NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT 187

QUICK-RESPONSE URBAN TRAVEL ESTIMATION TECHNIQUES AND TRANSFERABLE PARAMETERS

USER'S GUIDE

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
- TRAFFIC MEASUREMENTS
- URBAN TRANSPORTATION ADMINISTRATION
- URBAN COMMUNITY VALUES
- URBAN LAND USE
- URBAN TRANSPORTATION SYSTEMS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1978

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Staff
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This report will be of special interest to state and urban transportation planners involved in travel demand estimation. Of the numerous travel demand analysis techniques currently available, most use some form of computer models; but documentation and dissemination of many of the techniques have been quite limited. This research included a survey of current policy-related issues, an identification of available travel demand techniques to address these issues, and the development of new techniques to provide quicker response. This report provides simplified manual techniques and transferable parameters that can be used as viable alternatives to the more costly, data-intensive, computer models; a companion document, *NCHRP Report 186,* describes and evaluates other manual and computer methodologies that are available.

Most techniques for estimating urban travel demand were developed to evaluate alternative transportation systems for an entire region. Application of these comprehensive techniques to provide timely answers to current policy questions has proven very difficult. This research effort was initiated to assemble and modify existing techniques, as well as to develop new approaches, for use by transportation planners faced with the need to be more responsive to current issues.

This report provides detailed descriptions of manual techniques for use in each aspect of travel demand estimation; i.e., trip generation, trip distribution, modal choice, auto occupancy, time-of-day distribution, traffic assignment, capacity analysis, and development density versus highway spacing relationships. Numerous charts, tables, and nomographs are included to simplify each analysis step. Data requirements are also reduced by making maximum use of transferable parameters developed from other studies and urban areas. Three scenario applications of the manual techniques are included to illustrate the potential usefulness of the various analysis techniques. Much of the information contained in the report is also applicable to computer analysis. The presentation of the procedures is structured to allow their utilization by transportation planners with various levels of experience.

The Washington Metropolitan Council of Governments was the prime contractor for the first phase of this research, in which policy issues were identified and related to available analysis techniques (*NCHRP Report 186*). COMSIS Corporation served as a subcontractor for Phase I and was responsible for summarizing and evaluating the available techniques, as well as relating them to the policy issues. COMSIS was the prime contractor for the assembly and development of manual techniques in Phase II. In a departure from previous NCHRP research projects, instructional materials were developed for use in training sessions to assist state and local planners in the application of the numerous techniques contained in this report. The Transportation Center of the University of Tennessee, serving as a subcontractor to COMSIS Corporation, developed the training materials. These materials will be available from NCHRP in late 1978, to any organization wishing to conduct training sessions.

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The research reported herein was performed under NCHRP Project 8-12A by COMSIS Corporation and the Metropolitan Washington Council of Governments.

The Metropolitan Washington Council of Governments effort concentrated on the phases of the project dealing with policy issues. The work undertaken by COMSIS Corporation concentrated on procedures for quick response to policy issues. The COMSIS effort covered all material presented on manual methods and useful parameters except for the work related to development of density-highway spacing relationships accomplished by the Council of Governments.

Arthur B. Sosslau, President, COMSIS Corporation, and George V. Wickstrom, Director of Technical Services, Metropolitan Washington Council of Governments, were the principal investigators. Other personnel who contributed significantly to this report were:

For COMSIS Corporation: Amin B. Hassam, Assistant Planner; Maurice M. Carter, Associate; Mark E. Roskin, Associate; and Martin J. Fertal, Senior Associate.

For the Council of Governments, contributors included: Robert T. Dunphy, Chief of Research and Analysis; and Robert E. Griffiths, Senior Transportation Technician II.

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QUICK-RESPONSE URBAN TRAVEL ESTIMATION TECHNIQUES AND TRANSFERABLE PARAMETERS

USER'S GUIDE

SUMMARY

This report presents the results of a two-phase effort. Phase I included an investigation of the ability of travel estimation procedures to provide information that can respond quickly to urban policy issues. The results of that study are reported in a companion work, "Travel Estimation Procedures for Quick Response to Urban Policy Issues" (*NCHRP Report 186*). Phase II developed this "User's Guide" describing transferable parameters and their use with manual and computer techniques for providing quick-response travel estimation. The objective of both Phase I and Phase II was to provide operational travel estimation techniques with quick-response times.

In Phase I, policy issues facing transportation planning agencies were identified by onsite visits to agencies at the state, regional, and county levels. Responses to an issue questionnaire were received from many other urban areas of various size throughout the United States. In addition, current planning documents and literature were reviewed. Policy issues were compiled and classified, and the demands placed on travel estimating procedures were determined.

Available travel estimation procedures having the ability to provide rapid response were compiled, cataloged and described, and evaluated as to input, output, applicability, and complexity. A classification and evaluation system was devised to allow the potential user to determine which of the available procedures may be appropriate for a specific analysis purpose. Descriptions and evaluations of 40 models and procedures are included in the report, which should prove useful to transportation planners in selecting available techniques appropriate for quick response to policy issues. It was found that an effective and responsive transportation planning process must be capable of rapidly providing estimates of the values of criteria used in the evaluation of multimodal facility and service alternatives. These evaluation criteria include service, impacts, and costs at less than the regional scale. It was also found that emphasis has shifted away from long-range, regional capital facility planning to providing short-range, highway and transit improvements at subregional scales. Land use is a major issue and no longer can be treated as a fixed input to the transportation planning process.

No single existing travel estimation technique was found adequate to respond to all the many questions raised. Because of the widespread use and understanding of the conventional four-step (trip generation, distribution, mode split, and traffic assignment) travel simulation procedure, it was recommended that this procedure continue to form at least a partial basis on which the transportation planning process responds to new needs in the future.

Phase I concluded that a need exists for a simplified four-step computerized procedure supplemented by "pivot-point" and manual methods. Such a procedure will reduce time, costs, and manpower requirements, and will permit testing and evaluating more land-use and transportation alternatives. Additionally, a need

exists for reducing data input requirements as well as producing output summaries and displays relevant to citizens and decision-makers.

The four-step procedure was specifically not recommended to be used in estimating changes in use for nonwork transit travel or for fare and other noncapital transportation services. It was believed that in order to effectively deal with travel estimation for an extensive list of transit service options, the introduction and use of behavioral, disaggregate techniques aimed at specific travel markets will be required. It was found that these techniques can respond to transportation issues, but need to be made operational on real-world problems.

Meanwhile, ad hoc methods are also being used as analysts respond to new needs, and such methods can supplement quick response or conventional procedures.

Specifically, Phase I recommended that a set of capabilities be developed that include:

- Simplified computerized methods for the four-step (trip generation, distribution, mode split, and traffic assignment) procedure that is efficient and will provide quick response at the regional and subarea level.
- An efficient, policy-sensitive procedure that would evaluate transportation service and cost changes in terms of economics and social and environmental impacts on a macro (nonnetwork-specific) basis.
- Manual methods useful for short-range application at the corridor and project level.

A User's Guide was developed in Phase II to describe transferable parameters, factors, manual techniques, and the like, to enable the user to carry out a simplified analysis without the necessity of reference to other sources. The User's Guide (this report) covers the following elements of transportation planning: trip generation; trip distribution; mode choice; auto occupancy; time-of-day distribution; traffic assignment; capacity analysis; and development density/highway spacing relationships. Manual methods are described; however, tables, graphs, and other transferable parameters may be used by computer methods as "default" values where more appropriate local information may not be available.

The User's Guide also illustrates how models may be chained or modified and applied to provide a quicker and less expensive-to-use planning tool. Discussion is provided on pivot-point and sensitivity techniques for addressing transportation issues.

In the area of trip generation, tables are provided that allow estimates to be made from land-use and socioeconomic characteristics. These data allow estimates for specific generators; generalized estimates for an area including truck-trip estimates, external travel, and the like; and detailed estimation at a household level relating trip rates to income and/or car ownership. As is the case for other material, trip-generation rates are provided for the following population size groups: 50,000 to 100,000; 100,000 to 250,000; 250,000 to 750,000; and 750,000 and over (generally to about 2,000,000).

For trip distribution, the material provided and procedures described allow the calculation of trips between points. The process is applicable at the regional scale, corridor scale, on a local area/site basis, and is based on the gravity model formulation. Material provided includes: airline distance/travel time/distribution factor graphs; suggested forms for manual application; examples of application; and resource requirements.

For mode-choice analysis, a transformed version of the gravity formulation is used. This version basically estimates transit percent use from the ratio of auto impedance to an exponential value, divided by the sum of transit impedance to an exponential, plus auto impedance to an exponential. With such basic input as transit fare, parking costs, operating speeds, and headways, the user can determine a transit or auto impedance using a graph. Using these impedances, the user enters a graph and reads directly the market share. Techniques for testing policy options, such as increased fares or parking costs, are included.

For auto-occupancy and time-of-day analysis, a series of tables is provided. For auto occupancy, basic material is provided by city size and trip purpose. Additional data allow time-of-day occupancy estimates, estimates by trip length, and estimates by parking costs and by land use. Time-of-day tables include distributions of travel by purpose for auto drivers, transit users, and total number of persons. Other material is by facility type and location within an urban area.

For traffic assignment, three procedures are described for manual application: (1) stringing trips through a network with simplified bookkeeping of the resultant trip volumes; (2) a variation of the "Land Use and Arterial Spacing in Suburban Areas" developed by Gruen Associates for FHWA (*1*), which allows inclusion of a directionality procedure and location-specific attenuation factors; and (3) a sketch-planning diversion process for estimating possible shifts between competing facilities in a corridor. Capacity procedures are included for corridor and intersection analysis.

