significant number of persons might walk to a rapid transit facility, but which are so large that everyone cannot be expected to walk to a station. When determining the impedance for such a district, it will naturally be necessary to distinguish that portion of the population that does walk to the transit facility from the portion that does not. The percentage of population with walk access is determined with reference to three factors: the size of the district, the distribution of population within the district, and the mass transportation facility under consideration. Once the size of the district and its population distribution are known, the user can, according to the characteristics of a system, estimate the percentage of the population that might walk to it. For example, if rapid transit with exclusive guideway is being considered, he can use the number of persons residing within one-half mile of the transit station,

Figure 3-3. Example of District Aggregation for Analysis of Corridor 1



or ten minute walk time. If local transit service operating in mixed traffic is under consideration, only persons residing within one-quarter of a mile of access points, or a five-minute walk, should be counted. Other factors that can be considered in determining the proportion of the population that would have walk access include density of trip ends, density of transit stops, trips within one-quarter of a mile of transit stops, etc.

To establish geographical boundaries on the basis of passenger access, it is recommended that facilities in all Ring A districts be considered 100% accessible to walkers. Conversely, facilities in all Ring C districts should be considered totally inaccessible to walkers (0% walk). Ring B districts, containing mixed single and multi-family dwelling units, should be examined by the rules of thumb suggested above, keeping in mind the characteristics of the system under consideration.

In summary, the analysis unit structure recommended is:

a. Ideally, the basic analysis unit should comprise from 50 to 100 districts, covering the entire metropolitan area.

b. A ring/sector structure of superdistricts (aggregations of districts) should be employed.

c. The percent of the population that could walk to a rapid transit facility should be established in large districts with a significant amount of walking access to a facility.

The recommended procedure for delineating districts and corridors is:

1. Assemble maps and land use data (employment and population) for the region.

2. Outline areas on the map of common land use.

3. Draw line-haul transit facilities on map.

4. Delineate districts (possibly aggregating Traffic Analysis Zones), using trip-shed boundary and grouping similar land uses.

5. Sketch corridor boundaries for each transit line, if possible, without splitting the land use aggregation areas. The boundaries should place individual districts in the corridor which permits the shortest auto driving time to the transit system.

6. Divide the region up into three rings:

a.	Major employment core	Ring A
b.	Dense residential fringe	Ring B
c.	Outermost ring	Ring C

7. Estimate the percent of the population that could walk to a rapid transit station for the districts in Ring B. Ring C

would be considered too sparsely populated to be allowed walk trips. Ring A is considered to consist entirely of walk districts.

8. Define superdistricts, which consist of districts bounded by ring and corridor boundaries. For example, Superdistrict 2B consists of Districts 15, 16, 17, and 18.

9. For Corridor 1 the results of the creation of geographical boundaries for manual sketch planning should appear as shown schematically in Figure 3-3.

Note: For those planning regions with no delineated districts, Steps 1-9 are appropriate. For those areas where district-like analysis units exist, the above process can be started at Step 5.

Figure 3-4 shows a work sheet developed for demand estimates. It is designed for use with the manual technique, and each step number (as assigned in Figure 3-1) is shown at the left hand side of the sheet. This work sheet can be used as reference during the following discussion. After the delineation of corridors and analysis units, work sheets are prepared for each district from which the corridor at hand will be analyzed.

A2. The Establishment of Input Parameters

After the delineation of districts and corridors, the user must develop for different levels of analysis (the districts, the superdistricts, etc.) the input parameters needed for demand estimates. The main input variables are:

- the number of dwelling units and the number of persons employed, by district and by superdistrict;
- transit information: line-haul distance, fare, and mode of access to a line-haul facility for each interchange;
- highway information: airline distance, parking cost, running cost per mile, and average speed for each interchange.

The variables and their subsequent use are shown in Table 3-1. Most system information required is specific to a district-to-district interchange, such as run times, transfer times, distances, and some out-of-pocket costs.

A3. Trip Generation

Person trip-ends are estimated on the basis of productions and attractions in appropriate analysis units. For example, in the corridor of interest and the central area, Ring A, of the metropolitan region, the numbers of dwelling units and persons employed would be compiled for each district. For the rest of the region, such data are aggregated at the superdistrict level.

WORK SHEET

Corridor ______ Alternative ______ Sheet ____ of ____

Step	Origin District (i)		Destination District (j)									
A1	% of Walk in (i)											
A3a.1	Dwelling Unit in (i)=											
A3b.1	Production in (i)=	(P)										
A3a.2	Employment in (j)											
A3b.2	Attraction A_j	(A)										
	Transit											
A1	% of Walk in (j)											
A4a.1	Line-Haul Distance											
A4a.2	Transit Impedance											
A4a.3	Adjusted Impedance	(B)										
A4b.	Square of Impedance	$(C)=B^2$										
A4c.	Transit Index	(D)=A/C										
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	$(F)=E^2$										
A4e	Conductance Factor $(x10^6)$	$(G)=\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	$(J)=\Sigma H$										
A4i	Transit Trips	(K)=P*D/J										

Figure 3-4. Work Sheet for Manual Sketch Planning

REVERSE BLANK

Table 3-1. Input Parameter Specification and Subsequent Use

Input Parameter	Analysis Unit Geography	Subsequent Use	Step
Dwelling Units	District	Trip Generation	A3a.1
Employment	District	Trip Generation	A3a.2
Transit Travel			
Access Time	Origin District	Transit Impedance Calculation	A4a.2
Run Time	Origin District-Destination District (O-D)	"	"
Transfer Time	"	"	"
Fare	"	"	"
Line Haul Distance	"	"	"
Egress Time	Destination District	"	"
Highway Travel			
Access Time	Origin District	Highway Impedance Calculation	A4d.2
Run Time	Origin District-Destination District	"	"
Airline Distance	"	"	"
Operating Cost	"	"	"
Parking Cost	Destination District	"	"
Egress Time	"	"	"

There are two notable items about trip generation and computational efficiencies. The first is the aggregation of employment data for districts into superdistrict data outside the corridor of interest (Corridor 1; see Figure 3-3) and the central area. This results in trip determination at the superdistrict level in the area of non-emphasis. The second is the elimination of the calculation of productions for districts and superdistricts outside the corridor, because only trips produced within the corridor will be distributed. Trips originating outside the corridor and destined for the corridor will not be captured in this process and will be assumed not to use transit line-haul facility.

The following set of twenty-four hour work trip generation equations is suggested: *

Productions = 2.2 x dwelling units
Attractions = 1.7 x total employment (total persons)

Table 3-2 shows both the input and the results of the manual sketch planning trip generation process at the trip generation level, which is the level of aggregation of the metropolitan area depicted in Figure 3-3.

Trip-end figures need be generated only for the district/superdistrict delineation required for analysis of a corridor. It might be worthwhile to perform the calculations at the district level for the entire region if additional corridors are to be analyzed later. Whatever aggregation to superdistricts is necessary can also be performed at this point, since the corridor and rings have been delineated.

Figure 3-5 shows a partially completed sample work sheet for Origin District 6** of the urban area shown in Figure 3-3. The following discussion refers to this example work sheet. The dwelling unit value for District 6 is entered as 8500 (Step A3a.1). The corresponding trips produced for the district is calculated at 18,700 (2.2 x 8500) and entered in the work sheet directly below the dwelling units data (Step A3b.1). A similar set of results for each destination district/superdistrict is entered directly below the trip production results. For example, the employment figure in District 2 is 10,000 (Step A3a.2). The corresponding trip attraction figure, using the above generation equation, is 17,000 (10,000 x 1.7); and it is entered as Step A3b.2 on the work sheet.

If the user of manual sketch planning has a set of productions and attractions calculated that are unique to and representative of his urban area, they should be used rather than those calculated above. Known generators of large transportation activity should be specially treated (colleges, stadiums, military installations, etc.).

---

*These equations were developed using data from several transportation planning studies. As such they represent averages. If better information exists from local sources, it should be used.

**Completed set of work sheets for all districts is presented in Appendix E.

Table 3-2. Work Trip Generation Formulated for Corridor 1 Analysis

Super District	District	Dwelling Units	Employment	Productions	Attractions
	1	1,000	15,000	2,200	25,500
	2	1,000	10,000	2,200	17,000
	3	1,000	10,000	2,200	17,000
	4	6,500	9,000	14,300	15,300
	. . .	. . .	. . .	. . .	. . .
	12	1,000	10,000	2,200	17,000
	13	1,500	10,000	3,300	17,000
	14	1,500	10,000	3,300	17,000
	23	1,500	7,000	3,300	11,900
	24	1,500	9,000	3,300	15,300
	25	1,500	9,000	3,300	15,300
	. .	. .	. .	. .	. .
2B		35,000	30,000	77,000	51,000
3B		35,000	20,000	77,000	34,000
		. . .	. . .	. . .	. . .
6C		30,000	10,000	66,000	17,000
Regional Total		317,500	400,000	698,500	680,000

Note: Completed version of this table is presented in Appendix E.

A4. Trip Distribution and Mode Choice

Given the number of trips produced (by district or superdistrict, as the case may be), the next step is to distribute the trips by mode. This involves allocating trips to production-attraction pairs and estimating what modes the trips will use. The distribution model and mode-choice model are directly related, because the mode-choice model provides a measure (called impedance) of the difficulty of making a trip which is used both to distribute trips between the origin-destination pairs and to assign them by mode.

The distribution/mode-choice model incorporated in the manual sketch planning process is a form of the gravity model, a simplified version of the UMODEL default model in UTPS. It assigns travel to modes serving origin-destination pairs as functions of the different impedances of the modes. The impedances of each mode are derived by converting different travel times and costs to a composite time measure. The transformed impedances are then weighted by the attractions at the destination end of the trip. Travel from an origin zone is distributed, by mode, to a destination in proportion to the inverse square of the impedance by that mode between the origin and destination zones.

This can be stated mathematically as:

$$T_{ij}^{\ell} = P_i \frac{A_j \, (I_{ij}^{\ell})^{-2}}{\sum_j \sum_\ell A_j (I_{ij}^{\ell})^{-2}}$$

where T_{ij}^{ℓ} = the number of person trips between origin District i and Destination District j using Mode ℓ

P_i = the number of productions in District i

A_j = the number of attractions in District j

I_{ij}^{ℓ} = the weighted travel impedance between Districts i and j on Mode ℓ

Step A4a. Impedance Determination. To apply the above model directly, district-to-district* impedances must be determined for each mode under consideration. Impedances represent the time and cost

---

*For those destination districts that are either outside the corridor in which the origin district is located or outside the central area (Ring A), district values and travel times to them should be aggregated to superdistrict levels. The purpose of this is to reduce calculations.

WORK SHEET

Step												
A1	Origin District (i)	6	Corridor 1			Alternative 1			Sheet ___ of ___			
	% of Walk in (i)	20	Destination District (j)									
A3a.1	Dwelling Unit in (i)=	8500										
A3b.1	Production in (i)= 18700	(P)	1	2	3	4	5	6	7	8	9	10
A3a.2	Employment in (j)		15000	10000	10000	9000	9000	6000	6000			
A3b.2	Attraction A_j	(A)	25500	17000	17000	15300	15300	10200	10200			
	Transit											
A1	% of Walk in (j)		100	100	100	20	20	20	20			
A4a.1	Line-Haul Distance		3.5	2.7	2.7	1.5	1.5	0	0			
A4a.2	Transit Impedance		72	70	70	67	67	64	64			
A4a.3	Adjusted Impedance	(B)	81	79	79	149	149	143	143			
A4b.	Square of Impedance	(C)=B^2	6561	6241	6241	22201	22201	20449	20449			
A4c.	Transit Index	(D)=A/C	3.89	2.72	2.72	.69	.69	.50	.50			
	Highway											
A4d.1	Airline Distance		3.5	2.6	2.9	1.5	2.4	0				
A4d.2	Impedance	(E)	88	47	50	36	45					
A4d.3	Square of Impedance	(F)=E^2	7744	2209	2500	1296	2025					
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$	282	613	560							
A4f	District Index	(H)=AxG	7.19	10.42	9.52							
A4g	Access Integral	(J)=ΣH	198.65									
A4i	Transit Trips	(K)=P*D/J	366	256	256							

Figure 3-5. Partially Completed Work Sheet for Origin District 6

obstacles to making a trip and include such things as walking time, time spent waiting for a vehicle, parking cost, and transit fare. Impedance values are usually expressed in tables that show the travel access time, the transit fare, the highway distance, etc., from each district (a row in the table) to all other districts (columns in the table). To make an impedance table (usually called an impedance matrix), the user would have to use local data, such as projected fares and automobile operating costs. But other sorts of considerations would be important too: transit policies regarding transfers, minimization of waiting time, public information programs about schedules and service areas. There might be travel time studies. Maps would be made of service areas to determine probable highway routings, given the existing system. Perhaps there would be planning activity which indicates probable future routings and contemplated transit fare policies. The planner must draw on knowledge of the area.

Determining the components of impedance between all districts in the metropolitan area is difficult, and it will cost the user effort. Not only must he determine access times (time required to park or unpark an automobile, time spent walking to mass transportation facilities, etc.), transfer times, and out-of-pocket costs; but once he determines these, he must convert them to a common base. This usually involves (1) multiplying of vehicle waiting times by some factor (because waiting time is more irritating to the traveler than running time) and (2) the conversion of out-of-pocket costs to an equivalent time measure. This results in an impedance by mode for each origin-destination pair in question (the I_{ij}^{ℓ} of the previous formula). A typical calculation of weighted travel impedance is:

Weighted transit impedance = 1.0(running time) + 2.5(excess times) + 3.0(out-of-pocket cost/household income per minute)*

The units of impedance are called disutility minutes to call attention to the fact that impedance is not measured in ordinary minutes. As explained above, the disutility minutes are a combination of ordinary time (to represent running time), "penalized" time (to represent waiting time), and a time equivalent of cost (to represent out-of-pocket cost).

To avoid having to develop all the individual components and weights for the impedance calculation and to eliminate the evaluation of the above formula, two sets of graphs have been developed which can be used instead. These sets of graphs (one for highway and one for mass transportation facilities) use average or typical travel times, costs, and weighting factors. The user can enter these curves with a measure of distance for an interchange and determine the total weighted impedance.

The measure of distance for highway curves is airline miles between the centroids of the origin-destination

---

*See, for example, "A Utilitarian Theory of Travel Mode Choice" by R. H. Pratt, pp. 40-53. Highway Research Record Number 322, Washington, D. C.

*pair.**

The measure of distance for the mass transportation curves is the length in miles of the mass transportation line-haul facility used in travel between the origin-destination pair.

Figure 3-6 shows the distance measures to be used for the highway and mass transportation curves for an interchange from District 6 to District 1. These districts are shown in Figure 3-3. The highway distance for origin-destination movement 6-1 is 3.7 miles, the airline distance between the centroids of Districts 6 and 1. The distance for the mass transportation facility is 3.5 miles, the distance traveled on the line-haul facility. This would be the distance between the station of access and the station of egress on the line-haul portion of the mass transit facility.

If either the origin or the destination is so remote from the transit facility that no (or almost no) persons will use it, this is indicated by entering zero as the origin-destination distance and transit travel on the corridor facility is not calculated.

The highway graphs are designed so that the user may vary the following:

1. the running cost: 5¢, 10¢, and 15¢ per vehicle mile

2. the parking cost: less than $.75, $.75-$1.40, $1.40-$2.50, over $2.50

3. the average travel speed: 10 mph, 20 mph, 30 mph, 40 mph

There are three separate graphs labeled AUTO CURVES in Appendix A--one for each of the four possible running costs nested with the four possible parking costs. Each graph contains four curves, one for each of the average travel speeds.

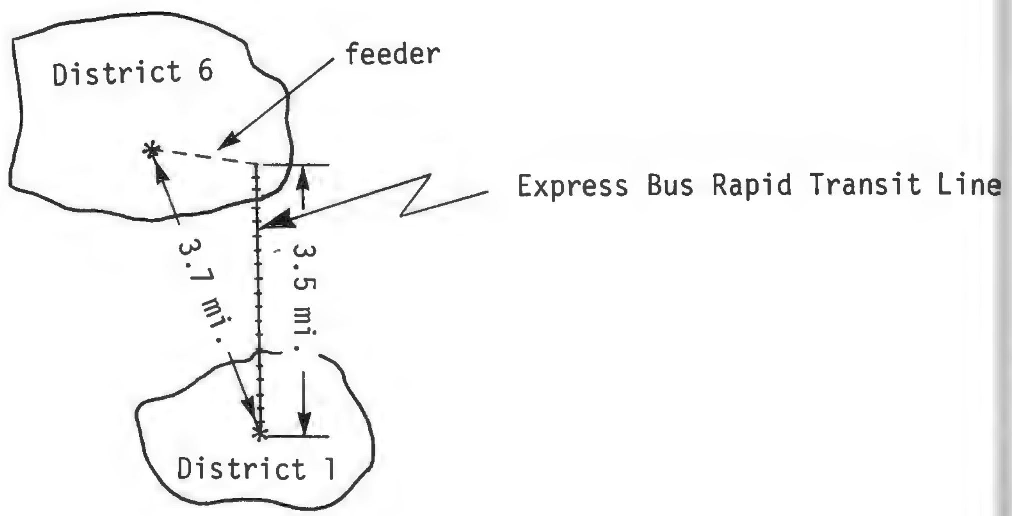
For demand estimation purposes, the perceived auto operating cost should be used. For evaluation purposes, the actual cost should be used. Perceived cost usually includes only gasoline, oil, and perhaps tire wear; this is lower than actual cost.

---

*The user can use actual over-the-road distance at this point. If he does, the impedance should be calculated, not obtained from curves. A detailed explanation of the impedance calculation is in Appendix A.

The centroids of the district should be located at the center of major activity, population, or employment. The district-to-district airline distance is that straightline distance between districts. For sketch planning purposes, measuring the distance on maps is adequate.

Figure 3-6. Distance Examples for Highway
and Mass Transportation Modes



The mass transit graphs cover thirteen combinations of the following:

1. access mode: walk, bus, auto

2. line-haul mode: conventional bus, (integrated and non-integrated) bus rapid, and rail rapid. (In the integrated rapid bus system, the feeder bus performs collection-distribution service in the outlying areas on local streets. The bus then enters the high speed corridor facility and proceeds to the CBD. In the non-integrated rapid bus system, a transfer must be made from the feeder bus to bus operating on the line-haul facility.)

3. distributor: reserved right-of-way distributor (R) and no reserved right-of-way distributor (C). (In the rapid bus mode, two different assumptions about downtown (CBD) distribution facilities are made. The first is that there is a reserved (R) right-of-way for buses in the downtown area--walking or transfer to another mass transit facility to reach the ultimate destination is required. The second is that the bus leaves the reserved right-of-way and circulates (C) as a distributor on surface streets in the downtown area.)

The specific cases covered are the following:

1. conventional bus - walk access

2. bus rapid - walk access - (R)

3. bus rapid - walk access - (C)

4. rail rapid - walk access

5. integrated bus rapid - bus access - (R)

6. integrated bus rapid - bus access - (C)

7. non-integrated bus - bus access - (R)

8. non-integrated bus - bus access - (C)

9. rail rapid - bus access

10. conventional bus - auto access

11. bus rapid - auto access - (R)

12. bus rapid - auto access - (C)

13. rail rapid - auto access

Only ten graphs are included since the impedance/distance relation for item 4 is the same as for item 2, and for items 9 and 13 the same as for items 7 and 11 respectively. Each graph contains seven curves for fares, varying from $.00 to $1.50 in $.25 increments.

Average values of wait, transfer, and egress time have been assumed in the derivation of the transit graphs. Values used are presented in Appendix A. One of the more critical items is the time expended riding a feeder bus to the limited or exclusive right-of-way system under consideration. In cases 5 through 9, 6 minutes has been assumed as the average ride on a feeder bus. From 3 to 15 minutes ride time on a feeder bus could be considered an appropriate range for the application of impedance/distance relationship graphs. If the district is of such a size or the distribution of population in a district is such that many feeder bus ride times greater than 15 minutes are expected, one of two things should be done:

1. the population (district production) that can use transit should be reduced to include only those within a 15 minute feeder bus ride to the line-haul facility, or

2. the impedance/distance relationship should be recalculated* using a value of feeder access ride time that is representative of the area under consideration.

If extensive feeder service is proposed in the outlying tributary area of the corridor, this will significantly increase the costs of the transit system. Some estimates of feeder service (daily Vehicle Miles Traveled) required should be made and subsequently accounted for in the costing portion of each of the corridor systems analyzed. At the CBD end of the corridor, any distribution systems not integral with but attributable to the corridor system should be identified and costed.

Step A4d. <u>Highway Impedance</u>. For the District 6 to District 1 interchange depicted in Figure 3-6, weighted highway impedance is determined using Figure 3-7, which is the appropriate graph selected from those in Appendix A.

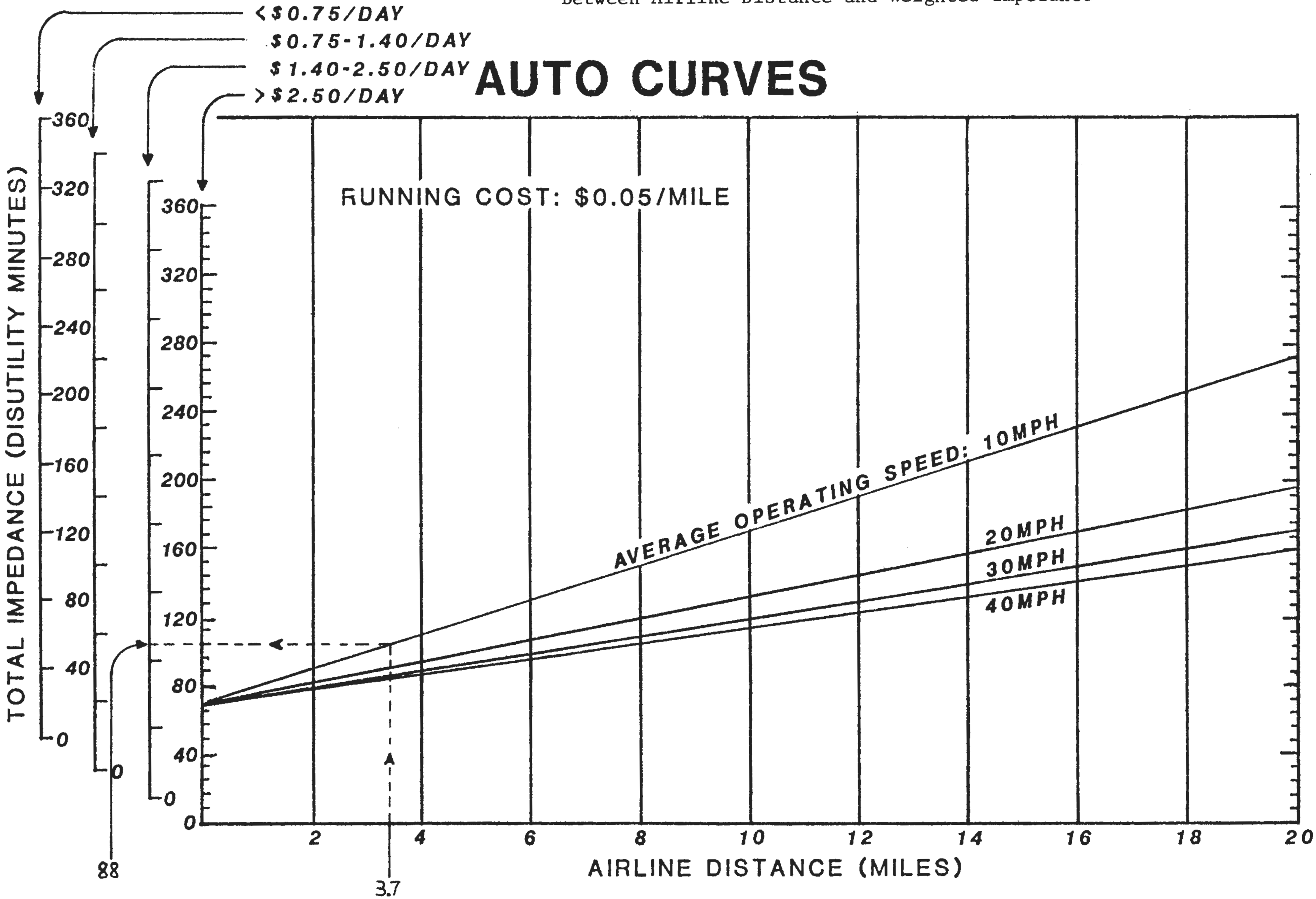
For the highway impedance determination, the x-axis of Figure 3-7 is entered at 3.7 miles--the airline distance between the centroids of Districts 6 and 1. Move straight up until the appropriate speed curve is met (10 miles per hour in this case, since the destination is in the CBD). At this point the total weighted impedance is read: 88.**

---

* See Appendix A for mathematical formulations.

**Throughout the examples in this Chapter, the results have been checked against the mathematical relations (in Appendix E). This has allowed for two-digit accuracy, which will be difficult to attain directly from the graphs.

Figure 3-7. Sample Curve for Highway Facilities Relating Relationship Between Airline Distance and Weighted Impedance



Estimating the travel speed between districts may pose some difficulty to the user. Often time estimates are more easily developed. Estimating assistance is provided in Figure 3-8 through Figure 3-10. The speed nomographs have been stratified by location of occurrence (CBD, Central City and Suburb) since travel time by facility type varies between these locations for equal miles traveled.

To use the speed nomographs, the user must determine the airline distance in each location (ring) and the percentage of travel that is expected to occur on the arterial system. The user may assume travel not occurring on the arterial system will occur on the freeway system. One set of estimates is required for each ring encountered traveling between analysis districts.

Entering the nomograph on the x-axis (% arterial travel) and the y-axis (airline distance), the user can determine the average operating speed for travel within a ring. Potentially, three average operating speeds can be obtained. To estimate the average operating speed between the districts, the user must weight the individual average operating speeds by the airline distance and determine a weighted average. Mathematically, the calculation is as follows:

$$\bar{s} = \frac{s_1 d_1 + s_2 d_2 + s_3 d_3}{\Sigma d}$$

Where:

$\bar{s}$ = district-to-district average auto operating speed

s_n = average operating speed as determined from the nomograph for ring n

d_n = airline distance in ring n

Figure 3-8

AUTO OPERATING SPEED CONVERSION

CENTRAL BUSINESS DISTRICT

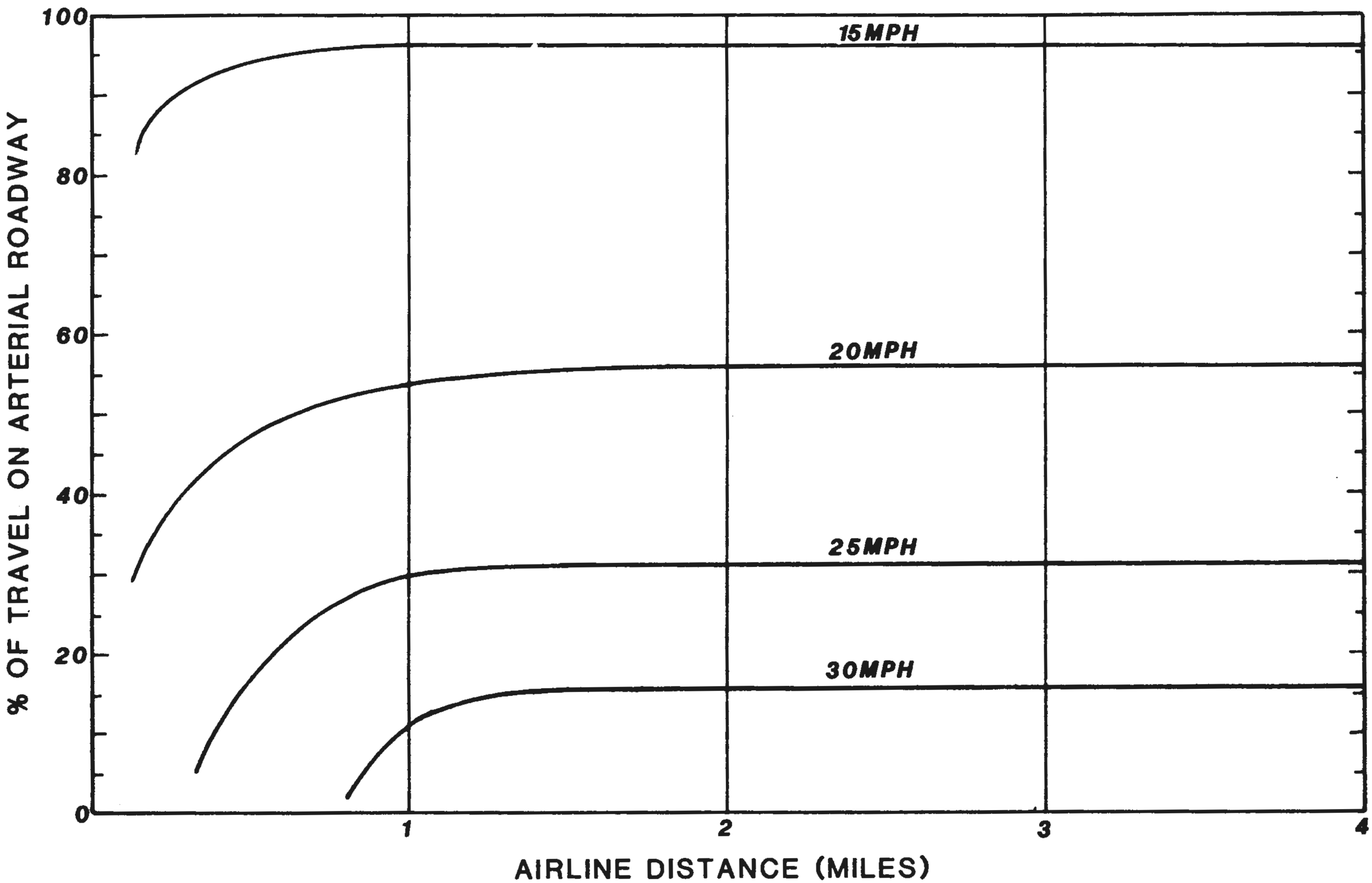


Figure 3-9

AUTO OPERATING SPEED CONVERSION

CENTRAL CITY

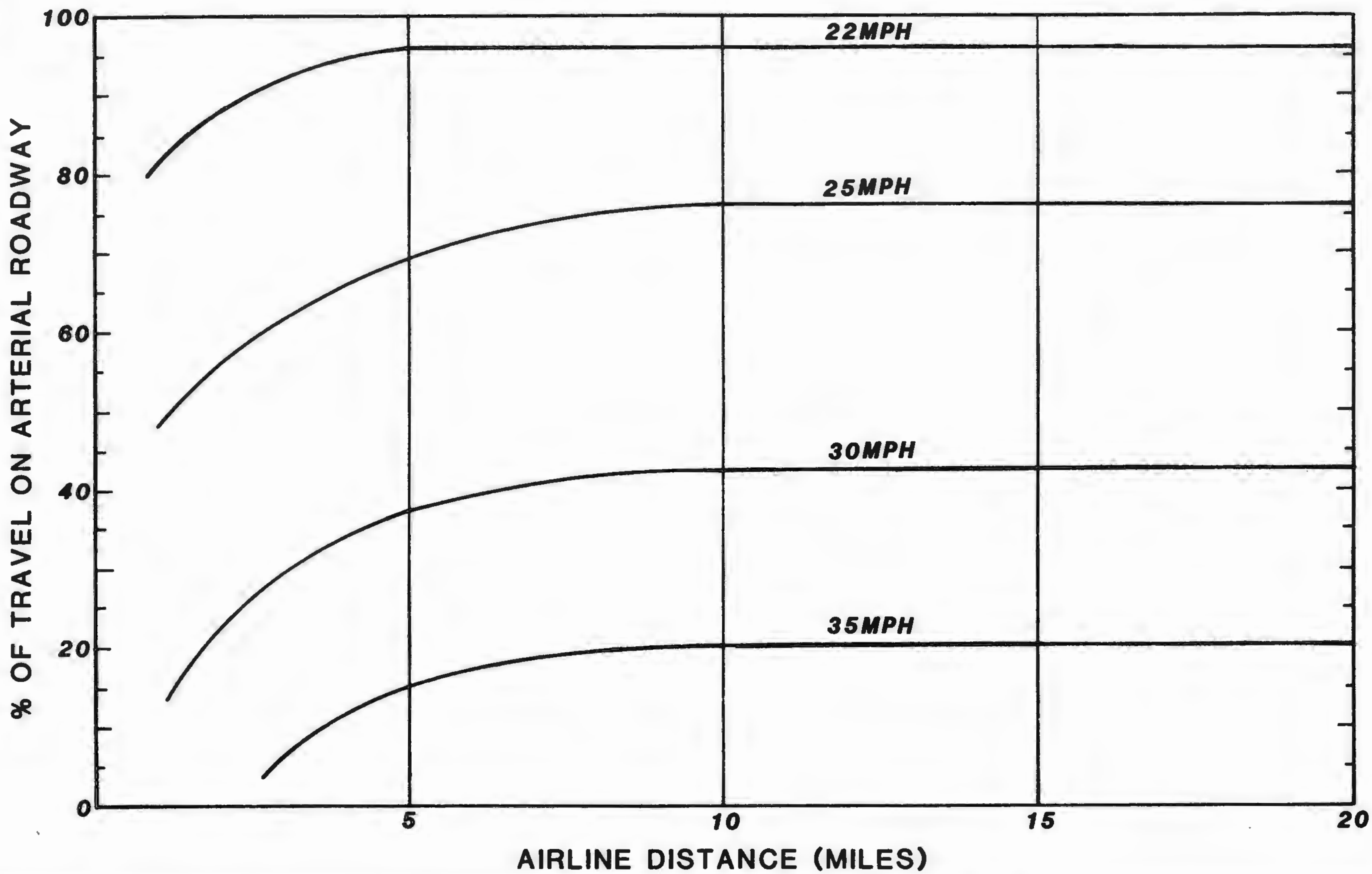
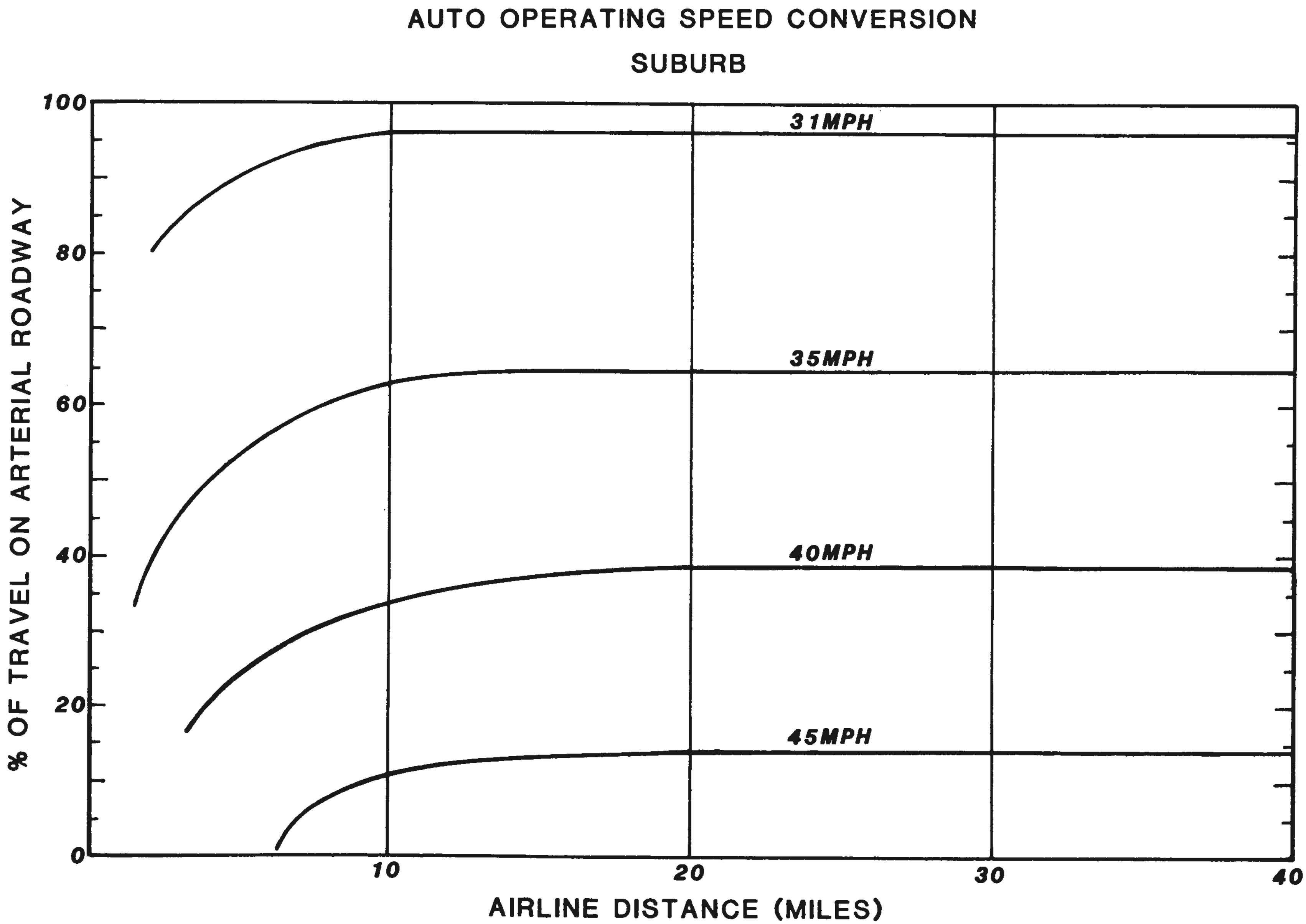


Figure 3-10



AUTO OPERATING SPEED CONVERSION
SUBURB
100
80
60
40
20
0
% OF TRAVEL ON ARTERIAL ROADWAY
31MPH
35MPH
40MPH
45MPH
10
20
30
40
AIRLINE DISTANCE (MILES)

Step A4a.2. Transit Impedance. For the mass transit facility there is a similar procedure, using the curves in Figure 3-11. For an assumed fare of 25¢ and a line-haul distance of 3.5 miles, the total weighted impedance is determined as 72. (To this point impedances between districts have been calculated as though there were 100% walking access at both ends of the trip.)

These airline distance and weighted impedance values for interchange 6-1 have been entered on the partially completed work sheet in Figure 3-5 as follows:

	Value	Step
Transit Line Haul Distance	3.5	A4a.1
Weighted Transit Impedance	72	A4a.2
Highway Airline Distance	3.7	A4d.1
Weighted Highway Impedance	88	A4d.2

Step A4a.3. Impedance Adjustment Calculations. So far we have not dealt with the case in which a zone has a mixture of walk access and feeder access. In this step a method is developed to deal with districts in which a portion of the population walks to one of the access points established in Step A1 above.

Three sets of curves were developed* for the purpose of adjusting impedances to account for the mixture of feeder and walk access in a district:

1. The first curve, illustrated in Figure 3-12, is to be used for integrated *bus rapid transit* with a walk distributor.

2. The second curve, illustrated in Figure 3-13, is to be used for *rail rapid transit* and *non-integrated bus rapid transit* with a walk distributor.

3. The third curve, illustrated in Figure 3-14, is to be used for any of the above three line haul modes with *downtown feeder distributor*.

The first two of the above cases are referred to as feeder-to-walk exchanges, and the third is a feeder-to-feeder exchange.

If a district interchange has feeder-to-walk exchange elements, the initially computed impedance is calculated assuming a 100% walk-to-walk

---

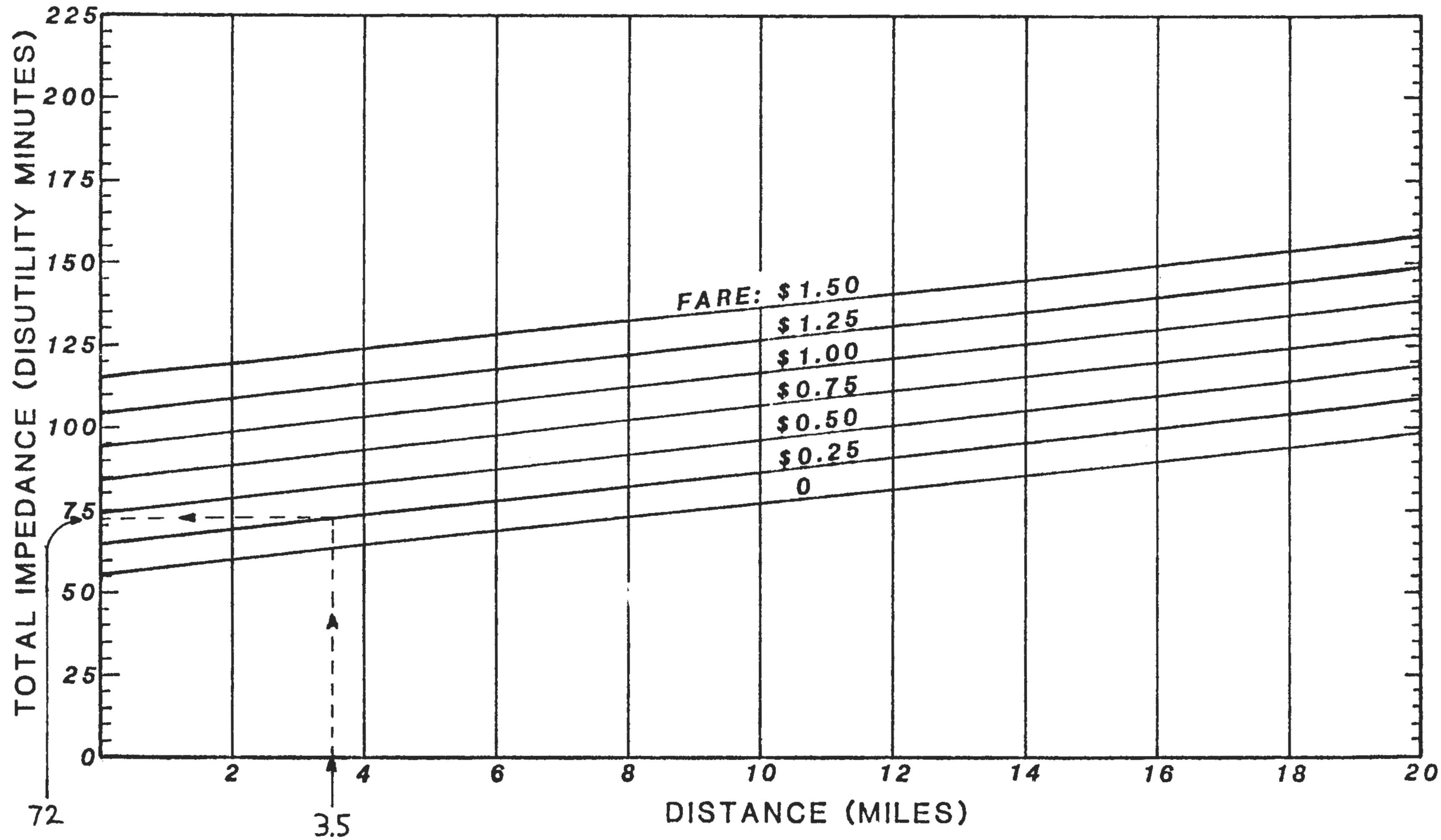
*See Appendix B for explanation of development.

Figure 3-11. Sample Curve for Mass Transportation Facilities Relating Relationship Between Exclusive Guideway Use Distance and Weighted Impedance

TRANSIT CURVES

MAIN LINE: Rail Rapid or Bus Rapid(R)

ACCESS: Walk



access interchange. This impedance is subsequently modified by using the appropriate sets of curves designated Set 1 and Set 2, respectively (Figures 3-12 and 3-13), depending on the type of line-haul system under consideration. If a feeder-to-walk access interchange is later analyzed as a feeder-to-feeder exchange (with the same assumptions as made above), then the curve appearing in Figure 3-14 should be used.

In the example (See the work sheet in Figure 3-5.), Districts 4, 5, 6 and 7 (Ring B) are each considered to have 20% population that could walk to a rapid transit station. One should recall that weighted transit impedances are initially derived by treating those interchanges as 100% walk accessed. The initially determined 100% walk impedance is designated "Iw" in Figures 3-12 and 3-13. For example, in Step A4a.2, the transit impedance from District 6 to District 1 was calculated to be 72, likewise the impedance from District 6 to District 7 is 64. Those calculations were made assuming 100% walk access. In order to derive the correct set of impedance values incorporating both walk and feeder bus access characteristics, the curves in Figure 3-13 (since the example relates to non-integrated bus rapid transit) are then used to derive a factor to be applied to the initially determined walk impedance of 72.

There is a 20% walk-access population in District 6 and a walk impedance of 72; interpolating between Iw values of 60 and 80 in Figure 3-13, the appropriate factor by which to multiply the initially determined walk-to-walk impedance is 1.12. The resultant adjusted impedance is 81 (1.12 x 72 = 80.6, rounded to 81). This is entered as Step A4a.3 on the work sheet for District Interchange 6-1 (Figure 3-5). The interchange from District 6 to District 7 is transformed from 100% walk access to a mixture of walk access and feeder-to-feeder using the curve in Figure 3-14 to derive the factor to modify the initially determined transit impedance of 64. The walk access percentage can apply to either the origin or destination district. If <u>either</u> end of the trip contains a feeder-to-walk estimate, an adjustment should be made. Thus, for a 20% walk access population in the origin district (6) and an initially determined walk impedance of 64, the adjustment factor is 2.23. The corrected impedance is 143. This is entered as Step A4a.3 on the work sheet for the interchange between Districts 6 and 7.

Note that in Figure 3-14, as the percent of walk access in the zone goes to zero, the impedance gets very large. This reflects an important assumption used to derive the curve in the feeder-to-feeder case.