A manual process is included for developing relationships between land use and highway spacing to permit the rapid development of a "first-cut" estimate of future highway needs based on a desired level of service. Level of service is determined from desired level-of-service volumes or a least-cost volume. Given a land-use distribution, trip length is computed, future trip ends are estimated, link volumes are determined, and then desirable spacings are determined. Comparisons of desired and existing spacings provide a measure of need for an area. A variation is to run the procedure backward, solve for desired volumes, and, with existing spacing, determine the amount of land use that can be accommodated by the highway system.

Three scenario applications were performed using the material in the User's Guide: (1) a site impact on the surrounding street system in a small urban area; (2) a corridor analysis in a medium size area; and (3) the land use/spacing relationships in a suburban county of a large urbanized area. These scenarios fully describe application of the material provided and also indicate that reasonable results can be achieved in relatively short periods of time with manual methods.

The study identifies desirable future research and indicates that more experience is needed to demonstrate the applicability of the manual methods and transferable parameters by state and local planners. Improvements should be made in the land use/spacing relationships to allow a policymaker to determine additional capacity and the associated costs to obtain a desired service level; with a given dollar level of available funds, to determine the service that can be provided and the land use that can be supported; and, if a no-build decision is made, determine how much land-use development can be supported and what will be the user costs. Other needs identified by the study include: addition of manual methods for environmental impact estimation; car-occupancy relationships sensitive to policy considerations, such as provision of special car pool lanes; site-trip generation rates by type and size of urbanized area (including geographical location); and direct estimation of trips between areas (direct demand). Particularly useful to the planner would be a set of elasticity values to allow quick determination of the effects of policy changes related to transportation.

CHAPTER ONE

INTRODUCTION

ORGANIZATION OF GUIDE

The material in this user's guide provides, for each major element of travel demand analysis, a manual technique and a set of factors and transferable parameters to enable the user to carry out a simplified transportation analysis. The intent is to allow the analysis to be undertaken without the necessity of deriving basic relationships, or of having locally obtained travel-demand data. Similarly, for computer analysis, the factors and transferable parameters provided serve as values that can be used in lieu of locally collected travel-demand data.

A chapter is provided for each major element of the travel-demand analysis process:

Chapter Two	Trip-Generation Estimation
Chapter Three	Trip Distribution
Chapter Four	Mode-Choice Analysis
Chapter Five	Automobile Occupancy Characteristics
Chapter Six	Time-of-Day Characteristics
Chapter Seven	Traffic-Assignment Procedures
Chapter Eight	Capacity Analysis
Chapter Nine	Development Density/Highway Spacing Relationships

To illustrate the possible interrelationships between these major elements, three scenario applications were undertaken and are reported in three subsequent chapters as follows:

Chapter Ten	Scenario for Site Development Impact Analysis: Boise, Idaho
Chapter Eleven	Scenario for Corridor Analysis: Columbus, Ohio
Chapter Twelve	Scenario for Land-Use/Highway Spacing Analysis: Fairfax, Virginia

A glossary has been provided to give the user clear definitions of the various terminologies used throughout this guide.

OUTLINE OF MATERIAL PROVIDED

The material provided consists of tables, graphs, nomographs, simplified methods, sample work sheets for certain processes, and other devices to aid in simplifying the analysis procedures. Basically these procedures parallel the four-step process generally used for transportation planning; that is, trip generation, trip distribution, mode choice, and traffic assignment.

In conjunction with the individual processes described, procedures and parameters are provided which aid in the application of such processes and which may not be generally familiar to the planner. As a quick reference to the analytic material in this guide, the following outline is provided.

Trip-Generation Estimation

- Average vehicle trip rates and other characteristics of generators (Table 1).
- Detailed trip-generation characteristics by urbanized area population (Table 2) for:

  50,000 to 100,000 population (Figs. 7 through 12)
  100,000 to 250,000 population (Figs. 13 through 18)
  250,000 to 750,000 population (Figs. 19 through 24)
  750,000 to 2,000,000 population (Figs. 25 through 30)
- Generalized trip-generation parameters and other useful characteristics (Table 3).

Trip Distribution

- Graphs for conversion of airline distance to travel time and distribution factors by trip purpose by urbanized area population for:

  50,000 to 100,000 population
  100,000 to 250,000 population
  750,000 to 2,000,000 population
  250,000 to 750,000 population
- Construction of the airline distance vs. travel time vs. distribution factor graphs (descriptive).
- Application of the manual trip distribution procedure to regionwide or corridor or site analysis (descriptive).
- Graph of time required to apply the manual trip distribution procedure (Fig. 39).
- Trip-distribution patterns for selected sites (Figs. 51 (descriptive).
- Trip distribution using available accessibility indices through 56).

Mode-Choice Analysis

- Nomographs for conversion of airline distance to total impedance for transit and auto modes (Figs. 60 through 70).
- Mode choice model nomographs by trip purpose (Figs. 74 through 76).
- Mode-choice analysis work sheets (Figs. 59 and 77).
- Estimating sensitivity to policy changes (descriptive).
- Nomographs for estimating change in transit patronage (Fig. 81).
- Transit rules of thumb.

Automobile-Occupancy Characteristics

- Average daily auto-occupancy rates by urbanized area population and trip purpose (Table 12).
- Auto-occupancy rate adjustment factors by time-of-day by trip purpose (Table 13).
- Auto-occupancy rate adjustment factors by trip distance by trip purpose (Table 14).
- Average daily auto-occupancy rates by income level of trip-maker and parking cost at trip destination (Table 15).
- Average daily auto occupancy rates by urbanized area population and land-use at trip destination (Table 16).

Time-of-Day Characteristics

- Hourly distribution of internal auto driver travel by trip purpose by urbanized area population for:

  50,000 to 100,000 population (Table 17)
  100,000 to 250,000 population (Table 22)
  250,000 to 750,000 population (Table 27)
  750,000 to 2,000,000 population (Table 32)

- Hourly distribution of internal auto driver and total vehicle travel by urbanized area population for:

  50,000 to 100,000 population (Table 18)
  100,000 to 250,000 population (Table 23)
  250,000 to 750,000 population (Table 28)
  750,000 to 2,000,000 population (Table 33)

- Hourly distribution of total travel on expressways/freeways by urbanized area population for:

  50,000 to 100,000 population (Table 19)
  100,000 to 250,000 population (Table 24)
  250,000 to 750,000 population (Table 29)
  750,000 to 2,000,000 population (Table 34)

- Hourly distribution of total travel on arterials by urbanized area population for:

  50,000 to 100,000 population (Table 20)
  100,000 to 250,000 population (Table 25)
  250,000 to 750,000 population (Table 30)
  750,000 to 2,000,000 population (Table 35)

- Hourly distribution of total travel on collectors by urbanized area population for:

  50,000 to 100,000 population (Table 21)
  100,000 to 250,000 population (Table 26)
  250,000 to 750,000 population (Table 31)
  750,000 to 2,000,000 population (Table 36)

- Conversion factors for critical periods of transit patronage (Table 37).
- Conversion factors for critical periods of internal person travel by urbanized area population for:

  50,000 to 100,000 population (Table 38)
  100,000 to 250,000 population (Table 39)
  250,000 to 750,000 population (Table 40)
  750,000 to 2,000,000 population (Table 41)

- Conversion factors for critical periods of internal auto driver travel by urbanized area population for:

  50,000 to 100,000 population (Table 42)
  100,000 to 250,000 population (Table 43)
  250,000 to 750,000 population (Table 44)
  750,000 to 2,000,000 population (Table 45)

Traffic Assignment Procedures

- Manual assignment method for small networks (descriptive).
- Work sheets for accumulating assignment volumes (Figs. 90, 94, and 96) and for accumulating turning movements (Fig. 98).
- Distribution of assignment volumes among available facilities (descriptive).
- Street requirements using traffic generation/traffic decay procedures (descriptive).
- Traffic shift method for facilities within corridors (descriptive).

Capacity Analysis

- Determination of intersection capacity (descriptive).
- Determination of corridor capacity (descriptive).
- Capacity nomographs for:

  One-way streets—no parking (Fig. 119)
  One-way streets—parking one side (Fig. 120)
  One-way streets—parking both sides (Fig. 121)
  Two-way streets—no parking (Fig. 122)
  Two-way streets—with parking (Fig. 123)
  Rural two-way streets—no parking (Fig. 124)
  Capacity conversion for cycle length (Fig. 125)

For each of the travel demand elements in the foregoing outline a narrative description has been provided in terms of the following:

- An introduction to the element.
- A description of how the procedures and parameters were developed.
- Pertinent graphs, tables, and descriptive information on procedures.
- Examples of application of the procedures and parameters.
- Data required for application of the procedures.
- Limitations of the procedures and parameters.
- Usefulness of locally developed procedures and parameters.
- Useful references.

SUMMARY OF MANUAL TECHNIQUES AND TRANSFERABLE PARAMETERS

The manual techniques and transferable parameters presented in subsequent chapters pertain to each element of the so-called four-step transportation planning process familiar to most transportation planners. The material for this process covers the elements of trip generation, trip distribution, mode choice, and traffic assignment. Supporting the use of these four basic steps are the additional elements of auto occupancy, time-of-day analysis, and capacity analysis. Material is also provided for evaluating the relationship between development density and highway spacing which ties together many of the other elements previously mentioned.

The elements covered can be used singularly or in combination depending on the analysis to be undertaken. In the description of the elements, alternate methodologies are presented, each appropriate to specific problems. For example, the traffic assignment chapter describes: (1) an all-or-nothing traditional assignment process that can be accomplished manually; (2) a traffic generation/decay procedure appropriate for determining street requirements; and (3) a traffic shift approach for corridors. The mode choice chapter provides a basic technique based on area-to-area travel as well as rules of thumb for quick estimates of patronage change based on alternative policy actions (i.e., fare change).

For each element some examples of application are also provided. The use of a series of elements is illustrated by the three scenarios described in Chapters Ten, Eleven, and Twelve.

Trip-Generation Estimation

The chapter on trip generation contains tables which enable trip estimates to be made from land-use and socioeconomic characteristics. These data provide: (1) estimates for specific generators; (2) generalized estimates on an areawide basis with rates for other pertinent travel characteristics, such as truck trip estimates and external travel through the study area, and the like; and (3) detailed estimation procedures on a household level relating trip rates to income and/or car ownership.

Trip Distribution

The purpose of the material and procedures described in this chapter is to allow the manual calculation of trips, as efficiently as possible, between different points. Additionally, the method described is applicable on a regional, corridor, or local area/site basis.

A process is described for manual application of the Gravity Model which results in a manageable process for a maximum of between 50 and 80 analysis areas. The material provided includes airline distance/travel time/distribution factors for four urbanized area population groups, suggested work sheets for manual application, examples for application to problems that are regional, corridor, and site-oriented.

One of the short-cut procedures described allows measurement of airline distance from a map (ruler) and a conversion to travel time and distribution factors using a graph. Also, tabulation and bookkeeping methods are described to facilitate manual application.

A process describing the use of accessibility indices computed for gross analysis areas for trip interchange estimates between sites or small areas is included based on accessibility contour plots. These indices can also be from output of regional models and then used directly for estimating an interchange between two points.

Graphs are included for a number of sites (special traffic generators) enabling the user to estimate trips to and from such sites rapidly. These graphs were obtained directly from available sources.

Mode-Choice Analysis

The mode-choice analysis procedure uses, as its basic building block, a transformed version of the "default model" contained in the program UMODEL of the U.S. Department of Transportation Urban Transportation Planning System (UTPS). The default model is a simultaneous model for trip distribution and mode split. The transformation has been achieved by developing a ratio of transit trips to auto trips and converting the ratio to a market share percentage for transit.

This approach requires the user to determine a market share for each analysis-area pair. With basic input information, such as airline distance, transit fare, parking cost, and operating speed, the user can determine a transit or auto impedance using curves provided. From the impedance values, the user can enter a nomograph and read directly the market share for the auto and transit modes. Also included are methods to allow the user to test policy options, such as increased fares or increased parking costs, and determine the market elasticity. Rules of thumb for quick estimates of transit-demand elasticity to changes such as fare are also included.

Automobile-Occupancy Characteristics

The tables provided in this chapter enable the conversion of auto person-trips to vehicle trips, or vice versa. The tables include: (1) a base table of auto occupancies by urbanized area population and trip purpose; (2) a table presenting factors for adjusting the basic 24-hr occupancies by purpose to occupancies for a particular hour; (3) a table providing factors for adjusting occupancies based on length of trip, by purpose; (4) a table providing auto occupancy by urbanized area population and land use at the trip destination (i.e., residential, manufacturing); and (5) a table providing occupancy data by income level cross-classified with parking costs.

Time-Of-Day Characteristics

The information contained in this chapter allows conversion of travel on a daily basis to travel on an hourly basis, and the development of directional volumes from nondirectional volume estimates. The approach taken for auto vehicle trips is to supply a series of summarized data tables for time-of-day analysis. The tables are primarily stratified by urbanized area population.

Tables are provided for: (1) distribution of travel by trip purpose and total purpose for internal auto drivers; (2) distribution of travel for total vehicle travel; (3) ratio, by hour of day, of total vehicles to internal auto drivers and; (4) distribution by facility type (freeway, arterials, collectors), by subregion [central business district (CBD), central city, suburb], and by orientation (radial, cross-town) where appropriate, of percent total vehicles and the directional split of travel in the AM peak direction.

For transit, factors are provided for conversions between daily patronage, combined peak-load volumes, peak-hour volumes, and peak-hour/peak-direction volumes.

Traffic-Assignment Procedures

Three procedures are described for traffic assignment. The first is a manual approach to assigning trips through a network and simplified bookkeeping of the resultant trip volumes. This approach is described at two levels: (1) detail assignments around a specific site including resultant facility volumes and turning movements; and (2) less detailed assignments to highway facilities at a corridor level or "sketch"-planning regional level. A method of smoothing assigned volumes between facilities is also provided. The second procedure is a variation of the methods developed by Gruen Associates (*1*) for simplified methods for major street planning. The improvements include a geographic orientation procedure as well as a specific method for developing traffic attenuation factors specific to the study area.

The third procedure is a sketch-planning process included for estimating probable shifts in volume between competing facilities in a corridor. This is based on the stochastic assignment process but does not require the use of an origin-destination (O-D) table or route determination. Rather, a diversion function is developed based on known volumes and operating speeds. This function is used to estimate shifts between facilities based on improvements in operation.

Capacity Analysis

Two primary types of analysis are described. A corridor analysis procedure is presented to investigate volume/capacity (V/C) conditions within a corridor and to profile those relationships along a corridor route. An intersection-analysis procedure is described to evaluate vehicular movements through intersections.

The corridor approach draws on and extends existing recommendations of the Federal Highway Administration (FHWA) for analyses at screenlines and cutlines. This approach analyzes volume/capacity conditions at key points along a corridor in an aggregate sense.

The intersection method described uses an analysis of lane-turning and through-movements to determine the volume and volume/capacity relationships of an intersection. It is presumed the intersection capacity analysis would be used to investigate the impacts of a site on local street conditions. The technique requires trip assignment, including tabulating turning movements at an intersection. Movements are analyzed to determine, in summation, the greatest volume of through and opposing traffic. That volume is compared to average capacities for service levels as defined by the *Highway Capacity Manual* to determine the service level at which the intersection is or will be operating. Nomographs are provided for capacity calculation at the level appropriate for planning using the manual methods provided in this guide.

Development Density/Highway Spacing Relationships

The basic purpose of the relationships developed between land use and highway spacing is to permit the rapid development of a "first-cut" estimate of future highway needs based on a desired level of highway service. Given a distribution within an area of land use, either in terms of activities (people, households, jobs) or acres by type of use, and given the presence of an existing highway system, future vehicle trip ends are computed and adjusted for improved transit service. The average trip distance is then computed from counts or from curves provided and adjusted for the future.

Average arterial volumes for a given spacing of freeways and arterials can then be determined from the computation of vehicle-miles of travel (VMT), and the level of service provided by each subarea can be computed. A comparison of the computed level of service with a desired level of service indicates a measure of highway needs for the study area.

It is also possible to adjust the land-use input to revise the level of service, or to compute the amount of additional land use that can be added for a given level of service.

USEFULNESS OF MANUAL TECHNIQUES AND TRANSFERABLE PARAMETERS

Many of the manual techniques and transferable parameters included in this guide will be useful for both manual *and* computerized application. This material is in the form of tables, graphs, nomographs, and charts and provides generally transferable parameters. The parameters have been consistently reported for four urbanized area population groups as follows:

50,000	to	100,000	population
100,000	to	250,000	population
250,000	to	750,000	population
750,000	to	2,000,000	population

Consistency in trip purposes has been maintained between the various elements. Material is provided in most cases for home-based work (HBW) trips, home-based nonwork (HBNW) trips, and nonhome-based (NHB) trips. Wherever possible, total travel demand is provided by mode without a purpose stratification.

For both computer and manual application, the factors and parameters provide "default" values to be used in lieu of local travel-demand data. Such a need may arise where local data are not in a suitable form, where the data are dated, or perhaps nonexistent. Where appropriate models and/or data are available, it is suggested that factors and parameters be developed from the local source. This is based on the premise that differences exist between urbanized areas even within a population group and/or geographic location and that the material provided in this document represents average conditions across areas.

The manual methods described are not appropriate for all types of problems. However, in many cases use of manual methods may be more suitable than a computer application. Computer methods are most appropriate for regional analysis at a detailed level of geography (i.e., a large number of analysis areas). For analyses requiring more than 80 analysis areas, manual methods are not feasible. However, for regional sketch-planning with perhaps 20 to 25 analysis areas, manual techniques are certainly appropriate. Likewise, in smaller study areas, for example, those with less than 100,000 population, regional analysis at a relatively detailed level may be accomplished manually.

Manual methods are most suitable for specific problem applications. The impacts of a new development on the surrounding transportation system can be assessed manually. Manual evaluation of alternate proposals for a corridor is also possible; however, if one expects to evaluate several corridors, computer methods may be more appropriate.

Another important consideration is staff capability. Where a staff is well experienced with computer application, many problems can be efficiently handled by computer through innovative application of available computer programs. Care should be taken, however, to consider manual application which, even in these cases, may be more efficient (less time, less cost) than computer application.

For manual application, clerical personnel, rather than the computer, are the resource. A problem that consumes 50 hr of clerical time with some technical supervision may be less expensive and require less elapsed time than the use of 10 hr of a computer professional, 20 hr of a transportation technician, 5 min of a computer, and some technical supervision. Clerical personnel can be hired on a temporary basis or can be used when required from other functions. This is not generally the case for the computer professional.

For quick-response applications, some preliminary work is desirable. When using the computer for planning purposes, a specific analysis can be accomplished in significantly less time if regional models are available, forecasts by zone completed, networks clean and usable, and the like, than if these must be accomplished when the need arises. The same holds true for manual-method application. If some base calculations have been completed, and forecast data are available, and familiarity with techniques already exists, then quick response is more easily achieved. If trip distributions, for example, are a repetitive requirement, then some preliminary work in applying the distribution method to a base set of analysis areas will provide accessibility indices that can be used when quick response is needed. Likewise, in a study area where a computer application has been made for regional planning, some of the computer output will be useful when manual analysis is required. In many instances, even where regional computer analyses have been completed, manual methods as described herein could provide quicker response at less cost than a computer analysis.

SCENARIO APPLICATIONS

To illustrate the applicability of the manual transportation planning techniques presented in this document, three scenarios were selected, each representing a "real-world" transportation problem.