> *If a collector-distributor mode other than walking is required at both ends of an interchange, mass transportation is minimally feasible for that interchange and zero trips is estimated for mass transit.*

In summary, the use of the impedance curves requires these steps for each district interchange pair:

Figure 3-12. Transit Impedance Modification Relationships for Integrated Bus Rapid Transit (Feeder to Walk)

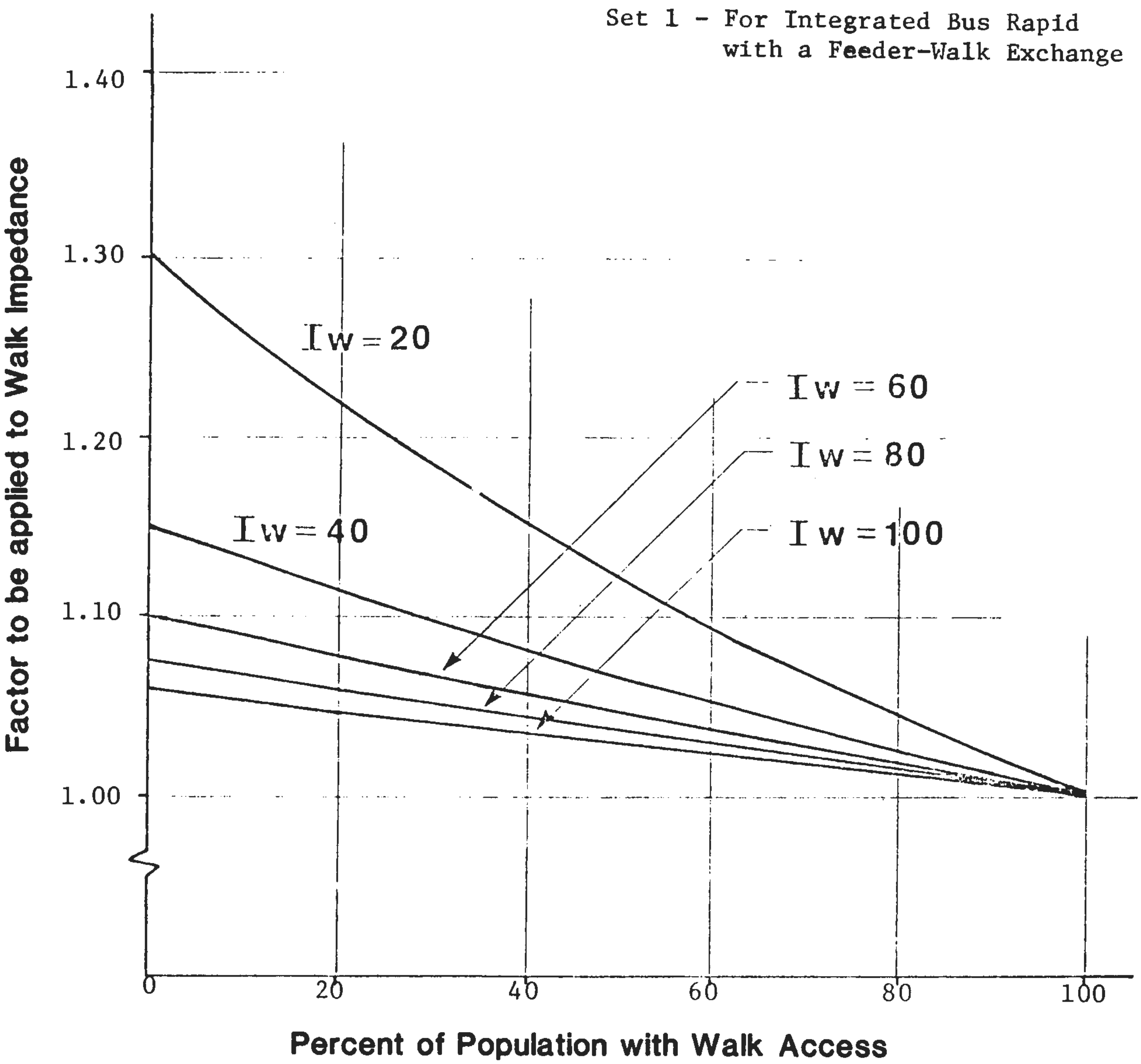


Figure 3-13. Transit Impedance Modification Relationships for Rail Rapid and Non-Integrated Bus Rapid Transit Facilities (Feeder-to-Walk)

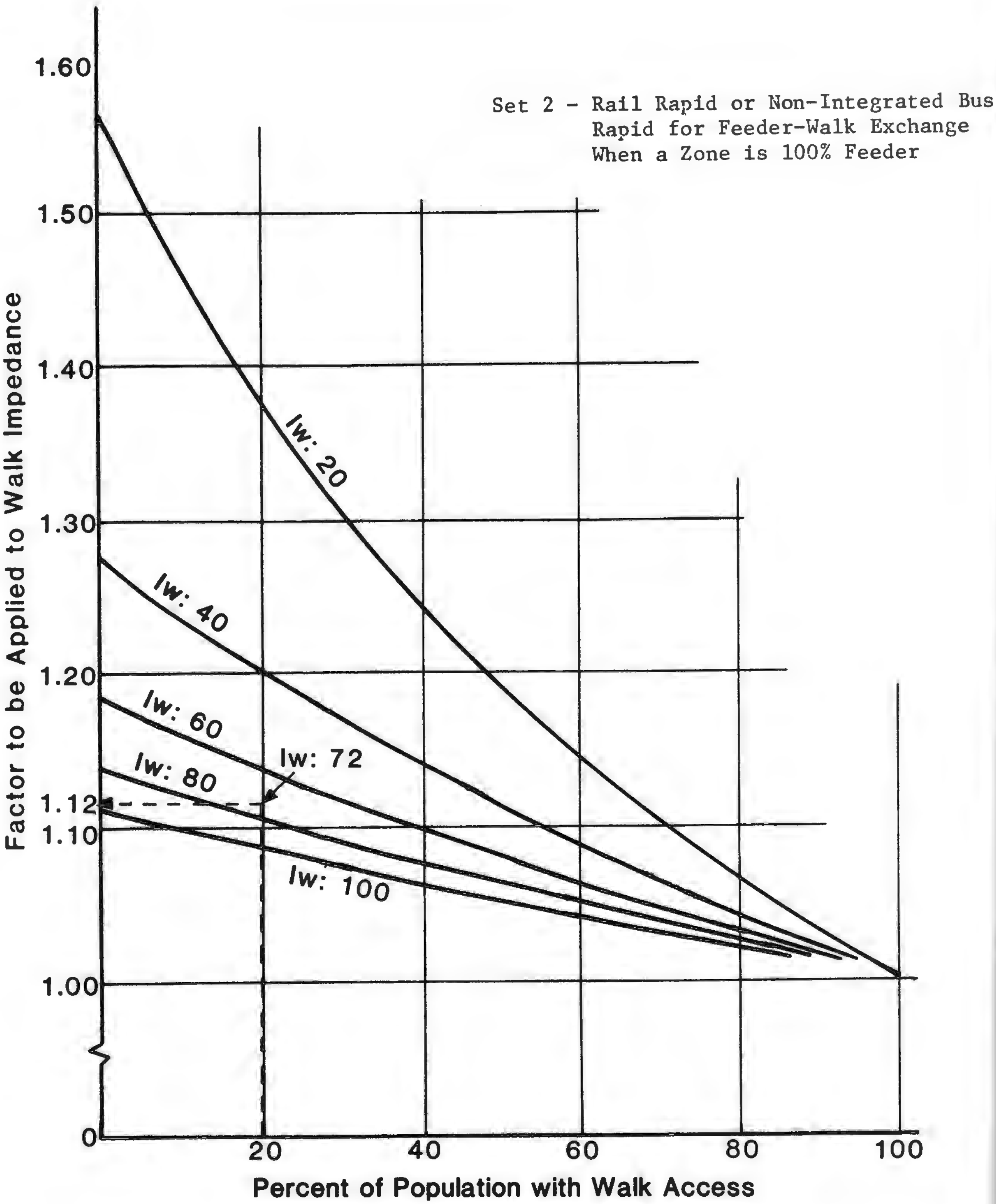
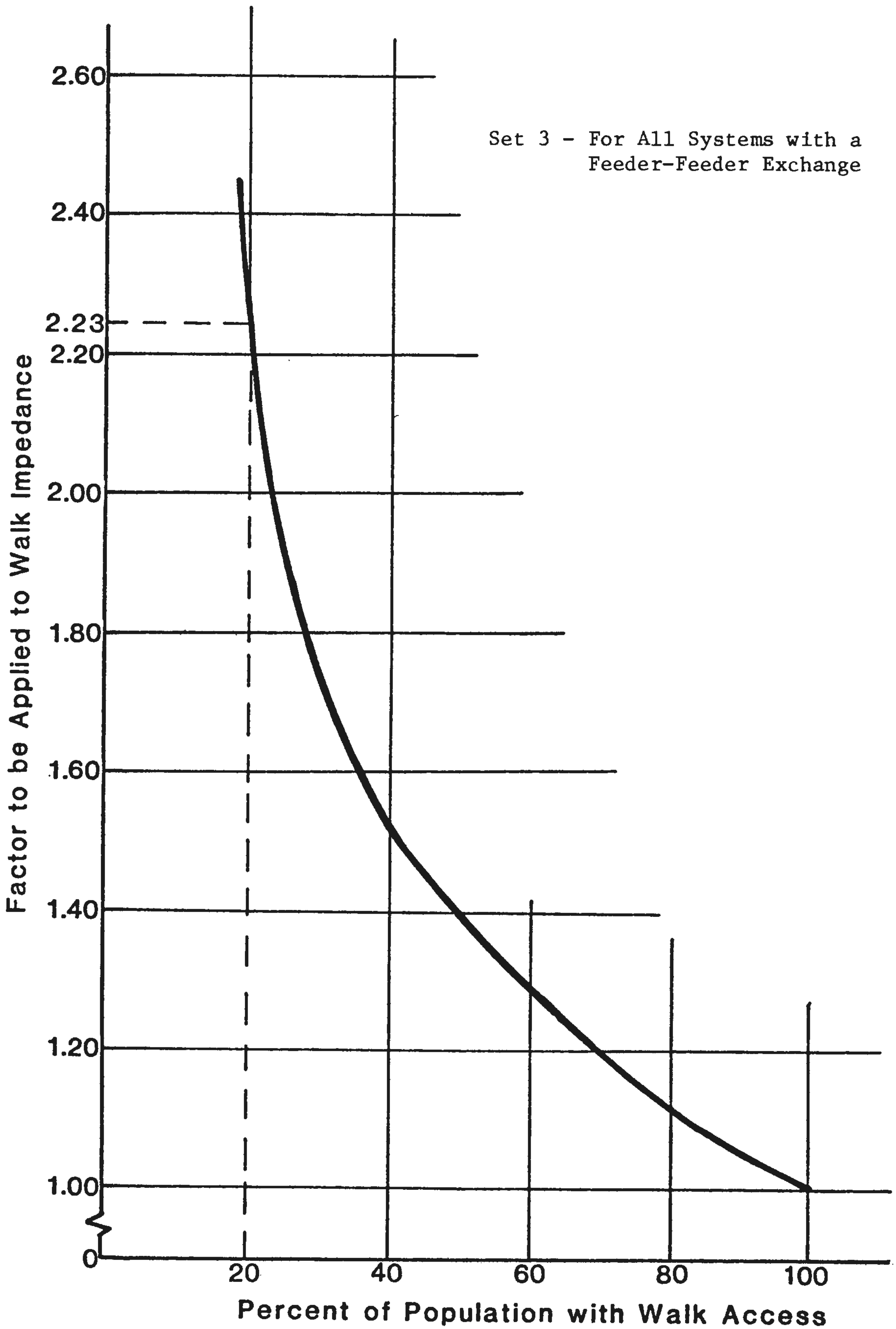


Figure 3-14. Transit Impedance Modification for All Mass Transit Facilities (Feeder-to-Feeder)



Item	Value	Step
For Mass Transportation:		
Length of Line-Haul System Use	Miles	A4a.1
Determine Initial Weighted Impedance Value	Weighted Impedance	A4a.2
For Trip Interchange in District with Walk Access, Modify Impedance	Modified Weighted Impedance	A4a.3
For the Highway System:		
Interchange Airline Distance	Miles	A4d.1
Determine Weighted Impedance	Weighted Impedance	A4d.2

Travel within districts presents a special case if these curves are used, since the centroid distance is zero. However, the intercept value of weighted impedance can be used to estimate the within-district auto impedances.

The intra-district impedance values should be constant among all walk access districts for the mass transportation mode. For the highway mode, an argument can be made for a constant intra-district impedance, with the exception of the CBD. This assumes that longer travel distances in larger districts are compensated by higher travel speeds. If the user feels that intra-district weighted impedances do vary by district, and if he has good estimates of them, then the variations should be accounted for.

The above procedure can be used to derive weighted impedance measures for all corridor origin-destination interchange pairs. The impedances for a portion of the interchange originating in District 6 are given in the work sheet in Figure 3.5.*

*A twenty-five cent flat fare was assumed in this example, and the mass transportation mode was a bus rapid transit system operating on reserved lanes. The assumptions made regarding the highway system were a ten mile per hour average operating speed, running cost of 5 cents a mile, and a nine-hour parking cost of 75 cents except in the CBD, where a value of $1.40-$2.50 was assumed. Mass transportation intra-district weighted travel impedances were assumed as 65. Highway system intra-district impedances were assumed as 25 with the exception of CBD districts, where 50 was used.

Steps A4b, e, f, g. Access Integral Calculation. Although the curves simplify things, there is a part of the distribution analysis that cannot be made easy: The gravity formula requires three calculations for each origin district i. Travel impedance (I) by each mode (ℓ) must be determined to all other districts. The square of the reciprocal of the impedance must be calculated. This must be weighted by the attractions of the destination district (A_j). The value $A_j(I_{ij}^{\ell})^{-2}$ is summed for all modes and destinations and used to apportion travel from the origin to all destinations. The calculation of this sum, termed the "access integral," is a straightforward but time-consuming process. The steps of the calculation will be described; then a shortcut procedure will be suggested which will be appropriate in some instances.

Steps A4b, d. Travel Impedance Transformation. The travel impedances from each origin district in the corridor to all other districts or superdistricts are squared and entered in the work sheet in rows named "squares of impedance" for each mode (A4b and A4d.3 in Figure 3-5). To assist the user, the relation of a number and its square is presented graphically in Figure 3-15 and in tabular form in Appendix C.

Step A4e. Calculation of Conductance Factor. The impedance values are combined for each mode to derive a composite (of both mass transit and highway elements) district-to-district impedance, as follows:

$$\frac{1}{I_{ij}^2} = \frac{1}{(I_{ij}^T)^2} + \frac{1}{(I_{ij}^H)^2} = \frac{(I_{ij}^T)^2 + (I_{ij}^H)^2}{(I_{ij}^T)^2 \times (I_{ij}^H)^2}$$

The superscripts T and H refer to the mass transportation and highway modes respectively. Since it is the square of the impedance divided into 10^6 which is actually used in the calculation, this value, the conductance factor, is determined directly. For example, in the work sheet of Figure 3-5, the squares of transit impedance and highway impedance for travel from District 6 to District 1 are determined as 6561 (81^2) and 7744 (88^2), respectively. These are entered in Steps A4b and A4d.3. The conductance factor is, therefore, $10^6 \times (\frac{1}{6561} + \frac{1}{7744})$. This is entered as 282 in the work sheet row named "Conductance Factor" as shown (Step A4e). The composite impedance equivalent to the conductance factor of 282 is 60. Note that this is smaller than either of the two component impedances (81 and 88). This may seem surprising, but reflection should convince the user that (as in the case of resistances in parallel in electric circuits), the effect of combining two impedances should be less than the lesser of the two impedances to be combined.

Step A4f. Determination of Attraction Weighted Conductance Factor. The accessibility of an interchange is computed by multiplying the conductance factor of each interchange by the attraction at the destination end of the interchange. On the work sheet, this requires multiplying the "Attraction A_j" (Step A3b.2) by the "Conductance Factor" (Step A4e). The result is entered as a "District Index" (Step A4f).

REVERSE BLANK

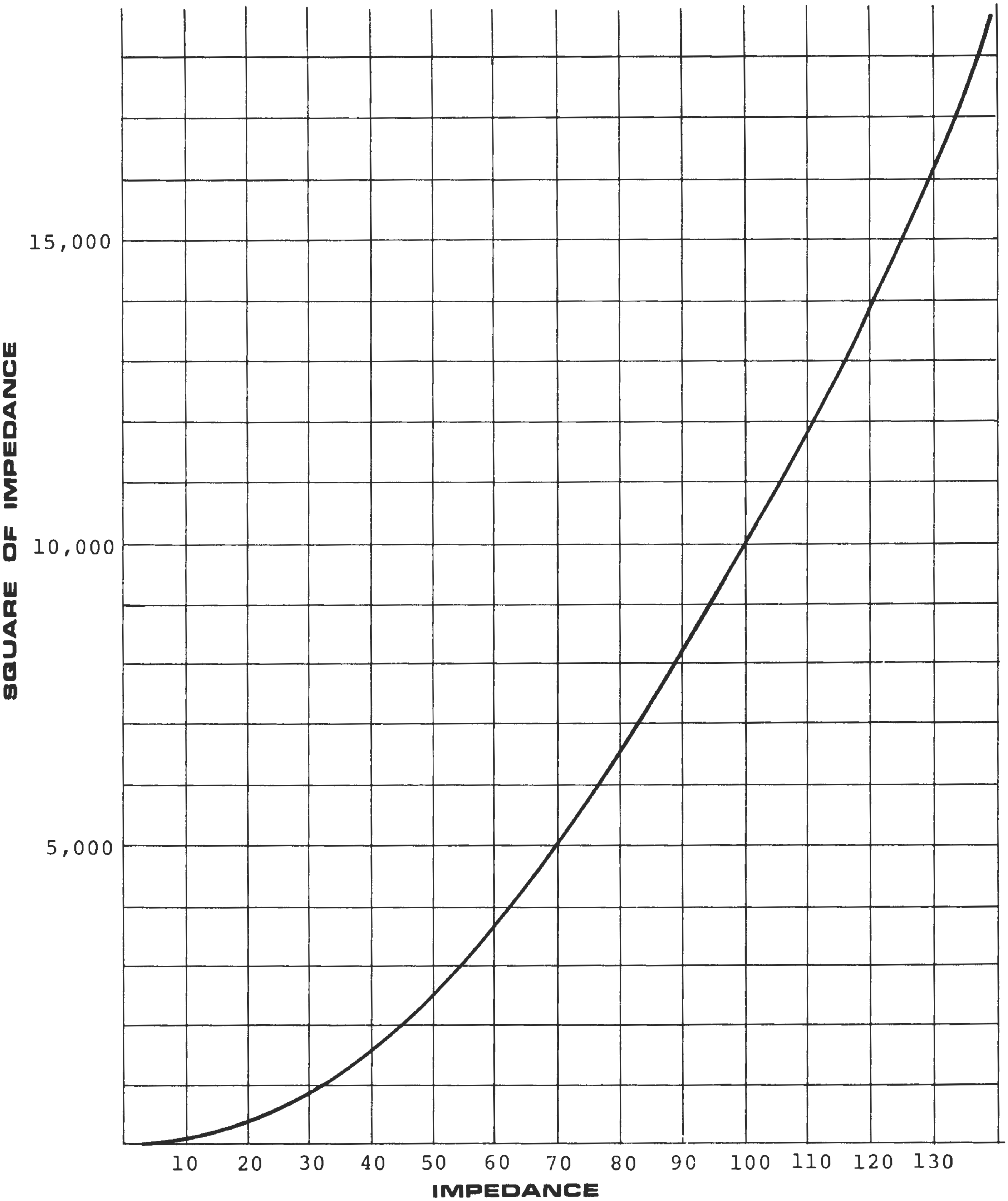


Figure 3-15. **Relations of Numbers and Their Corresponding Squares**

Step A4g. Determine Access Integral. The sum of individual district-to-district weighted indices is calculated across all destination districts or superdistricts from a single origin district. This is the access integral and is entered as Step A4g on the work sheet.

Step A4h. Develop Access Integral-CBD Distance Relationship. If the user has actually been performing the calculations as outlined in the previous steps, he will realize vividly what the imaginative reader may have suspected: The calculation of the access integrals is the bugbear of the entire manual procedure. Appendix F contains programs to calculate access integrals using two of the more common inexpensive programmable desk calculators, which the user may adopt directly or modify to suit his own equipment. These greatly simplify the process of calculating a single access integral. Even with their help, the labor of calculating access integrals for more than ten zones might seem formidable.

As a shortcut, the user, rather than calculate the access integrals for all districts in the corridor of interest, could calculate for a selected number of origin districts in the corridor (say a quarter to a third of the total number) and use this sample set to estimate access integrals for the remaining districts in the corridor.

This technique should be applied with confidence only to what might be called the idealized corridor: (1) a wedge-shaped area, (2) terminating in the CBD, (3) with a fairly smooth transition between dense CBD area through fringe to typical suburb, (4) containing no important secondary activity centers, and (5) served by a single coherent line-haul facility. If these conditions are met to some reasonable approximation, a sample of origin districts in the corridor should be selected to include a range of distances from the CBD and the access integrals calculated. Next, plot these sample access integrals against the airline distance between the centroids of the origin district and the CBD. A strong relationship should emerge for corridor-oriented regions. If it does, it can be used as a curve to look up access integrals for the remaining districts of the corridor.

If one decides to use this access integral-CBD relationship, it is important that access integrals be calculated for districts that lie at different distances from the city center and from the line-haul facility. At a minimum, the access integral must be calculated for a district in each ring of the corridor. It is preferable that several access integrals be calculated in the vicinity of the CBD, because access integrals in this area have the greatest degree of instability. If all goes well, a relationship such as is illustrated in Figure 3-16 should emerge. If the plotted relationship behaves peculiarly--e.g. if the value of the access integral rises as the distance from the CBD increases--the user should check his calculations. If there is no error, the distribution of attractions in the corridor should be reviewed to determine if they could be the cause of the anomaly. If that does not work, it might be necessary to calculate access integrals for several more districts in the corridor to derive a satisfactory access integral-CBD relationship. If this fails, each access integral will have to be calculated separately.

Figure 3-16. Access Integral as a Function of Distance from CBD

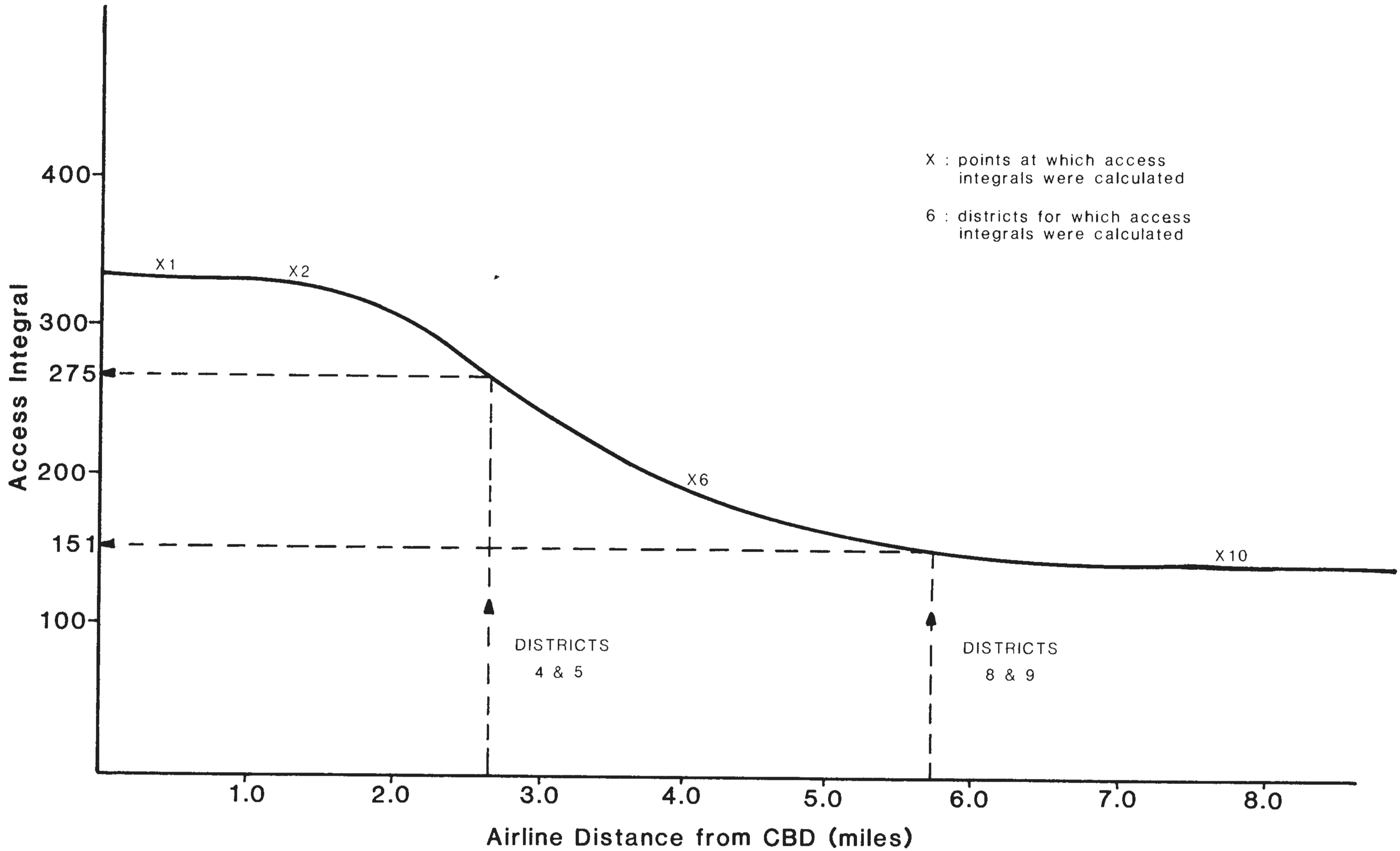


Figure 3-16 shows the relationships developed in the example for 24-hour work-trip travel. It shows the access integral values calculated explicitly for corridor origin Districts 1, 2, 6, and 10. This emphasizes that four access integral values out of eleven origin districts in the corridor provide enough information to develop the access integral-CBD relationship depicted in Figure 3-16. Note: for small distances near the center of the region, the slope of the curve flattens.

Figure 3-16 depicts the value of the access integrals--275--for Districts 4 and 5, both of which are 2.7 airline miles from the CBD. The corresponding values for Districts 8 and 9--5.8 miles from the CBD--is 151.

Step A4i. <u>Distribution of Trips by Mode</u>. The transit trips are distributed according to the following:

$$T_{ij}^{T} = P_i \frac{A_j \, (I_{ij}^{T})^{-2}}{\sum\limits_{j\ell}\sum A_j \, (I_{ij}^{\ell})^{-2}}$$

(Note that only transit trips that would use the line-haul facility need be estimated.)

All values are as previously defined, except that T_{ij}^{T} is the number of person transit trips between districts i and j. First, transit index values are prepared for each of the corridor's origin districts and recorded in Step A4c of the work sheet. This means dividing "Attraction A_j" values (Step A3b.2) by the "Square of Impedance" values of transit mode (Step A4b) on the work sheet. For example, for interchange 6-1 the transit index is calculated as 25,500 (Step A3b.2) divided by 6561 (Step A4b) to yield 3.89.

The next calculation yields the transit trips. The access integral for the origin district is either calculated beforehand or selected from the graph in Figure 3-16. In the example, District 6 was chosen for calculation of access integrals. Therefore, the exact access integral value of 198.65 (Step A4g) was used. The value of "Production P_i" (Step A3b.1) is multiplied by "Transit Index" value (Step A4c), then divided by the "Access Integral" (Step A4g) to yield transit trips (Step A4i). In Figure 3-5 the transit trips from District 6 to District 1 are determined as the Productions--18,700 (Step A3b.1) multiplied by the Transit Index--3.89 (Step A4c) and divided by the Access Integral--198.65 (Step A4g) to yield 366. The results are recorded as Transit Trips (Step A4i) in the work sheet.

Note that if the access integral is taken from the graph, there is no need to calculate composite impedances (Step A4e) or calculate the impedance for the highway mode. Also, there is no need to include attraction values (Step A3b.2) for districts outside the corridor. (These are used only for the calculation of access integrals.)

Figure 3-17 illustrates the completed work sheet used for distributing transit trips after the access integrals for selected districts, in this case District 8, were derived. Figure 3-16 shows the access integral-CBD relationships.

Step A4j. Highway Trip Calculations. If desired, parts of the highway interchange matrices could be calculated similarly as:

$$T_{ij}^{H} = P_i \frac{A_j (I_{ij}^{H})^{-2}}{\sum_j \sum_\ell A_j \, (I_{ij}^{\ell})^{-2}}$$

By following the described steps to derive transit travel, parts of the highway trip interchange matrix can also be constructed. District access integrals, the denominators of the distribution formula, are the same as those used for transit systems.

Note that this would be an incomplete picture of highway travel, since a greater portion of highway trips are intercorridor than are transit.

Step A4k. Total Trip Reconciliation. At this point the user should make sure that the total number of trips assigned from each district does not exceed or fall below the total trip productions in the district. This can occur when average access integrals estimated from curves (see Figure 3-16) have been used to distribute travel, and integrals have not been calculated for each district. In a district where the average integral is less than the actual integral, there might be over-distribution. Where this occurs, there are two possible methods of correction. The first is tedious but reliable: return to the access integral calculation procedure and calculate the "correct" access integral for this district. The second method is to add the number of trips assigned from the district and to compare this to productions. A correction factor is determined by dividing the production in the district by the sum of all trips assigned from the district. The original estimate of trips assigned from the district is then multiplied by the correction factor to produce an adjusted estimate. This is referred to as "normalizing" in the reconciliation of trip distribution model results. This is also popularly referred to as "fudging the results."

Attraction balancing (as in usual gravity model applications) is not performed in the manual technique for two reasons. The technique is designed for corridor analysis. Not all regional travel is assigned, only that originating in the corridor. Therefore, the magnitude of the attractions to be balanced cannot be determined from corridor travel. In a manual technique, the number of additional calculations required for

WORK SHEET

Corridor 1 Alternative 1 Sheet ___ of ___

Step			Destination District (j)									
A1	Origin District (i) 8											
	% of Walk in (i) 0											
A3a.1	Dwelling Unit in (i)= 4000											
A3b.1	Production in (i)= 8800	(P)	1	2	3	4	5	6	7	8	9	10
A3a.2	Employment in (j)		15000	10000	10000	9000	9000	6000	6000	7000	7000	4500
A3b.2	Attraction A_j	(A)	25500	17000	17000	15300	15300	10200	10200	11900	11900	7650
	Transit											
A1	% of Walk in (j)		100	100	100	20	20	20	20	0	0	0
A4a.1	Line-Haul Distance		5.3	4.5	4.5	3.3	3.3	1.8	1.8	-	-	-
A4a.2	Transit Impedance		57	54	54	51	51	47	47			
A4a.3	Adjusted Impedance	(B)	57	54	54	114	114	105	105			
A4b.	Square of Impedance	(C)=B^2	3249	2916	2916	12996	12996	11025	11025	-	-	-
A4c.	Transit Index	(D)=A/C	7.85	5.83	5.83	1.18	1.18	.93	.93	0	0	0
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	(F)=E^2										
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)=ΣH	151 (Obtained from Access Integral CBD Distance Relationship Shown in Figure 3-13)									
A4i	Transit Trips	(K)=P*D/J	457	340	340	69	69	54	54	0	0	0

Figure 3-17. Partially Completed Work Sheet Depicting Use of Exogeneously Determined Access Integral for Transit Distribution (District 8)

balancing would be too large. Preliminary investigation suggests that the error incurred when not balancing attractions is less than twenty percent.

At the end of this phase, a set of twenty-four hour transit travel demands is available for work travel for each district-to-district interchange. This travel is then assigned to the transit system under consideration. These are manipulated to derive estimates of total daily travel which are later used for complete system evaluation.

A5. Transit Travel Assignment

In manual sketch planning, the assignment procedure derives estimates of the daily ridership of the line-haul system and determines the daily two-directional volume at the maximum load points. These two values are basic to the computation of fare revenues and to the identification of rolling stock needs. The basic input is the transit trip matrix developed above.

The efficient calculation of the assignment requires, first, the isolation of transit trips that would use the line-haul system. This is accomplished by compiling the transit trips made in the corridor into a transit trip table. For this example, the transit trip matrix for Corridor 1 is shown in Table 3-3. In this table all trips from the corridor districts to the non-corridor districts in Ring A have been aggregated. These trips are those which would unload from the line-haul system through District 1 and proceed to their ultimate destination district.

The next step is to assign the line-haul transit trips manually to the individual links of the line-haul system. It should be noted that because of the size of the districts, both interdistrict and intradistrict volumes are considered in this assignment. When the user has loaded all trips on the transit line, the summation of trips on various segments allows the calculation of (1) the total line ridership and (2) trips at the maximum load points.

Step A5a. Compute Line Volumes and Maximum Load Point Volumes. In this step the user prepares the assignment of the line-haul trips to specific transit lines. This is done incrementally. For a specific trip interchange, the route is determined and the appropriate number of trips assigned to each link comprising that route. After all trip interchanges have been assigned in this way, the link totals are calculated and link volumes and maximum load point volumes determined.

First, the user should summarize the transit table, as represented in Table 3-3, into a table which depicts trips loaded onto the line-haul system from each district, inbound or outbound relative to the CBD. Table 3-4 is an example of an assignment summary table. To construct the loading section, one must consider the trips that load on the system from District 6 in a direction towards the CBD. This is the sum of the trip interchanges from District 6 to Districts 1 through 7. These interchange values are underlined in the sixth row in Table 3-3 and equal 2698 trips. The sum of the rest of the row representing District 6 equals the trips

Table 3-3. Transit Trips for Corridor 1

		Destination District												
		1	2	3	4	5	6	7	8	9	10	11	Other Ring A Districts	Total
Origin District	1	61	28	28	19	19	11	11	26	17	17	17	242	505
	2	39	27	27	18	18	11	11	27	27	17	17	206	445
	3	39	27	27	18	18	11	11	27	27	17	17	206	445
	4	224	153	153	53	53	24	24	48	48	31	31	1171	2013
	5	224	153	153	36	53	24	24	48	48	31	31	1171	1996
	6	366	256	256	65	65	47	47	102	102	65	65	1596	3032
	7	366	256	256	65	65	47	47	102	102	65	65	1596	3032
	8	457	340	340	69	69	54	54	0	0	0	0	1869	3252
	9	457	340	340	69	69	54	54	0	0	0	0	1869	3252
	10	735	546	546	110	110	86	86	0	0	0	0	3136	5355
	11	735	546	546	110	110	86	86	0	0	0	0	3136	5355
	Total	3703	2672	2672	632	649	455	455	380	380	243	243	16198	28682

Other Ring A Districts include:

12, 13, 14, 23, 24, 25, 34, 35, 36
45, 46, 47, 56, 57, and 58.

Text example underlined.

Table 3-4. Assignment Table for Example Network

LOADING

Origin Districts	Inbound (Includes intra)	Outbound
1	303	202
2	299	146
3	299	146
4	1807	206
5	1790	206
6	2698	334
7	2698	334
8	3252	0
9	3252	0
10	5355	0
11	5355	0

UNLOADING

Destination Districts	Inbound (Includes intra)	Outbound
1	19901	0
2	2644	28
3	2644	28
4	577	55
5	594	55
6	374	81
7	374	81
8	0	380
9	0	380
10	0	243
11	0	243

flowing from it outbound from the CBD (334 trips). To construct the unloading section of the assignment table, one must consider the total trips arriving in District 6. Inbound trips arriving in District 6 are the sum of those interchange values from Districts 6 through 11 to District 6, underlined in the sixth column of Table 3-3 (374 trips). Outbound trips unloaded to District 6 are the sum of the remaining interchange values in that column (81 trips).

Intrazonal trips and trips made to adjacent districts on opposite sides of the line-haul system are regarded as inbound. For example, trips from District 6 to Districts 6 and 7, 47 and 47, are included in the inbound trips loading from District 6. Similarly, trips to District 6 from Districts 6 and 7 are included in inbound trips unloading to District 6. In short, all intradistrict travel is circulated through the inbound portion of the line. This will yield high estimates of volumes.

A method of illustrating the assignment in Table 3-4 is shown in Figure 3-18. The linehaul portion of the transit system is drawn as one-way link pairs, and districts are connected to each line as shown in Figure 3-18. Using the summary results in Table 3-4, the user first should assign the trip volumes onto the lines connecting the districts to inbound and outbound portions of the line-haul transit system as shown in Figure 3-18. (For example, District 6's inbound loading is 2698, while outbound loading is 334. Similarly the inbound unloading is 374 and outbound unloading is 81). Then the user accumulates the loadings (and unloadings) occurring along the inbound and outbound transit lines. For example, in the inbound direction, the loading volume of 17214 (3253 + 3252 +5355 + 5355) at starting point occurs from transit trips originating in Districts 8 through 11. Then the loading volume of 5396 (2698 + 2698) from Districts 6 and 7 is added at the next node, thus increasing the line volume to 22610. At the following node a volume of 374 each is unloaded to Districts 6 and 7, leaving 21862 on the line haul system at that point. The user continues the assignment in this manner until he reaches the end of the line. When this is reached, the line volume should be unloaded to District 1 in the CBD. All travel to districts in Ring A are unloaded through District 1 with the exception of travel to Districts 2 and 3.

The user assigns outbound volumes in the same way. The line volume at the end should be distributed into Districts 8 through 11 in an analogous manner as was done with the inbound travel in the central area or Ring A districts.

Total passenger miles are then derived by multiplying the line volume in each segment by the length of that segment and summing this value over all segments. In Figure 3-18 the distances are in parentheses and the passenger miles appear on the bottom of each link segment.

The technique illustrated in Figure 3-18 has several advantages over conventional assignment procedures.

- It can easily be checked for correctness by the user.

- It allows the user to visualize the travel patterns on the line-haul system.

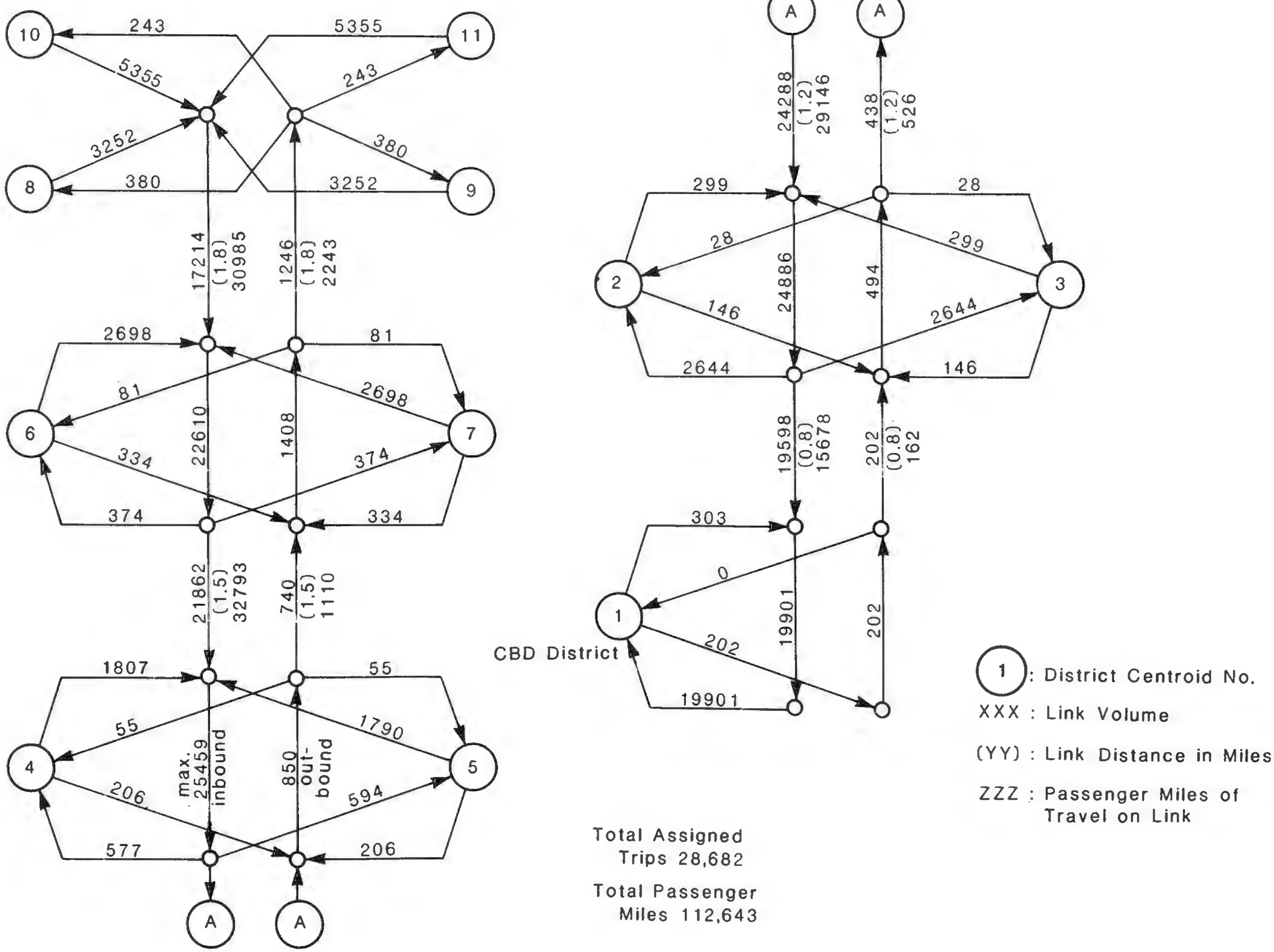


Figure 3-18. Example Line-Haul Network Configuration with Daily Travel Assigned to the System

- It recognizes that intradistrict trips and trips from opposite directions may add to the total line volume within a district.

Derivation of Design Values

The assignment of travel is shown in Figure 3-18 in terms of twenty-four hour work travel assigned to the transit mode (rapid bus). For subsequent physical sizing and impact analyses, two other derived figures are needed: estimates of the peak hour design volumes and total daily travel on the system. If local data are available, they should be used. Otherwise the factors related below can be used to convert work travel into the required forms.

Investigation of ridership of transit systems in various U. S. metropolitan areas has yielded some factors which can be applied to the twenty-four hour work trip travel to derive the necessary peak and daily ridership estimates. The twenty-four hour home-to-work transit travel divided by 2 will yield reasonable estimates of peak hour volumes. This factor accounts for both the peaking of home-to-work trip travel and the non-work travel which occurs during the peak work trip travel period.

A similar analysis indicated that approximately one-third of the total twenty-four hour travel consisted of home-to-work travel. Therefore, a daily estimate of travel can be derived, which is within tolerable limits, by multiplying the home-to-work travel assignment by three. There will be some error introduced because the work oriented travel (both home-to-work and work-to-home) is longer (up to 50 percent when trip lengths are considered) than non-work travel accomplished on the transit system. For sketch planning purposes this error can be ignored. The multiplication by this factor (3.0) of the daily home-to-work assigned trip values, maximum load point, and passenger miles of travel yields the basic demand information with which to begin the physical and cost analysis. This information for the case study is presented in Table 3-5.

Table 3-5. Peak Hour and Daily Design Volumes

Item	From 24-Hour H-W Assignment	Peak Hour	Daily
Trips Assigned	28,682	14,341	86,046
Directional Maximum Point Volume	25,459	12,730	76,377
Passenger Miles of Travel	112,643	56,322	337,929

NOTE: For purposes of sizing and costing the system, it is acceptable to round the peak hour and daily figures in Table 3-5 to the nearest hundred.

PHASE B. PHYSICAL AND COST ANALYSIS

Along with estimates of transit demand, analyses of the supply side of transit are necessary. From a social or community point of view, transit costs might not be the only factor in acceptance or rejection of a transit system. The realistic analysis of costs is necessary both in comparisons of alternative transportation proposals and in investigations of tradeoffs with other, nonmonetary benefits.

This section, therefore, describes the development of operating costs, fare revenues, capital costs, subsidies required per rider, and other system parameters.* It also examines physical and operational feasibilities and outlines model sensitivity tests whose results might feed back into Phase A, Demand Estimation. It must be remembered, however, that all data and figures developed are comparative values. The flow and relationship of the separate activities are identified in Figure 3-19. The steps discussed here are keyed to the values in parentheses.

B1. Specifications of System Parameters (Figure 3-20)

The first step is the specification of input variables needed to use the graphs. For each alternative to be investigated, the following types of parameters must be established:

- Regional objectives and transport policies
- Transit modes to be analyzed
- Physical characteristics
- Level of service and fare specifications
- Operational characterstics
- Cost characteristics

To make best use of the manual sketch planning technique, the user should already know what transit mode or modes he wants to evaluate.

Figure 3-20 summarizes all parameters needed to use the procedures in Phase B. The user should complete column (c) of this form at the beginning of the physical and cost analysis. As mentioned above, the user may use the default values in column (d); but the user's own observations and judgments of local conditions and policies are to be preferred.

The sample values used in Figure 3-20 represent a bus rapid transit line and use the transit demand estimates developed in the example for Phase A, Demand Estimations

---

*The case study in Appendix E illustrates hand calculation techniques to obtain those values without using the graphic procedures presented in this section.

Figure 3-19.