The guidelines established for selection of the urbanized areas for the three scenarios were based on population variation and geographical distribution of each area. Telephone calls were made to several potential study areas to uncover interest in the use of local problems for a scenario. A key guideline was that the problem would be current and that cooperation would be provided, at least in gathering necessary background information. Also, it was desired to apply the techniques to a site-impact, a corridor analysis, and a land development/highway spacing problem.

Boise, Idaho, was selected for the small urbanized area application; Columbus, Ohio, for the medium area application; and Fairfax County, Virginia, in suburban Washington, D.C., was selected for the large area application. Some census data for the three areas are shown as follows:

URBANIZED AREA	POPULATION	CARS/HH	MEDIAN FAMILY INCOME	% WORK TRIPS BY AUTO
Boise, ID	85,142	1.50	9,900	91.4
Columbus, OH	789,858	1.29	10,500	83.4
Fairfax, VA *	2,479,000	1.20	12,900	73.2

* Statistics given for Washington, D.C., urbanized area.

Personal visits were made to the areas to discuss the application and potential scenarios. In Boise, because of its growth, there are numerous requests to analyze and evaluate transportation impacts of proposed new developments. Quite often the time to evaluate these is short, and shortcut manual methods are employed when possible. It was expected that the impact of a new development would be a major concern of many smaller urbanized areas, and such a scenario was chosen for Boise.

In Columbus, a current problem was evaluation of an improvement proposed for a corridor—to widen a 2-lane highway to 4 lanes. The facility is on the outskirts of the area and, as such, is not within the area for which regional planning is currently accomplished. This appears to be a problem which would be of concern in many moderate size urbanized areas. Thus, the Columbus corridor problem became a second scenario.

The development density/highway facility spacing relationships are most applicable in new development areas. Fairfax County, in the Washington, D.C., suburbs, currently has a population exceeding 500,000 persons which is expected to exceed 750,000 persons in the next 20 years. Fairfax thus provided an ideal location for application of the land use/spacing relationships. The scenarios for Boise, Columbus, and Fairfax are discussed in Chapters Ten, Eleven, and Twelve.

CHAPTER TWO

TRIP-GENERATION ESTIMATION

INTRODUCTION

The amount of travel and its characteristics is functionally related to the use of land. For trip-generation estimation, land use is described in terms of the character, intensity, and location of land-use activities. Factors influencing trip generation include automobile ownership, income, household size, availability of public transportation, density of development, and the quality of the transportation system. Trip generation provides the vital transition between land use and travel.

The purpose of trip-generation estimation is to determine the number of trips to and from activities in an analysis area based on the aforementioned factors. Trip-generation estimation is important in a number of phases of transportation planning and traffic engineering activities. It is necessary for (a) regional study in considering a broad range of land uses and related social and economic characteristics; (b) in short-range planning in the evaluation of transportation needs for an urban area, or a specific corridor; and to (c) assess the impact of a new development such as a shopping center, residential development, or industrial park.

The diverse requirements for trip-generation estimation have resulted in the need for varying levels of trip-generation information. In this chapter, trip-generation data are presented as follows:

- For specific generators (Table 1).
- Detailed trip-generation characteristics for corridor and areawide studies (Table 2).
- Generalized characteristics for a regional study and corridor analysis (Table 3).

BASIS FOR DEVELOPMENT

The material presented in Tables 1 through 3 has been derived from available reports, transportation study data, and other research. Table 1, "Average Vehicle Trip Rates and Other Characteristics of Generators," has been derived from a number of reports presenting information for a variety of generator types (*2* to *19*). The trip rates provided are representative of a wide range of values for each generator. When appropriate, the user/planner may wish to collect more local data and perhaps even develop information similar to that given in Table 1.

The traffic data were collected with automatic counters which count vehicular traffic entering and exiting a site at a cordon surrounding the site. Data relative to characteristics of the site (floor area, employees, etc.) were obtained through personal interviews, actual measurements, and other means of contact (mail, telephone, etc.). Information to supplement the counts, such as auto occupancy and percent transit, came from some studies where manual counts were also made but more usually were estimated from transportation study reports and origin-destination (O-D) survey-type data. These trip data, especially percent transit, represent a wide range of trip-rate values and should therefore be used for gross approximations only.

The "Detailed Trip-Generation Characteristics" given in Table 2 have been derived from a number of urban transportation planning O-D studies—both basic data and published reports. The time period for the survey data is the period between 1965 and 1974 and can generally be thought of as representing an average 1970 condition. The data used were summarized into four urbanized area population groups as given in Table 2.

The average daily trip rates for each population group were compared with a summary of trip rates reported in the 1974 National Transportation Report (*16*) which represents an estimate of conditions in 1971 and as expected in 1989. Although there are differences in the findings, the comparison indicates that the data are of the proper magnitude. A summary of the trip rate comparison is provided below:

URBANIZED AREA POPULATION	PERSON-TRIPS/HH TABLE 2 (1970)	1974 REPORT * (1971)
50,000 to 100,000	14.1	unstable data
100,000 to 250,000	14.5	12.6
250,000 to 750,000	11.8	11.8
750,000 to 2,000,000	7.6	8.8

* Adjustments required to be consistent with definitions of the previous column.

The income ranges given in Table 2 represent income in terms of 1970 dollars. Therefore, if income is used to enter the table, care must be taken to represent the income in terms of 1970 dollars.

The "% HH by Autos Owned" (col. 4) was derived from 1970 census data which provides such distribution by urbanized area. The "Average Daily Person-Trips per Household by Number of Autos per Household" (col. 5) was derived from O-D surveys. The "Average Autos per Household" (col. 2) is a weighted number, having been calculated using the household distribution by auto ownership. The "Average Daily Person-Trips per Household" (col. 3) was computed by applying the auto ownership distribution to the distribution of daily person-trips per household by auto ownership. The "% Average Daily Person-Trips by Purpose" (col. 6) was not available in the form given for many of the studies for which the data on total trips by income and car ownership were available. For this reason, older survey data were also used to help derive the purpose distribution by population group and within the car ownership and income categories (*17*, *19*).

For Table 3, "Part A—Trip Production Estimates," the findings reported in Table 2 were used for the "Average Daily Person-Trips per Household" (col. 1) and "% Average Daily Person-Trips by Purpose," (col. 4). The "% Average Daily Person-Trips by Mode" (col. 3) was obtained from the current surveys as well as previously summarized information (*19*). "Auto Person-Trips as a % of Total Person-Trips" (col. 5) by purpose was estimated from past experience with travel survey data. The basic observation applied is that work trip percent transit is about double total percent transit in an urban area and that "other trips" percent transit is about half of total percent transit. The auto-trip-percent for nonhome-based trips was approximated to be in the same proportion that home-based work trips are of total home-based trips.

The "Auto Driver Trips as a % of Total Person-Trips" (col. 6) data were derived by applying the auto-occupancy relationships reported later in this guide (Table 12 and Chapter Five, "Automobile Occupancy Characteristics") to the data shown for "Auto Person-Trips as a % of Total Person Trips" (col. 5).

The information for Table 3, "Part B—Useful Characteristics for Trip Estimation," was obtained from travel

TABLE 1

AVERAGE VEHICLE TRIP RATES AND OTHER CHARACTERISTICS OF GENERATORS

GENERATOR[b]	VEHICLE TRIPS[c] TO & FROM PER DAY PER			PERCENT TRIPS IN HOUR SHOWN			TYPICAL AUTO OCCUPANCY	TYPICAL % TRANSIT OF TOTAL PERSON TRIPS[d]
	DWELLING UNIT	ACRE		A.M. PEAK	P.M. PEAK	PEAK HR. OF GEN.		
Residential								
Single Family								
1 Du/acre	9.3	9.3		8.0	10.8	10.8	1.62	3.2
2 Du/acre	9.3	18.6		8.0	10.8	10.8	1.62	3.2
3 Du/acre	10.2	30.6		8.0	10.8	10.8	1.67	3.2
4 Du/acre	10.2	40.8		8.0	10.8	10.8	1.67	3.2
5 Du/acre	9.1	45.5		8.0	10.8	10.8	1.62	3.2
Medium Density (Duplex, Townhouses etc.)								
5 Du/acre	7.0	35.0		8.0	10.8	10.8	1.57	5.6
10 Du/acre	7.0	70.0		8.0	10.8	10.8	1.57	5.6
15 Du/acre	7.0	105.0		8.0	10.8	10.8	1.57	5.6
Apartments								
15 Du/acre	6.0	90.0		7.9	10.8	10.8	1.56	12.4
25 Du/acre	6.0	150.0		7.9	10.8	10.8	1.56	12.4
35 Du/acre	6.0	210.0		7.9	10.8	10.8	1.56	12.4
50 Du/acre	6.0	300.0		7.9	10.8	10.8	1.56	12.4
60 Du/acre	6.0	360.0		7.9	10.8	10.8	1.56	12.4
Mobile Home Park								
5 Du/acre	5.5	27.5		8.3	10.8	12.5	1.54	1.0
10 Du/acre	5.5	55.0		8.3	10.8	12.5	1.54	1.0
15 Du/acre	5.5	82.5		8.3	10.8	12.5	1.54	1.0
Retirement Community								
10 Du/acre	3.5	35.0		12.1	12.1	12.1	1.48	6.0
15 Du/acre	3.5	52.5		12.1	12.1	12.1	1.48	6.0
20 Du/acre	3.5	70.0		12.1	12.1	12.1	1.48	6.0
Condominiums								
10 Du/acre	5.9	59.0		7.1	7.1	7.1	1.56	9.0
20 Du/acre	5.9	118.0		7.1	7.1	7.1	1.56	9.0
30 Du/acre	5.9	177.0		7.1	7.1	7.1	1.56	9.C
Planned Unit Develop.								
5 Du/acre	7.9	39.5		10.1	10.1	10.1	1.58	7.1
15 Du/acre	7.9	118.5		10.1	10.1	10.1	1.58	7.1
25 Du/acre	7.9	197.5		10.1	10.1	10.1	1.58	7.1
	SEE INDIVIDUAL GENERATOR BELOW							
Miscellaneous								
Service Station	Station 748	Pump 133		1.5	3.0	4.0	1.55	-
Race Track	Seat 0.61	Attendee 1.08		-	-	-	2.05	-
Pro-Baseball	0.16	1.18		-	-	-	2.05	
Military Base	Military Personnel 2.2 1000sq.ft. GFA	Civilian Employees 7.1 Employee	Total Employees 1.8 Acre	-	-	-	1.42	-

TABLE 1 (Continued)

GENERATOR[b]	VEHICLE TRIPS[c] TO & FROM PER DAY PER (SEE INDIVIDUAL GENERATOR BELOW)			PERCENT TRIPS IN HOUR SHOWN A.M. PEAK	P.M. PEAK	PEAK HR. OF GEN.	TYPICAL AUTO OCCUPANCY	TYPICAL % TRANSIT OF TOTAL PERSON TRIPS[d]
Retail								
Free Standing								
Supermarket	135.3	-	1000	0	8.7	12.6	1.64	1
Discount Store	50.2	57.2	-	0	5.1	9.7	1.64	1
Discount Store with Super Mkt	81.2	30.3	-	0	6.9	11.1	1.64	1
Department Store	36.1	32.8	900	-	-	-	1.64	2
Auto Supply	88.8	-	-	-	-	-	1.64.	1
New Car Dealer	44.3	-	-	-	-	-	1.64	1
Convenience (24 hrs.)	577.0	-	-	-	-	-	1.64	1
(15-16 hrs.)	322.0	-	-	-	-	-	1.64	1
Shopping Center								
Regional (over 1 million sq. ft.)	33.5	30.9	580	1.9	9.7	11.5	1.64	3
(1/2-1 million sq.ft)	34.7	20.4	370	2.8	9.6	-	1.64	3
Community (100,000-500,000 sq. ft.)	45.9	20.6	330	-	11.2	11.3	1.64	3
Neighborhood (under 100,000 sq. ft.)	97.0	-	-	3.3	11.5	12.4	1.64	3
Central Area (High Dens.)	40.0	-	900	-	-	-	1.64	12
Industrial/ Manufacturing								
~~Free Standing~~								
General Manufacturing	4.2	2.3	40.5	18.4	19.3	32.2	1.33	5
Warehouse	5.3	4.4	67.5	12.7	32.2	-	1.25	5
Research/ Develop.	5.1	2.4	60.8	21.1	20.4	-	1.33	5
Industrial Park	8.8	3.9	71.9	13.2	14.7	-	1.33	5
General Light Ind.	5.5	3.2	52.4	21.1	20.4	21.2	1.33	5
All Industry Avg.	5.5	3.0	59.9	15.8	19.4	-	1.40	5
Offices								
General	11.7	3.5	145	20.7	19.1	-	1.35	5
Medical	63.5	25.0	426	-	-	8.5	1.45	5
Governmental	48.3	12.0	66	8.5	16.0	-	1.35	5
Engineering	23.0	3.5	282	16.9	14.6	-	1.35	5
Civic Center	25.0	6.1	33	9.0	11.4	-	1.35	5
Office Park	21.0	3.3	277	16.9	14.6	-	1.35	5
Research Center	9.3	3.1	37	16.0	18.5	20.2	1.35	5
Restaurants								
Quality Restaurant	56.3	-	200	1.8	6.0	12.5	1.93	3
Other Sit-Down	198.5	-	932	29.0	6.4	-	1.93	3
Fast Food	533.0	-	1825	16.0	5.7	-	1.93	1
Banks	388	75	-	-	-	-	1.45	-
Parks & Recreation								
Marina	-	259.0	18.5	-	-	-	2.05	-
Golf Course	-	34.2	7.4	-	-	-	2.05	-
Bowling	-	-	296.3	-	-	-	2.05	-
Participant sports	-	-	26.5	-	-	-	2.05	-
City Park	-	-	60.0	-	-	-	2.05	-
County Park	-	26.5	5.1	-	-	-	2.05	-
State Park	-	61.1	0.6	-	-	-	2.05	-
Wilderness Park	-	-	0.07	-	-	-	2.05	-

TABLE 1 (Continued)

GENERATOR[b]	VEHICLE TRIPS[c] TO & FROM PER DAY PER: 1000sq.ft. GFA	EMPLOYEE	ACRE	PERCENT TRIPS IN HOUR SHOWN: A.M. PEAK	P.M. PEAK	PEAK HR OF GEN.	TYPICAL AUTO OCCUPANCY	TYPICAL % TRANSIT OF TOTAL PERSON TRIPS[d]
Parks & Recreation (cont'd)								
National Monument	-	-	11.9	-	-	-	2.05	-
Ocean Front	-	-	21.6	-	-	-	2.05	-
Lake/Boating	-	-	3.6	-	-	-	2.05	-
Animal Attractions	-	-	72.2	-	-	-	2.05	-
Hospitals	Staff	Bed	Acre	-	-			
All Categories	6.1	14.8	40	-	-	11.7	1.40	-
General	5.9	14.0	-	18.0	9.0	-	1.42	17
Childrens	10.1	25.2	-	-	-		1.42	17
Convalescent	4.5	3.2	-	-	-	-	1.42	10
University	7.8	37.0	-	12.5	10.5	-	1.41	10
Veterans	2.2	3.8		11.0	16.5	-	1.32	10
Nursing Home	-	2.7	-	5.2	7.8	13.3	1.40	10
Clinics	5.9	-	-	-	-	-	1.40	10
Educational	Student	Staff						
All Categories	1.8	13.6		-	-	-	1.40	-
Four Year Univ	2.5	9.8		11.0	9.0	-	1.40	13
Jr.College	1.5	28.2		11.5	7.5	11.9	1.55	13
Secondary School	1.4	19.9		11.5	4.9	-	1.55	4[e]
Elementary School	0.6	11.7		31.4	2.0	-	1.55	4[e]
Combined Elem/Sec.	0.8	11.8		-	-	-	1.55	4[e]
Libraries	41.8	51.0		-	-	16.0	1.55	6
Airports	Take-Off/Landing	Employee	Acre					
General Aviation	2.5	6.5	3.6	11.8	10.5	15.7	1.52	1
Commercial	11.8	16.8	-	9.7	17.3	-	1.52	3
Hotel/Motel	Room	Employee						
Hotel	10.5	11.3		7.9	5.7	8.3	1.56	2
Motel	9.6	10.6		6.7	5.9	9.0	1.56	0
Resort Hotel	10.2	10.3		2.6	6.8	7.8	1.93	0

a. The trip rates given are based on a limited number of studies and thus must be used with caution. The ITE Trip Generation Report(6) provides current data which is also periodically updated. The vehicle trip rates include external-internal and internal-external trip ends at generators as well as trucks, taxis and bus.

b. Most of the generators examined are located outside the central business districts of cities. The trip rates may thus be inapplicable to sites located within the dense urban core, particularly in large cities. Variations in generation rates may also exist because of the location of the generator either within a metropolitan area or outside that area.

c. The vehicle trip rates presented are actually volumes into and out of the site. As such, they may include some trips that would be passing the site on the adjacent street system, in any case, while making a trip for another reason, and they are induced to stop for impulse or convenience shopping, personal business or to drop off or pick up a passenger. The proportion of these trips has not been identified. Note also that ranges in trip rates can be expected and these can vary depending upon local conditions.

d. The typical transit % shown has a wide range of variation based on location within an urban area, level of service provided, etc., and as such, should be used only to provide gross approximations.

e. Does not include school bus transit.

TABLE 2

DETAILED TRIP-GENERATION CHARACTERISTICS[a]

URBANIZED AREA POPULATION: 50,000-100,000

Income Range 1970 $ (000's)	Avg Autos Per HH[d]	Average Daily Person Trips Per HH[e]	% HH by Autos Owned[b]				Average Daily Person Trips Per HH by No. of Autos/HH[c]				% Average Daily Person Trips by Purpose[f]		
			0	1	2	3+	0	1	2	3+	HBW	HBNW	NHB
0-3	0.56	4.5	53	39	7	1	2.0	6.5	11.5	12.5	21	57	22
3-4	0.81	6.8	32	58	10	1	2.2	8.0	13.0	15.0	21	57	22
4-5	0.88	8.4	26	61	12	1	2.6	9.5	14.5	16.5	21	57	22
5-6	0.99	10.2	20	62	17	1	3.0	11.0	15.5	18.0	18	59	23
6-7	1.07	11.9	15	64	20	1	3.0	12.5	16.5	19.5	18	59	23
7-8	1.17	13.2	11	64	23	2	3.5	13.3	17.0	21.5	16	61	23
8-9	1.25	14.4	8	62	28	2	4.8	14.0	17.5	22.5	16	61	23
9-10	1.31	15.1	6	60	32	2	5.5	14.3	17.5	24.0	16	61	23
10-12.5	1.47	16.4	3	49	44	3	6.2	15.0	18.5	25.5	15	62	23
12.5-15	1.69	17.7	2	38	52	8	6.1	15.0	19.0	25.5	14	62	24
15-20	1.85	18.0	2	28	57	13	6.0	13.5	19.5	23.0	13	62	25
20-25	2.03	19.0	1	21	58	20	6.0	13.0	20.0	23.0	13	62	25
25+	2.07	19.2	1	19	59	21	6.0	12.5	20.0	23.0	13	62	25
Weighted Average	1.55	14.1	12	47	35	6	4.6	12.6	17.2	21.4	16	61	23