PHASE B
PHYSICAL AND COST ANALYSIS

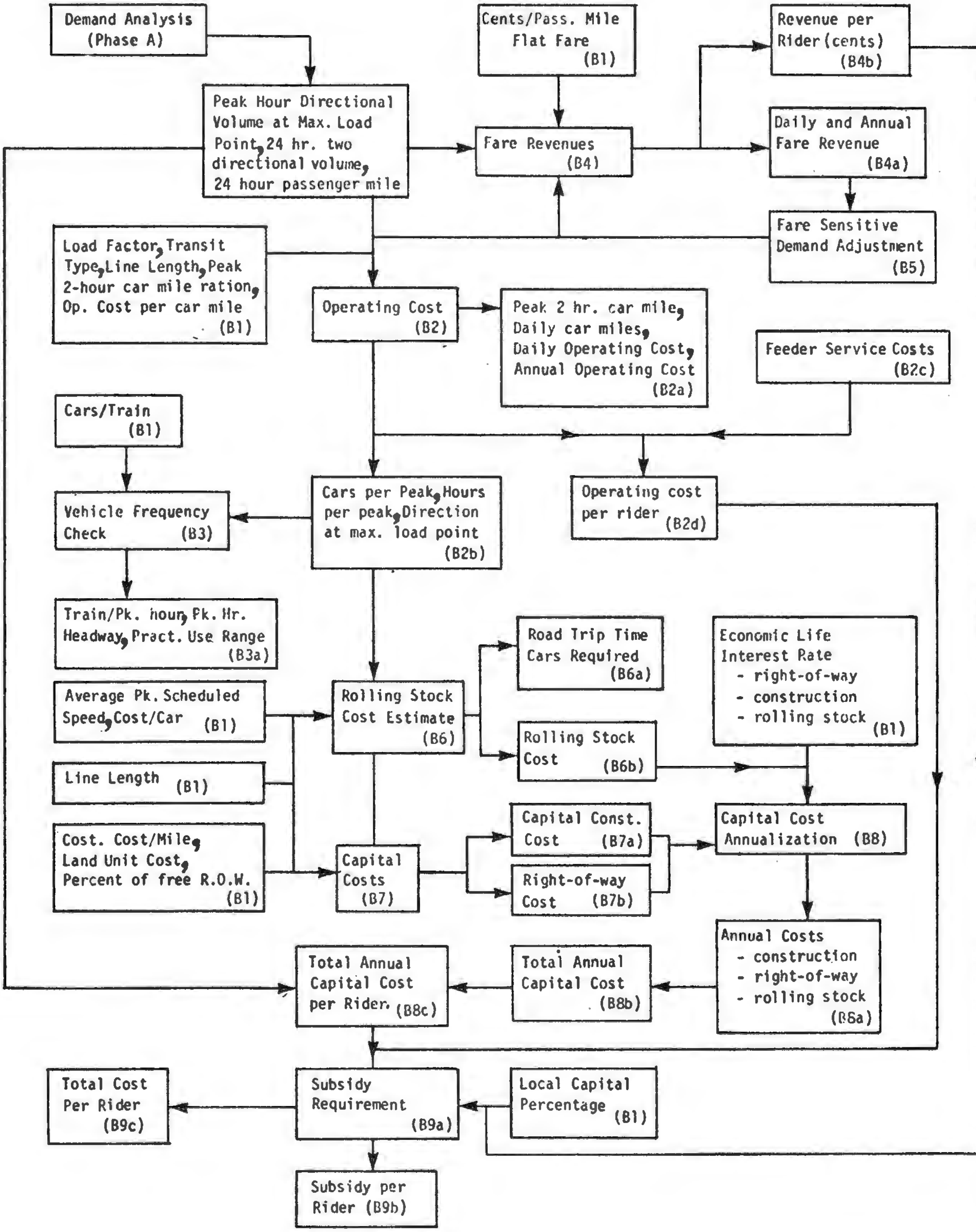


Figure 3-20. Input Variables Required for Phase B - Physical and Cost Analysis
EXAMPLE

Figure	Input Variable	Source of Input Variable	
		User Specified	Default Value*
(a)	(b)	(c)	(d)
3-18	24-Hour Two-Directional Line Volume	From Phase A 86,046	
	Peak Hour Directional Passenger Volume at Maximum Load Point	From Phase A 12,730	
	Desired Peak Operating Headway (Seconds)	Minimum 15 Maximum 600	
	Passenger Load Factor (Total Peak Hour Peak Direction Passengers Carried Divided by Seats Provided)	1.25	Rail Rapid Transit: 1.5 Light Rail: 1.5 Busway: 1.0 Conventional Bus: 1.0
	Line Length in Miles (Two Track Facility)	6	
	Peak Two-Hour Car Mile Factor (24 Hour Car Miles Operated Divided by Peak Two Hour Car Miles) Three Levels: Low Peaking: 10.0 Medium Peaking: 7.5 High Peaking: 5.0	H	Medium Peaking: 7.5

Figure 3-20. Input Variables Required for Phase B - Physical and Cost Analysis
EXAMPLE
(Continued)

Figure	Input Variable	Source of Input Variable	
		User Specified	Default Value*
(a)	(b)	(c)	(d)
3-18 (cont)	Operating Cost Per Car Mile in Dollars	1.50	Rail Rapid Transit: $1.65 Light Rail: $2.07 Busway: $1.50 Bus: $1.50 (Excluding Depreciation and Amortization)
3-19	Cars Passing Maximum Load Point (Peak Hour Peak Direction)	From Figure 3-18 227	
	Cars Per Train Operated	1	Rail Rapid Transit: 8 cars Light Rail: 2 cars Busway: 1 car Bus: 1 car
3-20	24-Hour Two-Directional Line Volume ("Fares Paid")	From Phase A (As modified under Section B.4, Fare Revenues) 74,546	
	Daily Passenger Miles	From Phase A 337,929	
	Graduated Fare Rate (In Cents Per Passenger Mile) ---OR--- Flat Fare Rate (In Cents Per Passenger)	5 OR 25	4 cents per mile OR 30 cents

Figure 3-20. Input Variables Required for Phase B - Physical and Cost Analysis
EXAMPLE
(Continued)

Figure	Input Variable	Source of Input Variable	
		User Specified	Default Value*
(a)	(b)	(c)	(d)
3-21	24-Hour Two-Directional Line Volume or Annual Line Volume	From Phase A 86,046	
	Fare Change in Percent	20	
3-22	Line Length in Miles (Two Track Facility)	6	
	Average Peak Hour Schedule Speed in Miles Per Hour	35	Rail Rapid Transit: 35 mph Light Rail: 13 mph Busway: 30 mph Bus: 10 mph
	Cars Passing Maximum Load Point (Peak Hour Peak Direction)	From Figure 3-18 227	
	Cost Per Car in Dollars	66,000	Rail Rapid Transit: $300,000 Light Rail: $100,000 Bus: $ 66,000

REVERSE BLANK

Figure 3-20. Input Variables Required for Phase B - Physical and Cost Analysis
EXAMPLE
(Continued)

Figure	Input Variable	Source of Input Variable: User Specified	Source of Input Variable: Default Value*
(a)	(b)	(c)	(d)
3-23	Line Length in Miles (Two Track Facility)	6	(In $ million) Rail Rapid / Light Rail / Busway At Grade(G): 11.1 / 1.2 / 3.9 Elevated(E): 15.0 / 13.4 / 11.0 Subway(S): 35.4 / 35.4 / 35.4
	Construction Unit Cost in Million Dollars Per Mile	3.9	
	Right of Way Unit Cost in Dollars Per Square Foot	10	
	Right of Way Adjustment Factor (Percent ROW Available at No Cost)	0	
3-24	Economic Life of Facilities in Years		Fixed Facilities / Rolling Stock Rail Rapid Transit: 40 years / 25 years Light Rail: 30 years / 20 years Bus: 30 years / 12 years
	Right of Way	100	
	Construction	30	
	Rolling Stock	12	
	Annual Interest Rate in Percent	7	
	Capital Cost in Million Dollars	From Figure 3-23	
	Construction	23.4	
	Right of Way	16	
		From Figure 3-22	
	Rolling Stock	5.5	

REVERSE BLANK

Figure 3-20. Input Variables Required for Phase B - Physical and Cost Analysis
EXAMPLE
(Continued)

Figure	Input Variable	Source of Input Variable: User Specified	Source of Input Variable: Default Value*
(a)	(b)	(c)	(d)
3-25	Total Annual Capital Cost Per Rider (in Cents)	From Figure 3-24 14.0	
	Local Share of Capital Cost (%)	33	
	Operating Cost Per Rider (in Cents)	64	
	Fare Revenue Per Rider (in Cents)	22	

*Default values are taken from the "Characteristics of Urban Transportation Systems" (CUTS) Manual published by the Urban Mass Transportation Administration.(July, 1977)

B2. Operating Costs (Figure 3-21)

Figure 3-21 provides daily and annual operating costs for the transit facility and also computes the daily operating cost per rider. Its first input is the peak-hour ridership volume at the maximum load point, estimated either in Phase A, Demand Estimation, or derived from other sources. An example of operating cost computation, presented in Figure 3-21, is based on the following data. The user enters the peak hour peak directional passenger volume at the maximum load point (12,730), as shown. To convert peak two-hour car miles to daily car miles, the line is extended to the appropriate scale of the peak two-hour car mile factor (H=high). The value obtained on this scale is then transferred to the L (low) scale (the entry point to the next nomograph) and the process is continued in the usual manner. The intersection of the annual operating cost value and the daily two-way line volumes yields the cost/rider on the line-haul facility. The input and the results obtained for the example are as follows:

Input:	
24-hour total line volume	86,046
Peak hour passenger volume at the maximum load point	12,730
Feeder bus miles (for this and other input variables, see Figure 3-20)	
Results:	
Cars per peak hour	227
Peak two-hour car miles	5,500
Daily car miles	27,200
Exclusive or partial guideway system	
B2a. Daily operating costs	$40,800
B2b. Annual operating costs - limited ROW system	$12,300,000
B2d. Daily operating cost per rider	47 cents

In this case study 5,000 miles of feeder bus service would be added to provide feeder access to the rapid transit busway. With an operating cost of $1.50 per vehicle mile, there is $7,500 of additional operating cost. This translates into a daily ridership cost of 9 cents per rider (on the total system) and $2.25 million annually. The resultant total system costs will be 56 cents per rider and $14.6 million annually.

B3. Vehicle Frequency Check (Figure 3-22) (Optional)

This graph permits the user to incorporate policy assumptions about peak hour train (or bus) frequencies. It also serves as an illustration and check of the peak-hour train frequencies and train makeups required by peak-hour volumes (Figure 3-22). This is identified as Step B3a in Figure 3-19. This step is optional and not necessary to the use of other graphs, although it represents a useful refinement.

The example of vehicle frequency checks in Figure 3-22 is based on the following data: Figure 3-21 shows that 227 vehicles per peak hour are required to satisfy demand. This requirement can be met through a 16-second headway with a bus operation of one car per train. An acceptable

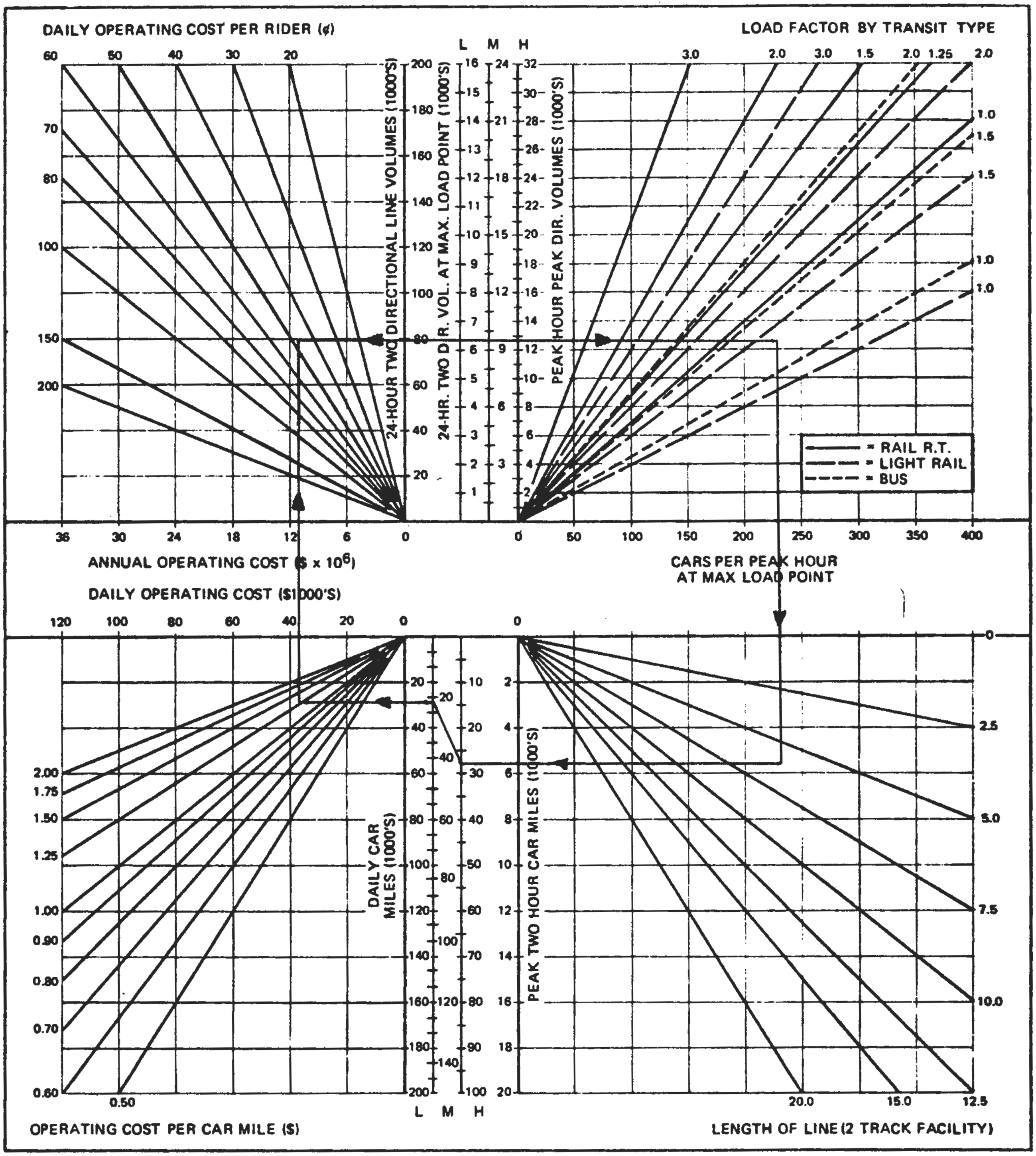


Figure 3-21. Operating Costs - Example

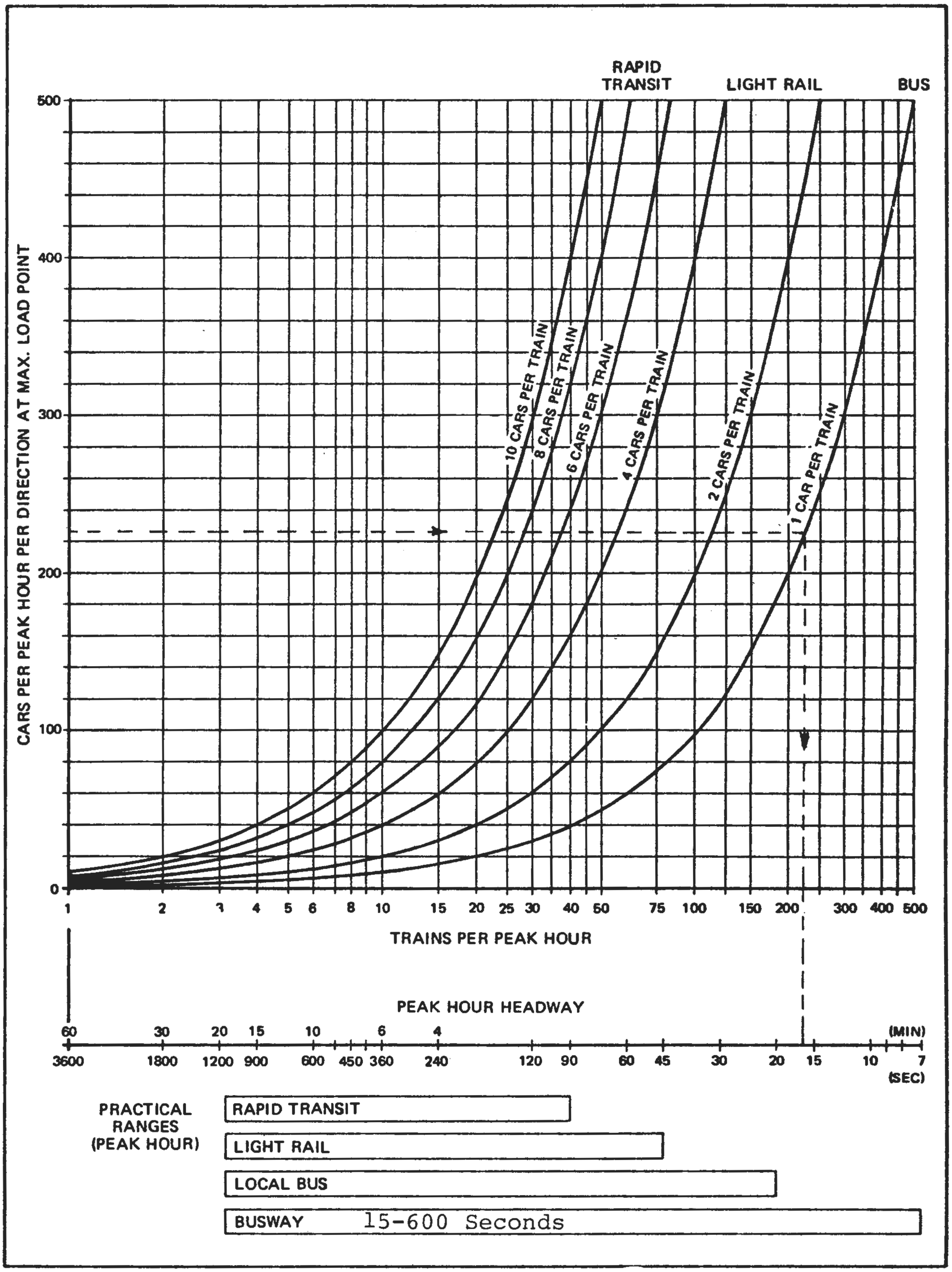


Figure 3-22. Vehicle Frequency Check - Example

range of headways is from 15 to 600 seconds. The 16-second headway derived in the example falls at the lower limit of this range.

B4. Fare Revenues (Figure 3-23)

Two possible methods are provided for in the derivation of fare revenues. The user can specify either a flat fare (left half of Figure 3-23) or a graduated fare rate (right half of Figure 3-23). Both methods will produce daily and annual fare revenue.

Under certain circumstances, the user may want to include system revenues from sources other than the fare box, such as concession and advertising revenues. It is best to be conservative about such unknowns in the example, so revenues other than fares are not considered here.

It should be noted that the basic input value to this graph, the 24-hour line volume, can be either in terms of total line volume or fares paid, depending on the type of analysis to be conducted. When using fares paid, the line volume must be reduced by one-half the number of transfers to other lines, since the return fares will be collected on other lines. Transfer volumes between line-haul routes will have to be estimated by the user. The transit trip table developed in Phase A will serve as a guide in estimating transfer volumes. As an alternative approach, it might be desirable to use "Total Line Volume" for revenue computations in cases in which all additional fare revenue is attributable to a new, added line.

The flat fares or average fare rates used in the graph should include all transfer charges.

The example of fare revenue computation in Figure 3-23 is based on the following data:

Input:	
24-hour line volume	86,046
Estimated transfers to and from other lines	21,100
Fares paid on evaluated line $(86{,}046 - \frac{21{,}100}{2})$	75,496
Daily passenger miles	337,929
Results	
Using graduated fare of 5 cents per passenger mile:	
B4a. Daily fare revenues	$16,896
Annual fare revenues	$5.1 million
Alternative computation using flat fare of 25 cents:	
Daily fare revenues	$18,900
Annual fare revenues	$5.7 million

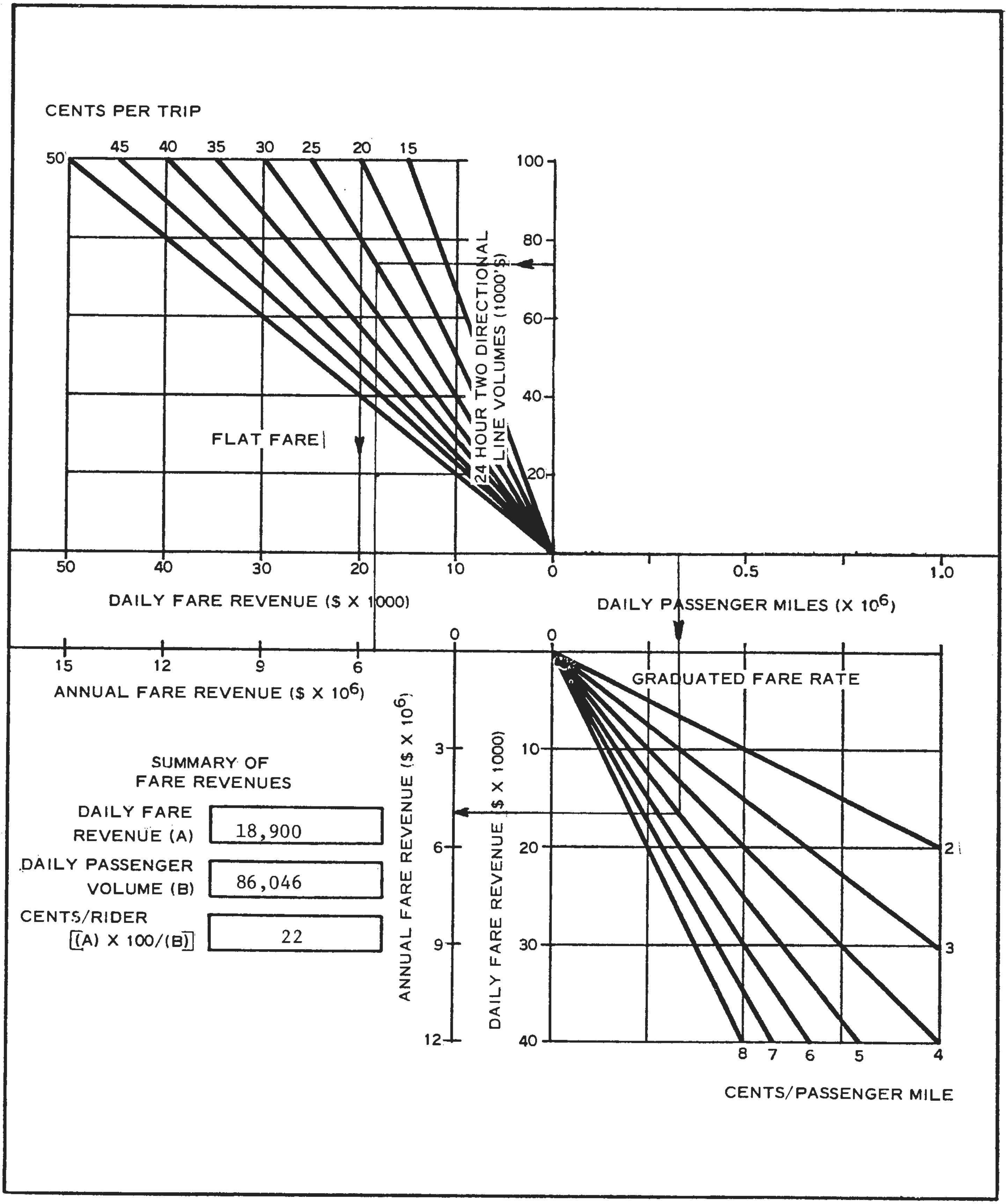


Figure 3-23. Fare Revenues - Example

B5. Fare Sensitive Demand Adjustment (Figure 3-24)

In certain situations it is desirable to measure the sensitivity of riders to changes in fares and service. One way to do this is to modify the travel cost and time parameters used in the mode choice element in Phase A - Demand Estimation and to obtain a revised passenger volume. Although this iteration can be achieved fairly quickly, the process can be cumbersome, especially if several fare levels must be investigated.

Figure 3-24, therefore, shows the relation of changes in fares and changes in ridership. The reduction of patronage because of fare increases is proven by the experience of transit operations in the United States.* Less is known about the increase of patronage because of reduced fares; but in the experience of Atlanta and San Diego, fare reductions had the expected result of increased demand.

With these qualifications, the graph is offered here for optional use. The adjusted daily ridership developed in this graph feeds back into Figure 3-23, Fare Revenues, and, depending on the change of ridership, possibly into Figure 3-21, Operating Costs. The use of Figure 3-24 is, however, not essential to the further use of the manual technique.

The example of fare sensitive demand adjustment computation as seen in Figure 3-24 uses the following data:

Input:	
Daily Ridership	86,046
Fare Change	+5¢/rider
Base Fare	25¢/rider
Results	
Percent fare change = 5/25 (100)	20%
Adjusted daily ridership	80,300

B6. Rolling Stock Costs (Figure 3-25)

This graph is used to estimate the costs of the rolling stock required. It assumes an average peak hour schedule speed, the computation of which should reflect station spacings and account for station dwell times and layover times. An intermediate output is the fleet size required, including an 8 percent allowance for spares and outages.

Figure 3-25 presents an example of rolling stock costs based on the following data:

---

*Simpson & Curtin, "Coordinated Transit for the San Francisco Bay Area Now to 1975," Final Report of the Northern California Transit Demonstration Project, San Francisco, California, 1967

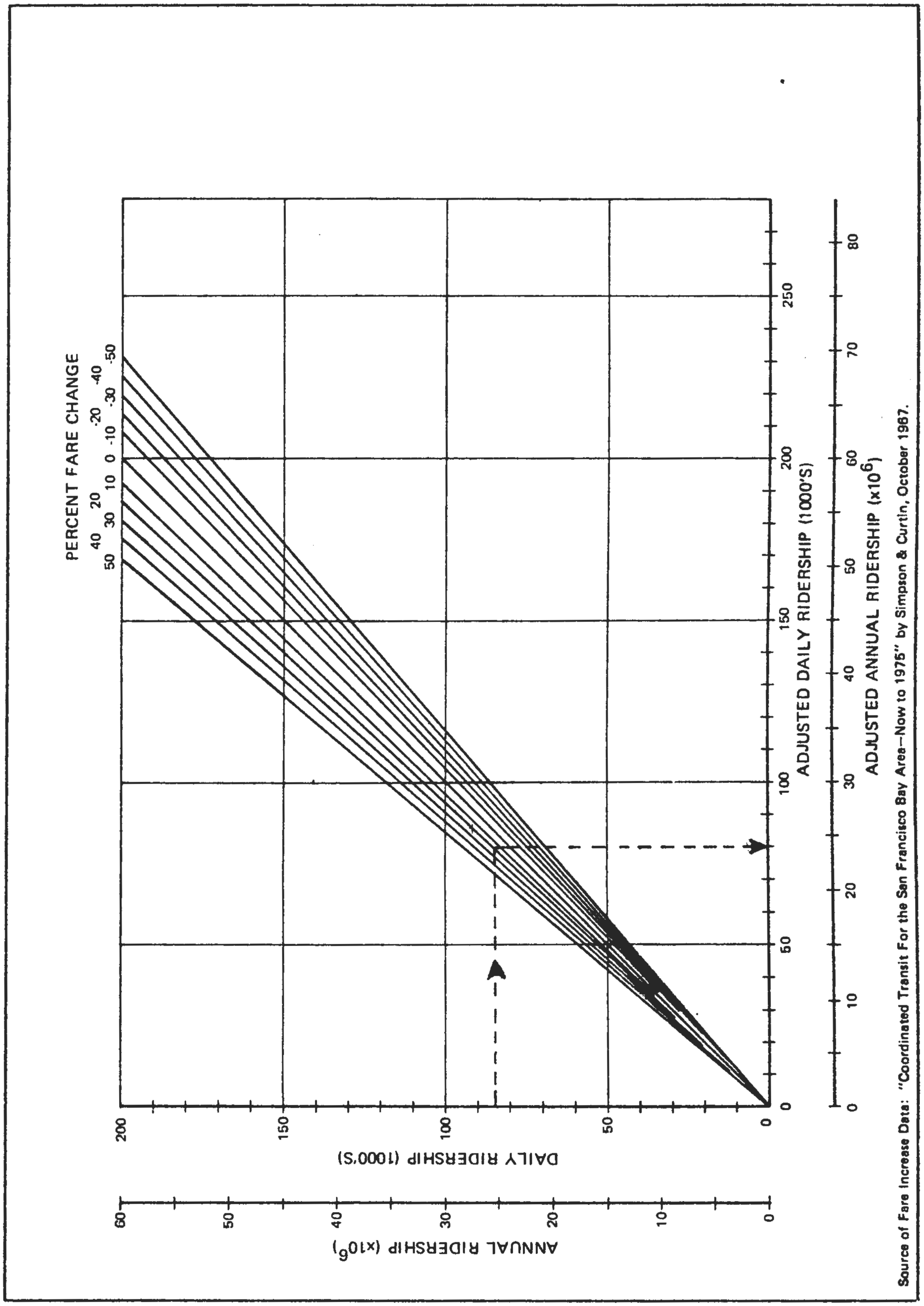


Figure 3-24. Fare Sensitive Demand Adjustment - Example

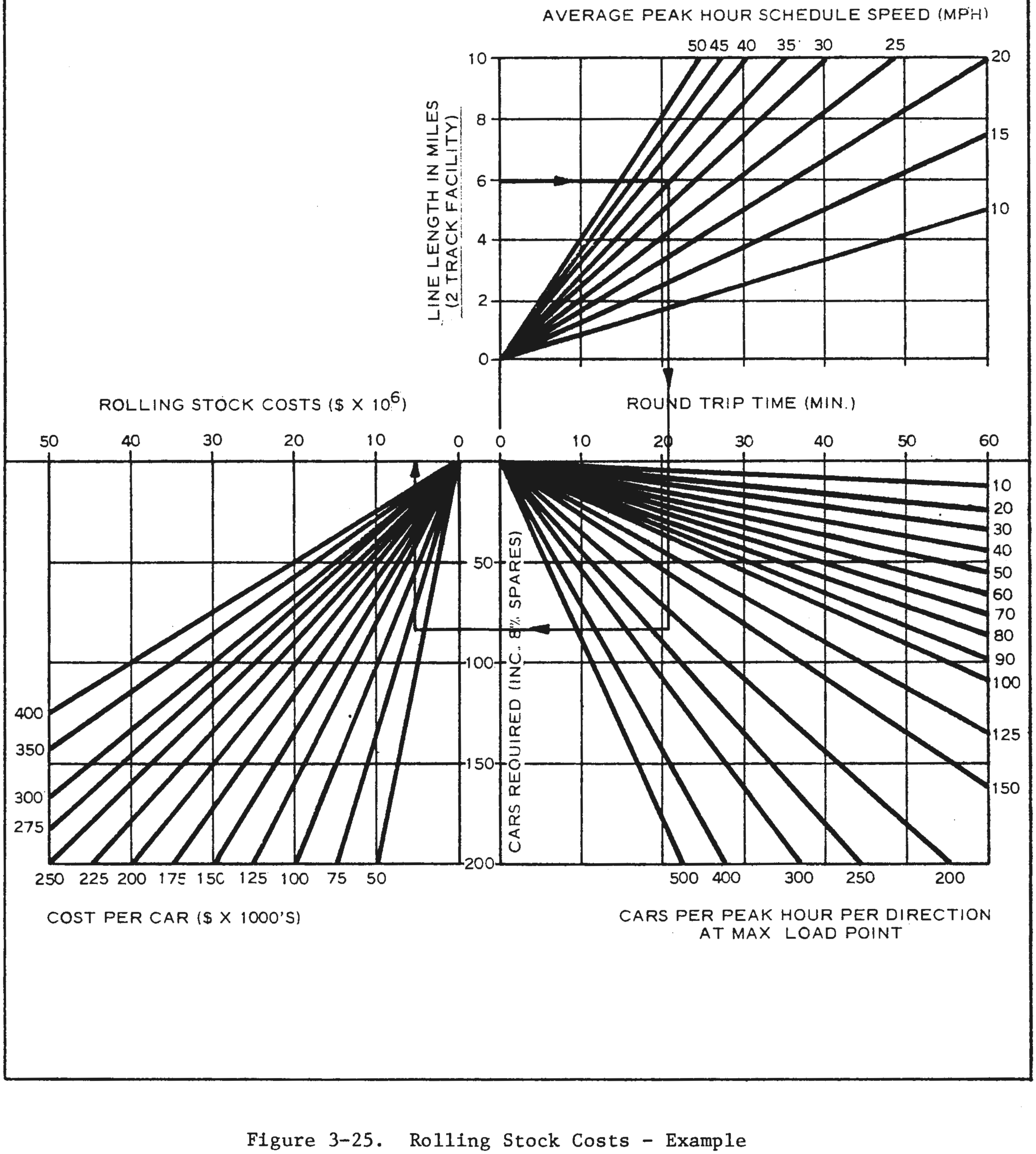


Figure 3-25. Rolling Stock Costs - Example

Input:	
Line length	6.0 miles
Desired overall operating speed	35 mph
Peak hour vehicles to be provided at maximum load point	227

Results:	
B6a. Round trip time	22 minutes
B6a. Cars required	84
B6b. Capital cost of rolling stock	$5.5 million

B7. Capital Costs (Figure 3-26)

Two components of capital costs are estimated in this graph: construction costs and right of way costs. Right-of-way costs can be constructed either as total costs or as adjusted net costs (excluding costs of right of way publicly owned or otherwise available at no capital expense).

When the right of way is shared by two transportation facilities, as when transit uses a freeway median, an appropriate allowance can be incorporated in the graph (as shown in the example below) for the allocation of right-of-way costs to the two facilities.

It should be noted that the unit construction cost in dollars per mile is usually an average for the entire length of line and for different types of construction (subway, elevated, at-grade). When more detailed information is available on the type of construction likely, it might be better to treat the line in segments distinguished by similar construction types and costs. The costs for the line segment are then aggregated into total construction costs for the entire line. A similar sequence of steps can be taken to derive total right-of-way costs.

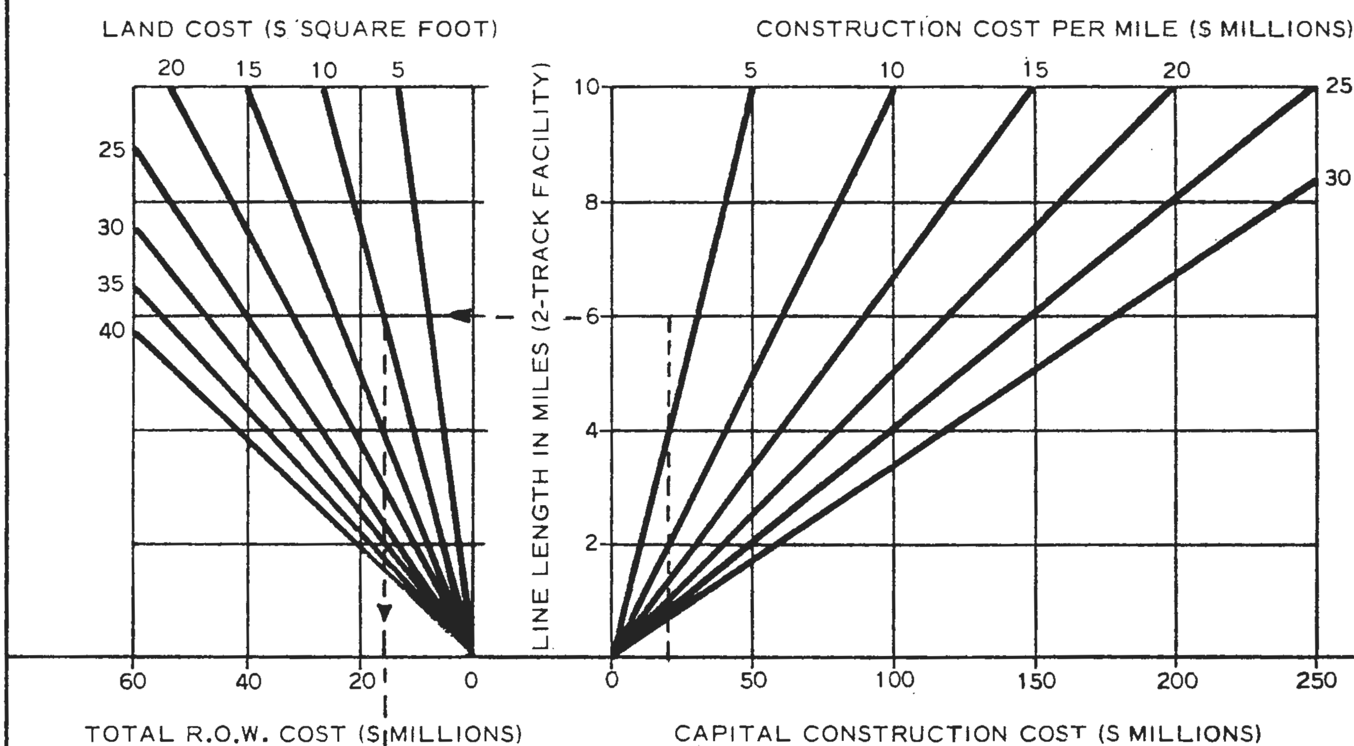
Construction cost as used in the graph includes the capital costs of all fixed facilities, such as roadway and tracks, stations and station acaess, yards and maintenance facilities, electrification, power distribution, and control equipment.* However, it excludes right-of-way and rolling stock capital costs, which are developed separately.

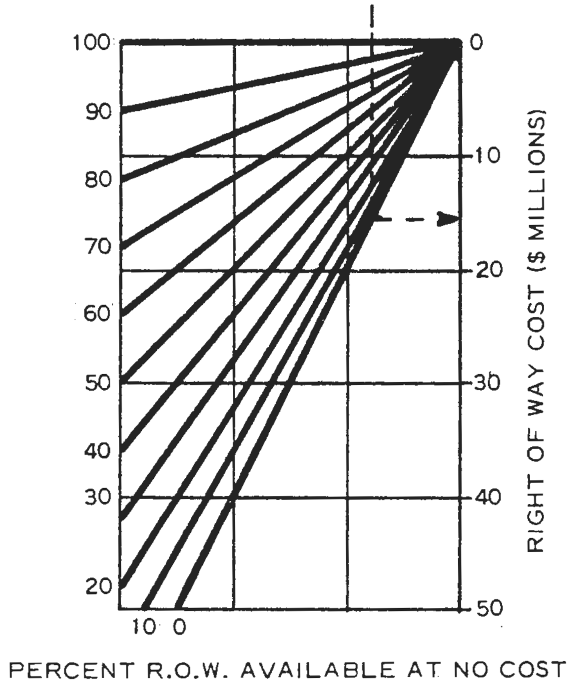
The example for capital cost computation, as illustrated in Figure 3-26 is based on the following data:

Input:	
Line length	6.0 miles
Construction cost	$3.9 million/mile
Right of way cost	$10/sq. ft.
Right of way width	50 feet

---

*See "Characteristics of Urban Mass Transportation Systems" (on UTPS computer tape: PB #233-580/AS, $4.75). Printed copies may be obtained by writing to address on Page iv.





CAPITAL COST SUMMARY

CONSTRUCTION COST	23,000,000
R.O.W. COST	16,000,000
SUBTOTAL	39,000,000
ROLLING STOCK COST	5,500,000
TOTAL CAPITAL COST	44,500,000

Figure 3-26. Capital Costs - Example

Results:

B7a.	Construction costs	$23 million
	Unadjusted right of way costs	$16 million
B7b.	Adjusted right of way costs	$16 million

B8. Cost Annualization (Figure 3-27)

This graph can be used to convert total capital costs into annual costs spread over the economic life of the facility. Capital cost components with different life spans require separate entries in the graph. Rolling stock and fixed facilities will generally involve different economic lives and possibly different annual interest rates.

An example of cost annualization, as illustrated in Figure 3-27, is based on the data below:

Input:

Total rolling stock cost	$5.5 million
Total construction cost	$23 million
Total right of way cost	$16 million
Rolling stock life	12 years
Construction cost life	30 years
Right of way life	100 years
Capitalization interest rate	7%

Results:

B8a.	Construction	$1,900,000 annual cost
	Right of way	$1,100,000 annual cost
	Rolling stock	$698,000 annual cost
B8b.	Total annual cost	$3,698,000
B8c.	Daily cost per rider = $3,698,000÷(3*x86,046) =	14¢

B9. Subsidy Requirement (Figure 3-28)

The manual sketch planning technique will frequently be used to prepare programs in which there is public involvement in financing. Figure 3-28, therefore, provides a means to summarize quickly the cost performance of a proposed system and to measure either the public subsidy required or the net profit that might be generated. The output from this graph is in terms of subsidy required or profit generated per rider.

An example of subsidy requirements is presented in Figure 3-28, based on the data below:

Input:

Daily revenues	$18,900
Daily riders	86,046
Daily operating cost per rider	56¢
Daily capital cost per rider	14¢

*This factor is derived by assuming 300 days/year and converting dollars to cents by multiplication of 100.

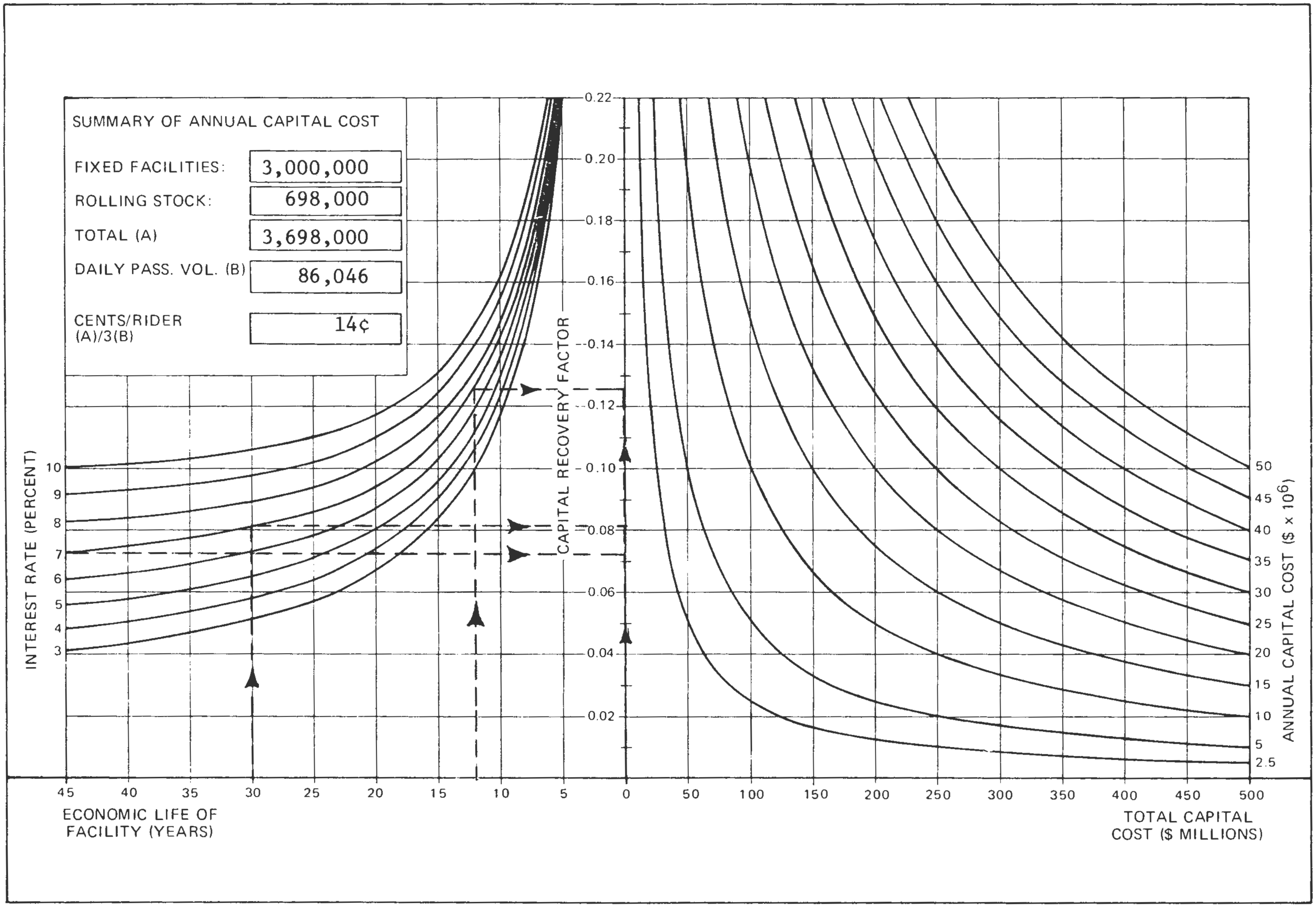


Figure 3-27. Cost Annualization - Example

REVERSE BLANK

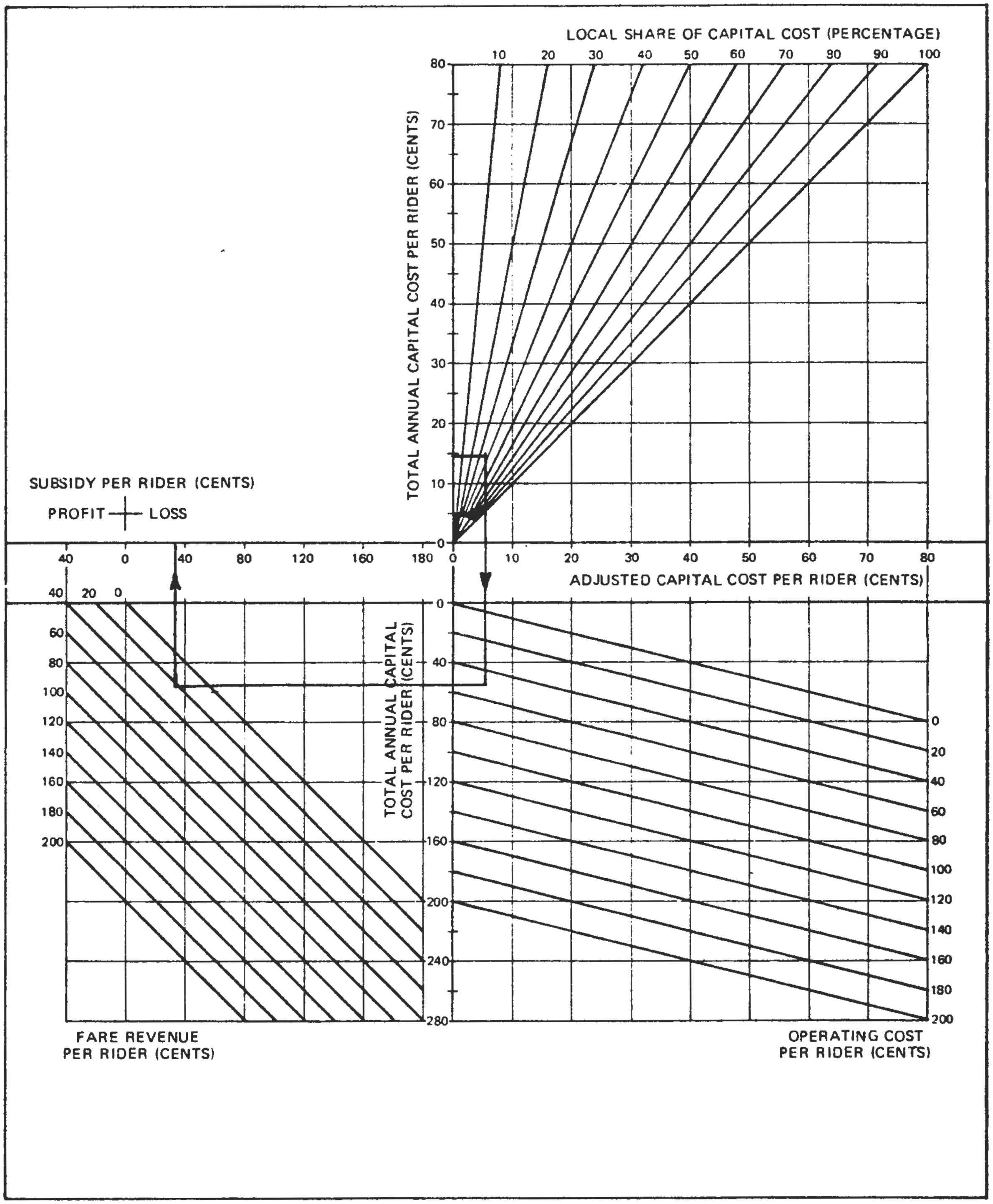


Figure 3-28. Subsidy Requirements - Example

Results:

B4b.	Fare revenue per rider	-22 cents
B2d.	Operating cost per rider	+56 cents
B8c.	Total annual capital cost rider	+14 cents
B9c.	Total cost per rider	+48 cents
B9a.	Non-local share of annual capital cost per rider	-09 cents
B9b.	Net subsidy per rider	+39 cents

Sensitivity Tests

Sensitivity tests are preliminary evaluations of the tradeoffs among the technical objectives and criteria of the project, its economic and financial feasibility, and its social and environmental effects. Only when these tradeoffs and their effects are known, in either quantitative or qualitative terms, can appropriate decisions be made.