URBANIZED AREA POPULATION: 100,000-250,000

Income Range 1970 $ (000's)	Avg Autos Per HH[d]	Average Daily Person Trips Per HH[e]	% HH by Autos Owned[b]				Average Daily Person Trips Per HH by No. of Autos/HH[c]				% Average Daily Person Trips by Purpose[f]		
			0	1	2	3+	0	1	2	3+	HBW	HBNW	NHB
0-3	0.49	4.0	57	37	6	0	1.0	7.5	10.5	13.8	20	63	17
3-4	0.72	6.8	36	56	8	0	1.7	9.2	13.3	16.4	22	60	18
4-5	0.81	8.4	29	61	10	0	2.5	10.2	14.5	17.6	22	58	20
5-6	0.94	10.2	21	65	13	1	3.5	11.4	14.5	19.0	22	58	20
6-7	1.01	11.7	17	66	16	1	4.5	12.5	15.6	20.5	20	58	22
7-8	1.14	13.6	12	65	21	2	5.4	13.8	17.0	22.2	20	57	23
8-9	1.25	15.3	9	61	28	2	5.8	15.0	17.5	23.0	20	57	23
9-10	1.34	16.2	6	58	33	3	6.3	15.8	18.0	23.5	19	57	24
10-12.5	1.50	17.3	4	50	40	6	6.8	16.0	19.0	24.5	19	57	24
12.5-15	1.65	18.7	2	40	51	7	7.0	16.0	20.4	25.0	19	56	25
15-20	1.85	19.6	2	28	57	13	7.2	15.0	21.0	25.5	18	56	26
20-25	2.01	20.4	1	20	61	18	7.5	15.0	21.0	25.5	18	55	27
25+	2.07	20.6	1	19	59	21	7.5	15.0	21.0	25.2	18	55	27
Wt. Avg.	1.55	14.5	14	48	33	6	5.4	13.7	18.4	22.4	20	57	23

TABLE 2 (Continued)

URBANIZED AREA POPULATION: 250,000-750,000

IncomeRange 1970 $ (000's)	Avg Autos Per HH[d]	Average Daily Person Trips per HH[e]	% HH by Autos Owned[b]				Average Daily Person Trips Per HH by No. of Autos/HH[c]				% Average Daily Person Trips by Purpose[f]		
			0	1	2	3+	0	1	2	3+	HBW	HBNW	NHB
0-3	0.47	3.3	58	37	5	0	1.4	5.6	9.3	9.3	10	67	23
3-4	0.77	5.8	38	50	10	2	2.0	7.4	10.8	11.1	13	64	23
4-5	0.88	6.9	29	57	12	2	2.5	8.0	11.5	11.9	21	57	22
5-6	1.01	8.4	20	62	16	2	2.9	9.0	12.1	12.7	22	56	22
6-7	1.10	9.5	14	65	19	2	3.5	9.7	12.7	13.5	22	55	23
7-8	1.24	10.9	8	64	25	3	4.0	10.6	13.5	14.4	20	55	25
8-9	1.33	11.7	6	60	30	4	4.6	11.0	14.2	15.3	20	55	25
9-10	1.40	12.4	4	57	35	4	5.2	11.2	14.8	16.2	20	55	25
10-12.5	1.58	13.5	2	46	46	6	5.5	11.3	15.6	17.6	20	55	25
12.5-15	1.72	14.6	2	36	53	9	5.5	11.4	16.4	18.8	20	53	27
15-20	1.88	15.5	2	26	58	14	5.2	11.5	16.7	19.1	20	52	28
20-25	2.04	16.0	1	20	59	20	5.0	12.0	16.7	18.6	20	50	30
25+	2.08	16.2	1	17	61	21	5.0	12.0	16.7	18.6	20	50	30
Wt. Avg.	1.41	11.8	12	44	37	7	4.3	10.0	14.4	15.8	20	55	25

URBANIZED AREA POPULATION: 750,000-2,000,000

IncomeRange 1970 $ (000's)	Avg Autos Per HH[d]	Average Daily Person Trips per HH[e]	% HH by Autos Owned[b]				Average Daily Person Trips Per HH by No. of Autos/HH[c]				% Average Daily Person Trips by Purpose[f]		
			0	1	2	3+	0	1	2	3+	HBW	HBNW	NHB
0-3	0.47	1.9	58	37	5	0	0.8	3.2	5.7	7.3	14	66	20
3-4	0.68	3.7	40	52	8	0	2.0	4.5	7.0	9.2	22	59	19
4-5	0.78	4.5	32	58	10	0	2.5	5.0	7.5	10.0	28	53	19
5-6	0.84	5.1	28	60	12	0	2.7	5.6	8.0	11.0	28	53	19
6-7	0.95	5.8	22	62	15	1	2.9	6.1	8.6	11.6	28	53	19
7-8	1.06	6.5	16	63	20	1	3.0	6.5	9.2	12.2	27	53	20
8-9	1.16	7.2	12	63	23	2	3.2	6.9	9.5	12.6	27	53	20
9-10	1.25	7.7	9	61	27	3	3.3	7.1	9.9	13.0	27	54	19
10-12.5	1.41	8.5	5	56	34	5	3.4	7.5	10.1	13.6	26	53	21
12.5-15	1.60	9.4	2	45	46	7	3.6	7.5	10.7	14.2	25	53	22
15-20	1.77	9.9	2	35	51	12	3.6	7.6	10.7	14.6	24	53	23
20-25	1.95	10.6	2	24	56	18	3.7	7.0	11.1	14.8	24	53	23
25+	2.02	11.0	2	20	58	20	4.0	7.0	11.3	14.8	23	54	23
Wt. Avg	1.31	7.6	15	48	32	6	3.1	6.5	9.5	12.6	25	54	21

a. Total of internal and external trips generated by area residents.
b. Source: 1970 Census.
c. Source: Origin-Destination Surveys.
d. Calculated (using b).
e. Calculated (using b and c)
f. Source: References (17 and 19).

TABLE 3

TRIP-GENERATION PARAMETERS

PART A - TRIP PRODUCTION ESTIMATES

Urbanized Area Population	Average Daily Person Trips Per HH[a]	% Average Daily Person Trips by Mode[b]			% Average Daily Person Trips by Purpose[a]			Auto Person Trips as a % of Total Person Trips[c]			Auto Driver Trips as a % of Total Person Trips[d]		
		Public Transit	Auto Passenger	Auto Driver	HBW	HBNW	NHB	HBW	HBNW	NHB	HBW	HBNW	NHB
50,000- 100,000	14	2	40	58	16	61	23	96	99	98	70	54	68
100,000- 250,000	14	6	30	64	20	57	23	88	97	94	64	54	66
250,000- 750,000	12	8	31	61	20	55	25	84	96	92	62	54	64
750,000-2,000,000	8	13	30	57	25	54	21	74	93	86	56	53	60

PART B - USEFUL CHARACTERISTICS FOR TRIP ESTIMATION

Urbanized Area Population	External Travel Characteristics		Total Areawide Truck Trips as a % of Areawide Auto Driver Trips[f]
	% of Total External Trips Passing Through Area[e]	% of Total External Trips to the CBD[e]	
50,000- 100,000	21	22	27
100,000- 250,000	15	22	17
250,000- 750,000	10	18	16
750,000-2,000,000	4	12	16

PART C - TRIP ATTRACTION ESTIMATING RELATIONSHIPS[g]
(All Population Groupings for either Vehicle or Person Trips)

TO ESTIMATE TRIP ATTRACTIONS FOR AN ANALYSIS AREA, USE:

$$\text{HBW Trip Attractions} = F_1 \left[1.7\ (\text{Analysis Area Total Employment})\right]$$

$$\text{HBNW Trip Attractions} = F_2 \left[10.0 \begin{pmatrix}\text{Analysis Area}\\ \text{Retail}\\ \text{Employment}\end{pmatrix} + 0.5 \begin{pmatrix}\text{Analysis Area}\\ \text{Non-Retail}\\ \text{Employment}\end{pmatrix} + 1.0 \begin{pmatrix}\text{Analysis Area}\\ \text{Dwelling}\\ \text{Units}\end{pmatrix}\right]$$

$$\text{NHB Trip Attractions} = F_3 \left[2.0 \begin{pmatrix}\text{Analysis Area}\\ \text{Retail}\\ \text{Employment}\end{pmatrix} + 2.5 \begin{pmatrix}\text{Analysis Area}\\ \text{Non-Retail}\\ \text{Employment}\end{pmatrix} + 0.5 \begin{pmatrix}\text{Analysis Area}\\ \text{Dwelling}\\ \text{Units}\end{pmatrix}\right]$$

Where: F_1, F_2 and F_3 are areawide control factors.

TO DEVELOP AREAWIDE CONTROL FACTORS, USE:

$$F_1 = \frac{\text{Areawide Productions for HBW Trips}}{1.7\ (\text{Areawide Total Employment})}$$

$$F_2 = \frac{\text{Areawide Productions for HBNW Trips}}{\left[10.0 \begin{pmatrix}\text{Areawide}\\ \text{Retail}\\ \text{Employment}\end{pmatrix} + 0.5 \begin{pmatrix}\text{Areawide}\\ \text{Non-Retail}\\ \text{Employment}\end{pmatrix} + 1.0 \begin{pmatrix}\text{Areawide}\\ \text{Dwelling}\\ \text{Units}\end{pmatrix}\right]}$$

$$F_3 = \frac{\text{Areawide Productions for NHB Trips}}{\left[2.0 \begin{pmatrix}\text{Areawide}\\ \text{Retail}\\ \text{Employment}\end{pmatrix} + 2.5 \begin{pmatrix}\text{Areawide}\\ \text{Non-Retail}\\ \text{Employment}\end{pmatrix} + 0.5 \begin{pmatrix}\text{Areawide}\\ \text{Dwelling}\\ \text{Units}\end{pmatrix}\right]}$$

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a. From Table 2.
b. Source: Ref. (19).
c. Source: Origin-Destination Surveys.
d. Calculated using c and Table 12, Chapter Five.
e. Source: Ref. (20).
f. Source: Ref. (19).
g. Source: Office of Planning Methodology and Technical Support, UMTA.

information summarized earlier from available survey information (*19*). The information on "% of Total External Trips Passing Through Area" (col. 2) and "% of Total External Trips to the CBD" (col. 3) is from a report published in 1961 based on surveys taken in the several preceding years (*20*). A few more recent surveys were reviewed and were found to compare favorably with the data given in Table 3, Part B. The information on truck trips was summarized from a number of transportation studies completed from the mid-1950's to the mid-1960's (*19*).