The manual sketch planning technique facilitates sensitivity and tradeoff investigations with its graphic approach and modular arrangement of planning steps. By reversing his path through individual graphs or the sequence of graphs (or phases), the user can in several ways test his assumptions in specific areas.

For example, a user might want to determine the per-rider fare needed to operate an express bus at a given service level in a break-even operation (where fare revenues equal operating costs). In this case the user would go through the following steps:

a. Assume desired bus frequency during the peak hour and determine the number of buses required per peak hour in peak direction, assuming two minute headway of 30 buses per hour (from Figure 3-29).

b. Enter Figure 3-30 at the "Cars Per Peak Hour" axis and determine daily patronage at maximum load point (2000) and, assuming a six mile length of line and $1.50 per mile daily operating costs ($5,400).

c. Convert maximum load point volume to total line volume (14,000) and calculate the flat fare that would be required to produce fare revenues ($5,400) equal to daily operating cost. Answer = 39¢

d. Compare total line volume with current bus volumes observed in the general corridor served by the proposed express bus route and determine whether the projected express bus patronage appears reasonable. (If desired, the established break-even fare level can be fed back into the Demand Estimation phase to determine the likely effect on patronage. See Figure 3-24.)

The resulting patronage and fare levels can be compared with existing demands and fares in the corridor to decide if the express bus line is a viable proposal.

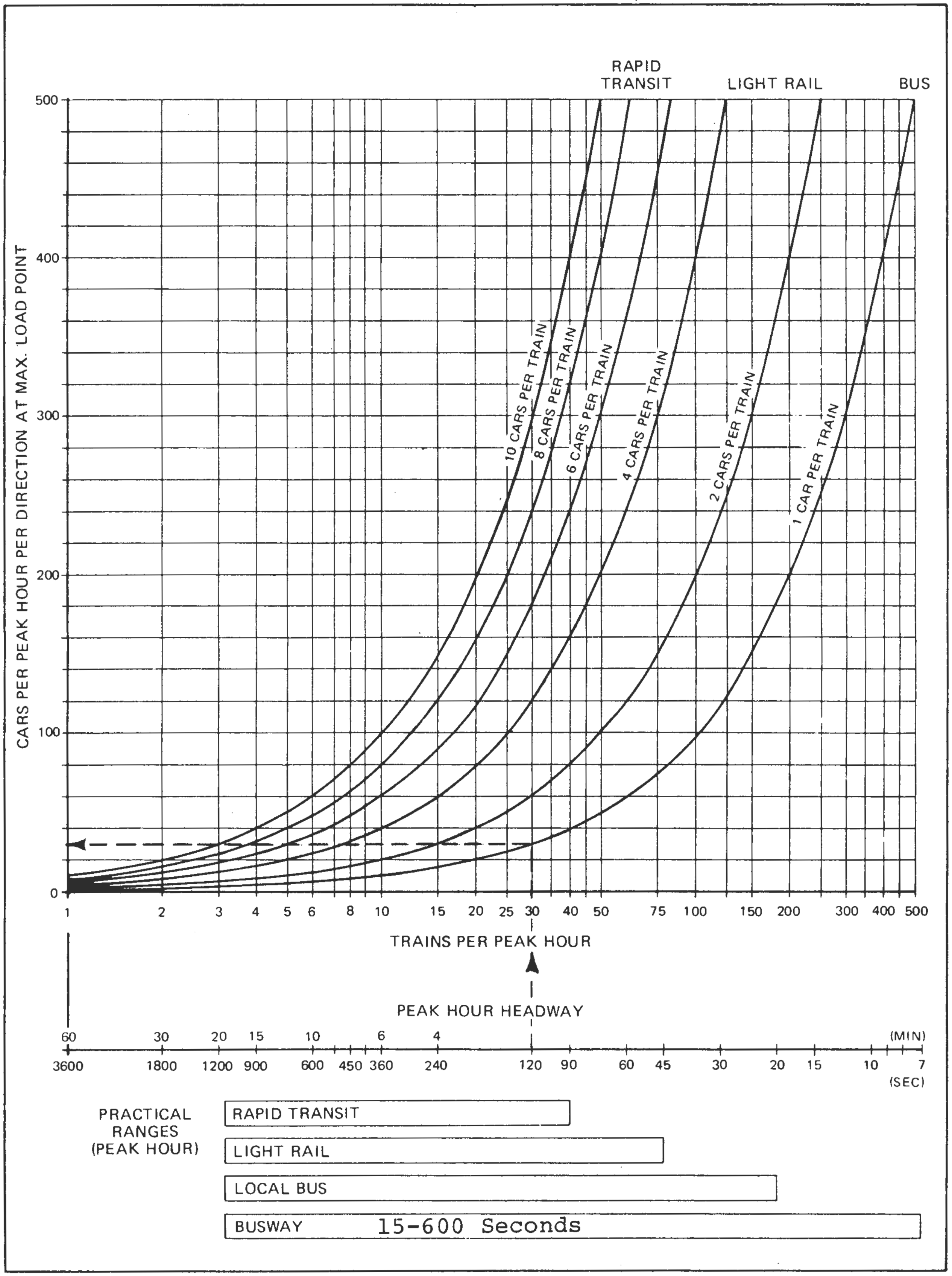
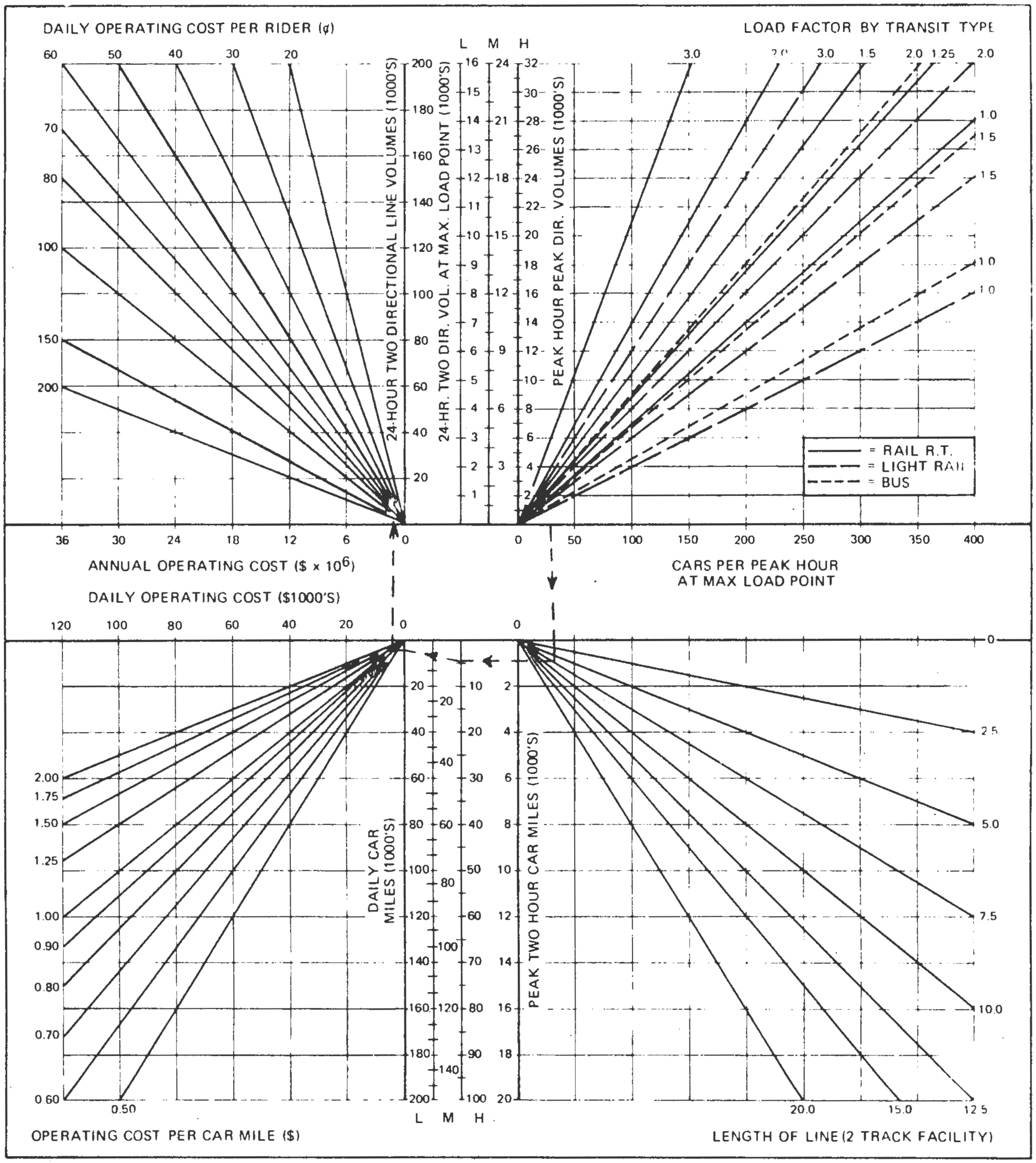


Figure 3-29. Vehicle Frequency Check Sensitivity Test - Example

REVERSE BLANK



Conversion factor (from peak hour peak direction to 24-hour two-directional volume)

$$\frac{\text{24-hour two-directional volumes}}{\text{peak hour peak direction volume}} = \frac{86{,}046}{12{,}730} = 6.76 = 7.0$$

Figure 3-30. Operating Costs Sensitivity Test - Example

The simplified example above indicates the type of problems and questions that the user can handle with the manual technique. More complex situations might require iterations through several steps and possibly some side calculations. The manual technique, however, gives the user a useful framework for analyzing the multitude of interactions between technics and policy in urban transportation planning.

REVERSE BLANK

PHASE C. IMPACT EVALUATION

Transportation systems affect the infrastructure of an urban region many ways. These effects, not necessarily related to flow of traffic, should be carefully weighted in the selection of transportation systems. In many cases these effects can be measured, but it is very difficult and often inappropriate to devise a single measure for them all. Accordingly, herein is presented a series of measures that can be used, tentatively experimented with, or rejected by the user according to their appropriateness within his community. The effects and their measures to be considered here are:

- Air pollution
- Energy consumption
- Accidents

These are, of course, only a few of the items that might be considered, but they are pertinent and conveniently quantifiable. The procedures outlined in this section are predicated on present technology and federal legislation. These matters must be reviewed constantly because they are in a state of constant change; and there are state laws and local ordinances that vary greatly from place to place.

1. Air Pollution

In the past few years, there has been a developing awareness that air quality affects health and well-being. The Congress has established emission standards for vehicles and stationary operations and passed laws dealing with the minimum air quality of an urban region. Therefore it is essential that the planner consider the air pollution effects of any transportation system he investigates. Table 3-6 lists the emission factors for present urban transportation modes. The factors are stated in units of grams of emissions per vehicle mile of travel. By multiplying these factors by the vehicle miles, the user can determine the average daily emissions by a system.

2. Energy Consumption

One goal of transportation planning should be to conserve fuel, for reasons of economy and of public policy. Table 3-6 also presents energy consumption factors for present urban transportation modes. The factors are specified in British Thermal Units (BTU's) per mile. They assume that a gallon of gasoline has 130,000 BTU's and that a kilowatt-hour is equivalent to 3,413 BTU's. By multiplying energy consumption factors by daily vehicle miles, the daily consumption of energy can be determined by each system.

Table 3-6. Emission, Energy Consumption, and Accident Factors

EMISSION FACTORS

	Pollutant (Grams per Vehicle Mile)		
	CO	HC	No_x
Gasoline Powered Automobiles(1973)*	68.95	9.53	4.54
Diesel Buses	10.90	14.70	13.84
Electric Rail (Oil Generated)	0.0068	0.54	17.69
Electric Rail (Coal Generated)	0.45	0.19	18.60

ENERGY CONSUMPTION FACTORS

Private Vehicles*	7,500 BTU's/Vehicle Mile
Buses	30,000 BTU/s/Vehicle Mile
Rapid Transit	18,116 BTU's/Vehicle Mile

ACCIDENT FACTORS
(per million vehicle miles)

	Fatalities	Total Passenger Accidents
Private Vehicles*	0.034	2.9
Buses	0.088	21.5
Rapid Transit	0.175	38.5

*Private vehicle assumptions: (a) average speed of 20 mph on arterial streets, (b) gasoline consumption of 0.058 gallons per mile, (c) 30% of VMT on freeways, 35% on arterials, 35% on local (accident factors).

3. Accidents

A considerable amount of time and effort has been spent to investigate the causes of traffic accidents and to derive techniques to reduce them; and transportation systems should be planned with an awareness of the accident problem and of the efforts being made to solve it. Table 3-6 lists average accident rates by type (per million vehicle miles) for present urban transportation modes. These rates, applied to vehicle mileage, yield an expected number of accidents for each alternative investigated.

Air pollution, energy consumption, and accidents for the example in Sections IIIA and IIIB above are calculated by multiplying the factors presented in Table 3-6 by the daily vehicle miles obtained in the Phase B analysis. The daily vehicle miles figure of 27,200 was obtained from Figure 3-21. The calculations are depicted in Table 3-7.

Table 3-7. Example Calculations of Impact Factors

Air Pollution	
- Carbon Monoxide (CO)	
	10.90 x 27,200 = 296,480 (grams per day)
- Hydrocarbons (HC)	
	14.70 x 27,200 = 399,840 (grams per day)
- Oxides of Nitrogen (NO_x)	
	13.84 x 27,200 = 376,448 (grams per day)
Energy Consumption	
	30,000 x 27,200 = 816,000,000 (BTU per day)
Accidents	
- Fatal	0.088 x 27,200 ÷ 10^6 = 0.0024 (persons per day)
- Total	21.5 x 27,200 ÷ 10^6 = 0.5848 (persons per day)

4. Summary Evaluation

Although no attempt is made to provide a single common measure for the impact factors listed above, there should be a summary sheet of impact values for each proposed system; and the results should be indexed for purposes of comparison.

This summary report and appropriate data displays will become valuable decision-making tools, not only for the planner himself but for the various publics with which he deals.

The output summary sheet of the quantifiable results yielded by the manual technique can be developed as shown in Table 3-8. This form summarizes, for each system studied, the important outputs from the three

Table 3-8. Summary Sheet of Outputs from Manual Technique
- Case Study -

Number	Output	Alternative I	Alternative II
1	Total Daily Line Volume (Passengers)	86,046	
2	Daily Passenger Volume at Maximum Load Point	12,730	
3	Annual Operating Cost ($)	14,550,000	
4	Operating Cost per Rider (cents)	56	
5	Peak Hour Headway (seconds)	16	
6	Annual Fare Revenue ($)	5,100,000	
7	Fare Revenue per Rider (cents)	22	
8	Rolling Stock Required (cars)	84	
9	Rolling Stock Cost ($)	5,500,000	
10	Right of Way Cost ($)	16,000,000	
11	Construction Cost ($)	23,000,000	
12	Total Capital Cost ($)	44,500,000	
13	Annual Rolling Stock Cost ($)	698,000	
14	Annual Construction and Right of Way Costs ($)	1,900,000 1,100,000	
15	Annual Total Capital Cost ($)	3,698,000	
16	Annual Capital Cost per Rider (cents)	14	
17	Air Pollution (grams per day) Carbon Monoxide (CO) Hydrocarbons (HC) Oxides of Nitrogen (NO_x)	 296,480 399,840 376,448	
18	Energy Consumption (BTU per day)	816,000,000	
19	Accidents (per day) Fatal Total	 0.0024 0.5848	

phases of the technique. Table 3-8 summarizes the outputs of the example with the assumption of a 25¢ flat fare. The form can be easily expanded, if desired, to include more than two alternatives or to allow for columns of index ratios or of differences between alternatives. These measures can then be weighted, ranked, and evaluated by the user according to the needs and objectives of his community.

Generally, local situations dictate the form of such summaries and suggest the relative emphasis placed on cost and impact elements. Not only quantifiable impact measures, but nonquantifiable and non-monetary effects of transportation alternatives should be analyzed, identified, and presented where appropriate in the summary.

DEVELOPING LOCALIZED MODELS

The simultaneous distribution/mode split model presented at the beginning of this chapter was developed from test data to specifically address the work trip type. Test data suggested it is appropriate to square each impedance when estimating travel between districts by each mode. Other work* has shown it is possible to develop mathematical relationships to determine the modal share of the home-based non-work and non-home-based trip types, also. Additionally, the research, and subsequent application of several models that have been developed, indicates a method for determining the calibration exponent that should be applied to the transit and highway impedance values.

This section is presented to provide guidance, at the discretion of the analyst, for determining calibration exponents based on locally available transportation planning data and, for developing application methods to address the non-work trip types. Generally, the application procedure for estimating transit demand is not changed although the user must exercise care in stating the input assumptions of the impedance quantity. Once the demand estimate is determined, the cost and impact analyses can proceed as presented.

Determining Localized Impedance Exponents

Phase A presented the mathematical expression for determining district-to-district trips by mode as:

$$T_{ij}^{\ell} = P_i \frac{A_j \, (I_{ij}^{\ell})^{-2}}{\Sigma_j \Sigma_{\ell} \, (I_{ij}^{\ell})^{-2}}$$

The impedance exponent (-2) has been determined from observed data using a constrained statement of impedance. The exponent applies to the work trip type. The referenced research has also shown the same impedance exponent can be derived graphically from the work purpose distribution factor curve used to apply the gravity model. The conclusion is that the estimator for mode determination behaves in a manner similar to the observed distribution of person travel for any given trip purpose.

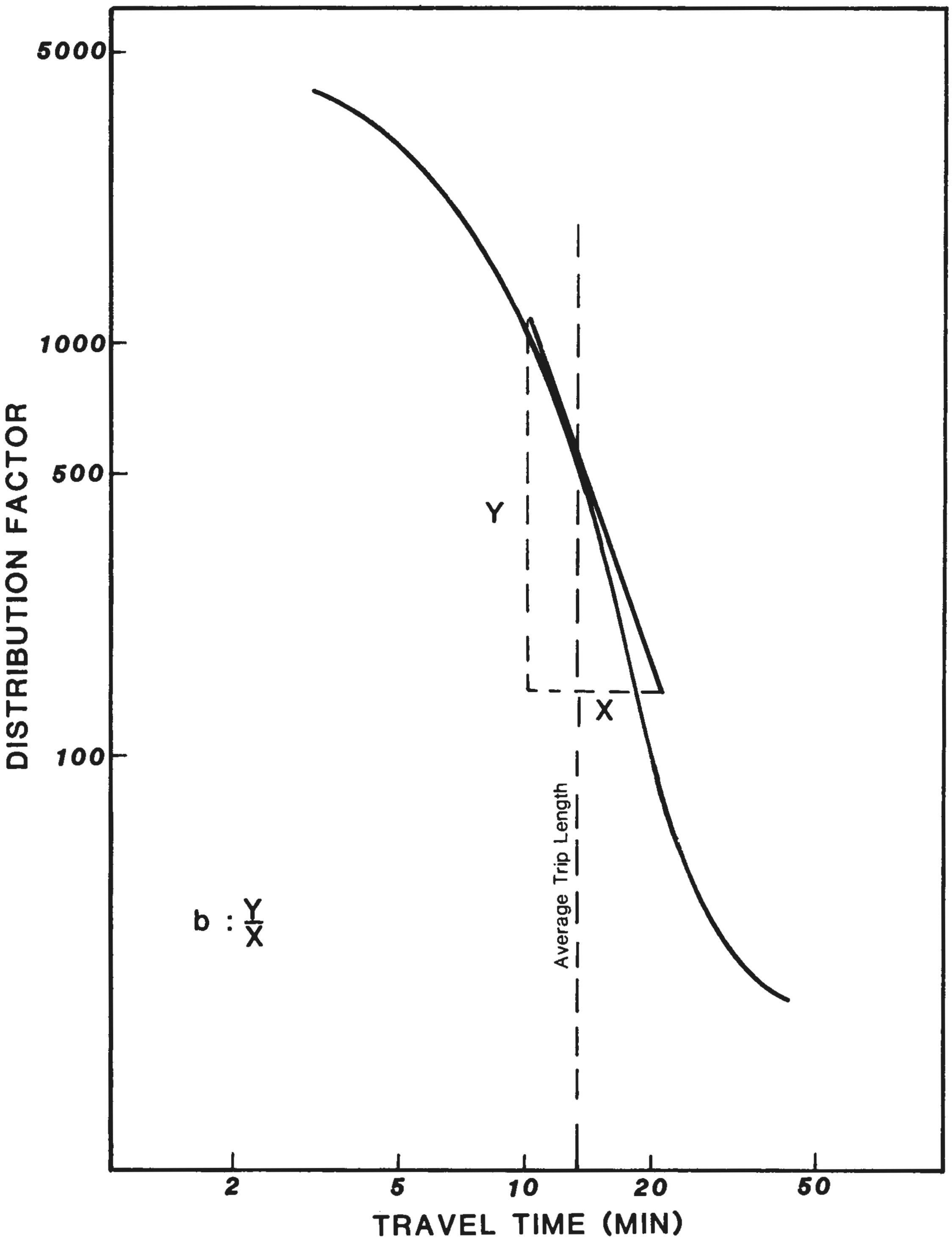
Development of localized impedance exponent is accomplished through the analysis of local trip distribution factor plots. Figure 3-31 shows a typical charting of trip distribution factors and travel time (log-log representation).

The impedance exponent has been defined as the slope of a tangent to the distribution factor curve constructed at the point of intersection of the distribution factor curve and the average trip length for the specific trip purpose.

---

*COMSIS Corporation, NCHRP Report 187 - *Quick Response Urban Travel Estimation Manual Techniques and Transferable Parameters - Users Guide;* Washington, D.C.; 1978.

Figure 3-31
Calibration of Impedance Exponent Using Gravity Model Distribution Factors



The analyst should carefully construct a tangent to the distribution factor curve at the average trip length and measure the x and y components in linear units. It is not necessary to measure the actual units of the scales. The slope of the tangent, b, is the vertical value, y, divided by the horizontal value, x. Hence the localized purpose specific impedance value is y divided by x. Care should be taken to observe that the slope of distribution factor curves is negative and the sign is a part of the exponent value.

Similar models have been developed for urban areas including Washington, D.C.; San Diego, California; Boise, Idaho, and Atlanta, Georgia. The impedance exponent of each model developed has been determined via the above method. Models have been developed for three trip purposes including home-based work, home-based non-work and non-home-based. Additionally, an analysis of generalized trip distribution factors from several urban areas has provided general guidance with regard to how the impedance exponent changes from one trip purpose to another. Should an urban area wish to extend this sketch planning method to the other trip purposes, but not have local trip distribution models, the following impedance exponents may be used.

Trip Purpose	Generalized Impedance Exponent
Home-based work	-2.0
Home-based non-work	-3.0
Non-home based	-2.7

Further analysis of the several trip distribution models has concluded there is little variability, by size of urban area, in the slope of a tangent at the point where the distribution factor curve crosses the average trip length time. Hence, the above generalized impedance exponents will provide results consistent with the level of detail of the overall method.

Should the user elect to perform a corridor analysis by trip purpose, the only modification to the demand analysis is the accumulation of transit trips rather than a factoring of the work trips to represent total daily transit patronage.

Impedance Specification for Non-Work Trip Types

The statement of impedance for the non-work trip types usually reflects conditions associated with a time of day other than the peak period. Obviously, this is a generality since some non-work travel does occur during the peak periods. The discussion presented here amplifies previous comments concerning the modification of individual impedance assumptions based upon local conditions. The assumptions used in the development of the auto and transit curves included in this report are presented in Appendix A. The following discussion is organized in similar fashion to the presentation in Appendix A.

The major component of the auto impedance that should be reviewed is the parking cost level at the trip destination. The Auto Curves as developed can be used in their current form. Parking cost for non-work trips is generally determined as the cost to park within the zone or district for a two hour period. Depending upon the parking pricing structure of the urban area, it may be equal to or less than the parking change associated with a work trip having a nine hour duration.

For the transit impedances, the analyst should evaluate the out-of-vehicle travel times that may be relevant to the base operating period, and the base period fare structure. The analyst may wish to increase the walk and wait or the transfer and wait times shown in Appendix A, Table A-3. As a general rule, the wait time for the initial boarding point should be not greater than fifteen minutes and the wait time associated with a transfer may reach one-half of the headway of the route an individual is transferring to.

The Transit Curves presented in Appendix A may be modified to reflect new impedance assumptions by calculating revised total weighted impedances as shown in Appendix A.

APPENDIX A
ALTERNATIVE TRANSPORTATION SYSTEMS IMPEDANCE CURVES

The first part of this appendix describes basic input values, stratifications, and those transportation network input values used to construct the impedance curves for both auto/highway and transit systems. This is followed by the impedance curves themselves.

1. Auto/Highway System

The curves are stratified by four parking cost ranges, three levels of running costs,* and four levels of speeds. A total terminal or access time of five minutes, weighted by a factor of 2.5, is also incorporated in each curve. All out-of-pocket costs, including one-half of the parking costs, are converted to equivalent minutes of impedance by dividing them by 2.5 cents per minute. (This is equivalent to $9,000 annual income.) The 2.5 cents per minute conversion factor is determined from research that indicates the individual values his non-working time at one-third of his working time. Thus, an annual income of $9,000 is equivalent to 7.5 cents per minute and one-third of the income per minute is equal to 2.5 cents. Airline distance, which is used to measure district-to-district distance, is multiplied by 1.27 to approximate over-the-road distance. The resulting over-the-road distance is used to calculate running times and equivalent times for running cost. Table A-1 below shows the nine-hour parking cost ranges, the range average, and equivalent time in minutes that have been incorporated in the disutility calculation for curves.

Table A-1. Impedance Equivalence of Parking Cost Levels

Parking Cost Levels	Average	Equivalent Time For One-Way Trip
Less than 75¢	$0.37	7.4
.75 - $1.40	1.07	21.5
$1.40 - $2.50	1.95	39.0
Over $2.50	3.00	60.0

The equivalent time is the time attributed to a one-way trip. Only half of the nine-hour parking charge is attributed to the inbound or home-to-work trips.

Following are sample impedance values calculated for distances of one, five, and ten miles, and subsequently used to construct an impedance curve incorporating a parking cost of less than 75¢, a running cost of five cents per mile, and an operating speed of ten mph. Given an operating cost, operating speed and trip distance, the net effect of a parking charge is a vertical shift in the impedance curve. The slope of the curve remains constant. To reduce the total number of curves, multiple vertical scales, representing parking cost levels, have been incorporated onto a single impedance nomograph.

*Running costs include only those costs identified as out-of-pocket: fuel, oil, tolls and maintenance. Depreciation and insurance costs are not included.

Item	Value	Weighting Factor		Weighted Impedance
Terminal time	= 5 min.	x 2.5	=	12.5 min.
Parking cost	= 37 ÷ (2.5)	x 1/2	=	7.4 min.
Total				19.9 min.

The above values remain constant for a trip of any distance under consideration. As such, these are added to distance dependent values to calculate total weighted impedance times for any distance.

Table A-2. Sample Calculation of Weighted Impedance for Selected Airline Distance (Operating Speed of 10 mph and Operating Costs of 5¢/Mile Assumed)

Air Line Distance (miles)	Over the Road Distance (miles)	Running Time (minutes)	Running Cost In Equivalent Time (minutes)	Total Weighted Impedance Time (minutes)
1.0	1.27	7.6	2.5	30.0
5.0	6.35	38.1	12.7	70.7
10.0	12.70	76.2	25.4	121.5

2. Transit System

Transit curves have been developed and stratified by (a) access modes (walk, local bus, and auto) at the origin end of the trip and the presence or lack of a downtown distributor on the destination end, (b) alternative line-haul systems (local bus, rapid bus, rapid rail), and (c) fares. Fares (in cents) are converted to equivalent times by dividing them by 2.5 cents per minute. Access times, such as walking, waiting, and transfer, are weighted by multiplying them by 2.5. Table A-3 shows the access times and travel times and/or speeds assumed for each stratification.

The following are sample calculations for rapid rail line-haul or non-integrated bus rapid systems with a bus feeder access:

Table A-3. Access and Transfer Time and Line-Haul Operating Speed Assumed in Impedance Curve Derivation

Access Mode	Line-Haul Mode	Unweighted Time (minutes)				
		Walk & Wait	On Access Feeder[1]	Transfer & Wait	Walk	Line-Haul Speed (mph)[2]
Walk	Conventional Bus	15	0	0	5	15
	Bus Rapid (R)[3]	15	0	0	7	35
	Bus Rapid (C)	15	0	0	5	20
	Rail Rapid	15	0	0	7	35
Bus	Integrated Bus Rapid (R)	15	6	0	7	35
	Integrated Bus Rapid (C)	15	6	0	5	20
	Non-Integrated Bus Rapid (R)	15	6	5	7	35
	Non-Integrated Bus Rapid (C)	15	6	5	5	20
	Rail Rapid	15	6	5	7	35
Auto[4]	Conventional Bus	1	3	7	5	15
	Bus Rapid (R)	1	3	5	7	35
	Bus Rapid (C)	1	3	5	5	20
	Rail Rapid	1	3	5	7	35

1. The access time on feeder systems (bus or highway) are averages. If the values presented in this table are not consistent with the level of service specified by the user, they should be modified to reflect the average time spent on feeder systems in the district(s) under consideration.

2. These speeds are taken from K. Bhatt's "A Comparative Analysis of Urban Transportation Costs" presented at the 54th Annual Meeting of Transportation Research Board, January 1975.

3. (R) - Bus operation on (R)ight-of-Way on a downtown distributor.
(C) - Bus (C)ompetes with auto traffic in downtown distributor area.

4. If parking charges are assessed at a park-and-ride lot for the auto access mode, these could be accounted for by converting them to equivalent time as is done with the downtown parking charges for the auto impedance curves in Table A-1.

With the assumption of a 25¢ fare, the constant non-interchange specific values for this system are:

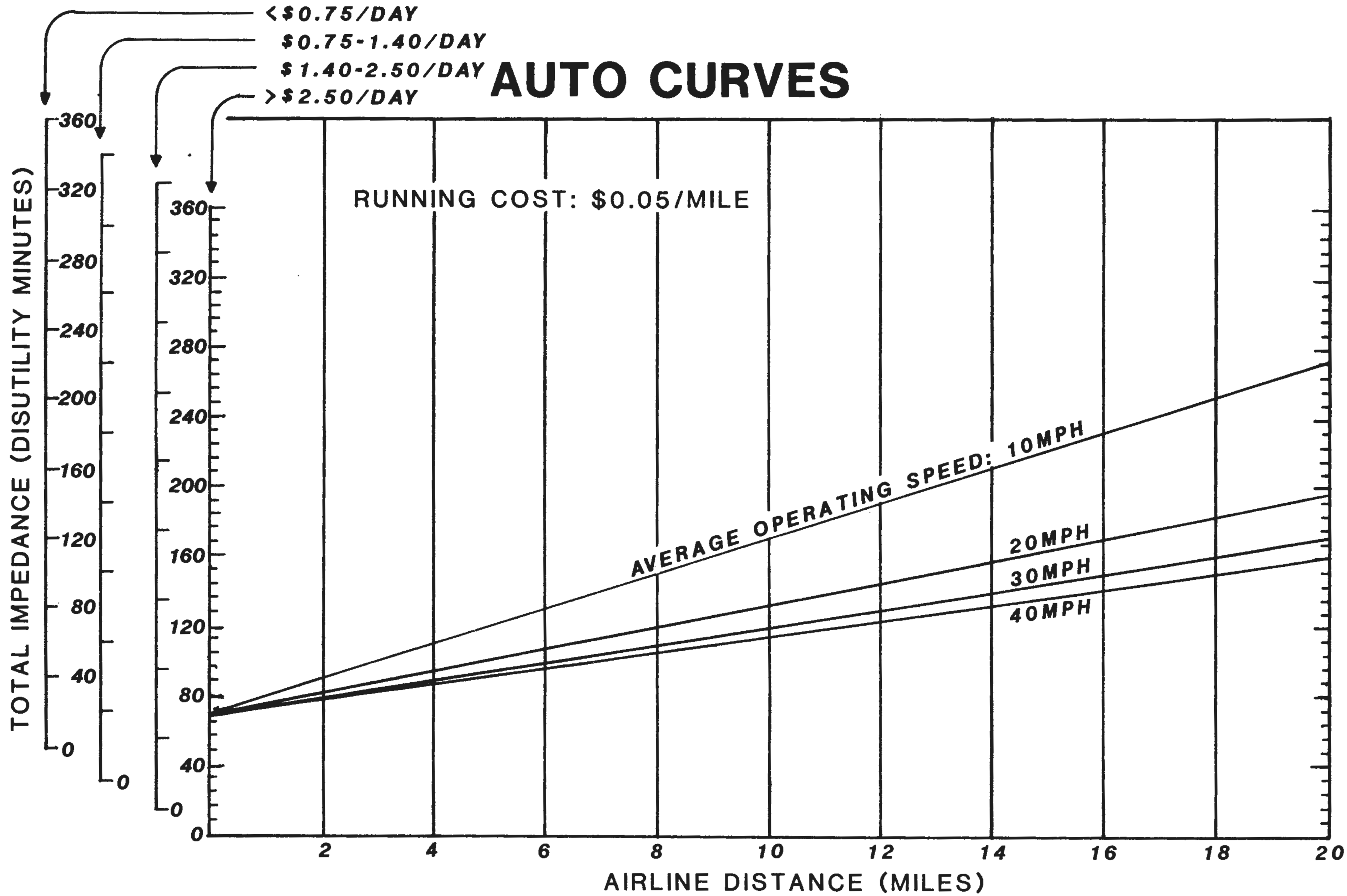
Item		Value		Weighting Factor		
Fare	=	25	÷	2.5	=	10 min.
Total Walk & Wait	=	(15+5+7)	x	2.5	=	68 min.
Travel time by feeder	=	6.0	x	1.0	=	6 min.
Total non-interchange specific fixed weighted impedance						84 min.

The following are the distance dependent values and the resultant total weighted impedances for the same systems, for selected distances:

Distance (miles)	Line-Haul Travel Time* (minutes)	Total Weighted Impedance
1.0	1.7	85.7
5.0	8.6	92.6
10.0	17.2	101.2

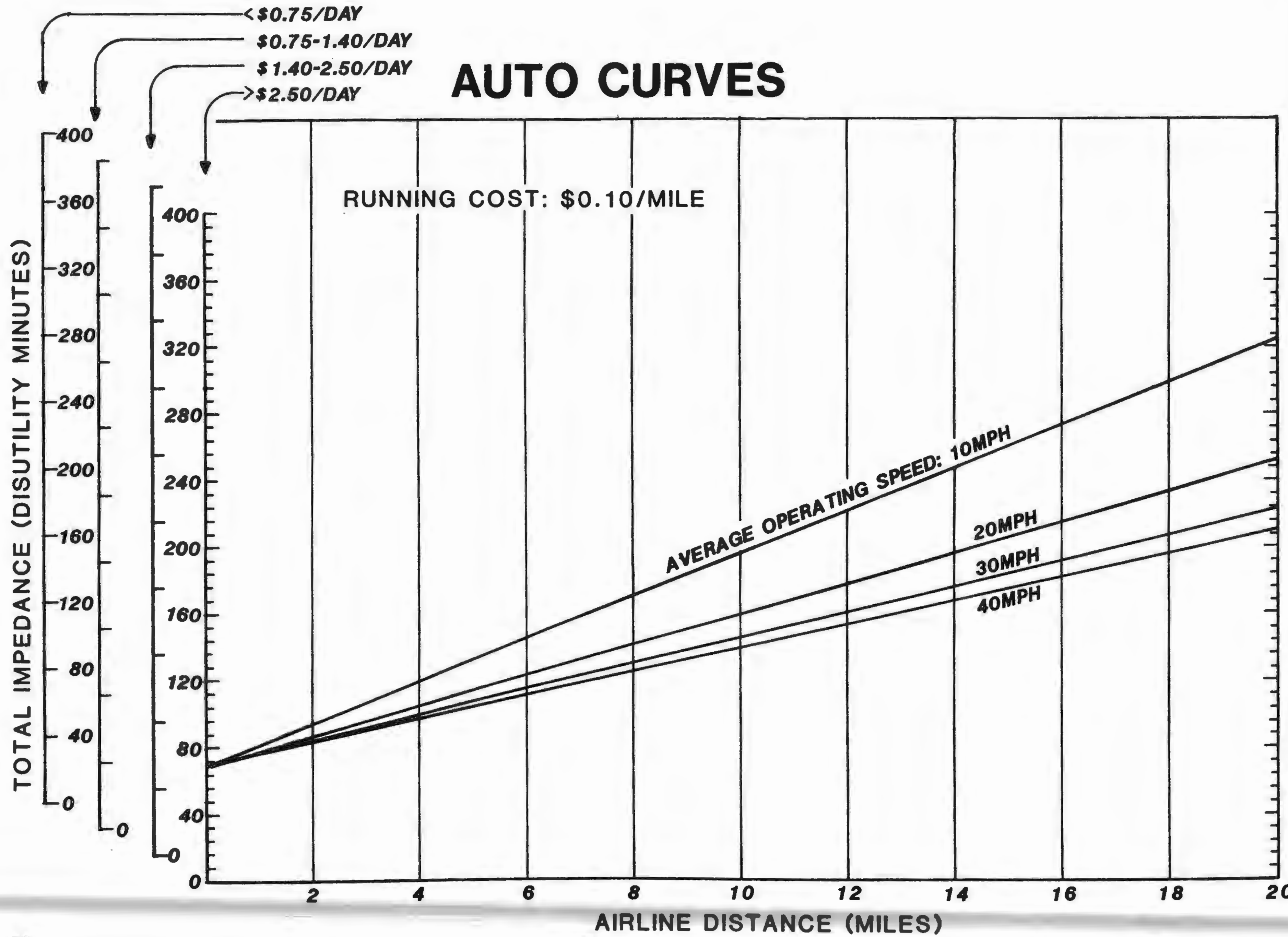
*A line-haul speed of 35 miles per hour is assumed in order to derive travel time values.

AUTO CURVES

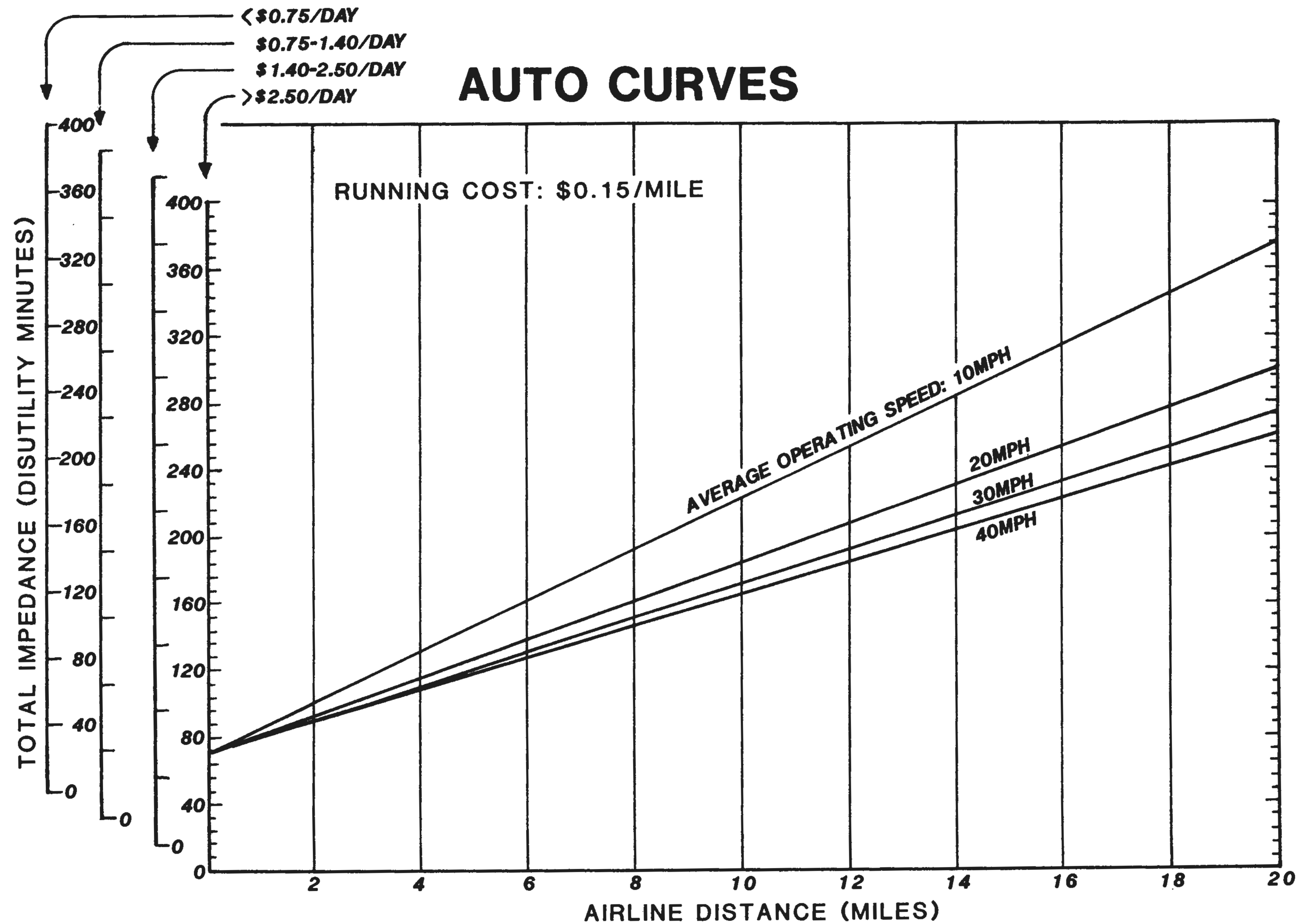


<$0.75/DAY
$0.75-1.40/DAY
$1.40-2.50/DAY
>$2.50/DAY
RUNNING COST: $0.05/MILE
AVERAGE OPERATING SPEED: 10MPH
20MPH
30MPH
40MPH
TOTAL IMPEDANCE (DISUTILITY MINUTES)
AIRLINE DISTANCE (MILES)
0
2
4
6
8
10
12
14
16
18
20
0
40
80
120
160
200
240
280
320
360

AUTO CURVES



<$0.75/DAY
$0.75-1.40/DAY
$1.40-2.50/DAY
>$2.50/DAY
RUNNING COST: $0.10/MILE
AVERAGE OPERATING SPEED: 10MPH
20MPH
30MPH
40MPH
TOTAL IMPEDANCE (DISUTILITY MINUTES)
400
360
320
280
240
200
160
120
80
40
0
2
4
6
8
10
12
14
16
18
20
AIRLINE DISTANCE (MILES)

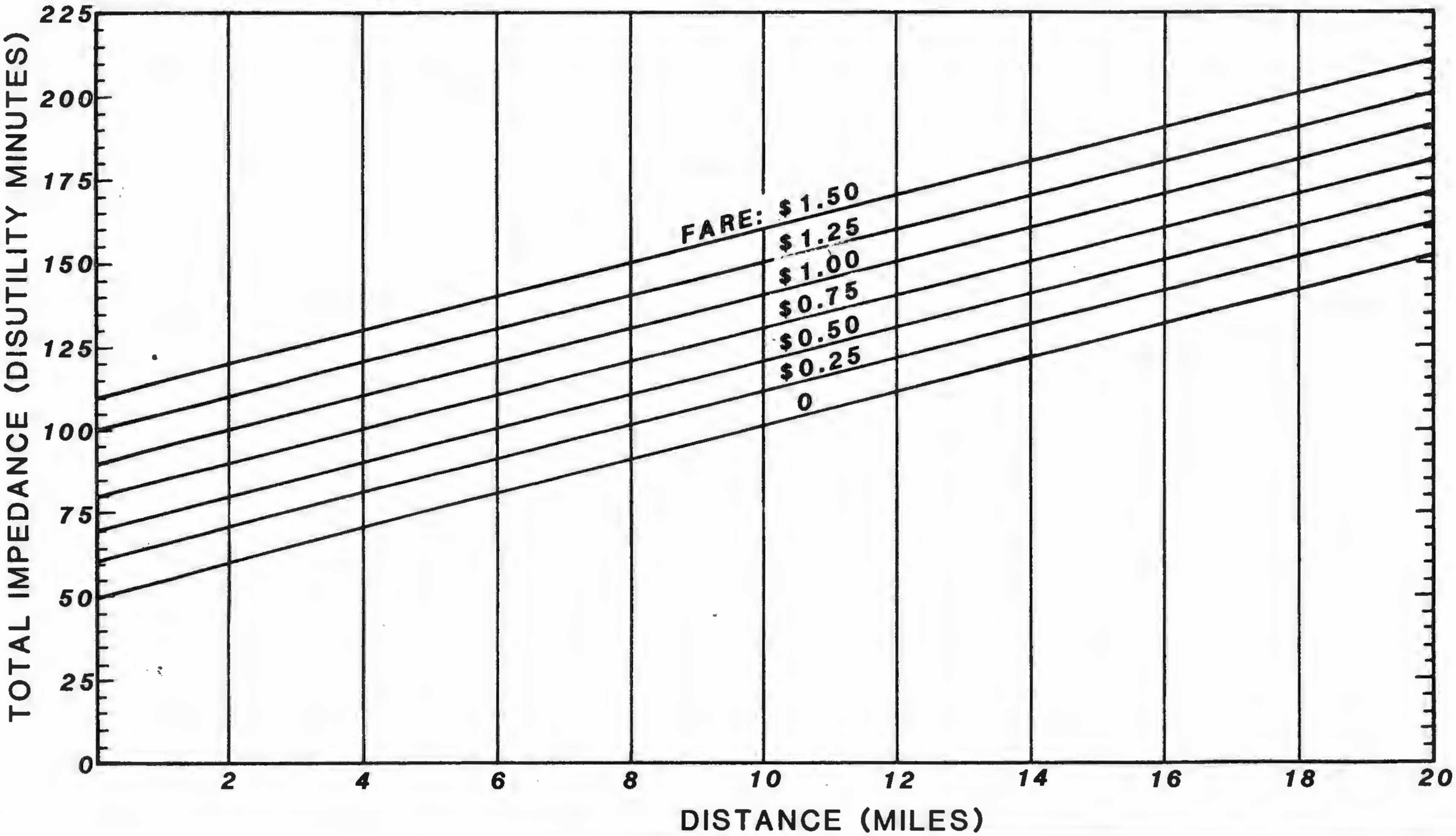


< $0.75/DAY
$0.75-1.40/DAY
$1.40-2.50/DAY
> $2.50/DAY
AUTO CURVES
RUNNING COST: $0.15/MILE
TOTAL IMPEDANCE (DISUTILITY MINUTES)
AIRLINE DISTANCE (MILES)
AVERAGE OPERATING SPEED: 10MPH
20MPH
30MPH
40MPH
0
40
80
120
160
200
240
280
320
360
400
2
4
6
8
10
12
14
16
18
20

TRANSIT CURVES

MAIN LINE: Conventional Bus

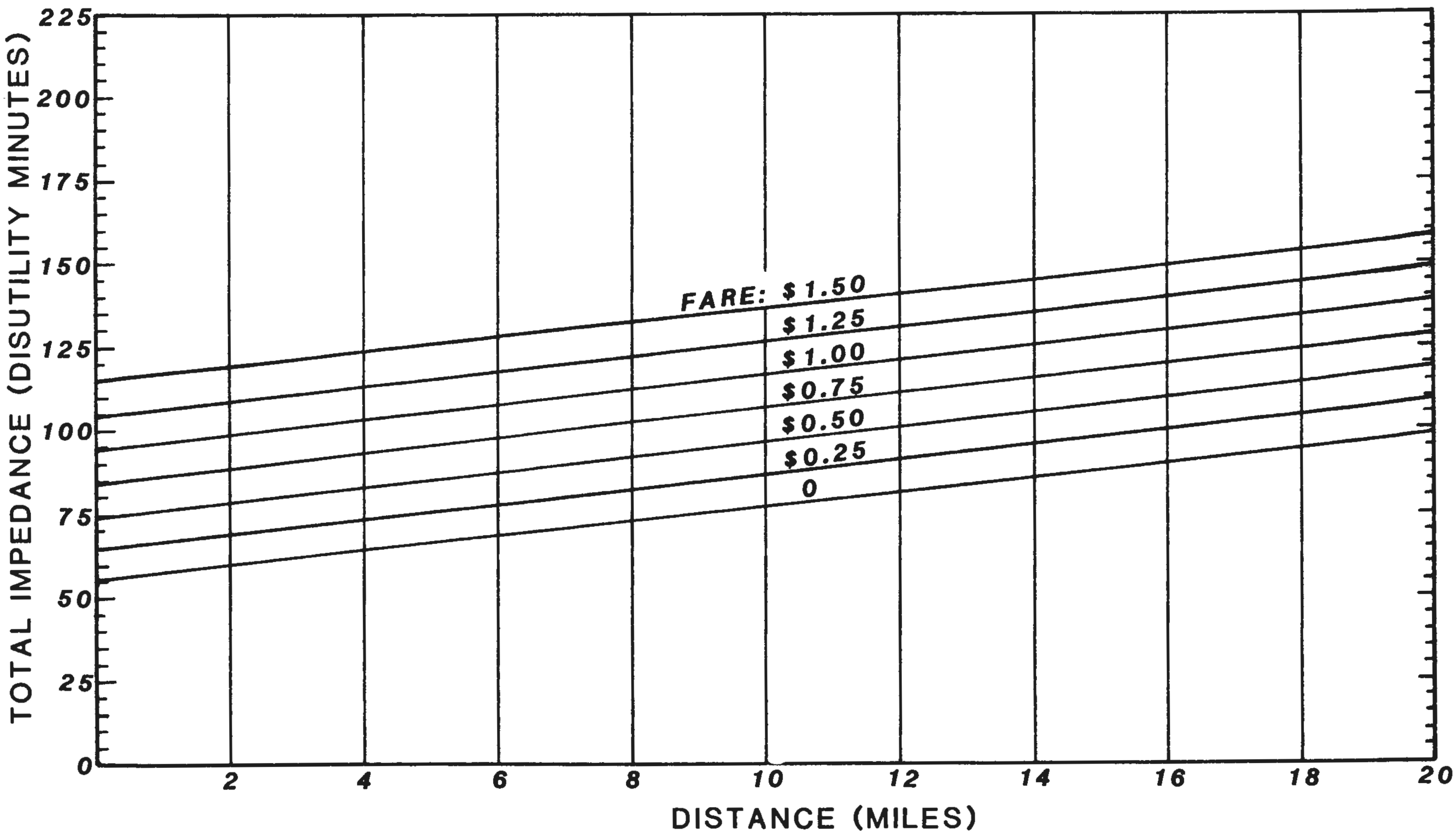
ACCESS: Walk



TRANSIT CURVES

MAIN LINE: Rail Rapid or Bus Rapid(R)

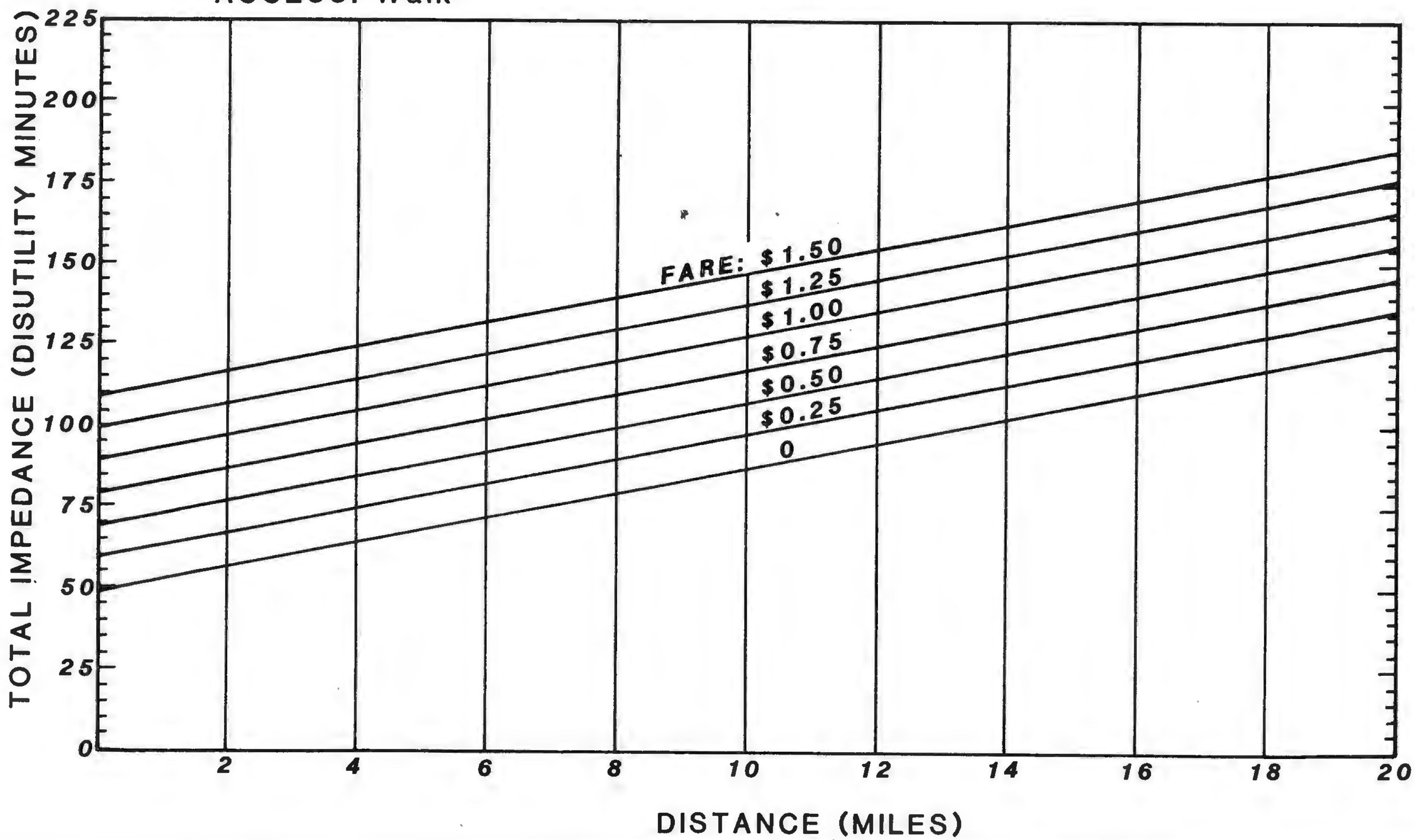
ACCESS: Walk



TRANSIT CURVES

MAIN LINE: Bus Rapid(C)

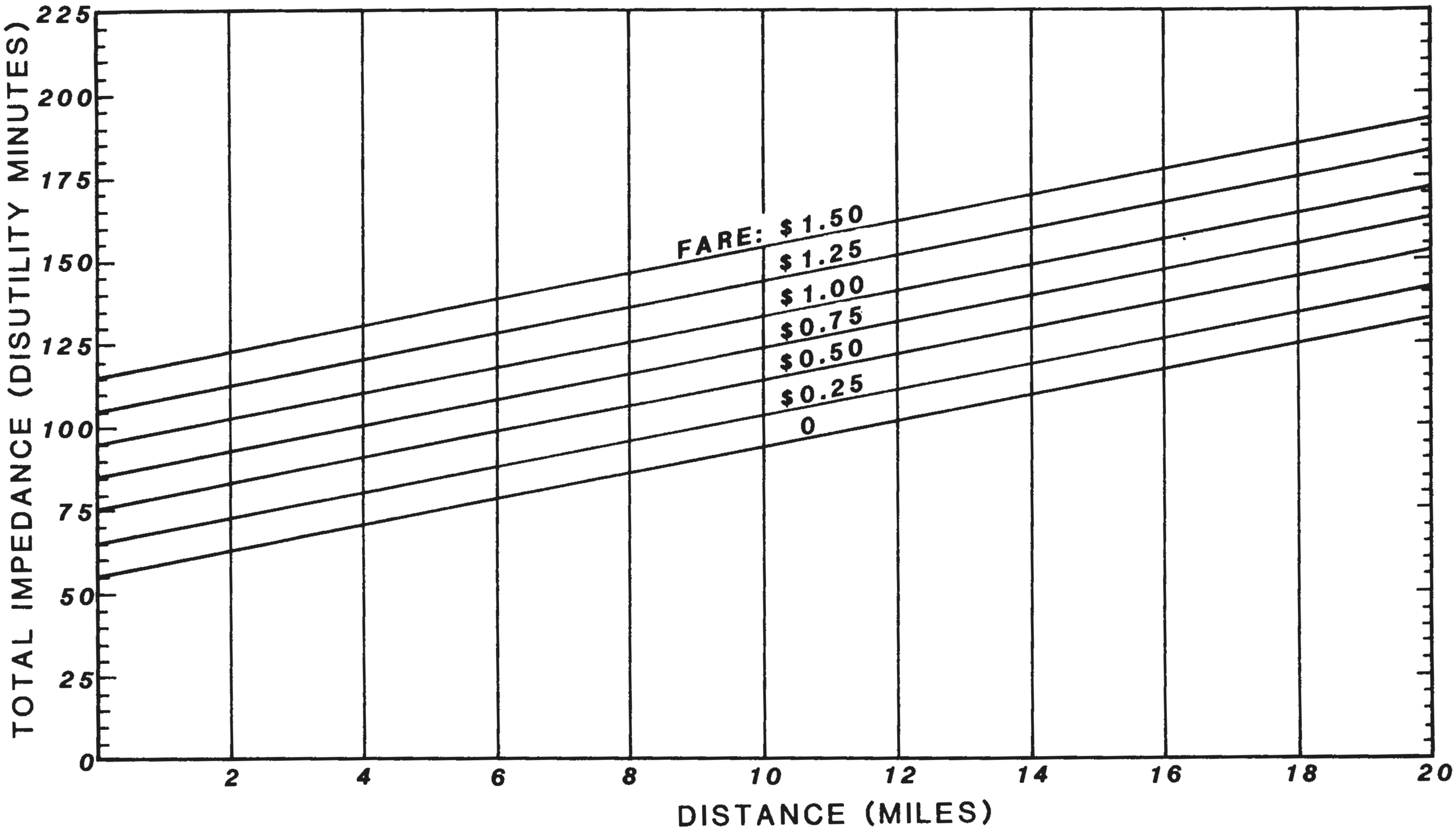
ACCESS: Walk



TRANSIT CURVES

MAIN LINE: Integrated Bus Rapid(C)

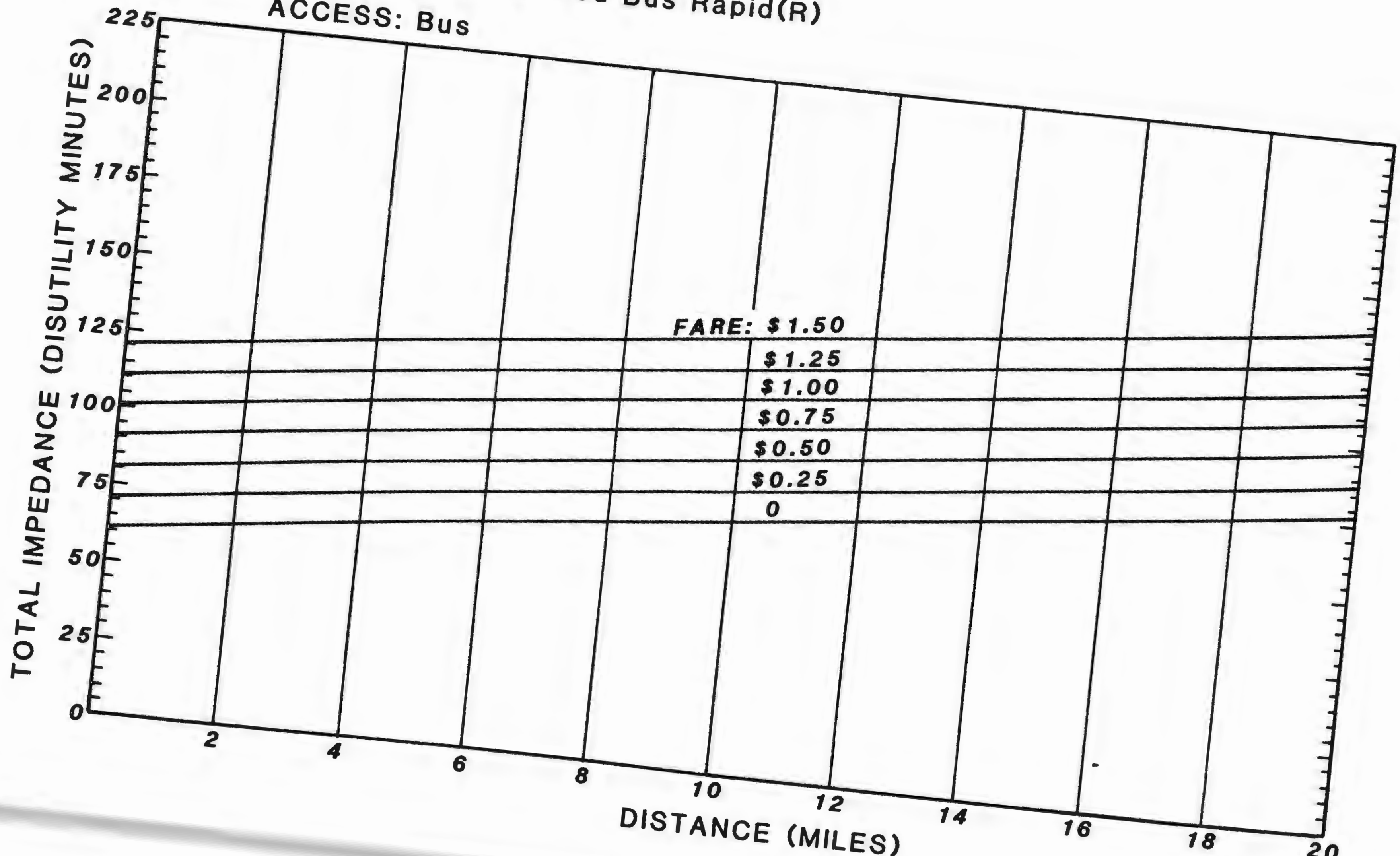
ACCESS: Bus



TRANSIT CURVES

MAIN LINE: Integrated Bus Rapid(R)

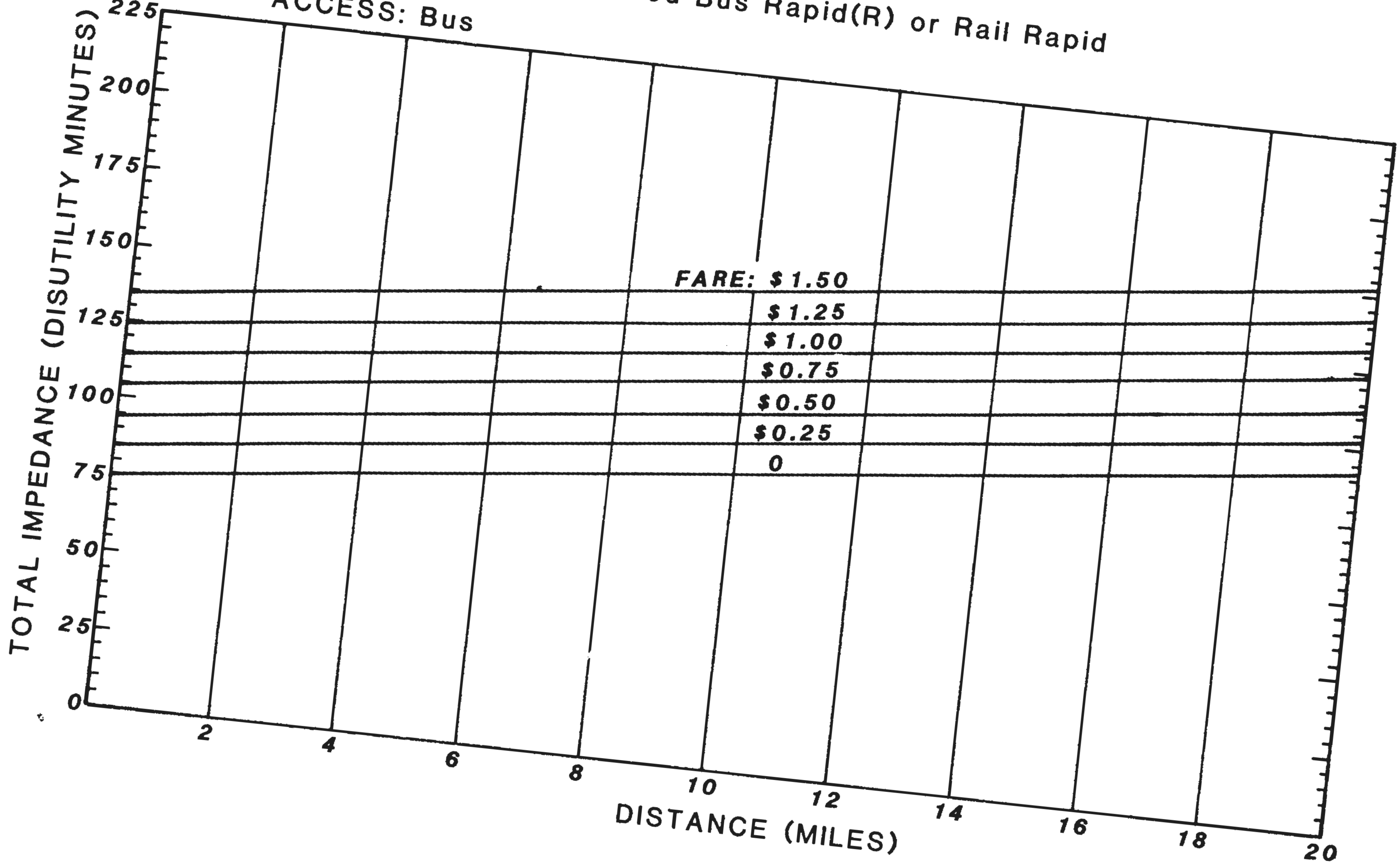
ACCESS: Bus



TRANSIT CURVES

MAIN LINE: Non Integrated Bus Rapid(R) or Rail Rapid

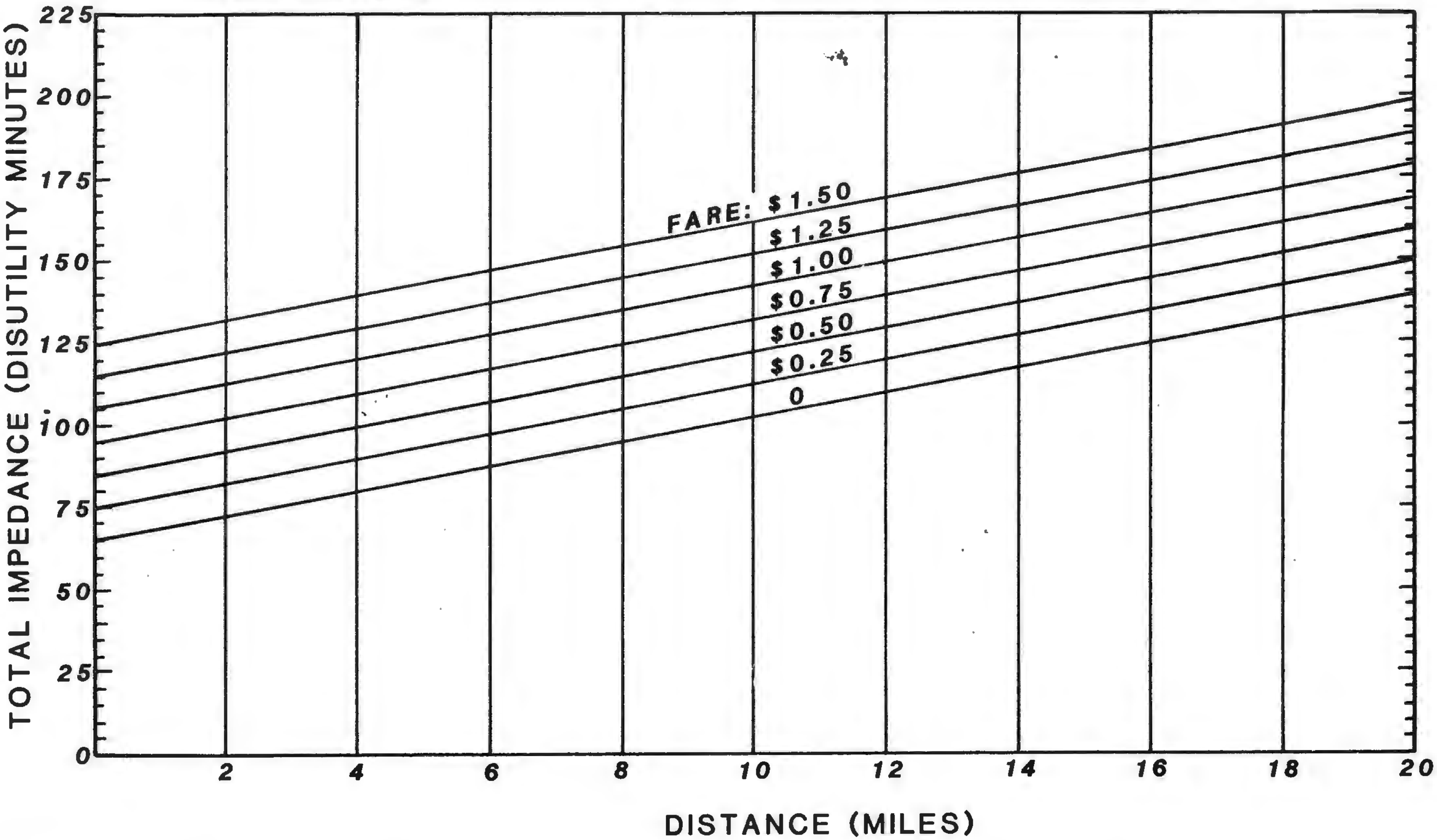
ACCESS: Bus



TRANSIT CURVES

MAINE LINE: Non Integrated Bus Rapid(C)

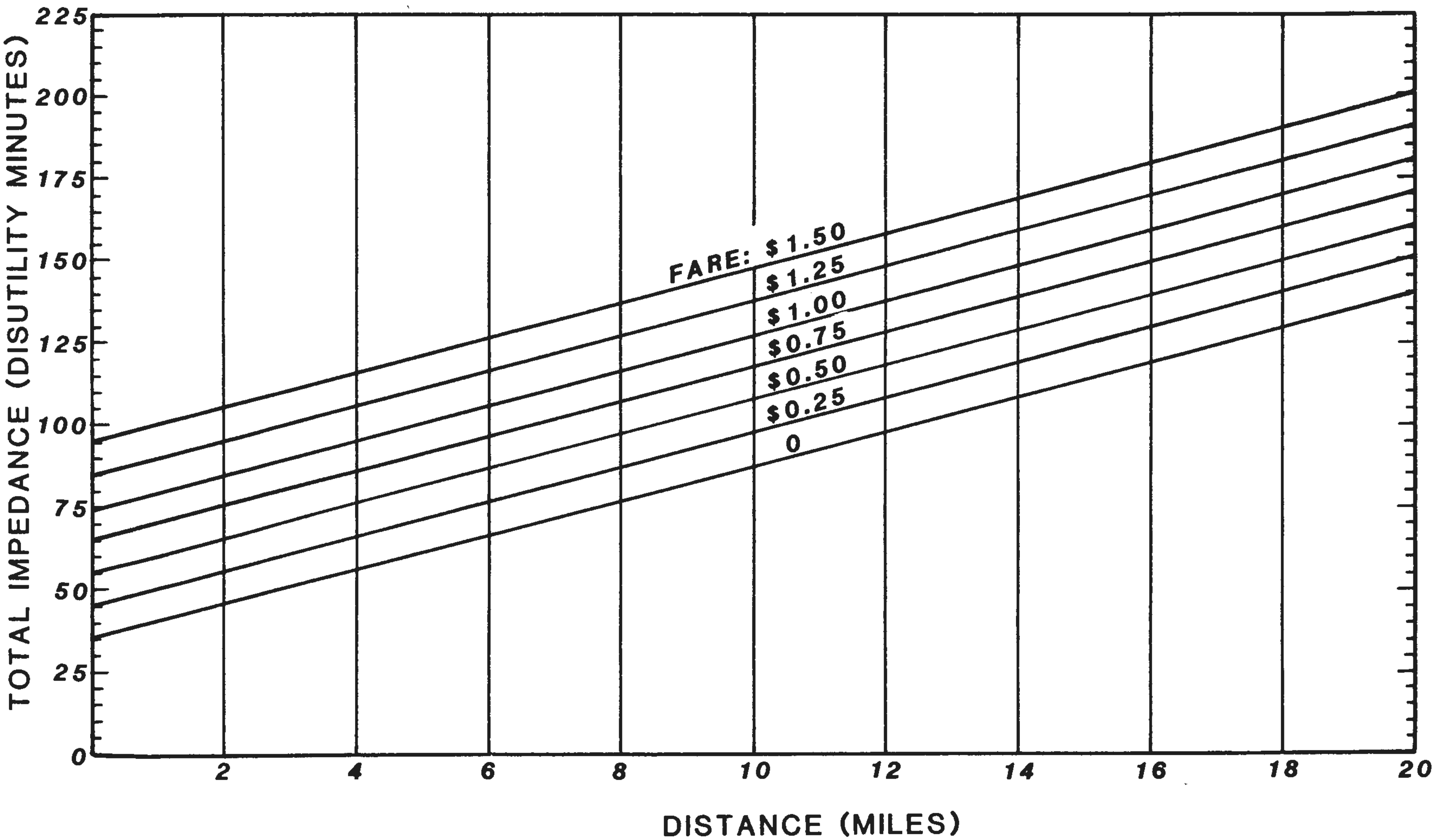
ACCESS: Bus



TRANSIT CURVES

MAIN LINE: Conventional Bus

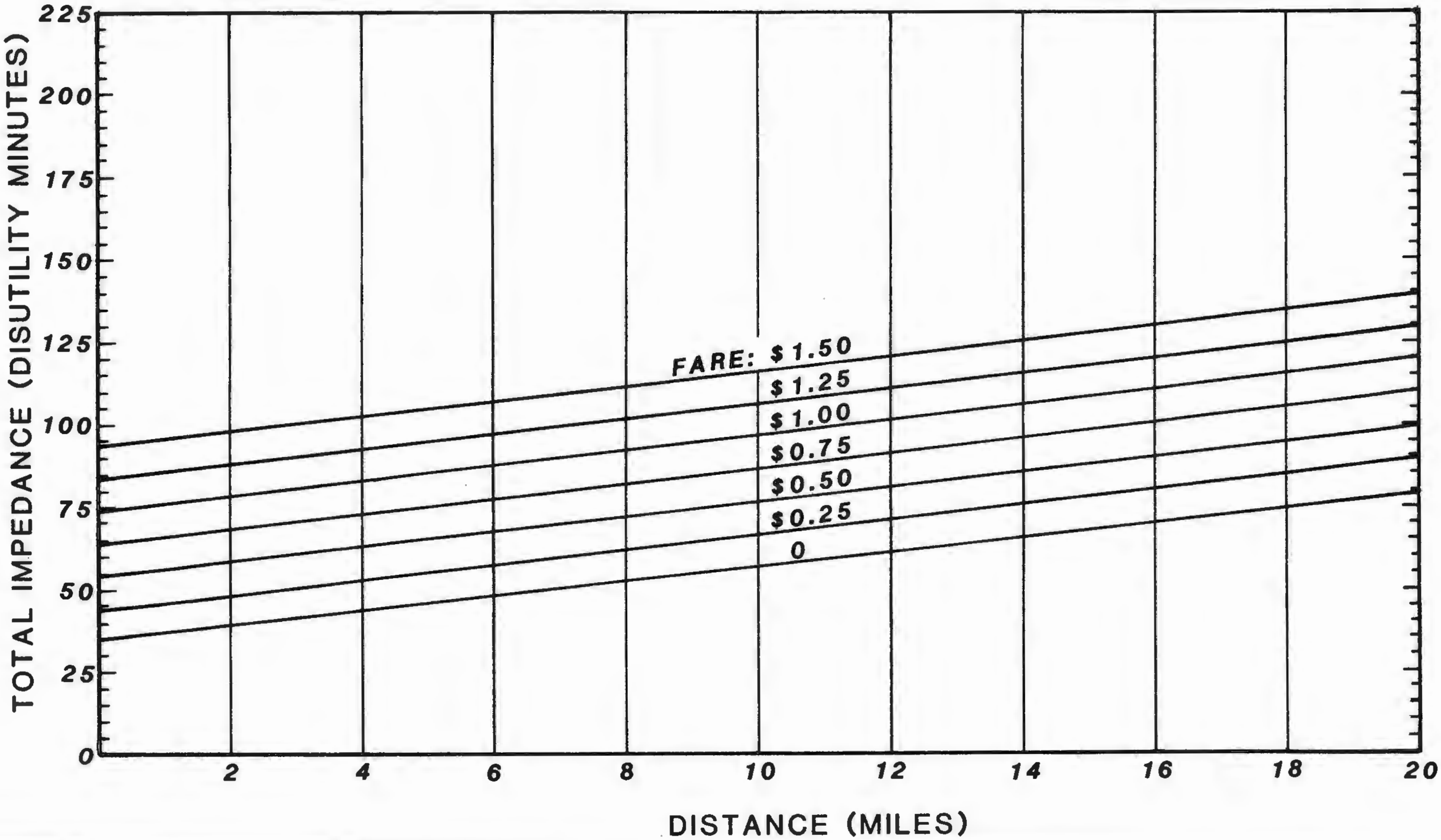
ACCESS: Auto



TRANSIT CURVES

MAIN LINE: Rail Rapid or Bus Rapid(R)

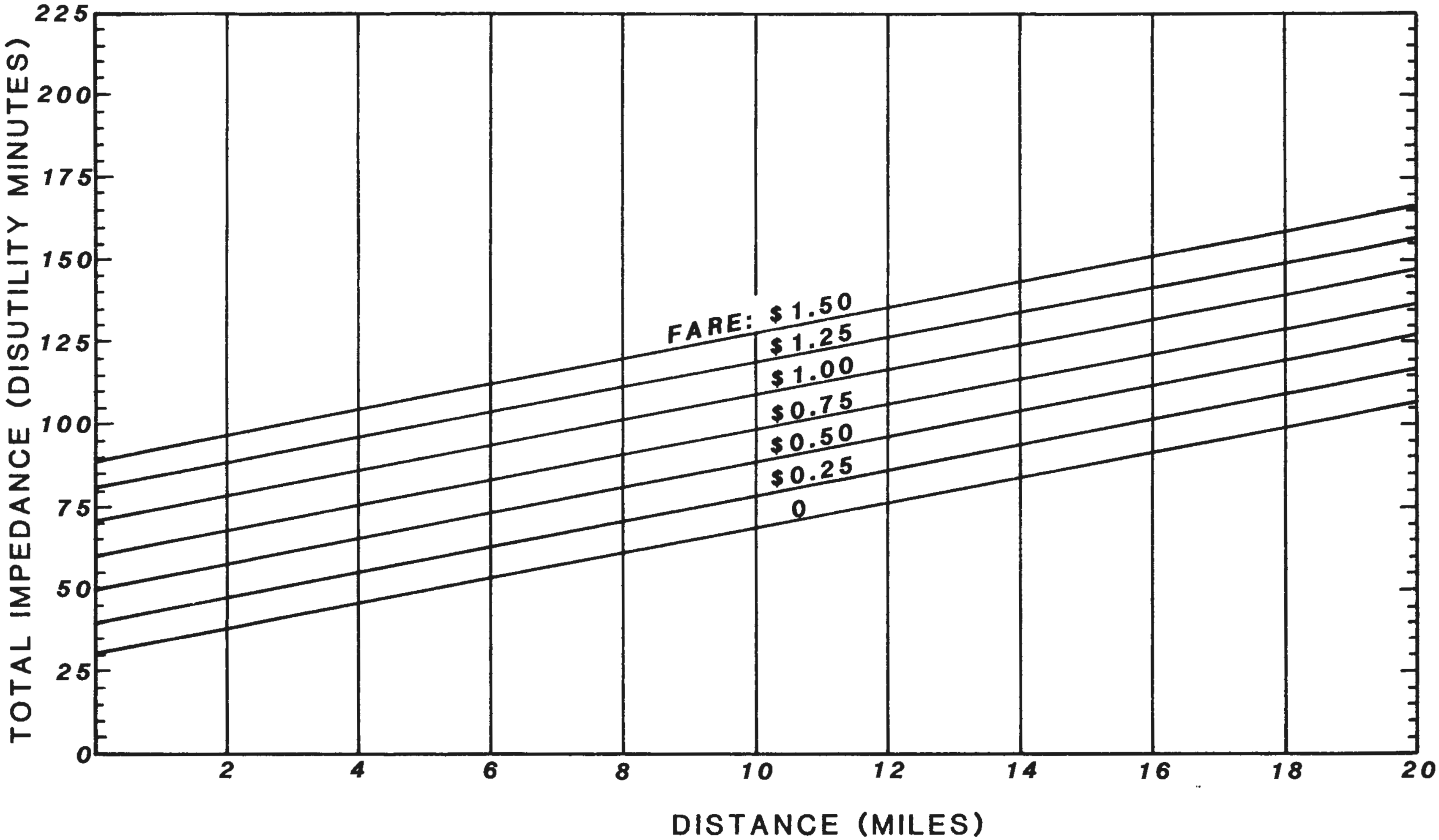
ACCESS: Auto



TRANSIT CURVES

MAIN LINE: Bus Rapid(C)

ACCESS: Auto



APPENDIX B

DERIVATION OF RELATIONSHIPS OF IMPEDANCE VALUES FOR DISTRICTS WITH BOTH WALK AND FEEDER ACCESS MODES

It is necessary to derive adjusted impedances when a district contains a significant number of people who can walk to a rapid transit facility, since impedances can be initially obtained only when the district is considered either all walk accessed (walk impedance) or all feeder accessed (feeder impedance).

This walk access portion of the population is reflected in the weighted impedance so that the ratio of walk access population to the rest of the population is directly proportional to the ratio of the walk accessed determined impedances to the adjusted impedance. That is, if the walking population accounts for 20% of the total district population, the 20% of the walk impedance and 80% of the feeder impedance should equal the adjusted impedance. This can be described in mathematical form as follows:

$$\frac{1}{(PI_w)^2} = \frac{R}{I_w^2} + \frac{(1-R)}{(I_w + x)^2}$$

where:

P = factor to be applied to walk impedance

R = percent of walk access in a district

I_w = walk accessed impedance

x = difference between walk impedance and feeder impedance (i.e.: $x = I_w - I_f$)

I_f = feeder accessed impedance

then

$$P = \frac{I_w + x}{\sqrt{R(I_w + x)^2 + I_w^2\,(1-R)}}$$

The adjustment factor to be applied to walk access impedance values incorporates three values: walk access impedance, percent of walk population in the district, and the difference between walk access impedance and feeder accessed impedance.

Two families of curves have been developed. The first is for integrated bus rapid systems, where the difference between walk and feeder accessed impedances is the riding time of 6 minutes on the feeder bus.*. The second is for non-integrated bus rapid or rail rapid systems, where the difference of 20 minutes stems from the riding and transfer wait time of the feeder access mode and the walk access arrival mode.

Special cases must be considered when x is infinite: i.e. when feeder-to-feeder exchange occurs, $I_f \to \infty$ and $x = I_f - I_w \to \infty$.

In the first equation the term $(1-R)/(I_w + x)^2$ becomes 0, and

$$P = \sqrt{\frac{1}{R}}$$

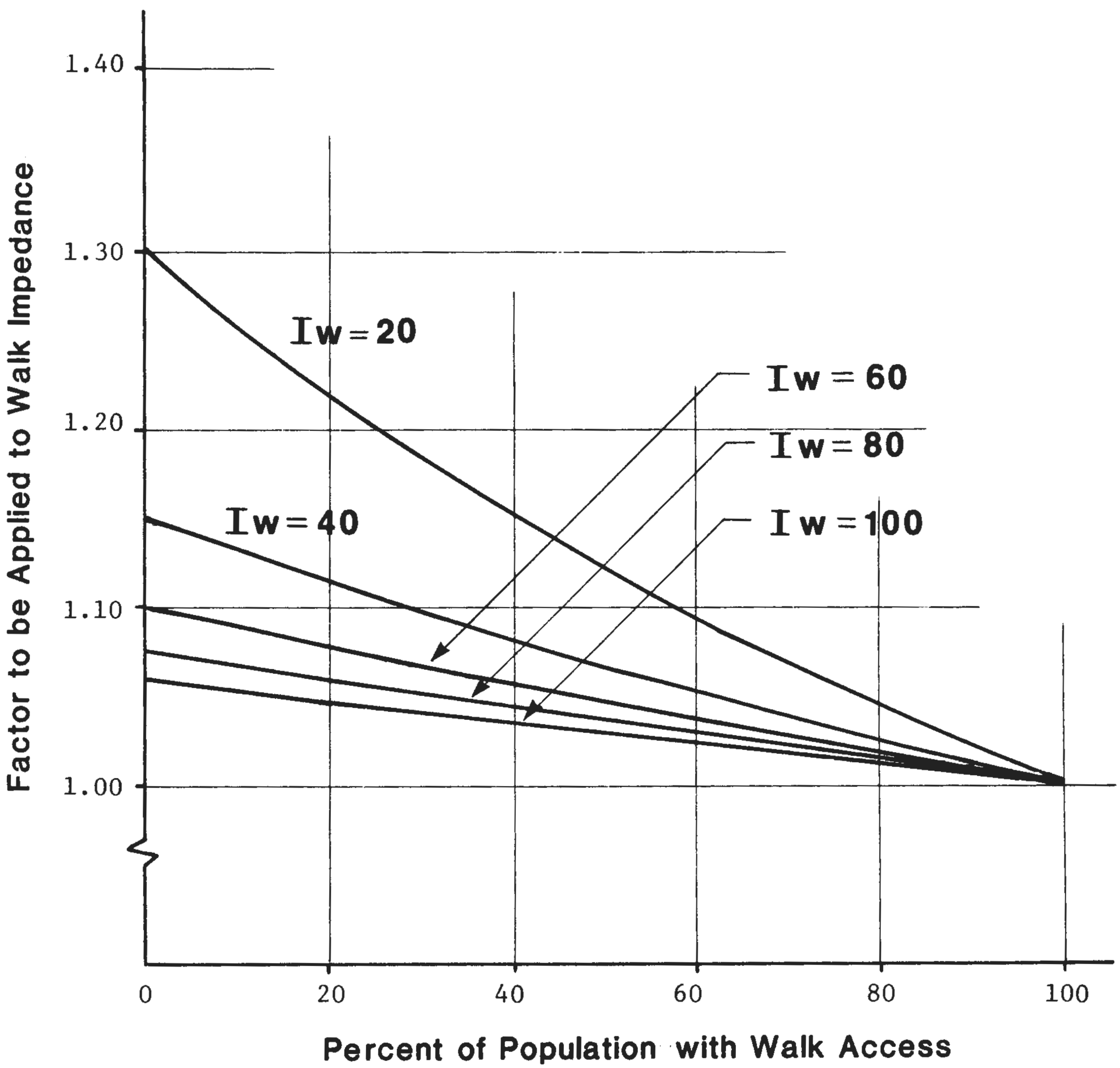
A third curve is based on this equation; and, as the case warrants, the factor approaches infinity as percentage of walk access approaches zero.

---

*See Appendix A for the value of assumed access and wait times in the derivation of impedance curves.