The factors and parameters provided in Table 3, "Part C—Trip Attraction Estimating Relationships," were obtained from the Office of Planning Methodology and Technical Support of the Urban Mass Transportation Administration (UMTA). The material was developed for the so-called default model of the Urban Transportation Planning System (UTPS) (*29*). Trip attraction values on a nonsite-specific basis are used for regional and corridor/local planning primarily as factors or weights for distributing trip productions and are scaled up or down with respect to trip-production estimates. The use of areawide adjustment is compatible with the accuracy usually desired.

DATA REQUIRED FOR APPLICATION

The data requirements for application of the information provided for trip generation include land-use and socioeconomic characteristics generally used for areawide planning and site-specific characteristics used in land-development analysis. The material provided allows some variation in data requirements based on data availability, level of analysis required, and time available.

For site-specific estimates the following input is required:

GENERATOR	INPUT REQUIRED
Residential	Type of residence and number of dwelling units or acres of development.
Industrial/manufacturing, offices	Gross floor area (GFA), or employees, or acres of development.
Restaurants	Gross floor area or acres of development.
Banks	Gross floor area or employees.
Parks and recreation	Acres (or employees for a few types).
Hospitals	Staff or beds.
Educational	Students or staff.
Airports	Take-offs and landings or employees or acres.
Hotels/motels	Rooms or employees.
Retail	Gross floor area or employees or acres.
Military bases	Military personnel and civilian employees or total employees.
Race tracks, baseball	Seats or attendees.
Service stations	Number of pumps.

Definitions of the appropriate units of measure for Table 1 follow:

- Dwelling unit (DU): A place of domicile such as a single-family home, apartment, and the like.
- Acre: 43,560 sq ft; as used here it includes all developed land area connected to a site, including parking lots, and the like.
- 1000 GFA: The gross floor area of a site under roof in terms of 1000 sq ft.
- Employee: A person who works at a location, generally in the employ of a business located at the site.
- Staff: For hospitals, a doctor, nurse or other employee; for schools, a faculty member, teacher or other employee.
- Student: A person enrolled full or part-time in courses at a school or other educational facility.
- Bed: For hospitals, the number of beds available for patient care.
- Take-off/landing: For airports, the sum of aircraft take-offs plus landings.
- Room: For hotels and motels, a room or suite of rooms available for overnight stay of a guest(s).
- Military personnel: A member of the armed forces assigned to work or train at a military installation.
- Civilian employee: A non-military worker whose place of employment is at a military establishment.
- Total employees: For a military base, the sum of civilian and military personnel.
- Seat, attendee, station, pump, and the like: Self-explanatory.

To use the material in Table 2, estimates are required of the number of households by income category. Using these two parameters the tables may be entered to obtain an estimate of average autos per household or the distribution of households by car ownership. Also, an estimate of average daily person-trips may be obtained as well as the number of trips by car ownership. In lieu of income, the table may be entered with average autos per household. If both income and an auto-ownership distribution are available for households, the table may be entered with both.

To use Table 3, Part A, only the number of households is required. For Part B, a cordon count and total regional auto driver trips are required. Part C requires, for each analysis area, total employment, retail employment, and number of dwelling units.

TRIP-GENERATION DATA AND EXAMPLES OF USE

Table 1, "Average Vehicle Trip Rates and Other Characteristics of Generators" provides information on vehicle trip rates for a number of different type generators. There are four major sets of information given for each generator described as follows:

1. *Vehicle trips to and from per day*. This provides up to three trip rates based on the most appropriate land-use measures for each type of site, such as trips per employee, acre, and dwelling unit. A trip is defined as a one-way vehicle movement with either the origin or the destination in the study area. Therefore, the trip rates shown represent the sum of the vehicular trips to and from a site (or trip ends) divided by a measure of the land use

such as number of dwelling units, acres, employees, and the like. Vehicles includes automobiles, trucks, taxis, and buses.

2. *Percent in hour shown.* This provides percentages that can be applied to daily trip (or trip end) estimates based on the trip rates to obtain the traffic generated in the AM peak hour and the PM peak hour of the surrounding street system, or if the peak hour of the generator differs from the AM or the PM peak, the peak hour of the generator should be used. For example, a general hospital can be expected to generate 14 trips per bed (Table 1). For a hospital with 100 beds, one can expect 1,400 trips (or trip ends) per day (100 × 14). In the AM peak hour (normally occurring between 7 and 9 AM in most areas), approximately 18 percent of total daily trips can be expected to enter or leave the facility, or 252 vehicles (0.18 × 1,400). In the PM peak hour (normally occurring between 4 and 6 PM in most areas), approximately 9 percent of total daily trips can be expected to enter or leave the facility, or 126 vehicles (0.09 × 1,400). Inasmuch as no percentage is given for "Peak Hr. of Gen." (col. 3), the peak hour of the hospital occurs in the AM.

3. *Typical auto occupancy.* This provides the means for converting vehicle trips to auto person-trips. Auto occupancy is the average number of persons per automobile, including the driver and any passengers. To obtain an estimate of auto person-trips, the vehicle trips from the column "Vehicle Trips To and From Per Day" (col. 2) is multiplied by the auto occupancy. For example, consider an acre of single-family residential area with 4 DU's per acre. The average vehicle trip rate (Table 1) is 10.2 per dwelling unit resulting in 40.8 trips to and from the area per day (10.2 trips/DU × 4 DU's). The number of auto person-trips would be estimated at 68 (40.8 × 1.67). Because vehicle trip rates include other vehicles in addition to automobiles, application of auto-occupancy rates to vehicle trips will result in a slight overestimate.

4. *Typical percent transit of total person-trips.* This provides the opportunity to estimate total person-trips, as well as transit trips, to and from a specific site. Percent transit is the percent of total person-trips expected on transit. For example, based on Table 1, 10 percent of the total person-trips (or trip ends) generated by a nursing home can be expected to be made by transit. If a nursing home had 100 beds, it would be expected to generate 270 daily vehicular trips to and from the facility (100 × 2.7). A vehicle occupancy of 1.40 for the nursing home implies 378 auto person-trips (270 × 1.4), corresponding to 90 percent of the total person-trips. Thus, total person-trips would be given by 378 × 100/90 = 420. Then, transit person-trips would be estimated at (420 − 378) or 42. The percent transit provided can only be considered a very rough estimate because public transportation use varies significantly by the location of a generator in an urbanized area, by the level of service provided and, by the character of the urbanized area. Transit data have been obtained for some specific sites (*2, 3*) as well as from origin-destination data using data summarized by land use or purpose.

Table 2, "Detailed Trip-Generation Characteristics," provides useful information for estimating trip rates based on differences in income and/or auto ownership. The data are from a number of transportation surveys that have been summarized into four urbanized area population groups. Income is in terms of a 1970 dollar, and incomes for other periods must be adjusted to this base when using the table. For example, if trip estimates are to be made for 1980, the number of households in each income category must be determined by converting 1980 incomes so that they are expressed in terms of a 1970 dollar base. To convert a dollar value for some other period to a 1970 dollar base, the consumer price index is used. The U.S. Department of Labor, Bureau of Labor Statistics provides this index for the United States as well as for many cities and Standard Metropolitan Statistical Areas (SMSA) (*21*). First the consumer price index must be converted to a 1970 dollar base if it was constructed with reference to another year. To accomplish such a conversion, the consumer price index for 1970 is divided into the original indices and the result multplied by 100. As an example, assume the following information with 1971 as the base equal to 100:

YEAR	CONSUMER PRICE INDEX 1971 BASE	INDEX CONVERTED TO 1970 BASE
1960	73.1	76.2
1965	77.9	81.2
1970	95.9	100.0
1971	100.0	104.3

To convert to a 1970 base, all values in the foregoing table (left column) would be divided by 95.9 and the result multiplied by 100 (right column). With this conversion accomplished, the index to a 1970 base is applied by dividing the index for the applicable year into the income data for that year.

The most complete forecast of income has been prepared through a joint effort of the Bureau of Economic Analysis of the Department of Commerce and the Economic Research Service of the Department of Agriculture for the U.S. Water Resources Council (*22*). The data are contained in seven volumes which include historical and projected measures of population, employment, personal income and earnings for states, economic areas, SMSA's, and water resource regions.

The data in Table 2 can be used in several ways. If an estimate of zonal average autos per household is available, an estimate of average daily trips per household can be made directly. For example, in an urbanized area of 50,000 to 100,000 population, 11.9 average daily person-trips per household can be expected to be produced where the average car ownership is 1.07 per household. This is an appropriate use where zonal averages are most easily developed or available. Where the number of households by income range is forecast, an estimate can be obtained of:

- Average autos per household.
- Average daily person-trips per household.
- Percent of trips by purpose.
- Percent of 0, 1, 2, and 3 + auto households.
- Trips per household for 0, 1, 2, and 3 + auto households.

A useful application of Table 2 is to obtain control totals for an urbanized area based on income distribution forecasts. These control totals would include the information listed previously for the entire urbanized area, thereby providing a basis for controlling estimates derived at the zone or household level.