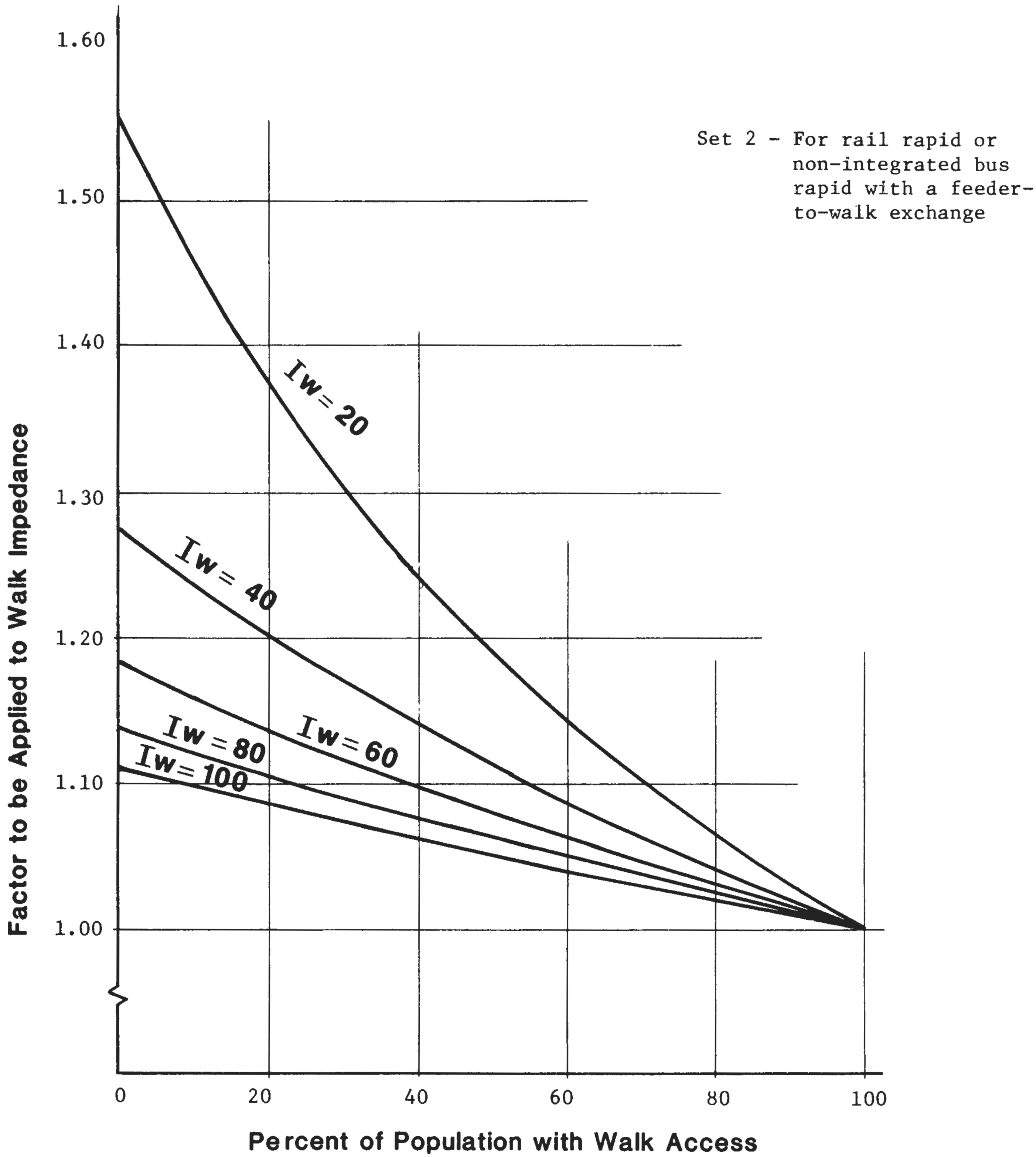
Figure B-1. Transit Impedance Modification Relationships for Integrated Bus Rapid Transit (Feeder to Walk)

Set 1 - For integrated bus rapid with a feeder-walk exchange



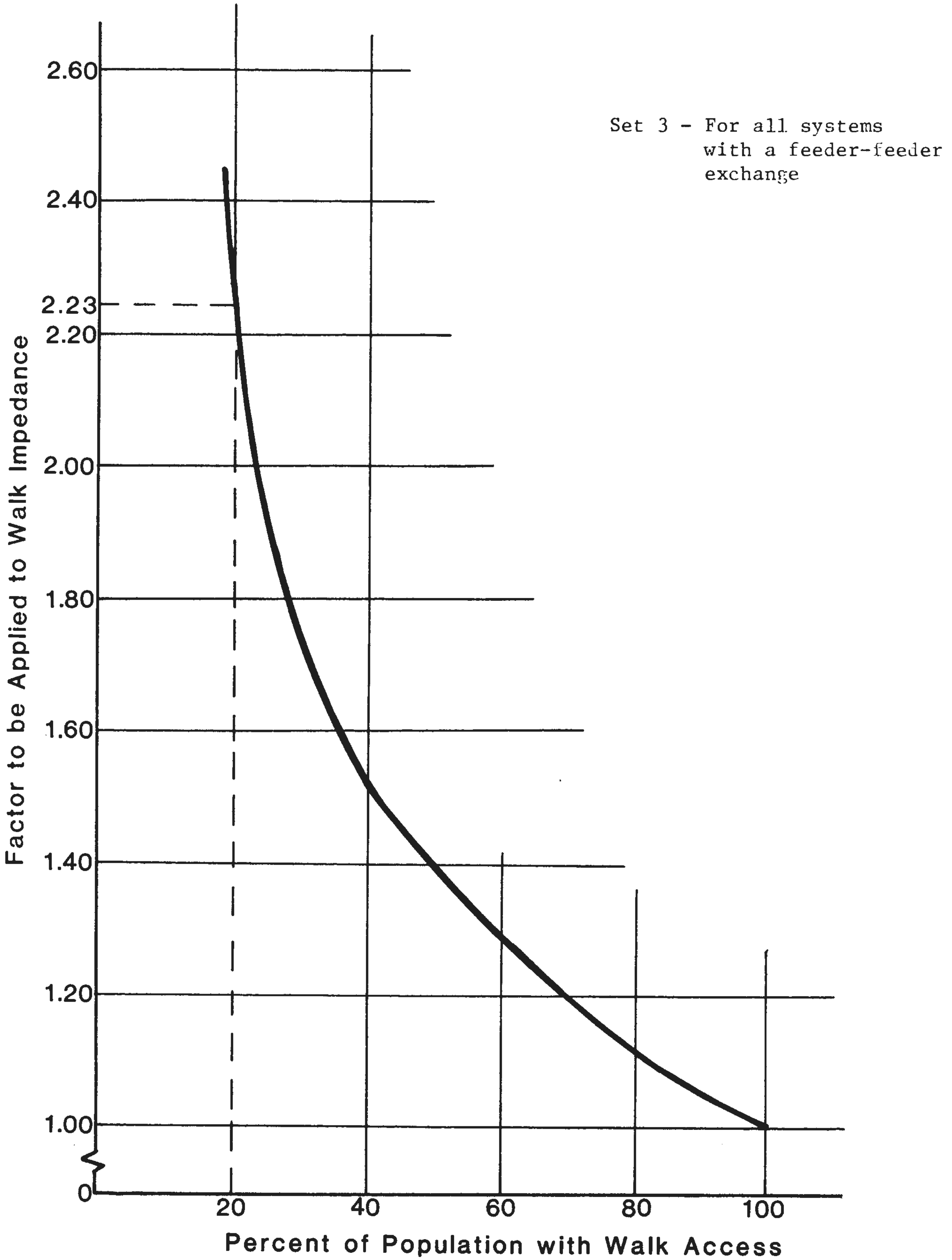
REVERSE BLANK

Figure B-2. Transit Impedance Modification Relationships for Rail Rapid and Non-Integrated Bus Rapid Transit Facilities (Feeder to Walk)



 REVERSE BLANK

Figure B-3. Transit Impedance Modification for All Mass Transit Facilities (Feeder to Feeder)



APPENDIX C

TABLE OF INTEGERS AND THEIR ASSOCIATED SQUARES

n	n^2	n	n^2	n	n^2	n	n^2
1	1	41	1,681	81	6,561	121	14,641
2	4	42	1,764	82	6,724	122	14,884
3	9	43	1,849	83	6,889	123	15,129
4	16	44	1,936	84	7,056	124	15,376
5	25	45	2,025	85	7,225	125	15,625
6	36	46	2,116	86	7,396	126	15,876
7	49	47	2,209	87	7,569	127	16,129
8	64	48	2,304	88	7,744	128	16,384
9	81	49	2,401	89	7,921	129	16,641
10	100	50	2,500	90	8,100	130	16,900
11	121	51	2,601	91	8,281	131	17,161
12	144	52	2,704	92	8,464	132	17,424
13	169	53	2,809	93	8,649	133	17,689
14	196	54	2,916	94	8,836	134	17,956
15	225	55	3,025	95	9,025	135	18,225
16	256	56	3,136	96	9,216	136	18,496
17	289	57	3,249	97	9,409	137	18,769
18	324	58	3,364	98	9,604	138	19,044
19	361	59	3,481	99	9,801	139	19,321
20	400	60	3,600	100	10,000	140	19,600
21	441	61	3,721	101	10,201	141	19,881
22	484	62	3,844	102	10,404	142	20,164
23	529	63	3,969	103	10,609	143	20,449
24	576	64	4,096	104	10,816	144	20,736
25	625	65	4,225	105	11,025	145	21,025
26	676	66	4,356	106	11,236	146	21,316
27	729	67	4,489	107	11,449	147	21,609
28	784	68	4,624	108	11,664	148	21,904
29	841	69	4,761	109	11,881	149	22,201
30	900	70	4,900	110	12,100	150	22,500
31	961	71	5,041	111	12,321		
32	1,024	72	5,184	112	12,544		
33	1,089	73	5,329	113	12,769		
34	1,156	74	5,476	114	12,996		
35	1,225	75	,5625	115	13,225		
36	1,296	76	5,776	116	13,456		
37	1,369	77	5,929	117	13,689		
38	1,444	78	6,084	118	13,924		
39	1,521	79	6,241	119	14,161		
40	1,600	80	6,400	120	14,400		

APPENDIX D

CASE STUDY FOR CORRIDOR 1 ANALYSIS

The example case study used in the main text is elaborated upon here. The completed version of Table 3-2 in Section IIIA is presented in Table D-1, followed by a set of work sheets. The shortcut method of obtaining access integral values is employed. Districts 1, 2, 6, and 10 are used to calculate the representative access integral values to plot "Access Integral/Distance from CBD Relationship" curve. Transit travel assignment is not included in this appendix, since the example for intra-corridor travel is presented in the text.

Physical and cost analysis was carried out by actual calculation rather than by using the graphical procedures presented in Section IIIB. Table D-2 summarizes the input variables used for the example. The step numbers in parentheses throughout the text correspond to the steps in Section IIIB of the main text. Table D-3 summarizes the results of the calculations.

Operating Costs and Example Calculations (B.2)

The first step is to compute the daily operating costs for the transit facility and determine the daily operating cost per rider. The first input required for this calculation is the 24-hour passenger volume at the maximum load point, estimated either in Phase A, Demand Estimation, or derived from other sources.

An example of operating cost computations based on the following data is summarized in Table D-2.

The following steps are used to determine operating costs:

a. From the maximum load point volume, calculate the total number of cars that must pass the maximum load point during the peak hour. This is calculated by dividing the peak hour passengers at the maximum load point by the capacity of the vehicle.

- Input

Peak Hour Maximum Load Point Volume	12,730 passengers
Vehicle Capacity	45 passengers/vehicle
Peak Period Load Factor	1.25

- Calculation

Number of Peak Hour Vehicles Required =

$$\frac{\text{Peak Hour Maximum Load Point Volume}}{\text{Peak Period Load Factor x Vehicle Capacity}} =$$

$$\frac{12730 \text{ passengers}}{1.25 \times 45 \text{ passenger/vehicle}} = 226.31\text{, rounded to } 227 \text{ vehicles}$$

REVERSE BLANK

TABLE D-1. Work Trip Generation Formatted for Corridor 1 Analysis (A3.b)

Super District	District	Dwelling Units	Employment	Productions	Attractions
	1	1,000	15,000	2,200	25,500
	2	1,000	10,000	2,200	17,000
	3	1,000	10,000	2,200	17,000
	4	6,500	9,000	14,300	15,300
	5	6,500	9,000	14,300	15,300
	6	8,500	6,000	18,700	10,200
	7	8,500	6,000	18,700	10,200
	8	4,000	7,000	8,800	11,900
	9	4,000	7,000	8,800	11,900
	10	6,000	4,500	13,200	7,650
	11	6,000	4,500	13,200	7,650
	12	1,000	10,000	2,200	17,000
	13	1,500	10,000	3,300	17,000
	14	1,500	10,000	3,300	17,000
	23	1,500	7,000	3,300	11,900
	24	1,500	9,000	3,300	15,300
	25	1,500	9,000	3,300	15,300
	34	---	8,000	---	13,600
	35	1,000	6,000	2,200	10,200
	36	1,000	6,000	2,200	10,200
	45	500	7,000	1,100	11,900
	46	500	4,000	1,100	6,800
	47	500	4,000	1,100	6,800
	56	500	4,000	1,100	6,800
	57	1,000	3,000	2,200	5,100
	58	1,000	3,000	2,200	5,100
2B		35,000	30,000	77,000	51,000
3B		35,000	20,000	77,000	34,000
4B		20,000	20,000	44,000	34,000
5B		20,000	30,000	44,000	51,000
6B		25,000	30,000	55,000	51,000
2C		25,000	22,000	55,000	37,400
3C		30,000	18,000	66,000	30,600
4C		15,000	17,000	33,000	28,900
5C		15,000	15,000	33,000	25,500
6C		30,000	10,000	66,000	17,000
Regional Total		317,500	400,000	698,500	680,000

REVERSE BLANK

Table D-2. Physical and Cost Inputs - Bus Rapid Transit Example

Input	Value
Peak hour passenger volume at maximum load point	12,730
Total daily ridership	86,046
Vehicle capacity (passenger)	45
Peak period passenger load factor	1.25
Passenger miles of travel (24 hour)	337,929
Feeder bus miles of travel (24 hour)	5,000
Line-haul facility length (miles)	6.0
Desired peak operating headway (seconds)	15 minimum
Peak	600 maximum
Average peak operating speed (mph)	
Peak	35
Vehicle unit operating cost ($/vehicle mile)	$1.50
Vehicle unit cost ($/vehicle)	$66,000
Vehicles/train	1
Construction unit cost ($/mile of facility)	$3.9 million
Land acquisition unit cost ($/sq. ft.)	$10.00
Total land acquired (sq. ft.)	1,584,000
Economic life of:	
Rolling stock (yrs.)	12
Construction (yrs.)	30
Right of way (yrs.)	100
Interest rate for capital recovery factor determination	7%
Fare structure	25¢ flat fare

Note: Cost characteristics determined from U.S. D.O.T. CUTS manual dated 7/77

 REVERSE BLANK

Table D-3. Summary Input and Output Values of Alternative 6.0 Mile Bus Rapid Transit

Demand		
Total daily passengers		86,046
Maximum load point peak-hour demand (directional)		12,730
Person miles of travel daily		337,929
Revenue - Daily		
Flat fare - 25¢		\$18,900
Graduated fare - 5¢/passenger mile		\$16,896
Per capita rider		
Flat fare - 25¢		21.96¢
Graduated fare - 5¢/mile		19.64¢
Cost - Daily		
Operating		\$48,360
Capital		12,446
Rolling stock	\$2,327	
Construction	6,287	
Right of way	3,832	
Per Capita		
Operating		56.20¢
Capital		14.46¢
Rolling stock	2.70¢	
Construction	7.31¢	
Right of way	4.45¢	
Total Cost		
Daily		\$60,806
Per Capita		70.66¢

b. With the vehicles/train factor and the desired operating policy of trains (expressed in terms of service frequencies or headways), if any, determine the number of trains that will pass the maximum load point in the peak hour. (B.3)

- Input

Vehicles/Train	1 car/train
Peak Period Maximum Headway	10 minutes
Minimum Headway	15 seconds

- Calculation

$$\text{Peak Hour No. of Trains} = \frac{\text{No. of Peak Hour Vehicles Required}}{\text{Train Size}} =$$

$$\frac{\text{227 vehicles}}{\text{1 vehicle/train}} = \text{227 trains/hour or a train every 16 seconds}$$

The peak period headway is within the minimum and maximum range specified. If the maximum headway is not met, the vehicle requirements must be increased to meet the maximum headway specifications. If this results in the provision of excess vehicles at the maximum load point, the sizes of the trains should be reduced. Conversely, if the minimum headway requirements are not met, the size of the trains should be increased.

c. Determine the number of daily vehicle miles generated from b. above by multiplying the number of peak hour vehicle requirements by the line length and by appropriate expansion factors. Typical expansion factors range from 5 to 10 for the 24-hour day.

- Input

Line length	6 miles
Daily expansion factor	10

- Calculation

Total daily vehicle mileage = trains/hr x vehicles/train x miles/line x round trip factor x daily expansion factor =

227 x 1 x 6 x 2 x 10 = 27,240

d. To obtain daily operating costs, multiply the daily vehicle miles of travel by the vehicle unit operating cost

- Input

Vehicle unit operating cost	$1.50 /vehicle mile

- Calculation

Daily operating costs = vehicle miles/day x cost vehicle mile =

27,240 vehicle miles/day x $1.50 vehicle/mile = $40,860/day

e. To derive the daily operating cost per rider, divide the total operating costs by the total daily passengers.

- Input

Total daily ridership	86,046

- Calculation

Per capita operating cost = daily operating costs/daily ridership =

$40,860/86,046 = 47.49¢/rider

The daily feeder bus miles of service (5,000) are multiplied by the vehicle unit operating cost ($1.50/vehicle mile) to yield a cost of $7,500/day. This cost is divided by the total number of daily riders (86,046) to yield a per ride cost of 8.71¢. This added to the line-haul costs yields a system cost of 56.20 cents/passenger. The corresponding total system daily cost is $48,360.

Daily Fare Revenue Calculation and Examples (B.4)

There are two methods of calculating fare revenues. These relate to two different fare structures: a flat fare (fixed regardless of the amount of use of the system), or a graduated fare (fare proportional to use).

In the case of a flat fare, some estimate must be made of transfers to and from other portions of the system. The corresponding 24-hour line-haul patronage is reduced by one-half this amount when calculating revenue. The determination of the revenue from a flat fare of 25¢ applied to the patronage estimates derived from the demand module in Phase A is as follows:

- Input

Total daily ridership	86,046
Estimated transfer to and from other portions of the system	21,100
Flat fare	25¢/ride

- Calculation

$$\text{Fare collected on evaluated line} = 86{,}046 - \frac{21{,}100}{2} = 75{,}496$$

Daily revenue = 75,496 x 0.25 = $18,874

Per capita daily revenue = $18,874/86,046 = 21.93¢/rider

For revenue estimates calculated using graduated fares, the revenue generated per rider should be calculated.

With a graduated fare of 5¢/passenger mile, the revenue calculations are:

- Input

    Total daily passenger miles — 337,929
    Graduated fare — 5¢ passenger/mile
    Total daily passengers — 86,046

- Calculation

    Daily revenue = 337,929 x 0.05 — $16,896
    Per capita daily revenue - $16,896/86,046 — 19.63¢

Capital Cost Requirements and Example Calculations (B.6 and B.7)

There are three components of capital cost that are distinguished for analysis. These are:

a. Rolling Stock
b. Construction Cost
c. Land acquisition or right of way cost

a. Rolling Stock

The size of the rolling stock fleet usually is the size of the fleet required for peak hour service.* The fleet size is determined by dividing the maximum number of vehicles required at the peak hour maximum load point by 60 and multiplying the result by the scheduled round trip time, in minutes. This value is increased by eight percent to allow for spares.

In the example, a desired peak hour operating speed yields the following results:

- Input

    Line length — 6.0 miles
    Desired overall operating speed — 35 mph
    Peak hour vehicles to be provided at maximum load point — 227 vehicles

- Calculation

    Round trip time =

$$\frac{2 \text{ x line length (miles)}}{\text{desired operating speed (mph)}} \times \frac{60 \text{ min}}{\text{hr}} =$$

$$\frac{2 \times 6}{35} \times 60 = \qquad 20.6 \text{ minutes}$$

Number of vehicles required = $\frac{227}{60} \times 20.6 = 7.79$ — 78 vehicles

Total vehicles required including spares =

78 x 1.08 = 84 — 84 vehicles

---

*An exception to this is when higher standards for off-peak service, such as seating requirements or scheduled operation would require a larger fleet to satisfy non-peak requirements.

The total capital outlay for rolling stock is then computed by multiplying the number of vehicles required by the unit cost of the vehicles. In the example, the following data yield:

- Input

Vehicle unit costs	$66,000/vehicle

- Calculation

Rolling stock total cost - 84 x $66,000	$5,544,000

Then two steps are taken to convert this total cost to a daily rider per capita cost. The first is to convert the daily cost to an annual cost, with the use of a capital recovery factor, which accounts for the value of money and the economic life of the facility in question (in this instance rolling stock). This annual cost is converted to a daily cost by division of the annual cost by the number of equivalent days in a year.

In the example the following calculations yield:

- Input

Economic life of rolling stock	12 years
Interest rate to be used in capital recovery calculation	7%
Total daily passengers	86,046

- Calculation

Capital recovery factor for a life of 12 years at a 7% interest rate (from capital recovery factor tables)	.1259
Annual costs = 5,544,000 x .1259	$697,987
Daily costs = 697,987 ÷ 300*	$2,327
Daily cost/rider = 2,327 ÷ 86,046	2.70¢

b. Construction Costs

Construction costs are estimated by applying a unit cost of construction to the length of the line-haul facility. The derived cost is converted to a daily rider per capita figure in a calculation analogous to that of the rolling stock cost.

Construction cost includes the capital cost of all fixed facilities, such as roadway and tracks, stations and station access, yards and maintenance facilities, electrification, power distribution, and control equipment. However, it does not include right of way and rolling stock capital costs, which are developed separately. It should be noted that the construction unit cost in dollars per mile usually represents an average value for the entire length of line--and for different types of construction (subway, elevated, at grade). When more detailed information is available on the type of construction likely, it is better to consider the line in district

---

*There are assumed to be 300 equivalent operating days in a year. This factor accounts for and reflects existing provisions of Saturday and Sunday service.

segments of similar construction types and costs. The costs for each line segment are then aggregated into total line construction costs.

The example for construction cost computation is based on the following data:

- Input

Line length	6.0 miles
Construction unit cost	$3,900,000/mile
Economic life of construction	30 years
Interest rate to be used in capital calculations	7%
Total daily passengers	86,046

- Calculation

Total construction cost = 6.0 x 3,900,000	$ 23,400,000
Capital recovery factor for a life of 30 years and a 7% interest rate (from capital recovery factor table)	0.0806
Annual cost = $23,400,000 x .0806	$1,886,040
Daily cost =$1,886,040÷ 300	$6,287
Daily cost/rider = $6,287 ÷ 86,046	7.31¢

c. Right of Way Costs

Total right of way costs can be estimated in different ways. A simple way is to multiply the area required for the facility by the unit cost of land. The total costs are converted to daily per capita rider costs by the same procedure used to obtain rolling stock and construction costs.

In the sample the following data yields:

- Input

Line length	6.0 miles
Average right of way width	50 feet
Unit cost of land $/sq. ft.	$10.00
Economic life of right of way	100 years
Interest rate to be used in capital recovery calculations	7%
Total daily passengers	86,046

- Calculation

Total land taken for right of way = 6 x 5280 x 50	1,584,000 sq. ft.
Total right of way cost = 1,584,000 x $10	$15,840,000
Capital recovery factor for a life of 100 years at an interest rate of 7% (from capital recovery factor table)	.07257
Annual Cost = $15,840,000 x .07257	$1,149,508.80
Daily cost = $1,149,508.80 ÷ 300	$3,831.70
Daily cost/rider = $3,831.70 ÷ 86,046	4.45¢

WORK SHEET

Corridor 1 Alternative 1 Sheet 1 of 4

Step	Origin		Destination District (j)									
A1	District (i) 1											
	% of Walk in (i) 100											
A3a.1	Dwelling Unit in (i)= 1000											
A3b.1	Production in (i)= 2200	(P)	1	2	3	4	5	6	7	8	9	10
A3a.2	Employment in (j)		15000	10000	10000	9000	9000	6000	6000	7000	7000	4500
A3b.2	Attraction A_j	(A)	25500	17000	17000	15300	15300	10200	10200	11900	11900	7650
	Transit											
A1	% of Walk in (j)		100	100	100	20	20	20	20	0	0	0
A4a.1	Line-Haul Distance		0	.8	.8	2.0	2.0	3.5	3.5	5.3	5.3	5.3
A4a.2	Transit Impedance		64	66	66	68	68	72	72	57	57	57
A4a.3	Adjusted Impedance	(B)	64	66	66	77	77	81	81	57	57	57
A4b.	Square of Impedance	(C)=B^2	4096	4356	4356	5929	5929	6561	6561	3249	3249	3249
A4c.	Transit Index	(D)=A/C	6.23	3.90	3.90	2.58	2.58	1.55	1.55	3.66	3.66	2.35
	Highway											
A4d.1	Airline Distance		0	1.0	1.0	2.0	2.0	3.5	3.5	5.3	5.3	7.3
A4d.2	Impedance	(E)	50	30	30	41	41	56	56	74	74	95
A4d.3	Square of Impedance	(F)=E^2	2500	900	900	1681	1681	3136	3136	5476	5476	9025
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$	644	1341	1341	764	764	471	471	490	490	419
A4f	District Index	(H)=AxG	16.40	22.80	22.80	11.69	11.69	4.80	4.80	5.83	5.83	3.21
A4g	Access Integral	(J)=ΣH	305.66									
A4i	Transit Trips	(K)=P*D/J	61	28	28	19	19	11	11	26	26	17

WORK SHEET

Corridor 1 Alternative 1 Sheet 2 of 4

Step	Item	Formula	11	12	13	14	23	24	25	34	35	36
A1	Origin District (i) 1											
	% of Walk in (i) 100		Destination District (j)									
A3a.1	Dwelling Unit in (i)= 1000											
A3b.1	Production in (i)= 2200 (P)		11	12	13	14	23	24	25	34	35	36
A3a.2	Employment in (j)		4500	10000	10000	10000	7000	9000	9000	8000	6000	6000
A3b.2	Attraction A_j	(A)	7650	17000	17000	17000	11900	15300	15300	13600	10200	10200
	Transit											
A1	% of Walk in (j)		0	100	100	100	100	100	100	100	100	100
A4a.1	Line-Haul Distance		5.3	1.4	2.2	2.2	1.4	2.2	2.2	1.4	2.2	2.2
A4a.2	Transit Impedance		57	68	73	73	68	73	73	68	73	73
A4a.3	Adjusted Impedance	(B)	57	68	73	73	68	73	73	68	73	73
A4b.	Square of Impedance	$(C)=B^2$	3249	4624	5329	5329	4624	5329	5329	4624	5329	5329
A4c.	Transit Index	(D)=A/C	2.35	3.68	3.19	3.19	2.57	2.87	2.87	2.94	1.91	1.91
	Highway											
A4d.1	Airline Distance		7.3	.6	1.2	1.5	1.1	1.8	2.0	1.2	2.1	2.1
A4d.2	Impedance	(E)	95	58	32	36	63	39	41	64	42	42
A4d.3	Square of Impedance	$(F)=E^2$	9025	3864	1024	1296	3969	1521	1681	4096	1764	1764
A4e	Conductance Factor $(x10^6)$	$(G)=\frac{C+F}{CxF}$	419	475	1164	959	468	845	782	460	755	755
A4f	District Index	(H)=AxG	3.21	8.08	19.8	16.3	5.57	12.9	12.0	6.26	7.70	7.70
A4g	Access Integral	$(J)=\Sigma H$										
A4i	Transit Trip	(K)=P*D/J	17	26	23	23	18	21	21	21	14	14

WORK SHEET

Corridor 1 Alternative 1 Sheet 3 of 4

Step	Item		Destination District (j): 45	46	47	56	57	58	2B	3B	4B	5B
A1	Origin District (i)	1										
	% of Walk in (i)	100										
A3a.1	Dwelling Unit in (i)=	1000										
A3b.1	Production in (i)= 2200	(P)										
A3a.2	Employment in (j)		7000	4000	4000	4000	3000	3000	30000	20000	20000	30000
A3b.2	Attraction A_j	(A)	11900	6800	6800	6800	5100	5100	51000	34000	34000	51000
	Transit											
A1	% of Walk in (j)		100	100	100	100	100	100	0	0	0	0
A4a.1	Line-Haul Distance		1.4	2.2	2.2	1.4	2.2	2.2	–	–	–	–
A4a.2	Transit Impedance		68	73	73	68	73	73	∞	∞	∞	∞
A4a.3	Adjusted Impedance	(B)	68	73	73	68	73	73				
A4b.	Square of Impedance	(C)=B^2	4624	5329	5329	4624	5329	5329	–	–	–	–
A4c.	Transit Index	(D)=A/C	2.57	1.28	1.28	1.47	.96	.96	0	0	0	0
	Highway											
A4d.1	Airline Distance		1.1	2.0	1.8	.6	1.5	1.2	3.2	4.0	4.1	4.0
A4d.2	Impedance	(E)	63	41	39	58	36	32	53	61	62	61
A4d.3	Square of Impedance	(F)=E^2	3969	1681	1521	3364	1296	1024	2809	3721	3844	3721
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$	468	783	845	514	959	1164	356	269	260	269
A4f	District Index	(H)=AxG	5.57	5.32	5.74	3.50	4.84	5.94	18.2	9.15	8.84	9.15
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	18	9	9	11	7	7	0	0	0	0

WORK SHEET

Corridor 1 Alternative 1 Sheet 4 of 4

Step	Item	Formula										
A1	Origin District (i) 1											
	% of Walk in (i) 100		Destination District (j)									
A3a.1	Dwelling Unit in (i)= 1000											
A3b.1	Production in (i)= 2200.	(P)	6B	2C	3C	4C	5C	6C				
A3a.2	Employment in (j)		30000	22000	18000	17000	15000	10000				
A3b.2	Attraction A_j	(A)	51000	37400	30600	28900	25500	17000				
	Transit											
A1	% of Walk in (j)		0	0	0	0	0	0				
A4a.1	Line-Haul Distance		—	—	—	—	—	—				
A4a.2	Transit Impedance											
A4a.3	Adjusted Impedance	(B)	∞	∞	∞	∞	∞	∞				
A4b.	Square of Impedance	$(C)=B^2$	—	—	—	—	—	—				
A4c.	Transit Index	(D)=A/C	0	0	0	0	0	0				
	Highway											
A4d.1	Airline Distance		3.2	6.8	7.4	7.7	7.4	6.8				
A4d.2	Impedance	(E)	53	89	96	98	96	89				
A4d.3	Square of Impedance	$(F)=E^2$	2809	7921	9216	9604	9216	7921				
A4e	Conductance Factor ($x10^6$)	$(G)=\frac{C+F}{CxF}$	356	126	109	104	109	126				
A4f	District Index	(H)=AxG	1.82	4.71	3.34	3.01	2.78	2.14				
A4g	Access Integral	$(J)=\Sigma H$										
A4i	Transit Trips	(K)=P*D/J	0	0	0	0	0	0				

WORK SHEET

Corridor 1 Alternative 1 Sheet 1 of 4

Step			1	2	3	4	5	6	7	8	9	10
A1	Origin District (i) 2											
	% of Walk in (i) 100		Destination District (j)									
A3a.1	Dwelling Unit in (i)= 1000											
A3b.1	Production in (i)= 2200	(P)	1	2	3	4	5	6	7	8	9	10
A3a.2	Employment in (j)		15000	10000	10000	9000	9000	6000	6000	7000	7000	4500
A3b.2	Attraction A_j	(A)	25500	17000	17000	15300	15300	10200	10200	11900	11900	7650
	Transit											
A1	% of Walk in (j)		100	100	100	20	20	20	20	0	0	0
A4a.1	Line-Haul Distance		.8	0	0	1.2	1.2	2.7	2.7	4.5	4.5	4.5
A4a.2	Transit Impedance		66	65	65	67	67	70	70	54	54	54
A4a.3	Adjusted Impedance	(B)	66	65	65	76	76	79	79	54	54	54
A4b.	Square of Impedance	(C)=B^2	4356	4225	4225	5776	5776	6241	6241	2916	2916	2916
A4c.	Transit Index	(D)=A/C	5.85	4.02	4.02	2.65	2.65	1.63	1.63	4.08	4.08	2.62
	Highway											
A4d.1	Airline Distance		1.0	0	.7	1.2	1.7	2.6	2.9	4.3	4.7	6.3
A4d.2	Impedance	(E)	62	25	28	32	3.8	47	50	64	68	85
A4d.3	Square of Impedance	(F)=E^2	3844	625	784	1024	1444	2209	2500	4096	4624	7225
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$	490	1837	1512	1150	866	613	560	587	559	481
A4f	District Index	(H)=AxG	12.50	31.23	25.70	17.60	13.25	6.25	5.71	6.99	6.65	3.68
A4g	Access Integral	(J)=ΣH	330.45									
A4i	Transit Trips	(K)=P*D/J	39	27	27	18	18	11	11	27	27	17

WORK SHEET

Corridor 1 Alternative 1 Sheet 2 of 4

Step	Origin District (i) 2		Destination District (j)									
A1	% of Walk in (i) 100											
A3a.1	Dwelling Unit in (i)= 1000											
A3b.1	Production in (i)= 2200	(P)	11	12	13	14	23	24	25	34	35	36
A3a.2	Employment in (j)		4500	10000	10000	10000	7000	9000	9000	8000	6000	6000
A3b.2	Attraction A_j	(A)	7650	17000	17000	17000	11900	15300	15300	13600	10200	10200
	Transit											
A1	% of Walk in (j)		0	100	100	100	100	100	100	100	100	100
A4a.1	Line-Haul Distance		4.5	2.2	3.0	3.0	2.2	3.0	3.0	2.2	3.0	3.0
A4a.2	Transit Impedance		54	72	76	76	72	76	76	72	76	76
A4a.3	Adjusted Impedance	(B)	54	72	76	76	72	76	76	72	76	76
A4b.	Square of Impedance	(C)=B^2	2916	5184	5776	5776	5184	5776	5776	5184	5776	5776
A4c.	Transit Index	(D)=A/C	2.62	3.28	2.94	2.94	2.30	2.65	2.65	2.62	1.77	1.77
	Highway											
A4d.1	Airline Distance		6.6	1.5	1.5	2.1	2.0	2.6	2.9	2.0	3.0	2.9
A4d.2	Impedence	(E)	87	67	36	42	72	47	50	72	51	50
A4d.3	Square of Impedance	(F)=E^2	7569	4489	1296	1764	5184	2209	2500	5184	2601	2500
A4e	Conductance Factor ($\times 10^6$)	(G)=$\frac{C+F}{CxF}$	475	416	945	740	386	626	573	386	558	573
A4f	District Index	(H)=AxG	3.63	7.07	16.1	12.6	4.59	9.58	8.77	5.25	5.69	5.84
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	17	22	20	20	15	18	18	17	12	12

WORK SHEET

Corridor 1 Alternative 1 Sheet 3 of 4

Step			Destination District (j)									
A1	Origin District (i) 2											
	% of Walk in (i) 100											
A3a.1	Dwelling Unit in (i)= 1000											
A3b.1	Production in (i)= 2200	(P)	45	46	47	56	57	58	2B	3B	4B	5B
A3a.2	Employment in (j)		7000	4000	4000	4000	3000	3000	30000	20000	20000	30000
A3b.2	Attraction A_j	(A)	11900	6800	6800	6800	5100	5100	51000	34000	34000	51000
	Transit											
A1	% of Walk in (j)		100	100	100	100	100	100	0	0	0	0
A4a.1	Line-Haul Distance		2.2	3.0	3.0	2.2	3.0	3.0	—	—	—	—
A4a.2	Transit Impedance		72	76	76	72	76	76	∞	∞	∞	∞
A4a.3	Adjusted Impedance	(B)	72	76	76	72	76	76				
A4b.	Square of Impedance	$(C)=B^2$	5184	5776	5776	5184	5776	5776	—	—	—	—
A4c.	Transit Index	(D)=A/C	2.30	1.18	1.18	1.31	.88	.88	0	0	0	0
	Highway											
A4d.1	Airline Distance		1.8	2.6	2.1	1.2	1.5	.7	2.4	4.7	5.0	4.2
A4d.2	Impedance	(E)	70	47	42	64	36	28	45	68	72	63
A4d.3	Square of Impedance	$(F)=E^2$	4900	2209	1764	4096	1296	784	2025	4624	5184	3969
A4e	Conductance Factor $(x10^6)$	$(G)=\frac{C+F}{CxF}$	397	626	740	437	945	1449	495	216	193	252
A4f	District Index	(H)=AxG	4.72	4.26	5.03	2.97	4.82	7.39	25.2	7.34	6.56	12.9
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	15	8	8	9	6	6	0	0	0	0

WORK SHEET

Step			Destination District (j)									
	Origin District (i) 2		Corridor 1 Alternative 1 Sheet 4 of 4									
A1	% of Walk in (i) 100											
A3a.1	Dwelling Unit in (i)= 1000											
A3b.1	Production in (i)= 2200	(P)	6B	2C	3C	4C	5C	6C				
A3a.2	Employment in (j)		30000	22000	18000	17000	15000	10000				
A3b.2	Attraction A_j	(A)	51000	37400	30600	28900	25500	17000				
	Transit											
A1	% of Walk in (j)		0	0	0	0	0	0				
A4a.1	Line-Haul Distance		—	—	—	—	—	—				
A4a.2	Transit Impedance											
A4a.3	Adjusted Impedance	(B)	∞	∞	∞	∞	∞	∞				
A4b.	Square of Impedance	$(C)=B^2$	—	—	—	—	—	—				
A4c.	Transit Index	(D)=A/C	0	0	0	0	0	0				
	Highway											
A4d.1	Airline Distance		2.7	6.8	8.2	8.5	7.6	6.1				
A4d.2	Impedance	(E)	48	89	103	106	98	83				
A4d.3	Square of Impedance	$(F)=E^2$	2304	7921	10609	11236	9604	6889				
A4e	Conductance Factor $(x10^6)$	$(G)=\frac{C+F}{CxF}$	434	126	94	89	104	145				
A4f	District Index	(H)=AxG	22.1	4.71	2.88	2.57	2.65	2.47				
A4g	Access Integral	$(J)=\Sigma H$										
A4i	Transit Trips	(K)=P*D/J	0	0	0	0	0	0				

WORK SHEET

Step	Origin District (i)	10										
A1			Corridor 1		Alternative 1			Sheet 1 of 4				
	% of Walk in (i)	0	Destination District (j)									
A3a.1	Dwelling Unit in (i)=	6000										
A3b.1	Production in (i)=	13200 (P)	1	2	3	4	5	6	7	8	9	10
A3a.2	Employment in (j)		15000	10000	10000	9000	9000	6000	6000	7000	7000	4500
A3b.2	Attraction A_j	(A)	25500	17000	17000	15300	15300	10200	10200	11900	11900	7650
	Transit											
A1	% of Walk in (j)		100	100	100	20	20	20	20	0	0	0
A4a.1	Line-Haul Distance		5.3	4.5	4.5	3.3	3.3	1.8	1.8	—	—	—
A4a.2	Transit Impedance		57	54	54	51	51	47	47			
A4a.3	Adjusted Impedance	(B)	57	54	54	114	114	105	105	∞	∞	∞
A4b.	Square of Impedanc	(C)=B^2	3249	2916	2916	12996	12996	11025	11025	—	—	—
A4c.	Transit Index	(D)=A/C	7.85	5.83	5.83	1.18	1.18	.92	.92	0	0	0
	Highway											
A4d.1	Airline Distance		7.3	6.3	6.6	5.2	5.8	3.8	4.8	2.0	3.9	0
A4d.2	Impedance	(E)	126	85	87	74	79	59	69	41	61	25
A4d.3	Square of Impedance	(F)=E^2	15876	7225	7569	5476	6241	3481	4761	1681	3721	625
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$	371	481	475	260	237	378	301	595	869	1600
A4f	District Index	(H)=AxG	9.46	8.18	8.08	3.98	3.63	3.86	3.07	7.08	3.20	12.24
A4g	Access Integral	(J)=ΣH	140.96									
A4i	Transit Trips	(K)=P*D/J	735	546	546	110	110	86	86	0	0	0

WORK SHEET

Step	Origin District (i) 10		Corridor 1 Alternative 1 Sheet 2 of 4									
A1	% of Walk in (i) 0		Destination District (j)									
A3a.1	Dwelling Unit in (i)= 6000											
A3b.1	Production in (i)= 13200	(P)	11	12	13	14	23	24	25	34	35	36
A3a.2	Employment in (j)		4500	10000	10000	10000	7000	9000	9000	8000	6000	6000
A3b.2	Attraction A_j	(A)	7650	17000	17000	17000	11900	15300	15300	13600	10200	10200
	Transit											
A1	% of Walk in (j)		0	100	100	100	100	100	100	100	100	100
A4a.1	Line-Haul Distance		—	6.7	7.5	7.5	6.7	7.5	7.5	6.7	7.5	7.5
A4a.2	Transit Impedance			59	85	85	59	85	85	59	85	85
A4a.3	Adjusted Impedance	(B)	∞	59	85	85	59	85	85	59	85	85
A4b.	Square of Impedance	(C)=B^2	—	3481	7225	7225	3481	7225	7225	3481	7225	7225
A4c.	Transit Index	(D)=A/C	0	4.88	2.35	2.35	3.42	2.11	2.11	3.91	1.41	1.41
	Highway											
A4d.1	Airline Distance		3.9	7.7	7.2	8.0	8.3	8.8	9.2	8.3	9.3	9.2
A4d.2	Impedance	(E)	61	130	93	102	136	110	113	13.6	115	113
A4d.3	Square of Impedance	(F)=E^2	3721	16900	8649	10404	18496	12100	12769	18496	13225	12769
A4e	Conductance Factor ($\times 10^6$)	(G)=$\frac{C+F}{C \times F}$	269	346	256	235	341	221	217	341	214	217
A4f	District Index	(H)=AxG	2.06	5.88	4.35	4.00	4.06	3.38	3.32	4.64	2.18	2.21
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	0	457	233	233	320	209	209	366	140	140

WORK SHEET

Step	Origin District (i) 10		Corridor 1	Alternative 1	Sheet 3 of 4							
A1	% of Walk in (i) 0		Destination District (j)									
A3a.1	Dwelling Unit in (i)= 6000											
A3b.1	Production in (i)= 13200	(P)	45	46	47	56	57	58	2B	3B	4B	5B
A3a.2	Employment in (j)		7000	4000	4000	4000	3000	3000	30000	20000	20000	30000
A3b.2	Attraction A_j	(A)	11900	6800	6800	6800	5100	5100	51000	34000	34000	51000
	Transit											
A1	% of Walk in (j)		100	100	100	100	100	100	0	0	0	0
A4a.1	Line-Haul Distance		6.7	7.5	7.5	6.7	7.5	7.5	—	—	—	—
A4a.2	Transit Impedance		59	85	85	59	85	85				
A4a.3	Adjusted Impedance	(B)	59	85	85	59	85	85	∞	∞	∞	∞
A4b.	Square of Impedance	(C)=B^2	3481	7225	7225	3481	7225	7225	—	—	—	—
A4c.	Transit Index	(D)=A/C	3.42	.94	.94	1.95	.71	.71	0	0	0	0
	Highway											
A4d.1	Airline Distance		8.0	8.8	8.0	7.4	7.2	6.6	7.8	10.7	11.2	9.4
A4d.2	Impedance	(E)	133	110	102	127	93	87	100	128	134	115
A4d.3	Square of Impedance	(F)=E^2	17689	12100	10404	16129	8649	7569	10000	16384	17956	13225
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$	344	221	235	3.49	254	271	100	61	56	76
A4f	District Index	(H)=AxG	4.09	1.50	1.60	2.37	1.30	1.38	5.10	2.07	1.90	3.88
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	320	93	93	183	70	70	0	0	0	0

WORK SHEET

Corridor 1 Alternative 1 Sheet 4 of 4

Step	Item		Destination District (j)									
A1	Origin District (i) 10											
	% of Walk in (i) 0											
A3a.1	Dwelling Unit in (i)= 6000											
A3b.1	Production in (i)= 13200	(P)	6B	2C	3C	4C	5C	6C				
A3a.2	Employment in (j)		30000	22000	18000	17000	15000	10000				
A3b.2	Attraction A_j	(A)	51000	37400	30600	28900	25500	17000				
	Transit											
A1	% of Walk in (j)		0	0	0	0	0	0				
A4a.1	Line-Haul Distance		—	—	—	—	—	—				
A4e.2	Transit Impedance		∞	∞	∞	∞	∞	∞				
A4a.3	Adjusted Impedance	(B)										
A4b.	Square of Impedance	$(C)=B^2$	—	—	—	—	—	—				
A4c.	Transit Index	(D)=A/C	0	0	0	0	0	0				
	Highway											
A4d.1	Airline Distance		6.0	9.1	13.9	14.8	12.0	5.7				
A4d.2	Impedance	(E)	81	113	161	170	141	78				
A4d.3	Square of Impedance	$(F)=E^2$	6561	12769	25921	28900	19881	6084				
A4e	Conductance Factor $(x10^6)$	$(G)=\frac{C+F}{CxF}$	152	78	38	35	50	164				
A4f	District Index	(H)=AxG	7.75	2.92	1.16	1.01	1.28	2.79				
A4g	Access Integral	$(J)=\Sigma H$										
A4i	Transit Trips	(K)=P*D/J	0	0	0	0	0	0				

WORK SHEET

Corridor 1 Alternative 1 Sheet 1 of 4

Step	Item		Destination District (j) 1	2	3	4	5	6	7	8	9	10
A1	Origin District (i) 6											
	% of Walk in (i) 20											
A3a.1	Dwelling Unit in (i)= 8500											
A3b.1	Production in (i)= 18700	(P)										
A3a.2	Employment in (j)		15000	10000	10000	9000	9000	8000	6000	7000	7000	4500
A3b.2	Attraction A_j	(A)	25500	17000	17000	15300	15300	10200	10200	11900	11900	7650
	Transit											
A1	% of Walk in (j)		100	100	100	20	20	20	20	0	0	0
A4a.1	Line-Haul Distance		3.5	2.7	2.7	1.5	1.5	0	0	1.8	1.8	1.8
A4a.2	Transit Impedance		72	70	70	67	67	64	64	47	47	47
A4a.3	Adjusted Impedance	(B)	81	79	79	149	149	143	143	105	105	105
A4b.	Square of Impedance	$(C)=B^2$	6561	6241	6241	22201	22201	20449	20449	11025	11025	11025
A4c.	Transit Index	(D)=A/C	389	2.72	2.72	.69	.69	.50	.50	1.08	1.08	.69
	Highway											
A4d.1	Airline Distance		3.5	2.6	2.9	1.5	2.4	0	2.2	1.8	3.2	3.8
A4d.2	Impedance	(E)	88	47	50	36	45	25	43	39	53	59
A4d.3	Square of Impedance	$(F)=E^2$	7744	2209	2500	1296	2025	625	1849	1521	2809	3481
A4e	Conductance Factor $(x10^6)$	$(G)=\frac{C+F}{CxF}$	282	613	560	817	539	1649	590	748	447	378
A4f	District Index	(H)=AxG	7.19	10.42	9.52	12.50	8.25	16.82	6.02	8.90	5.32	2.89
A4g	Access Integral	$(J)=\Sigma H$	198.65									
A4i	Transit Trips	(K)=P*D/J	366	256	256	65	65	47	47	102	102	65

WORK SHEET

Corridor 1 Alternative 1 Sheet 2 of 4

Step	Item	Formula	Destination District (j)									
A1	Origin District (i) 6											
	% of Walk in (i) 20											
A3a.1	Dwelling Unit in (i)= 8500											
A3b.1	Production in (i)= 18700	(P	11	12	13	14	23	24	25	34	35	36
A3a.2	Employment in (j)		4500	10000	10000	10000	7000	9000	9000	8000	6000	6000
A3b.2	Attraction A_j	(A)	7650	17000	17000	17000	11900	15300	15300	13600	10200	10200
	Transit											
A1	% of Walk in (j)		0	100	100	100	100	100	100	100	100	100
A4a.1	Line-Haul Distance		1.8	4.9	5.7	5.7	4.9	5.7	5.7	4.9	5.7	5.7
A4a.2	Transit Impedance		47	85	95	95	85	95	95	85	95	95
A4a.3	Adjusted Impedance	(B)	105	94	104	104	94	104	104	94	104	104
A4b.	Square of Impedance	(C)=B^2	10025	8836	10816	10816	8836	10816	10816	8836	10816	10816
A4c.	Transit Index	(D)=A/C	.69	1.92	1.57	1.57	1.35	1.41	1.41	1.54	.94	.94
	Highway											
A4d.1	Airline Distance		4.8	3.9	3.6	4.5	4.3	5.0	5.4	4.5	5.5	5.4
A4d.2	Impedance	(E)	69	92	57	98	64	72	76	98	76	76
A4d.3	Square of Impedance	(F)=E^2	4761	8464	3249	9604	4096	5184	5776	9604	5776	5776
A4e	Conductance Factor (x10^6)	(G)=$\frac{C+F}{CxF}$	300	231	400	197	357	285	266	217	266	266
A4f	District Index	(H)=AxG	2.30	3.93	6.80	2.34	6.07	4.36	4.07	2.95	2.71	2.71
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	65	181	148	148	127	133	133	145	88	88

WORK SHEET

Corridor 1 Alternative 1 Sheet 3 of 4

Step	Item	Formula										
A1	Origin District (i) 6		Destination District (j)									
	% of Walk in (i) 20											
A3a.1	Dwelling Unit in (i)= 8500											
A3b.1	Production in (i)= 18700	(P)	45	46	47	56	57	58	2B	3B	4B	5B
A3a.2	Employment in (j)		7000	4000	4000	4000	3000	3000	30000	20000	20000	30000
A3b.2	Attraction A_j	(A)	11900	6800	6800	6800	5100	5100	51000	34000	34000	51000
	Transit											
A1	% of Walk in (j)		100	100	100	100	100	100	0	0	0	0
A4a.1	Line-Haul Distance		4.9	5.7	5.7	4.9	5.7	5.7	—	—	—	—
A4a.2	Transit Impedance		85	9.5	95	85	95	95	∞	∞	∞	∞
A4a.3	Adjusted Impedance	(B)	94	104	104	94	104	104				
A4b.	Square of Impedance	(C)=B^2	8836	10816	10816	8836	10816	10816	—	—	—	—
A4c.	Transit Index	(D)=A/C	1.35	.63	.63	.77	.47	.47	0	0	0	0
	Highway											
A4d.1	Airline Distance		4.3	5.0	4.4	3.7	3.6	3.0	4.7	7.1	7.5	6.0
A4d.2	Impedance	(E)	96	72	64	90	57	50	6.8	92	9.7	81
A4d.3	Square of Impedance	(F)=E^2	9216	5184	4096	8100	3249	2500	4624	8464	9464	6561
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$	222	285	337	237	400	492	216	118	106	152
A4f	District Index	(H)=AxG	2.64	1.94	2.29	1.61	2.04	2.51	11.0	4.01	3.60	7.75
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	127	59	59	72	44	44	0	0	0	0

WORK SHEET

Origin District (i): 6 — Corridor 1 — Alternative 1 — Sheet 4 of 4

Step	Item	Formula	Destination District (j)									
A1	% of Walk in (i) 20											
A3a.1	Dwelling Unit in (i)= 8500											
A3b.1	Production in (i)= 18700	(P)	6B	2C	3C	4C	5C	6C				
A3a.2	Employment in (j)		30000	22000	18000	17000	15000	10000				
A3b.2	Attraction A_j	(A)	51000	37400	30600	28900	25500	17000				
	Transit											
A1	% of Walk in (j)		0	0	0	0	0	0				
A4a.1	Line-Haul Distance		—	—	—	—	—	—				
A4a.2	Transit Impedance											
A4a.3	Adjusted Impedance	(B)	∞	∞	∞	∞	∞	∞				
A4b.	Square of Impedance	$(C)=B^2$	—	—	—	—	—	—				
A4c.	Transit Index	(D)=A/C	0	0	0	0	0	0				
	Highway											
A4d.1	Airline Distance		3.0	7.2	10.4	11.0	9.0	5.0				
A4d.2	Impedance	(E)	51	93	126	132	112	72				
A4d.3	Square of Impedance	$(F)=E^2$	2601	8649	15876	17424	12544	5184				
A4e	Conductance Factor ($x10^8$)	$(G)=\frac{C+F}{CxF}$	384	116	62	57	80	193				
A4f	District Index	(H)=AxG	19.6	4.34	1.90	1.65	2.04	3.28				
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	0	0	0	0	0	0				

WORK SHEET

Corridor 1 Alternative 1 Sheet 1 of 3

Step			Destination District (j)									
A1	Origin District (i)	3										
	% of Walk in (i)	100										
A3a.1	Dwelling Unit in (i)=	1000										
A3b.1	Production in (i)= 2200	(P)	1	2	3	4	5	6	7	8	9	10
A3a.2	Employment in (j)		15000	10000	10000	9000	9000	6000	6000	7000	7000	4500
A3b.2	Attraction A_j	(A)	25500	17000	17000	15300	15300	10200	10200	11900	11900	7650
	Transit											
A1	% of Walk in (j)		100	100	100	20	20	20	20	0	0	0
A4a.1	Line-Haul Distance		.8	0	0	1.2	1.2	2.7	2.7	4.5	4.5	4.5
A4a.2	Transit Impedance		66	65	65	67	67	70	70	54	54	54
A4a.3	Adjusted Impedance	(B)	66	65	65	76	76	79	79	54	54	54
A4b.	Square of Impedance	$(C)=B^2$	4356	4225	4225	5776	5776	6241	6241	2916	2916	2916
A4c.	Transit Index	(D)=A/C	5.85	4.02	4.02	2.65	2.65	1.63	1.63	4.08	4.08	2.62
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	$(F)=E^2$										
A4e	Conductance Factor $(x10^6)$	$(G)=\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)=ΣH	330.45 (Same As District 2)									
A4i	Transit Trips	(K)=P*D/J	39	27	27	18	18	11	11	27	27	17

WORK SHEET

Step	Item		Destination District (j)									
A1	Origin District (i) 3		Corridor 1			Alternative 1			Sheet 2 of 3			
	% of Walk in (i) 100											
A3a.1	Dwelling Unit in (i)= 1000											
A3b.1	Production in (i)= 2200	(P)	11	12	13	14	23	24	25	34	35	36
A3a.2	Employment in (j)		4500	10000	10000	10000	7000	9000	9000	8000	6000	6000
A3b.2	Attraction A_j	(A)	7650	17000	17000	17000	11900	15300	15300	13600	10200	10200
	Transit											
A1	% of Walk in (j)		0	100	100	100	100	100	100	100	100	100
A4a.1	Line-Haul Distance		4.5	2.2	3.0	3.0	2.2	3.0	3.0	2.2	3.0	3.0
A4a.2	Transit Impedance		54	72	76	76	72	76	76	72	76	76
A4a.3	Adjusted Impedance	(B)	54	72	76	76	72	76	76	72	76	76
A4b.	Square of Impedance	(C)=B^2	2916	5184	5776	5776	5184	5776	5776	5184	5776	5776
A4c.	Transit Index	(D)=A/C	2.62	3.28	2.94	2.94	2.30	2.65	2.65	2.62	1.77	1.77
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	(F)=E^2										
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	17	22	20	20	15	18	18	17	12	12

WORK SHEET

Corridor 1 Alternative 1 Sheet 3 of 3

Step	Origin District (i) 3		Destination District (j)									
A1	% of Walk in (i) 100											
A3a.1	Dwelling Unit in (i)= 1000											
A3b.1	Production in (i)= 2200	(P)	45	46	47	56	57	58				
A3a.2	Employment in (j)		7000	4000	4000	4000	3000	3000				
A3b.2	Attraction A_j	(A)	11900	6800	6800	6800	5100	5100				
	Transit											
A1	% of Walk in (j)		100	100	100	100	100	100				
A4a.1	Line-Haul Distance		2.2	3.0	3.0	2.2	3.0	3.0				
A4a.2	Transit Impedance		72	76	76	72	76	76				
A4a.3	Adjusted Impedance	(B)	72	76	76	72	76	76				
A4b.	Square of Impedance	$(C)=B^2$	5184	5776	5776	5184	5776	5776				
A4c.	Transit Index	(D)=A/C	2.30	1.18	1.18	1.31	.88	.88				
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	$(F)=E^2$										
A4e	Conductance Factor $(x10^6)$	$(G)=\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	15	8	8	9	6	6				

WORK SHEET

Step			Corridor 1	Alternative 1	Sheet 1 of 3						
	Origin District (i) 4										
A1	% of Walk in (i) 20		Destination District (j)								
A3a.1	Dwelling Unit in (i)= 6500										
A3b.1	Production in (i)= 14300	(P)	1	2	3	4	5	6	7	8	9	10
A3a.2	Employment in (j)		15000	10000	10000	9000	9000	6000	6000	7000	7000	4500
A3b.2	Attraction A_j	(A)	25500	17000	17000	15300	15300	10200	10200	11900	11900	7650
	Transit											
A1	% of Walk in (j)		100	100	100	20	20	20	20	0	0	0
A4a.1	Line-Haul Distance		2.0	1.2	1.2	0	0	1.5	1.5	3.3	3.3	3.3
A4a.2	Transit Impedance		68	67	67	55	55	67	67	51	51	51
A4a.3	Adjusted Impedance	(B)	77	76	76	123	123	149	149	114	114	114
A4b.	Square of Impedance	(C)–B^2	5929	5776	5776	15129	15129	22201	22201	12996	12996	12996
A4c.	Transit Index	(D)–A/C	4.30	2.94	2.94	1.01	1.01	.46	.46	.92	.92	.59
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	(F)–E^2										
A4e	Conductance Factor ($x10^6$)	(G)–$\frac{C+F}{CxF}$										
A4f	District Index	(H)–AxG										
A4g	Access Integral	(J)–ΣH	275.0 (Obtained From Graph)									
A4i	Transit Trips	(K)–P*D/J	224	153	153	53	53	24	24	48	48	31

WORK SHEET

Step	Origin District (i)	4	Corridor 1 Alternative 1 Sheet 2 of 3									
A1	% of Walk in (i)	20	Destination District (j)									
A3a.1	Dwelling Unit in (i)= 6500											
A3b.1	Production in (i)= 14300	(P)	11	12	13	14	23	24	25	34	35	36
A3a.2	Employment in (j)		4500	10000	10000	10000	7000	9000	9000	8000	6000	6000
A3b.2	Attraction A_j	(A)	7650	17000	17000	17000	11900	15300	15300	13600	10200	10200
	Transit											
A1	% of Walk in (j)		0	100	100	100	100	100	100	100	100	100
A4a.1	Line-Haul Distance		3.3	3.4	4.2	4.2	3.4	4.2	4.2	2.8	4.2	4.2
A4a.2	Transit Impedance		51	72	82	82	72	82	82	70	82	82
A4a.3	Adjusted Impedance	(B)	114	81	91	91	81	91	91	79	91	91
A4b.	Square of Impedance	(C)=B^2	12996	6561	8281	8281	6561	8281	8281	6241	8281	8281
A4c.	Transit Index	(D)=A/C	.59	2.59	2.05	2.05	1.81	1.85	1.85	2.18	1.23	1.23
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	(F)=E^2										
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	31	135	107	104	94	96	96	113	64	64

WORK SHEET

Step	Origin District (i) 4		Corridor 1 Alternative 1 Sheet 3 of 3									
A1	% of Walk in (i) 20		Destination District (j)									
A3a.1	Dwelling Unit in (i)= 6500											
A3b.1	Production in (i)= 14300	(P)	45	46	47	56	57	58				
A3a.2	Employment in (j)		7000	4000	4000	4000	3000	3000				
A3b.2	Attraction A_j	(A)	11900	6800	6800	6800	5100	5100				
	Transit											
A1	% of Walk in (j)		100	100	100	100	100	100				
A4a.1	Line-Haul Distance		3.4	4.2	4.2	3.4	4.2	4.2				
A4a.2	Transit Impedance		72	82	82	72	82	82				
A4a.3	Adjusted Impedance	(B)	81	91	91	81	91	91				
A4b.	Square of Impedance	(C)=B^2	6561	8281	8281	6561	8281	8281				
A4c.	Transit Index	(D)=A/C	1.81	.82	.82	1.04	.62	.62				
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	(F)=E^2										
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	94	43	43	54	32	32				

WORK SHEET

Corridor 1 Alternative 1 Sheet 1 of 3

Step	Item	Formula	Destination District (j): 1	2	3	4	5	6	7	8	9	10
A1	Origin District (i) 5											
	% of Walk in (i) 20											
A3a.1	Dwelling Unit in (i)= 6500											
A3b.1	Production in (i)= 14300	(P)										
A3a.2	Employment in (j)		15000	10000	10000	9000	9000	6000	6000	7000	7000	4500
A3b.2	Attraction A_j	(A)	25500	17000	17000	15300	15300	10200	10200	11900	11900	7650
	Transit											
A1	% of Walk in (j)		100	100	100	20	20	20	20	0	0	0
A4a.1	Line-Haul Distance		2.0	1.2	1.2	1.2	0	1.5	1.5	3.3	3.3	3.3
A4a.2	Transit Impedance		68	67	67	67	55	67	67	51	51	51
A4a.3	Adjusted Impedance	(B)	77	76	76	114	123	149	149	114	114	114
A4b.	Square of Impedance	(C)= B^2	5929	5776	5776	22201	15129	22201	22201	12996	12996	12996
A4c.	Transit Index	(D)=A/C	4.30	2.94	2.94	.69	1.01	.46	.46	.92	.92	.59
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	(F)= E^2										
A4e	Conductance Factor ($x10^6$)	(G)= $\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)=ΣH	275.0 (Obtained From Graph)									
A4i	Transit Trips	(K)=P*D/J	224	153	153	36	53	24	24	48	48	31

WORK SHEET

Corridor 1 Alternative 1 Sheet 2 of 3

Step	Item		Destination District (j): 11	12	13	14	23	24	25	34	35	36
A1	Origin District (i)	5										
	% of Walk in (i)	20										
A3a.1	Dwelling Unit in (i)=	6500										
A3b.1	Production in (i)=	14300 (P)										
A3a.2	Employment in (j)		4500	10000	10000	10000	7000	9000	9000	8000	6000	6000
A3b.2	Attraction A_j	(A)	7650	17000	17000	17000	11900	15300	15300	13600	10200	10200
	Transit											
A1	% of Walk in (j)		0	100	100	100	100	100	100	100	100	100
A4a.1	Line-Haul Distance		3.3	3.4	4.2	4.2	3.4	4.2	4.2	2.8	4.2	4.2
A4a.2	Transit Impedance		51	72	82	82	72	82	82	70	82	82
A4a.3	Adjusted Impedance	(B)	114	81	91	91	81	91	91	79	91	91
A4b.	Square of Impedance	(C)= B^2	12996	6561	8281	8281	6561	8281	8281	6241	8281	8281
A4c.	Transit Index	(D)=A/C	.59	2.59	2.05	2.00	1.81	1.85	1.85	2.18	1.23	1.23
	Highway											
A4d.	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	(F)= E^2										
A4e	Conductance Factor ($x10^6$)	(G)= $\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)= ΣH										
A4i	Transit Trips	(K)=P*D/J	31	135	107	104	94	96	96	113	64	64

WORK SHEET

Corridor 1 Alternative 1 Sheet 3 of 3

Step	Origin District (i)	5	Destination District (j)									
A1	% of Walk in (i)	20										
A3a.1	Dwelling Unit in (i)= 6500											
A3b.1	Production in (i)= 14300	(P)	45	46	47	56	57	58				
A3a.2	Employment in (j)		7000	4000	4000	4000	3000	3000				
A3b.2	Attraction A_j	(A)	11900	6800	6800	6800	5100	5100				
	Transit											
A1	% of Walk in (j)		100	100	100	100	100	100				
A4a.1	Line-Haul Distance		3.4	4.2	4.2	3.4	4.2	4.2				
A4a.2	Transit Impedance		72	82	82	72	82	82				
A4a.3	Adjusted Impedance	(B)	81	91	91	81	91	91				
A4b.	Square of Impedance	(C)=B^2	6561	8281	8281	6561	8281	8281				
A4c.	Transit Index	(D)=A/C	1.81	.82	.82	1.04	.62	.62				
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	(F)=E^2										
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	94	43	43	54	32	32				

WORK SHEET

Step			Corridor 1	Alternative 1		Sheet 1 of 3					
A1	Origin District (i) 7										
	% of Walk in (i) 20		Destination District (j)								
A3a.1	Dwelling Unit in (i)= 8500										
A3b.1	Production in (i)= 18700	(P)	1	2	3	4	5	6	7	8	9	10
A3a.2	Employment in (j)		15000	10000	10000	9000	9000	6000	6000	7000	7000	4500
A3b.2	Attraction A_j	(A)	25500	17000	17000	15300	15300	10200	10200	11900	11900	7650
	Transit											
A1	% of Walk in (j)		100	100	100	20	20	20	20	0	0	0
A4a.1	Line-Haul Distance		3.5	2.7	2.7	1.5	1.5	0	0	1.8	1.8	1.8
A4a.2	Transit Impedance		72	70	70	67	67	64	64	47	47	47
A4a.3	Adjusted Impedance	(B)	81	79	79	149	149	143	143	105	105	105
A4b.	Square of Impedance	(C)=B^2	6561	6241	6241	22201	22201	20449	20449	11025	11025	11025
A4c.	Transit Index	(D)=A/C	3.89	2.72	2.72	.69	.69	.50	.50	1.08	1.08	.69
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	(F)=E^2										
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)=ΣH	198.65 (Same As District 6)									
A4i	Transit Trips	(K)=P*D/J	366	256	256	65	65	47	47	102	102	65

WORK SHEET

Corridor 1 Alternative 1 Sheet 2 of 3

Step	Item	Formula										
A1	Origin District (i)	7										
	% of Walk in (i)	20										
A3a.1	Dwelling Unit in (i)=	8500										
A3b.1	Production in (i)= 18700	(P)										
	Destination District (j)		11	12	13	14	23	24	25	34	35	36
A3a.2	Employment in (j)		4500	10000	10000	10000	7000	9000	9000	8000	6000	6000
A3b.2	Attraction A_j	(A)	7650	17000	17000	17000	11900	15300	15300	13600	10200	10200
	Transit											
A1	% of Walk in (j)		0	100	100	100	100	100	100	100	100	100
A4a.1	Line-Haul Distance		1.8	4.9	5.7	5.7	4.9	5.7	5.7	4.9	5.7	5.7
A4a.2	Transit Impedance		47	85	95	95	85	95	95	85	95	95
A4a.3	Adjusted Impedance	(B)	105	94	104	104	94	104	104	94	104	104
A4b.	Square of Impedance	$(C)=B^2$	11025	8836	10816	10816	8836	10816	10816	8836	10816	10816
A4c.	Transit Index	(D)=A/C	.69	1.92	1.57	1.57	1.35	1.41	1.41	1.54	.94	.94
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	$(F)=E^2$										
A4e	Conductance Factor $(x10^6)$	$(G)=\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	$(J)=\Sigma H$										
A4i	Transit Trips	(K)=P*D/J	65	181	148	148	127	133	133	145	88	88

WORK SHEET

Corridor 1 Alternative 1 Sheet 3 of 3

Step	Item		Destination District (j)									
A1	Origin District (i) 7											
	% of Walk in (i) 20											
A3a.1	Dwelling Unit in (i)= 8500											
A3b.1	Production in (i)= 18700	(P)	45	46	47	56	57	58				
A3a.2	Employment in (j)		7000	4000	4000	4000	3000	3000				
A3b.2	Attraction A_j	(A)	11900	6800	6800	6800	5100	5100				
	Transit											
A1	% of Walk in (j)		100	100	100	100	100	100				
A4a.1	Line-Haul Distance		4.9	5.7	5.7	4.9	5.7	5.7				
A4a.2	Transit Impedance		85	95	95	85	95	95				
A4a.3	Adjusted Impedance	(B)	94	104	104	94	104	104				
A4b.	Square of Impedance	$(C)=B^2$	8836	10816	10816	8836	10816	10816				
A4c.	Transit Index	(D)=A/C	1.35	.63	.63	.77	.47	.47				
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	$(F)=E^2$										
A4e	Conductance Factor $(x10^6)$	$(G)=\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	127	59	59	72	44	44				

WORK SHEET

Corridor 1 Alternative 1 Sheet 1 of 3

Step	Origin District (i) 8		Destination District (j)									
A1	% of Walk in (i) 0											
A3a.1	Dwelling Unit in (i)= 4000											
A3b.1	Production in (i)= 8800	(P)	1	2	3	4	5	6	7	8	9	10
A3a.2	Employment in (j)		15000	10000	10000	9000	9000	6000	6000	7000	7000	4500
A3b.2	Attraction A_j	(A)	25500	17000	17000	15300	15300	10200	10200	11900	11900	7650
	Transit											
A1	% of Walk in (j)		100	100	100	20	20	20	20	30	0	0
A4a.1	Line-Haul Distance		5.3	4.5	4.5	3.3	3.3	1.8	1.8	—	—	—
A4a.2	Transit Impedance		57	54	54	51	51	47	47			
A4a.3	Adjusted Impedance	(B)	57	54	54	114	114	105	105	∞	∞	∞
A4b.	Square of Impedance	(C)=B^2	3249	2916	2916	12996	12996	11025	11025	—	—	—
A4c.	Transit Index	(D)=A/C	7.85	5.83	5.83	1.18	1.18	.93	.93	0	0	0
	Highway											
A4d.1	Airline Distance												
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	(F)=E^2										
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)=ΣH	151 (Obtained From Graph)									
A4i	Transit Trips	(K)=P*D/J	457	340	340	69	69	54	54	0	0	0

WORK SHEET

Step			Corridor 1	Alternative 1	Sheet 2 of 3							
A1	Origin District (i) 8											
	% of Walk in (i) 0		Destination District (j)									
A3a.1	Dwelling Unit in (i)= 4000											
A3b.1	Production in (i)= 8800	(P)	11	12	13	14	23	24	25	34	35	36
A3a.2	Employment in (j)		4500	10000	10000	10000	7000	9000	9000	8000	6000	6000
A3b.2	Attraction A_j	(A)	7650	17000	17000	17000	11900	15300	15300	13600	10200	10200
	Transit											
A1	% of Walk in (j)		0	100	100	100	100	100	100	100	100	100
A4a.1	Line-Haul Distance		—	6.7	7.5	7.5	6.7	7.5	7.5	6.7	7.5	7.5
A4a.2	Transit Impedance		~~60~~	60	85	85	60	85	85	60	85	85
A4a.3	Adjusted Impedance	(B)		60	85	85	60	85	85	60	85	85
A4b.	Square of Impedance	$(C)=B^2$	—	3600	7225	7225	3600	7225	7225	3600	7225	7225
A4c.	Transit Index	(D)=A/C	0	4.72	2.35	2.35	3.31	2.13	2.13	378	1.41	1.41
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	$(F)=E^2$										
A4e	Conductance Factor $(x10^6)$	$(G)=\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	0	275	137	137	193	124	124	220	82	82

WORK SHEET

Corridor 1 Alternative 1 Sheet 3 of 3

Step			Destination District (j)									
A1	Origin District (i) 8											
	% of Walk in (i) 0											
A3a.1	Dwelling Unit in (i)= 4000											
A3b.1	Production in (i)= 8800	(P)	45	46	47	56	57	58				
A3a.2	Employment in (j)		7000	4000	4000	4000	3000	3000				
A3b.2	Attraction A_j	(A)	11900	6800	6800	6800	5100	5100				
	Transit											
A1	% of Walk in (j)		100	100	100	100	100	100				
A4a.1	Line-Haul Distance		6.7	7.5	7.5	6.7	7.5	7.5				
A4a.2	Transit Impedance		60	85	85	60	85	85				
A4a.3	Adjusted Impedance	(B)	60	85	85	60	85	85				
A4b.	Square of Impedance	$(C)=B^2$	3600	7225	7225	3600	7225	7225				
A4c.	Transit Index	(D)=A/C	3.31	.94	.94	1.89	.71	.71				
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	$(F)=E^2$										
A4e	Conductance Factor ($x10^6$)	$(G)=\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	$(J)=\Sigma H$										
A4i	Transit Trips	(K)=P*D/J	193	55	55	110	41	41				

WORK SHEET

Step	Origin District (i)		Corridor 1	Alternative 1	Sheet 1 of 3							
A1	Origin District (i) = 9											
	% of Walk in (i) 0		Destination District (j)									
A3a.1	Dwelling Unit in (i)= 4000											
A3b.1	Production in (i)= 8800	(P)	1	2	3	4	5	6	7	8	9	10
A3a.2	Employment in (j)		1500	10000	10000	9000	9000	6000	6000	7000	7000	4500
A3b.2	Attraction A_j	(A)	25500	17000	17000	15300	15300	10200	10200	11900	11900	7650
	Transit											
A1	% of Walk in (j)		100	100	100	20	20	20	20	0	0	0
A4a.1	Line-Haul Distance		5.3	4.5	4.5	3.3	3.3	1.8	1.8	—	—	—
A4a.2	Transit Impedance		57	54	54	51	51	47	47			
A4a.3	Adjusted Impedance	(B)	57	54	54	114	114	105	105	∞	∞	∞
A4b.	Square of Impedance	$(C)=B^2$	3249	2916	2916	12996	12996	11025	11025	—	—	—
A4c.	Transit Index	(D)=A/C	7.85	5.83	583	1.18	1.18	.93	.93	0	0	0
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	$(F)=E^2$										
A4e	Conductance Factor $(x10^6)$	$(G)=\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	$(J)=\Sigma H$	151 (Obtained From Graph)									
A4i	Transit Trips	(K)=P*D/J	457	340	340	69	69	54	54	0	0	0

WORK SHEET

Corridor 1 Alternative 1 Sheet 2 of 3

Step	Origin District (i)	9											
A1	% of Walk in (i)	0		Destination District (j)									
A3a.1	Dwelling Unit in (i)=	4000											
A3b.1	Production in (i)=	8800	(P)	11	12	13	14	23	24	25	34	35	36
A3a.2	Employment in (j)			4500	10000	10000	10000	7000	9000	9000	8000	6000	6000
A3b.2	Attraction A_j		(A)	7650	17000	17000	17000	11900	15300	15300	13600	10200	10200
	Transit												
A1	% of Walk in (j)			100	100	100	100	100	100	100	100	100	100
A4a.1	Line-Haul Distance			0	6.7	7.5	7.5	6.7	7.5	7.5	6.7	7.5	7.5
A4a.2	Transit Impedance			∞	60	85	85	60	85	85	60	85	85
A4a.3	Adjusted Impedance		(B)		60	85	85	60	85	85	60	85	85
A4b.	Square of Impedance		$(C)=B^2$	—	3600	7225	7225	3600	7225	7225	3600	7225	7225
A4c.	Transit Index		(D)=A/C	0	4.72	2.35	2.35	3.31	2.13	2.13	3.78	1.41	1.41
	Highway												
A4d.1	Airline Distance												
A4d.2	Impedance		(E)										
A4d.3	Square of Impedance		$(F)=E^2$										
A4e	Conductance Factor $(x10^6)$		$(G)=\frac{C+F}{CxF}$										
A4f	District Index		(H)=AxG										
A4g	Access Integral		(J)=ΣH										
A4i	Transit Trips		(K)=P*D/J	0	275	137	137	193	124	124	220	82	82

WORK SHEET

Corridor 1 Alternative 1 Sheet 3 of 3

Step			Destination District (j)									
A1	Origin District (i) 9											
	% of Walk in (i) 0											
A3a.1	Dwelling Unit in (i)= 4000											
A3b.1	Production in (i)= 8800	(P)	45	46	47	56	57	58				
A3a.2	Employment in (j)		7000	4000	4000	4000	3000	3000				
A3b.2	Attraction A_j	(A)	11900	6800	6800	6800	5100	5100				
	Transit											
A1	% of Walk in (j)		100	100	100	100	100	100				
A4a.1	Line-Haul Distance		6.7	7.5	7.5	6.7	7.5	7.5				
A4a.2	Transit Impedance		60	85	85	60	85	85				
A4a.3	Adjusted Impedance	(B)	60	85	85	60	85	85				
A4b.	Square of Impedance	$(C)=B^2$	3600	7225	7225	3600	7225	7225				
A4c.	Transit Index	(D)=A/C	3.31	.94	.94	1.89	.71	.71				
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	$(F)=E^2$										
A4e	Conductance Factor $(x10^6)$	$(G)=\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	193	55	55	110	41	41				

WORK SHEET

Origin District (i): 11 | % of Walk in (i): 0 | Dwelling Unit in (i) = 6000 | Production in (i) = 13200 (P)

Corridor 1   Alternative 1   Sheet 1 of 3

Step	Item		Destination District (j) 1	2	3	4	5	6	7	8	9	10
A3a.2	Employment in (j)		15000	10000	10000	9000	9000	6000	6000	7000	7000	4500
A3b.2	Attraction A_j	(A)	25500	17000	17000	15300	15300	10200	10200	11900	11900	7650
	Transit											
A1	% of Walk in (j)		100	100	100	20	20	20	20	0	0	0
A4a.1	Line-Haul Distance		5.3	4.5	4.5	3.3	3.3	1.8	1.8	–	–	–
A4a.2	Transit Impedance		57	54	54	51	51	47	47	∞	∞	∞
A4a.3	Adjusted Impedance	(B)	57	54	54	114	114	105	105			
A4b.	Square of Impedance	(C)=B^2	3249	2916	2916	12996	12996	11025	11025	–	–	–
A4c.	Transit Index	(D)=A/C	7.85	5.83	5.83	1.18	1.18	.92	.92	0	0	0
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	(F)=E^2										
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)=ΣH	140.96 (Same As District 10)									
A4i	Transit Trips	(K)=P*n/J	735	546	546	110	110	86	86	0	0	0

WORK SHEET

Corridor 1 Alternative 1 Sheet 2 of 3

Step			Destination District (j)									
A1	Origin District (i) 11											
	% of Walk in (i) 0											
A3a.1	Dwelling Unit in (i)= 6000											
A3b.1	Production in (i)= 13200	(P)	11	12	13	14	23	24	25	34	35	36
A3a.2	Employment in (j)		4500	10000	10000	10000	7000	9000	9000	8000	6000	6000
A3b.2	Attraction A_j	(A)	7650	17000	17000	17000	11900	15300	15300	13600	10200	10200
	Transit											
A1	% of Walk in (j)		0	100	100	100	100	100	100	100	100	100
A4a.1	Line-Haul Distance		—	6.7	7.5	7.5	6.7	7.5	7.5	6.7	7.5	7.5
A4a.2	Transit Impedance			59	85	85	59	85	85	59	85	85
A4a.3	Adjusted Impedance	(B)	∞	59	85	85	59	85	85	59	85	85
A4b.	Square of Impedance	$(C)=B^2$	—	3481	7225	7225	3481	7225	7225	3481	7225	7225
A4c.	Transit Index	(D)=A/C	0	4.88	2.35	2.35	3.42	2.11	2.11	3.91	1.41	1.41
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	$(F)=E^2$										
A4e	Conductance Factor $(x10^6)$	$(G)=\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	$(J)=\Sigma H$										
A4i	Transit Trips	(K)=P*D/J	0	457	233	233	320	209	209	366	140	140

WORK SHEET

Corridor 1 Alternative 1 Sheet 3 of 3

Step	Item		Destination District (j)									
A1	Origin District (i) 11											
	% of Walk in (i) 0											
A3a.1	Dwelling Unit in (i)= 6000											
A3b.1	Production in (i)= 13200	(P)	45	46	47	56	57	58				
A3a.2	Employment in (j)		7000	4000	4000	4000	3000	3000				
A3b.2	Attraction A_j	(A)	11900	6800	6800	6800	5100	5100				
	Transit											
A1	% of Walk in (j)		100	100	100	100	100	100				
A4a.1	Line-Haul Distance		6.7	7.5	7.5	6.7	7.5	7.5				
A4a.2	Transit Impedance		59	85	85	59	85	85				
A4a.3	Adjusted Impedance	(B)	59	85	85	59	85	85				
A4b.	Square of Impedance	(C)= B^2	3481	7225	7225	3481	7225	7225				
A4c.	Transit Index	(D)=A/C	3.42	.94	94	1.95	.71	.71				
	Highway											
A4d.1	Airline Distance											
A4d.2	Impedance	(E)										
A4d.3	Square of Impedance	(F)= E^2										
A4e	Conductance Factor ($x10^6$)	(G)= $\frac{C+F}{CxF}$										
A4f	District Index	(H)=AxG										
A4g	Access Integral	(J)=ΣH										
A4i	Transit Trips	(K)=P*D/J	320	93	93	183	70	70				

APPENDIX E

MATHEMATICAL FORMULATIONS AND ASSUMPTIONS

A. TRIP GENERATION

PP(N) = Population of the Nth district
P(N) = Productions of the Nth district

$$P(N) = 2.2\ [PP(N)] \quad (1)$$

EM(N) = Employment of the Nth district
A(N) = Attractions of the Nth district

$$A(N) = 1.7\ [EM(N)] \quad (2)$$

B. TRIP DISTRIBUTION AND MODE CHOICE

TIIJ = Transit impedance in disutility minutes between Districts I and J

HIIJ = Highway impedance in disutility minutes

CIIJ = Composite highway and transit conductance

$$\frac{1}{(CIIJ)^2} = \frac{1}{(TIIJ)^2} + \frac{1}{(HIIJ)^2} = \frac{(TIIJ)^2 + (HIIJ)^2}{(TIIJ)^2 \times (HIIJ)^2} \qquad (3)$$

A(J) = Attractions in District J
P(I) = Productions in District I
ND = Number districts
TRIJ = Transit trips between Districts I and J

$$TRIJ = \frac{A(J) \times (TIIJ)^2}{\Sigma(A(J) \times (CIIJ)^2)} \qquad (4)$$

C. OPERATING COSTS

V24M = 24 hour two directional volume at the maximum load point
RP = Peak hour passenger ratio
VPP = Peak hour peak direction line volume

$$VPP = V24M \times RP \quad (5)$$

RP has the following default values:

Peaking Condition		RP
High	H	0.16
Medium	M	0.12
Low	L	0.08

CAP = Vehicular seating capacity
LF = Passenger load factor
NC = Cars passing the maximum load point in the peak hour

$$NC = \frac{VPP}{CAP \times LF} \quad (6)$$

CAP has the following default values:

Mode		CAP
Rail Rapid Transit	R	70
Light Rapid Transit (PCC)	L	40
Bus	B	45

LF has the following default values:

Mode		High	Medium	Low
Rail Rapid Transit	R	3	2	1
Light Rapid Transit (PCC)	L	3	2	1
Bus	B	2	1.5	1

L = One way line length in miles
CM2P = Car miles operated in the peak 2 hours

$$CM2P = 4\ NC \times L \quad (7)$$

PR = Peak two hour car mile ratio
DCM = Daily car miles operated

$$DCM = CM2P \times PR \quad (8)$$

PR has the following default values:

Peaking Condition		PR
High	H	5
Medium	M	7.5
Low	L	10

CCM = Operating cost in dollars per car mile
DDC = Daily operating cost in dollars

DOC = DCM x CCM (9)

AOC = Annual operating cost in dollars

AOC = 300 DOC (10)

DCR = Daily operating cost in cents per rider

DCR = 100 DOC/V24M (11)

D. VEHICLE FREQUENCY CHECK

NC = Cars passing the maximum load point in the peak hour
CPT = Cars per train
TPH = Trains per peak hour

$$TPH = NC/CPT \qquad (12)$$

HM = Peak hour headway in minutes

$$HM - 60/TPH \qquad (13)$$

HSEC = Peak hour headway in seconds

$$HSEC = 3600/TPH = 60\ HM \qquad (14)$$

E. FARE REVENUES

V24L = 24-hour two directional line volume
MTL = Average trip length in miles
DPM = Daily passenger miles

$$DPM = V24L \times MTL \qquad (15)$$

CPM = Graduated fare rate in cents per passenger mile
DFR = Daily fare revenue in dollars

$$DFR = DPM \times CPM/100 \text{ (Graduated fare)} \qquad (16)$$

AFR = Annual fare revenue in dollars

$$AFR = 300\ DFR \qquad (17)$$

FCT = Flat fare rate in cents per trip

$$DFR = V24L \times FCT/100 \text{ (Flat rate fare)} \qquad (18)$$

RPR = Revenue in cents per rider

$$RPR = DFR/V24L \qquad (19)$$

F. FARE SENSITIVE DEMAND ADJUSTMENT

V24L = 24-hour two directional line volume
AR = Annual ridership

$$AR = 30\ V24L \quad (20)$$

PFC = Percent fare change
PRC = Percent ridership change

(1) PFC>0

$$PRC = -0.291\ PFC - 1.09^{*} \quad (21)$$

ADR = Adjusted daily ridership

$$ADR = (1+PRC/100) \times V24L$$

$$ADR = (-0.00291\ PFC + 0.9891) \times V24L \quad (22)$$

(2) PFC=0

$$PRC = 0$$

$$ADR = V24L \quad (23)$$

(3) PFC<0**

$$PRC = -0.291\ PFC + 1.09 \quad (24)$$

$$ADR = (1 + PRC/100) \times V24L \quad (25)$$

$$ADR = (-0.00291\ PFC + 1.0109) \times V24L$$

AAR = Adjusted annual ridership

$$AAR = 300\ ADR \quad (26)$$

---

*This formulation was derived from data collected by Simpson and Curtin, "Coordinated Transit for the San Francisco Bay Area--Now to 1975," Final Report of the Northern California Transit Demonstration Project. A linear equation was fitted between (PFC=10; PRC=-4) and (PFC=37.5; PRC=-12).

**It is assumed that PRC for PFC<0 will be equal and opposite to PRC for PFC>0.

G. ROLLING STOCK COSTS

L	= One way line length in miles
S	= Average round trip operating speed in miles per hour
TM	= Round trip time in minutes

$$TM = 120\ L/S \qquad (27)$$

NC	= Cars passing the maximum load point in the peak hour
NCS	= Number of cars required including spares

$$NCS = 1.08\ NC \times TM/60 = 0.018\ NC \times TM \qquad (28)$$

NOTE: The percentage of spare cars is assumed to be 8.

CPC	= Cost per car in dollars
RSC	= Rolling stock cost in dollars

$$RSC = NCS \times CPC \qquad (29)$$

H. CAPITAL COSTS

L = One way line length in miles
CRM = Construction cost rate in dollars per mile
TCC = Total construction cost in dollars

$$TCC = L \times CRM \quad (30)$$

RWW = Right of way width in feet
ULC = Unit land cost in dollars per square foot
URC = Unadjusted right of way cost in dollars

$$URC = 5280 \times L \times RWW \times ULC = 264{,}000L \times ULC \quad (31)$$

NOTE: RWW is assumed to be 50 feet.

RWF = Percent right of way available at no cost
TRC = Right of way cost in dollars

$$TRC = (1 - RWF/100)URC \quad (32)$$

TC = Total capital cost in dollars

$$TC = TCC + TRC \quad (33)$$

I. COST ANNUALIZATION

ELF = Years of economic life for fixed facilities
IFP = Percentage rate of interest for fixed facilities
IF = Fractional rate of interest for fixed facilities

$$IF = IFP/100 \qquad (34)$$

CRFF = Capital recovery factor for fixed facilities

$$CRFF = \frac{IF(1 + 1F)^{ELF}}{(1 + 1F)^{ELF} - 1} \qquad (35)$$

TC = Total capital cost in dollars
ANF = Annual cost of fixed facilities in dollars

$$ANF = CRFF \times TC \qquad (36)$$

ELR = Years of economic life for rolling stock
IRP = Percentage rate of interest for rolling stock
IR = Fractional rate of interest for rolling stock

$$IR - IRP/100 \qquad (37)$$

CRFR = Capital recovery factor for rolling stock

$$CRFR = \frac{IR(1 + IR)^{ELR}}{(1 + IR)^{ELR} - 1} \qquad (38)$$

RSC = Rolling stock cost in dollars
ANR = Annual cost of rolling stock in dollars

$$ANR = CRFR \times RSC \qquad (39)$$

TACC = Total annual capital cost in dollars

$$TACC = ANF + ANR \qquad (40)$$

V24L = 24-hour two directional line volume
CCR = Total annual capital cost in cents per rider

$$CCR = 100 \times TACC/300 \times V24L = TACC/3 \times V24L \qquad (41)$$

J. SUBSIDY REQUIREMENT

CCR = Total annual capital cost in cents per rider
LPC = Local share of capital cost as a percentage
ACR = Adjusted capital cost in cents per rider

$$ACR = CCR \times LPC/100 \qquad (42)$$

DCR = Daily operating cost in cents per rider
COR = Total cost in cents per rider

$$COR = ACR + DCR \qquad (43)$$

RPR = Revenue in cents per rider
SPR = Subsidy in cents per rider

$$SPR = COR - RPR \qquad (44)$$

K. EMISSION IMPACT

DCM = Daily car miles
TEF(N) = Grams of pollutant N per transit vehicle mile
TWP(N) = Daily grams of pollutant N due to transit

$$TWP(N) = TEF(N) \times DCM \qquad (45)$$

N signifies the following pollutants:

N	Pollutant	
1	CO	Carbon monoxide
2	HC	Hydrocarbons
3	NO_x	Oxides of nitrogen

TEF(N) has the following default values:

	Pollutant		
Mode	1 CO	2 HC	3 NO_x
Rail Rapid Transit (Oil Generation)	0.0068	0.54	17.69
Rail Rapid Transit (Coal Generation)	0.45	0.19	18.60
Bus (Diesel)	10.90	14.70	13.84
Auto (Gasoline)	68.95	9.53	4.54

L. ENERGY IMPACT

DCM = Daily car miles
EPM = Energy consumption in BTU per mile
TED = Transit energy consumed in BTU per day

$$TED = DCM \times EPM \qquad (46)$$

EPM has the following default values:

Mode	EPM
Rail Rapid Transit	18,116
Bus	30,000
Private Automobile	7,500

M. ACCIDENT IMPACT

DCM = Daily car miles
RTF = Fatal transit accidents per million vehicle miles
ATF = Daily fatal transit accidents

$$ATF = RTF \times DCM/1{,}000{,}000 \quad (47)$$

RTT = Total transit accidents per million vehicle miles
ATT = Daily total transit accidents

$$ATT = RTT \times DCM/1{,}000{,}000 \quad (48)$$

RTF and RTT have the following default values:

Mode	RTF	RTT
Rail Rapid Transit	0.175	38.5
Bus	0.088	21.5

APPENDIX F

PROGRAMS FOR HAND CALCULATORS

This appendix contains two programs illustrating the applicability of programmable desk calculators to the manual sketch planning technique. The section of the technique chosen to illustrate this use invokes the operation of alternatives either to part or all of the work sheet of Figure 3-4.

1. A program for the Sharp PC-1001 which calculates the access integral as a function of adjusted transit impedance and highway impedance and zonal attractions.

2. A program for the Hewlett-Packard HP-65 which calculates the access integral as a function of transit distance, airline distance, walk access in the origin and destination zones and zonal attractions.

These two programs are included to illustrate the possibilities of expediting the calculation; they are not exhaustive. Many of the steps in all three of the phases could be speeded up by the use of programmable calculators.

The first of these two programs (Exhibit G.1) is included to illustrate the use of a medium size programmable desk calculator (8 addressable storage registers and 64 overlapping program steps). When this program was tested to recreate the calculation in Appendix G, it reduced the total time needed to calculate the steps involved to one-fifth of the time consumed by the direct method. The total time consumed in calculating the access integral was reduced by approximately one-half.

The second of the two programs (Exhibit G.2) illustrates the use of a larger programmable desk calculator (9 addressable storage registers, 100 non-overlapping program steps, and a number of testing and branching instructions). The use of this program eliminates reference to the nomographs in calculating the access integral and should represent a considerable additional savings in time as compared with the first program.

Exhibit F.1

Calculation of Access Integral on
Sharp PC-1001 Desk Calculator

Stored Program

Stored Step	Operation	Comments
	F	
	PRO	
1	H	enter adjusted transit impedance (B)
	1	
2	x	
3	=	B^2
4	÷	
5	1	
6	RC	
7	=	$1/B^2$
8	X→M	
9	0	store $1/B^2$ in memory 0
10	H	enter highway impedance (E)
	1	
11	x	
12	=	E^2
13	÷	
14	1	
15	RC	
16	=	$1/E^2$
17	+	
18	MR	recall $1/B^2$
19	0	
20	=	composite conductance squared
21	x	
22	H	
	1	

Stored Step	Operation	Comments
23	=	district index
24	M+	accumulate district index
25	1	
26	F	
27	END	

Operating Instructions

CM

0

CM

1

S) Repeat for each zone (from here)

ENTER Adjusted Transit Impedance

S

ENTER Highway Impedance

S

ENTER Attraction

S) (to here)

MR

1 Displays Access Integral

HP-65 Program Form

Title: Calculation of Access Integral Page 1 of 1

SWITCH TO W/PRGM. PRESS [f] [PRGM] TO CLEAR MEMORY.

KEY ENTRY	CODE SHOWN	COMMENTS
LBL		
A		
ENTER		PCT WALK IN i
STO1		
LBL		
B		
ENTER		ATTRACTION J
STO2		
ENTER		TRANSIT LINE-HAUL
ENTER		
f		
SF1		
f		
STK		
DSP		
.		
2		
LBL		
C		
STO1		
STO2		
STO		
X		
2		
RCL		
1		
+		
X≶Y		
÷		
√		ADJUSTED IMPEDANCE
ENTER		AIR-LINE DISTANCE
X		
3		
.		
2		
+		
÷		
f		
√		
RCL1		
÷		
RCL2		
+		
X≷Y		
+		SQUARE OF IMPEDANCE
STO3		
R↓		
R↓		
RCL3		
X		

KEY ENTRY	CODE SHOWN	COMMENTS
RCL4		
+		
STO4		
GTO		
B		
RCL4		ACCESS INTEGRAL
RTN		

64

REGISTERS
R_1
R_2
R_3
R_4
R_5
R_6
R_7
R_8
R_9

LABELS: A, B, C, D, E, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9

FLAGS: 1, 2

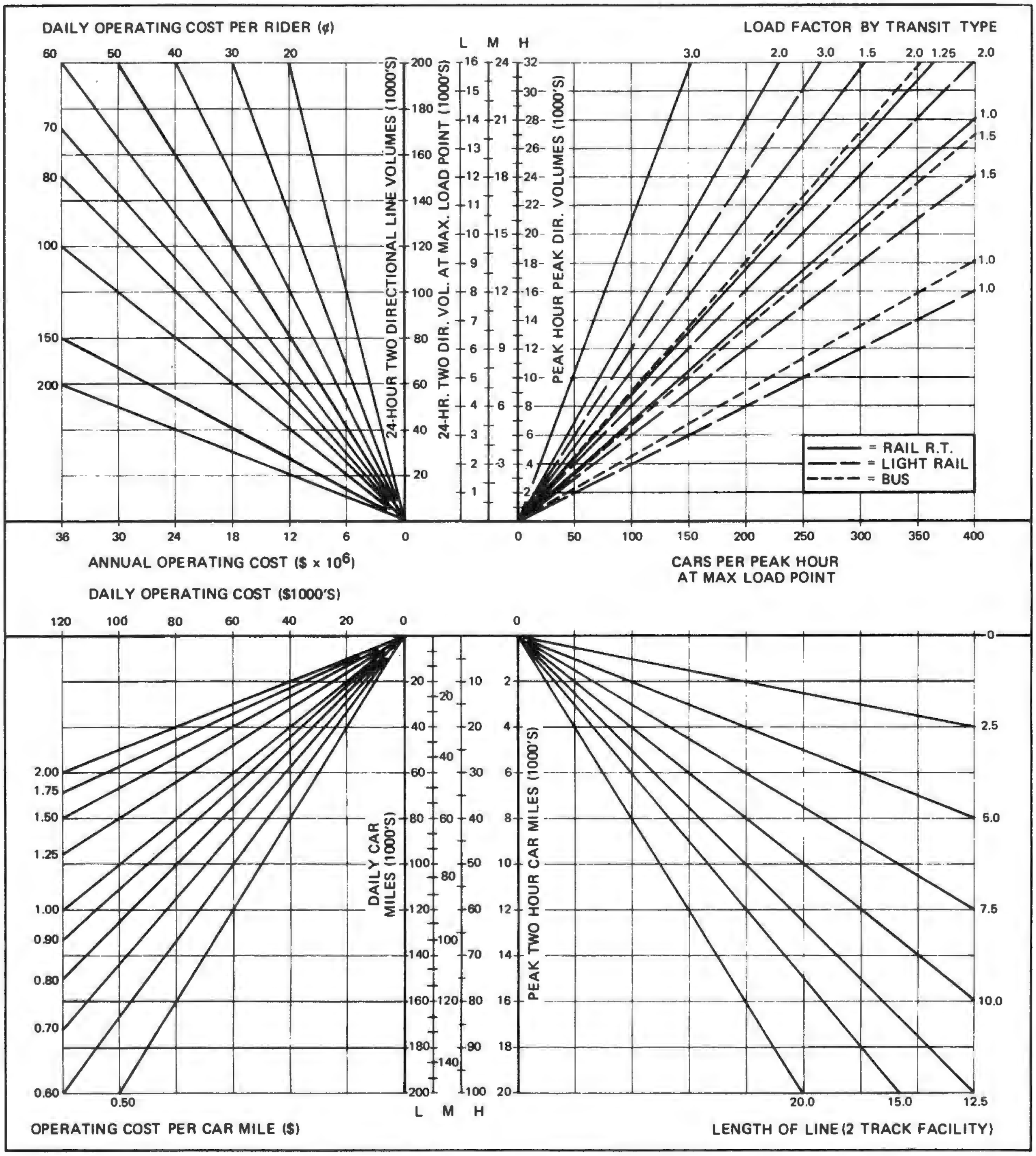
HEWLETT hp PACKARD

9320-0616

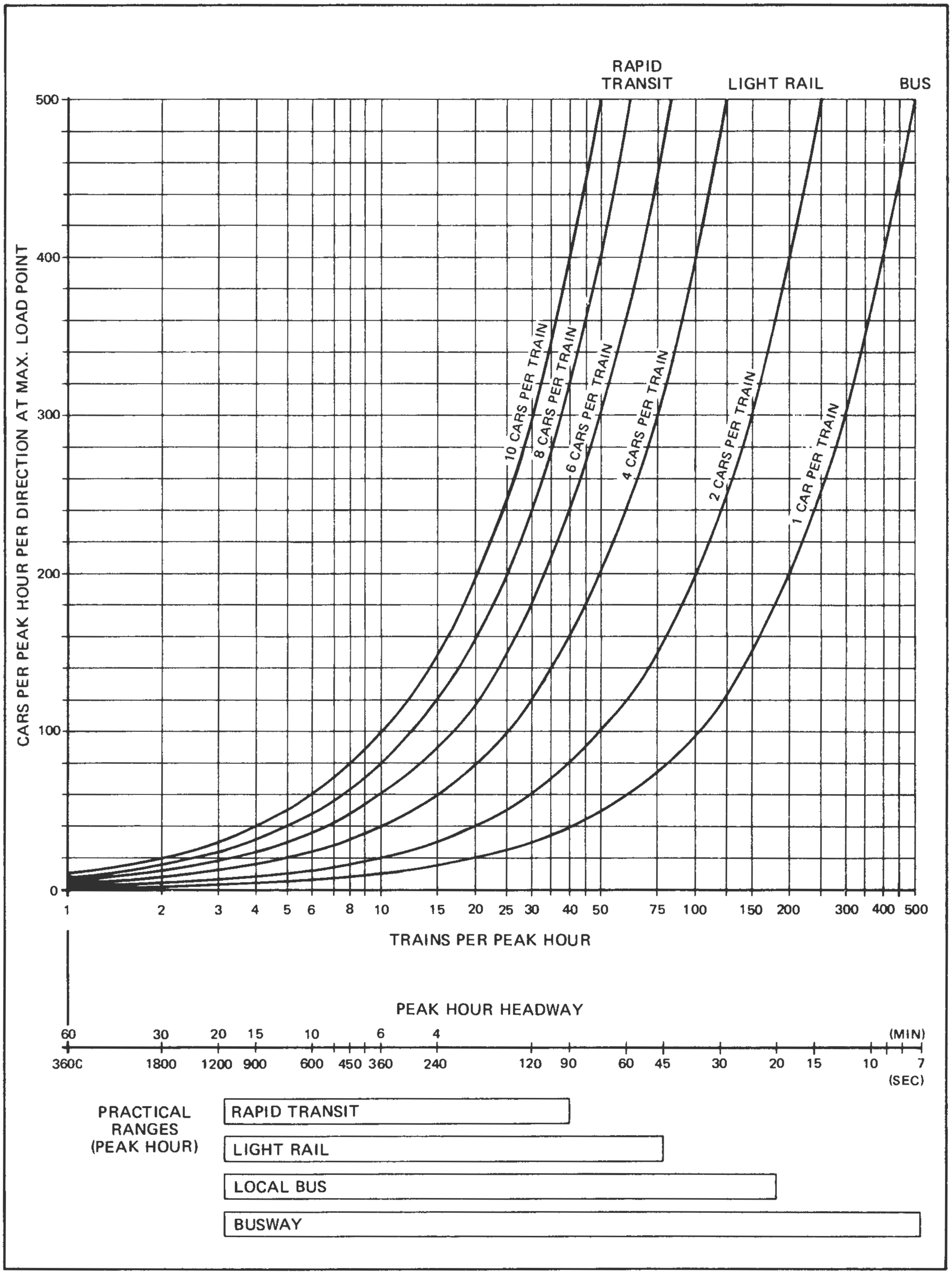
TO RECORD PROGRAM INSERT MAGNETIC CARD WITH SWITCH SET AT W/PRGM.

APPENDIX G

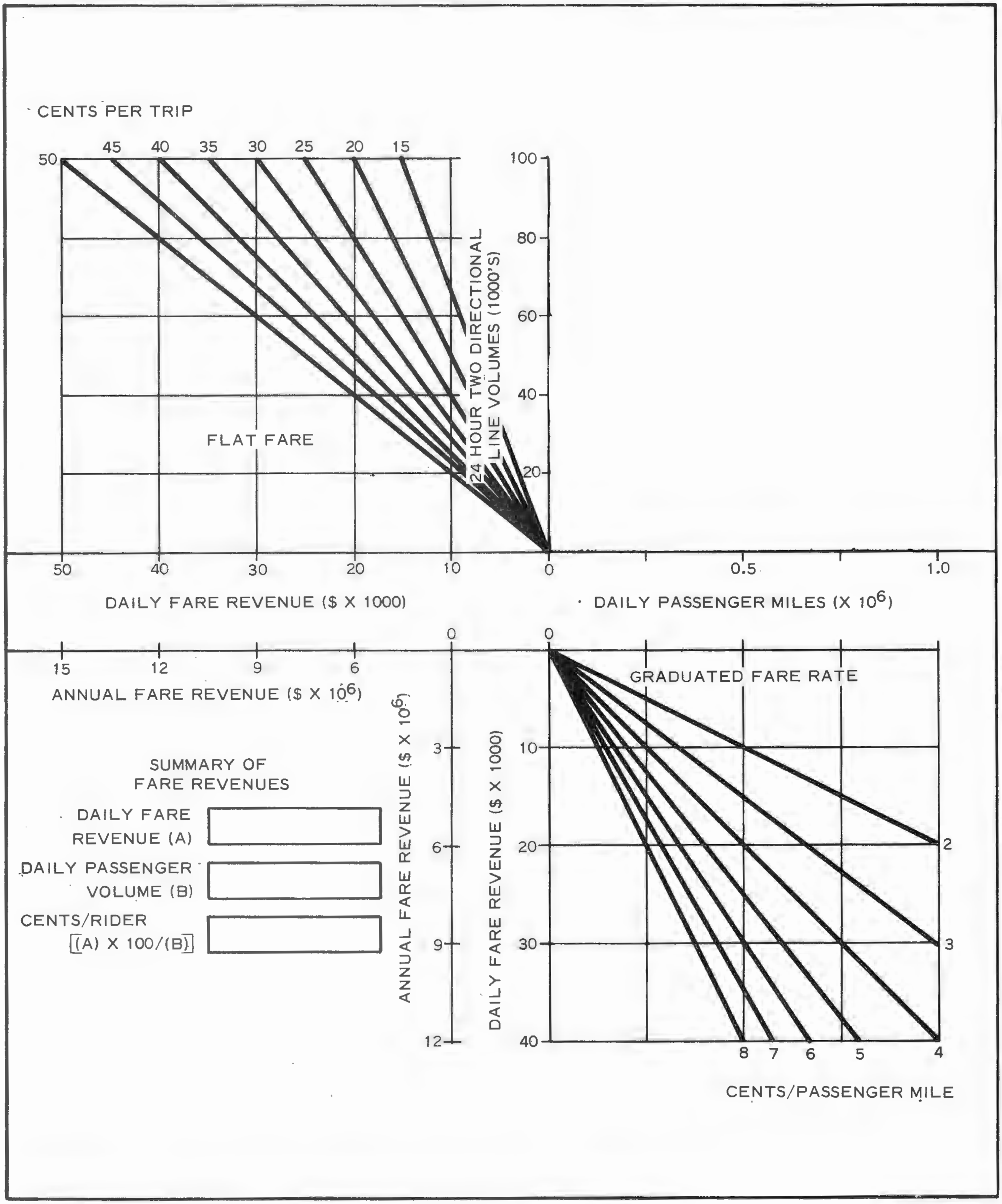
REPRODUCIBLE COPIES OF NOMOGRAPHS AND WORK SHEET



Operating Costs

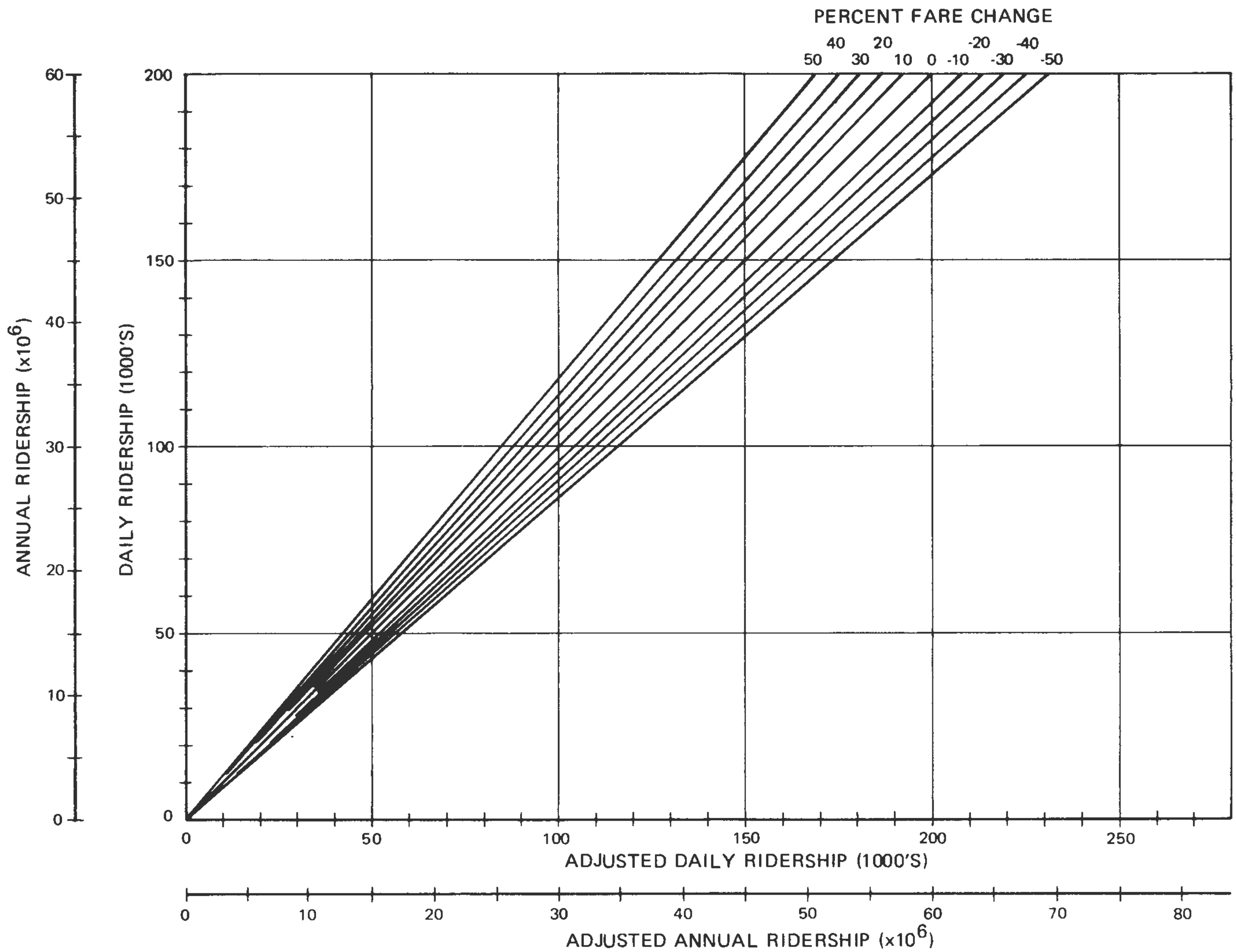


Vehicle Frequency Check

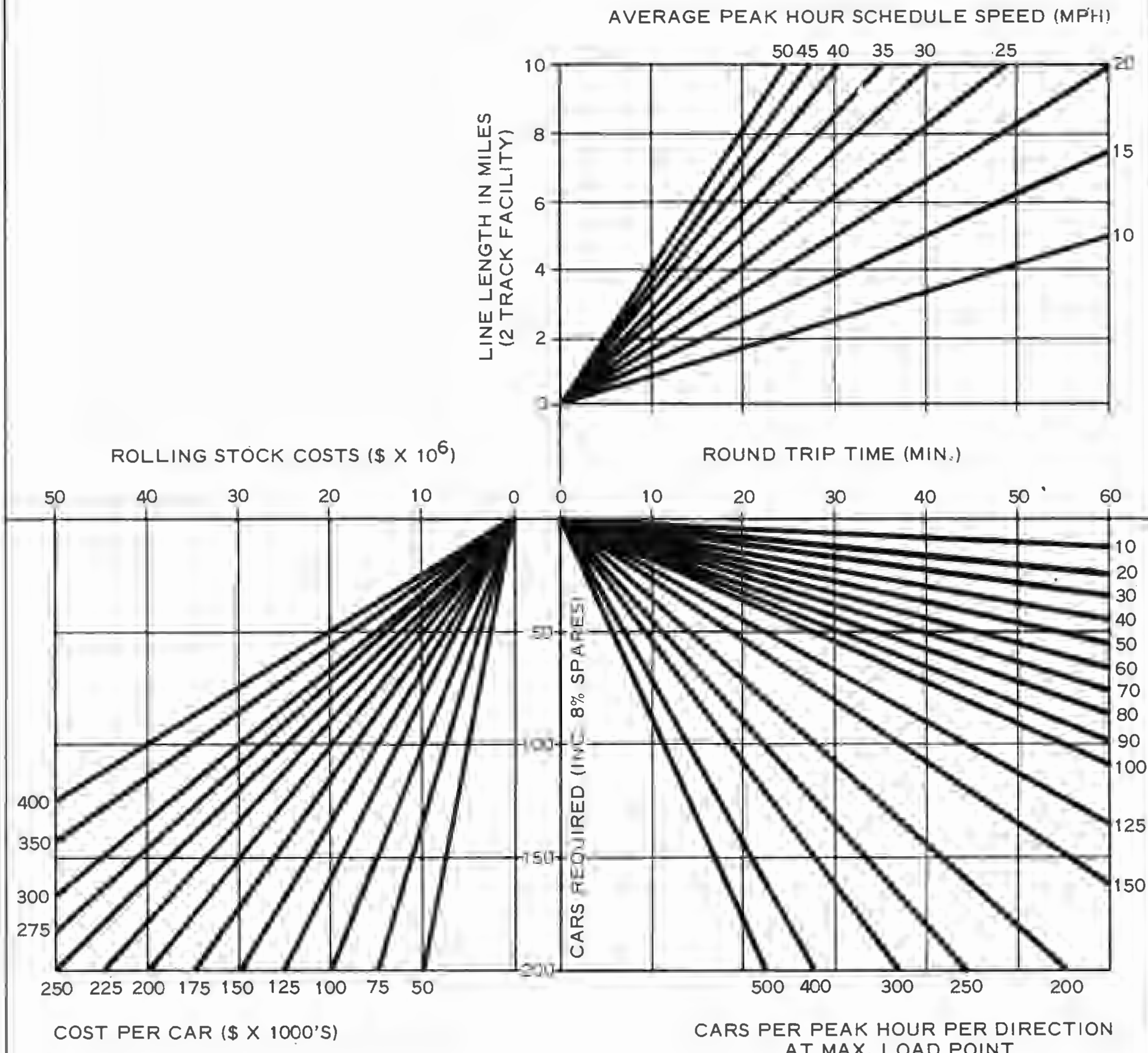


Fare Revenues

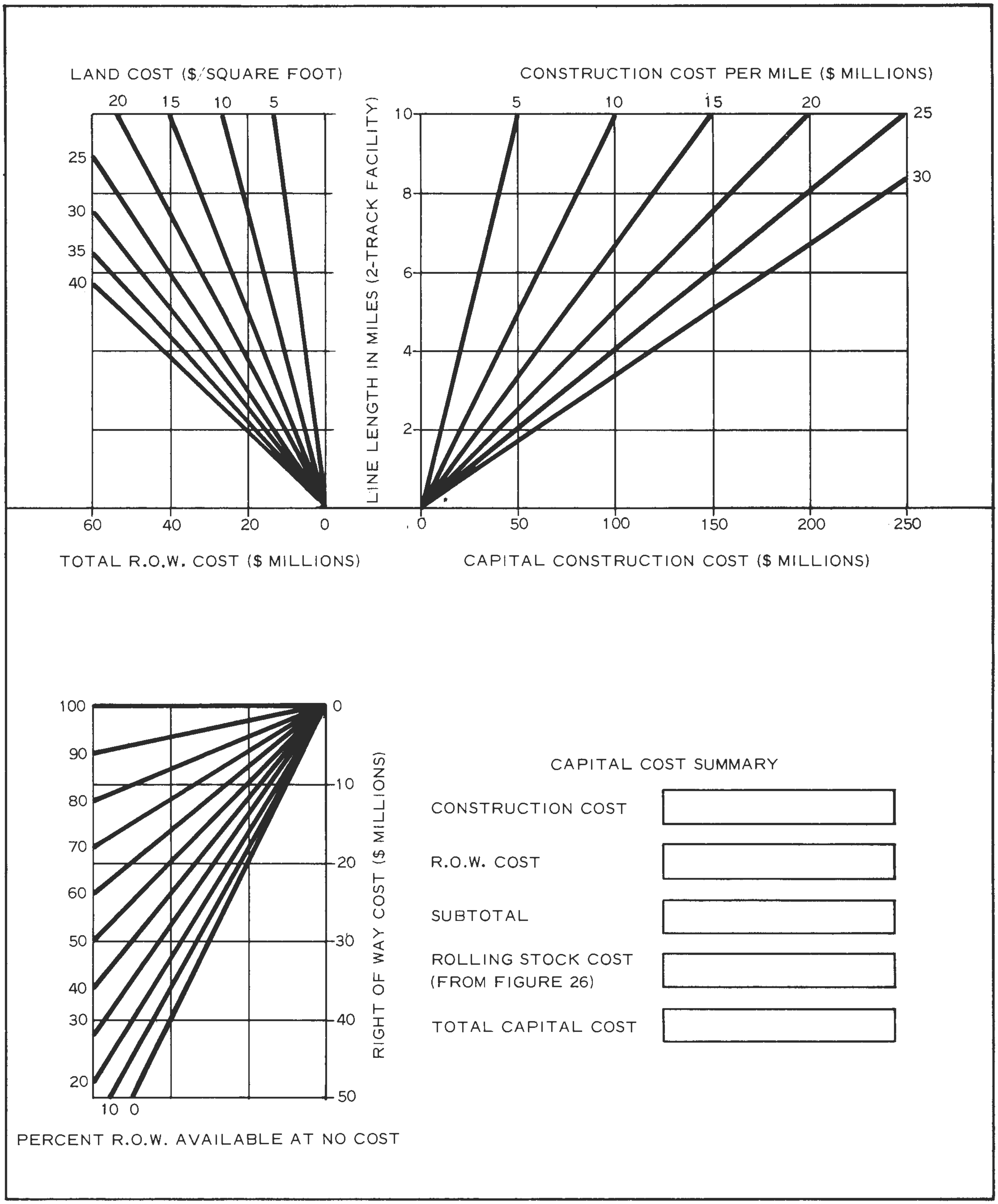
Fare Sensitive Demand Adjustment



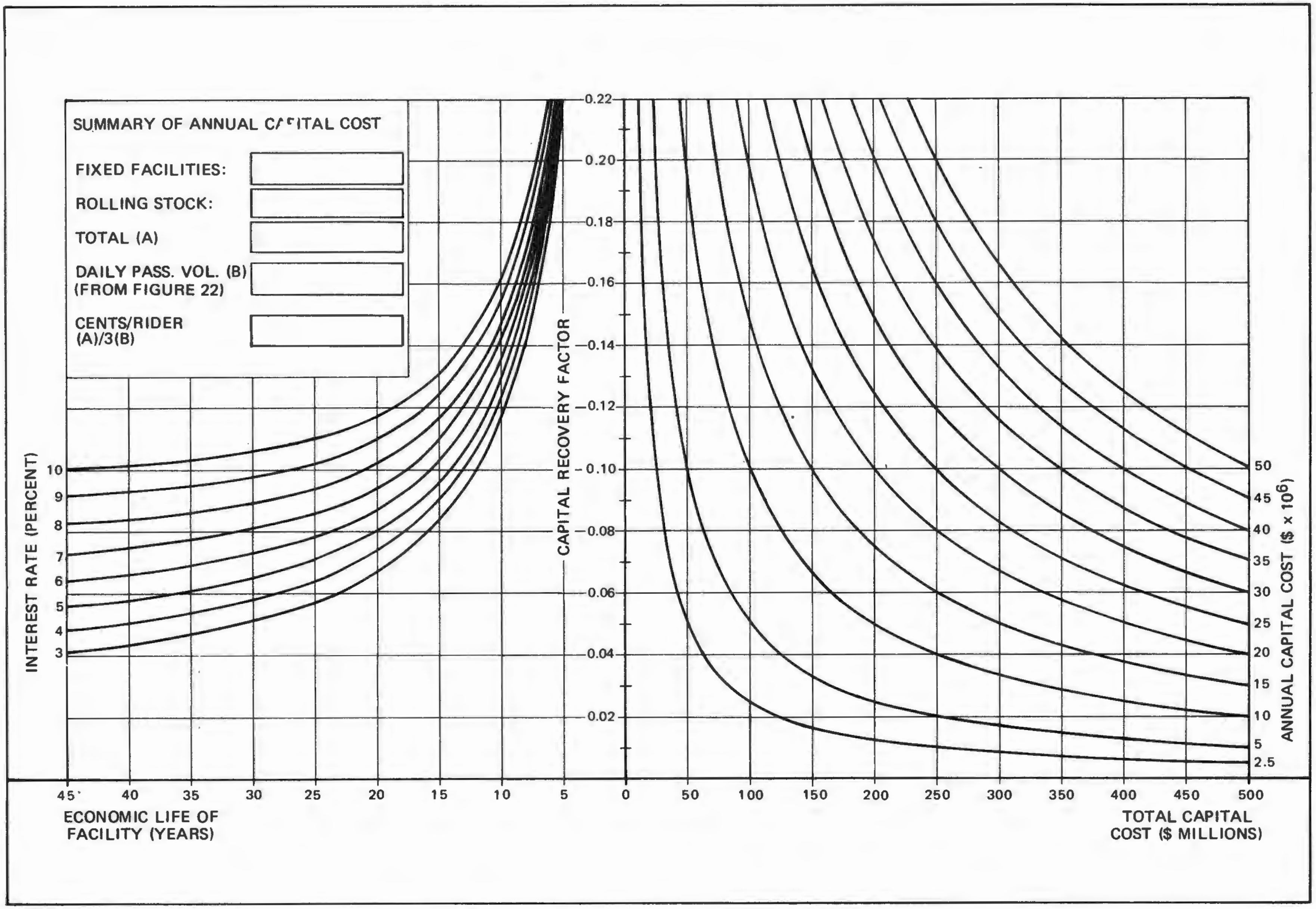
Source of Fare Increase Data: "Coordinated Transit For the San Francisco Bay Area—Now to 1975" by Simpson & Curtin, October 1967.

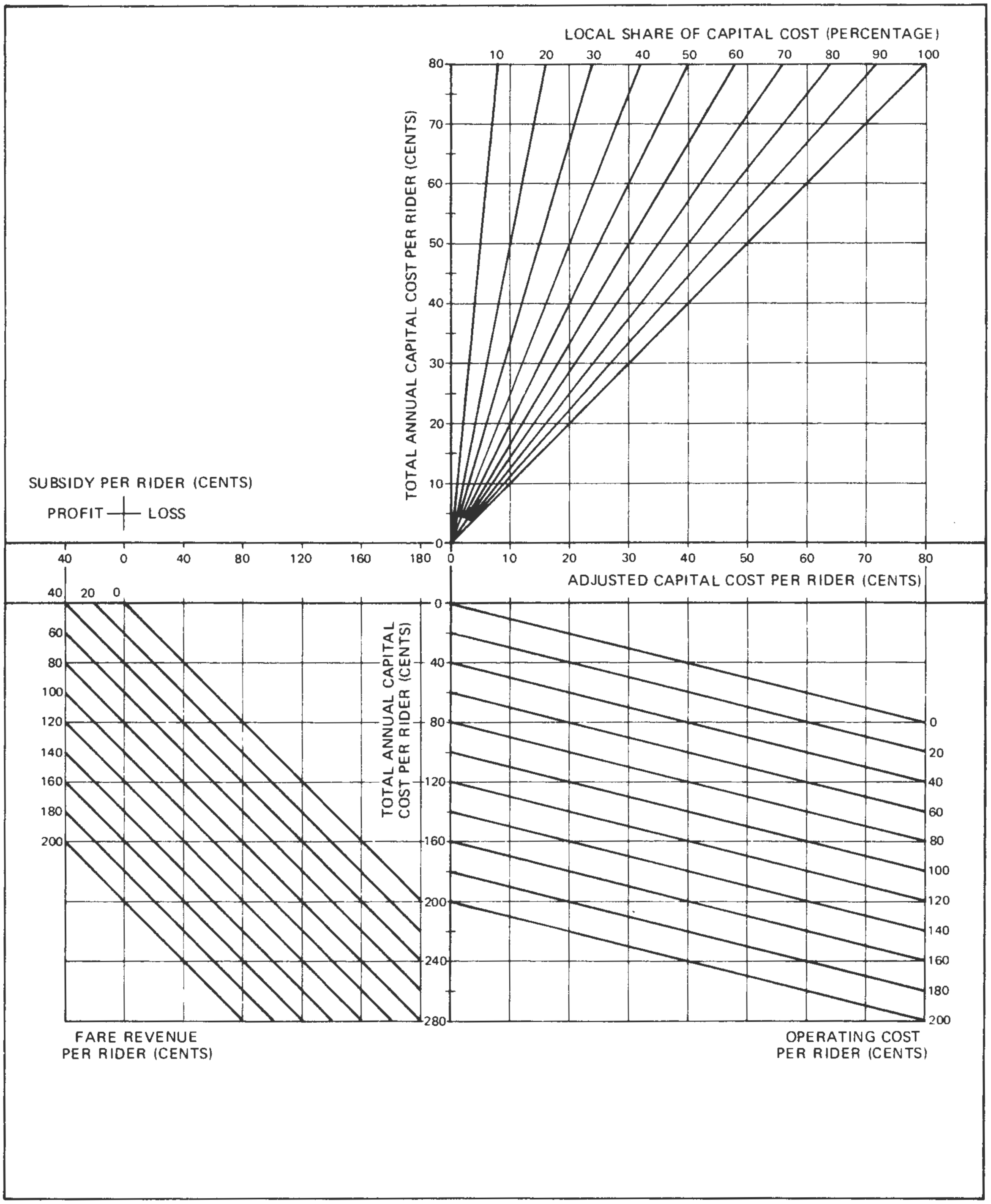


Rolling Stock Costs

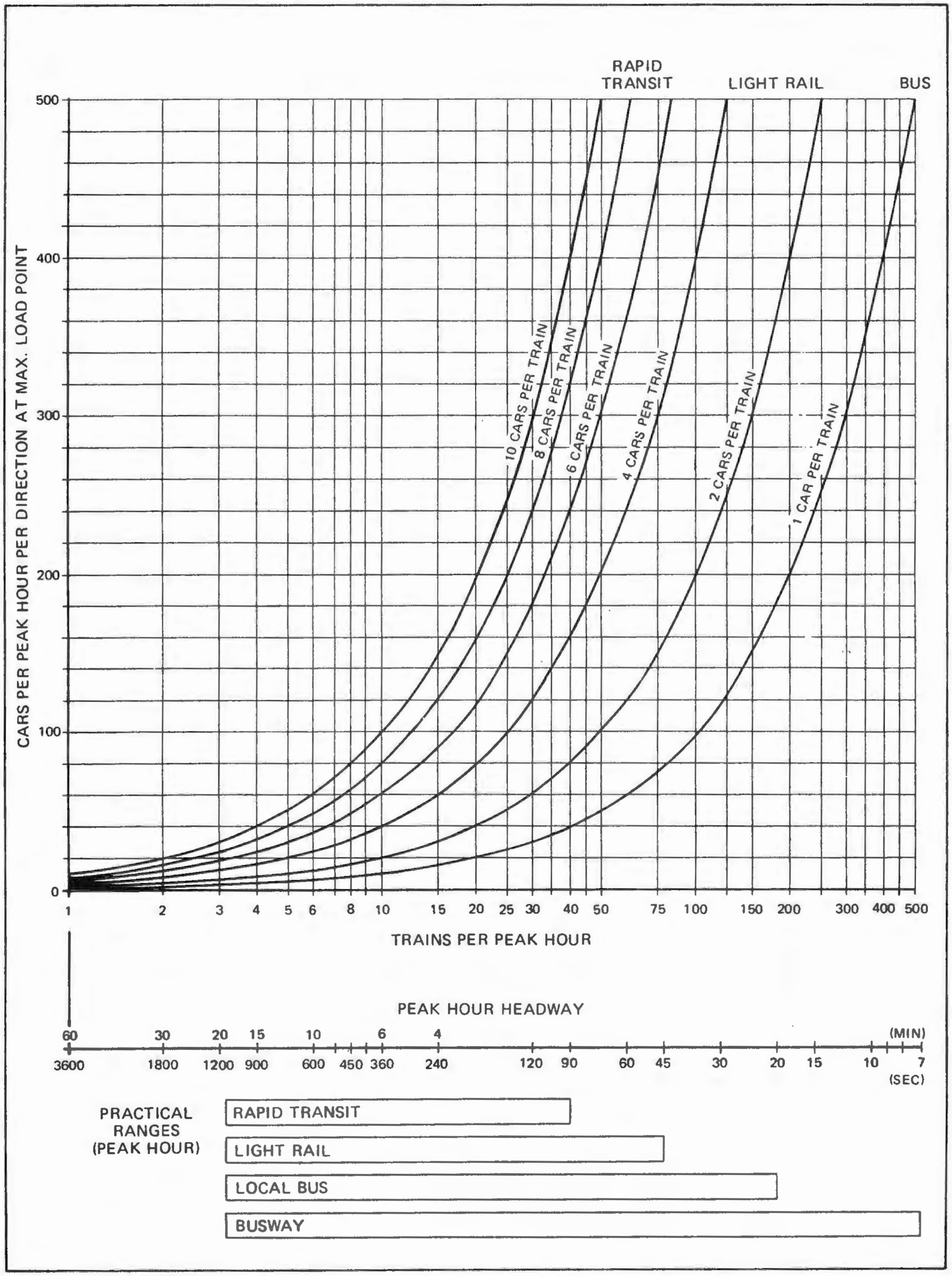


Capital Costs

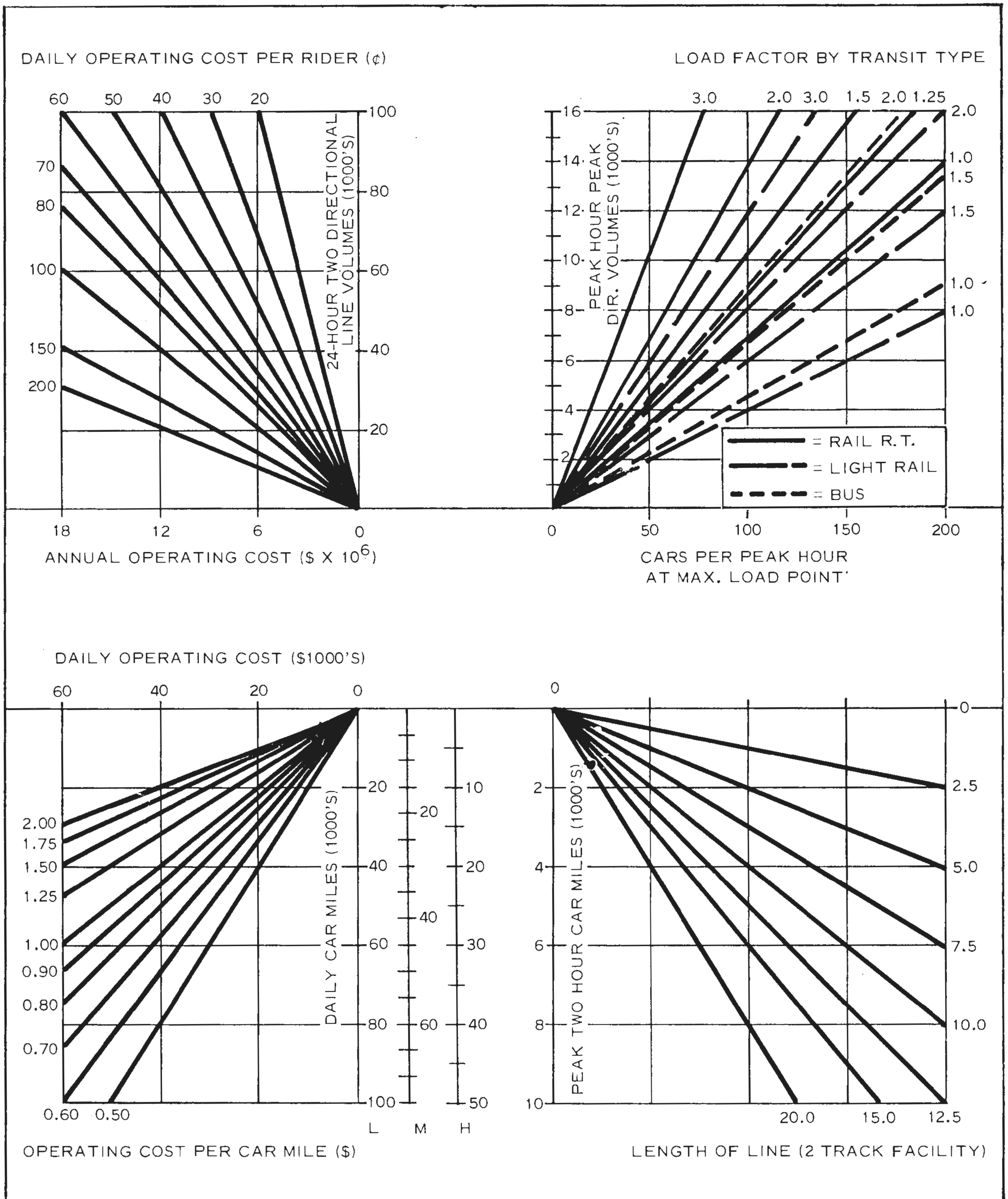

SUMMARY OF ANNUAL CAPITAL COST
FIXED FACILITIES:
ROLLING STOCK:
TOTAL (A)
DAILY PASS. VOL. (B) (FROM FIGURE 22)
CENTS/RIDER (A)/3(B)
INTEREST RATE (PERCENT)
10
9
8
7
6
5
4
3
CAPITAL RECOVERY FACTOR
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
45
40
35
30
25
20
15
10
5
0
ECONOMIC LIFE OF FACILITY (YEARS)
50
100
150
200
250
300
350
400
450
500
TOTAL CAPITAL COST ($ MILLIONS)
ANNUAL CAPITAL COST ($ x 10^6)
50
45
40
35
30
25
20
15
10
5
2.5



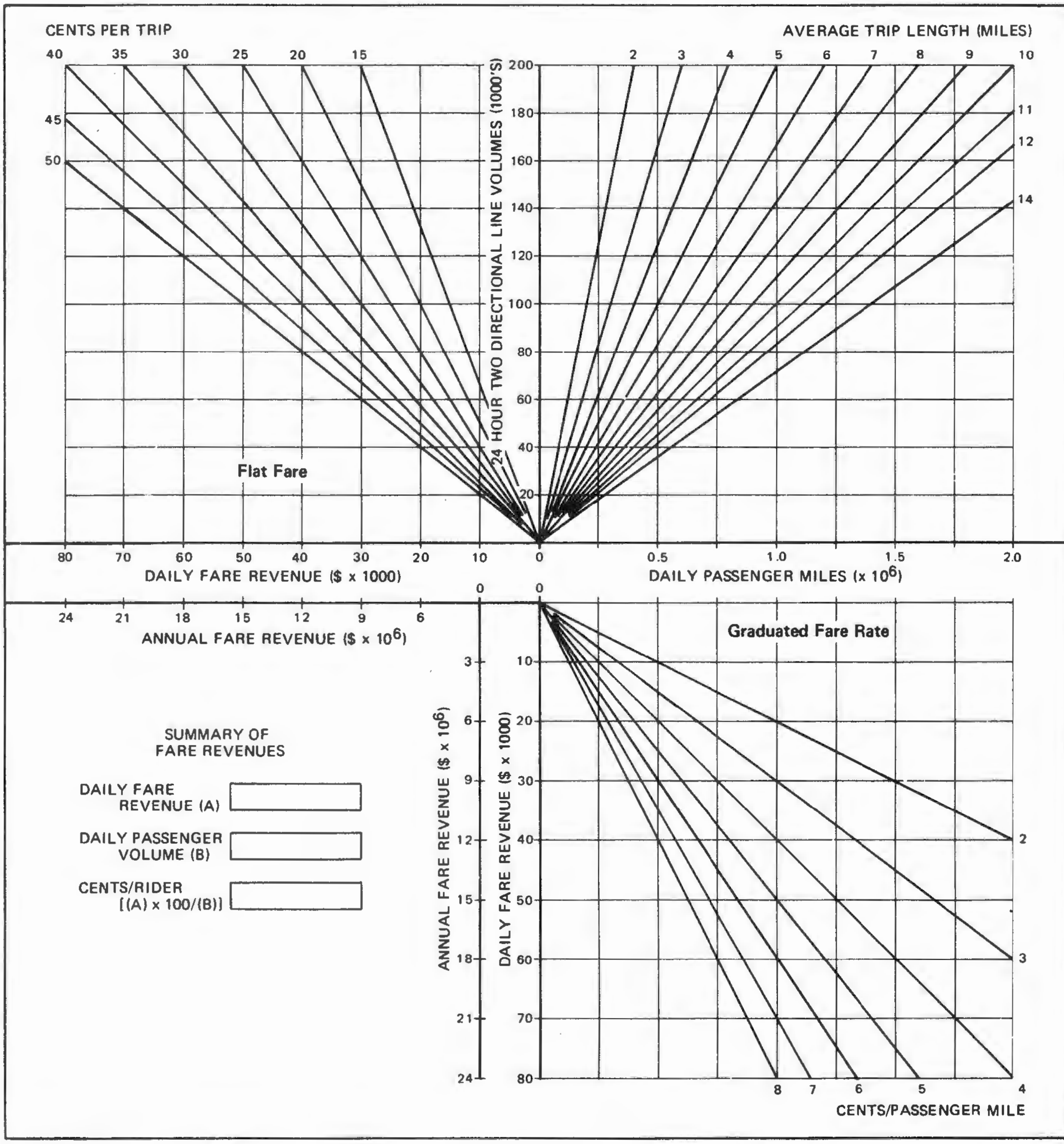
Subsidy Requirement



Vehicle Frequency Check Sensitivity Test



Operating Costs Sensitivity Test



Fare Revenue Sensitivy Test

WORK SHEET

Step	Origin District (i)		Corridor _______ Alternative _______ Sheet____of _____
A1	% of Walk in (i)		Destination District (j)
A3a.1	Dwelling Unit in (i)=		
A3b.1	Production in (i)=	(P)	
A3a.2	Employment in (j)		
A3b.2	Attraction A_j	(A)	
	Transit		
A1	% of Walk in (j)		
A4a.1	Line-Haul Distance		
A4a.2	Transit Impedance		
A4a.3	Adjusted Impedance	(B)	
A4b.	Square of Impedance	(C)=B^2	
A4c.	Transit Index	(D)=A/C	
	Highway		
A4d.1	Airline Distance		
A4d.2	Impedance	(E)	
A4d.3	Square of Impedance	(F)=E^2	
A4e	Conductance Factor ($x10^6$)	(G)=$\frac{C+F}{CxF}$	
A4f	District Index	(H)=AxG	
A4g	Access Integral	(J)=ΣH	
A4i	Transit Trips	(K)=P*D/J	

☆U.S. GOVERNMENT PRINTING OFFICE: 1979-291-568/191