The "Average Daily Person-Trips per Household" (col. 2) information in Table 3, "Part A—Trip Production Estimates," is based on the information presented in Table 2. The information in column 6, Table 2, "% Average Daily Person-Trips By Purpose" is an expansion of the 1970 average condition and may vary if the trip rate varies. A review of the "% Average Daily Person-Trips by Purpose" (Table 2, col. 6) as related to income and/or average autos per household suggests that using these for another year would not cause significant variation in results. Likewise, the "Auto Person-Trips as a % of Total Person-Trips" and "Auto Driver Trips as a % of Total Person-Trips" (Table 3, Part A, cols. 5 and 6) can be used for years other than 1970 as long as the basis underlying their development as previously described is clearly understood. Table 3, "Part B—Useful Characteristics for Trip Estimation," presents rough-cut approximations that can also be useful for a forecast, again keeping in mind the basis of their development.

To illustrate the use of the material in Parts A and B of Table 3, assume an urbanized area with 200,000 population and 65,000 households. With 14 average daily person-trips per household (Part A), a total of 910,000 internal plus external trips can be expected. Twenty percent of these would be home-based work (HBW) trips, or 182,000 daily person-trips; 57 percent home-based nonwork (HBNW), or 518,700; and 23 percent nonhome-based (NHB), or 209,300. Of the total 910,000 person-trips, 6 percent or 54,600 can be expected to be transit person-trips; 30 percent or 273,000, auto passenger trips; and 64 percent or 582,400, auto driver trips. To obtain auto person-trips by purpose, the total trips by purpose would be multiplied by 0.88, 0.97, and 0.94, respectively, to obtain HBW, HBNW, and NHB trips. The results would be: 160,160 HBW person-trips by auto; 503,139 HBNW person-trips by auto; and 196,742 NHB person-trips by auto. Auto driver (auto vehicle) trips for different purposes would be similarly calculated using 0.64, 0.54, and 0.66, respectively, for a total of 534,716 trips. From Part B, truck trips can be estimated at approximately 90,902 (534,716 auto driver trips × 0.17). If cordon-line counts are available, the number of external trips passing through the area would equal 15 percent of total external trips. However, to make use of cordon counts that include through trips twice, an adjustment is necessary to determine the absolute number of trips involved.

This adjustment is best shown by an example. Assume a cordon count of 100,000 vehicles per day. These are made up of internal-external trips, external-internal trips, and external-external trips. The external-external, or through trips, are counted twice. To calculate such trips, the 15 percent from Table 3, Part B, would be used as follows:

$$\text{Count} = \text{Trips} \times (1 + \text{Proportion of through trips})$$
$$\text{Count} = \text{Trips} \times (1 + 0.15)$$

If the total cordon count is 100,000, for example, the total external trips would be estimated as $\frac{100{,}000}{1.15}$, or 86,957 trips; of these, 15 percent are through trips, or 13,043. To visualize this graphically, refer to Figure 1. From Table 3, Part B, the number of external trips expected to be destined for the CBD would be 0.22 × 86,957 or 19,131.

Table 3, "Part C—Trip Attraction Estimating Relationships," allows estimation of trip attractions. For HBW, HBNW, and NHB trip purposes, in order to adjust the attraction rates to "fit" a particular size urbanized area, the trip-production control total for the area should first be developed using either the material in Table 2 or Table 3, Part A. For the example described previously, total area productions controls were:

HBW	182,000
HBNW	518,700
NHB	209,300
Total	910,000

Assume, for example, the following employment-residential mix:

Total employment	75,000
Retail employment	15,000
Dwelling units	65,000

Areawide control factors are next developed using the relationships in Table 3, Part C, as follows:

$$F_1 = \frac{182{,}000}{1.7(75{,}000)} = 1.43$$
$$F_2 = \frac{518{,}700}{10(15{,}000) + 0.5(60{,}000) + 1.0(65{,}000)} = 2.12$$
$$F_3 = \frac{209{,}300}{2(15{,}000) + 2.5(60{,}000) + 0.5(65{,}000)} = 0.98$$

These controls are used when attraction rates for analysis areas are desired. For example, if an analysis area has a total employment of 1,000, a retail employment of 200, and 500 dwelling units, the trip attractions would be calculated as follows:

$$\text{HBW} = 1.43 \times 1.7 \times 1{,}000 = 2{,}431$$
$$\text{HBNW} = 2.12\,[(10 \times 200) + (0.5 \times 800) + (1.0 \times 500)] = 6{,}148$$
$$\text{NHB} = 0.98\,[(2 \times 200) + (2.5 \times 800) + (0.5 \times 500)] = 2{,}597$$

It is possible to use the material provided in Table 1 for specific activity sites to develop trip-end estimates through aggregation for an entire urbanized area, corridor, or small area. With a generalized land-use map providing land allocated to various uses and with more specific details on certain generators (i.e., educational facilities, hospitals, etc.), total trip ends by analysis unit (block, zone, district, etc.) can be developed for residential and nonresidential uses. The data in Table 2 or Table 3 can be used to develop a control for the entire study area as well as to adjust the total trip ends developed from Table 1.

For example, assume the total person-trip ends for some urbanized area of 150,000 population, based on the material in Table 1, is estimated at 1,200,000. The total number of person-trips is one-half of this or 600,000. Using the material in Table 3 for this size area, the average daily person-trips per household is estimated at 14. If there are an average of three persons per household, this urbanized area would have 50,000 households and generate approximately 700,000 person-trips. The size area being handled, then, can be expected to generate about 17 percent more person-trips than the averages produced by using the rates in Table 1. This is a convenient way to adjust Table 1 values for specific urbanized areas. The adjusted values are an approximation because the figures in Table 1 include truck trips and trips made by external area residents; also, Table 3 values are for internal and internal-external trips made by area residents.

To use Table 2 in estimating trips by household for a study area (region, zone, district, corridor, etc.), an estimate is required of the number of households by income range (1970 dollar base). With this estimate, the user can obtain from the table for a particular urbanized area, the average autos per household, average daily person-trips per household, percent households by autos owned, average daily person-trips per household by number of autos per household, and percent average daily person-trips by purpose. For example, if there are 1,000 households in the \$6,000 to \$7,000-income range in an urbanized area of 750,000 to 2,000,000 population, the following results would be computed:

Average autos per household	= 0.95
Total autos (1,000 × 0.95)	= 950
Average trips per household	= 5.80
Total trips generated (1,000 × 5.80)	= 5,800
Households with 0 cars	= 22% or 220 HH
Households with 1 car	= 62% or 620 HH
Households with 2 cars	= 15% or 150 HH
Households with 3 cars	= 1% or 10 HH
Trips by 0 car households	= 2.9/HH or 638
Trips by 1 car households	= 6.1/HH or 3,782
Trips by 2 car households	= 8.6/HH or 1,290
Trips by 3 car households	= 11.6/HH or 116
Total trips by all households	
Trips generated: HBW	= 28% or 1,624
Trips generated: HBNW	= 53% or 3,074
Trips generated: NHB	= 19% or 1,102.

The HBW and HBNW trips are generated at the household, whereas the NHB trips are generated elsewhere. Chapter Ten, "Scenario for Site Development Impact Analysis: Boise, Idaho," describes an approach to handle this difference.

To use the information in Table 3, the following input is required:

INFORMATION	REQUIRED INPUT
Part A—Trip-production estimates	Number of households
Part B—Useful trip characteristics	Cordon count; regional auto driver trips
Part C—Trip-attraction estimates	Total employment; retail employment; dwelling units

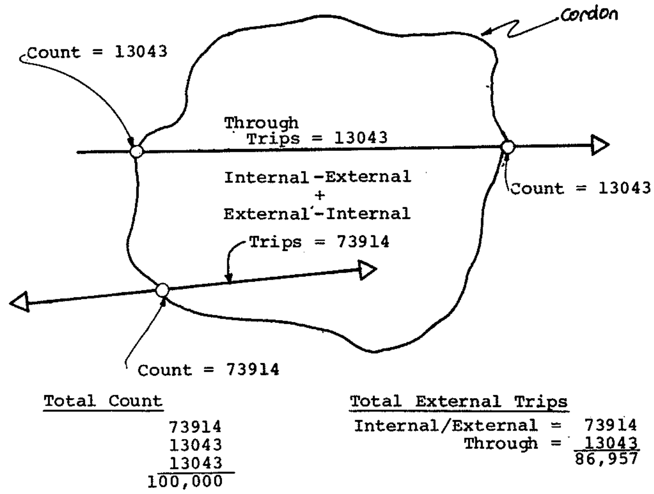


Figure 1. Relationship of cordon count to external trips.

The material contained in Table 2 is shown graphically in Figures 2 through 4 to visually portray the trip-generation relationships provided for the user who might find it more convenient to use graphs. Figure 2 provides average daily person-trips per household as such trips vary with average autos owned per household for the four urbanized area population groups. Figure 3 shows the relationship of auto ownership to income and Figure 4 shows the relationship to trips to income and autos owned.

Limitation of Data

In using the information in Table 1, the user must keep in mind that the values given are averages and that they vary by location in an urbanized area, by size of urbanized area, and by location within the United States (i.e., east coast versus west coast, etc.). However, the material does provide "order-of-magnitude" estimates that are useful for many applications.

The trip data and car-ownership data in Table 2 have been summarized from a number of urbanized areas and grouped by population. Consideration must be given to the fact that trip rates for a specific area may vary significantly based on special characteristics (e.g., high proportion of retired persons and high tourism).

The information in Table 3 regarding external trips is based on rather dated material and should therefore be used with caution. The material provided in all the tables allows use at various levels of detail and provides some choice to the user as to level of analysis appropriate for a specific application.

USEFULNESS OF REGIONAL GENERATION RATES

If manual techniques are to be applied for some level of study (i.e., corridor, site) in an urbanized area where regional planning efforts have resulted in pertinent data or procedures for trip generation, the local results should be considered for the special study. Generally, regional data will provide more specific information for the area in question than the material provided herein, which provides averages for regions of several sizes.

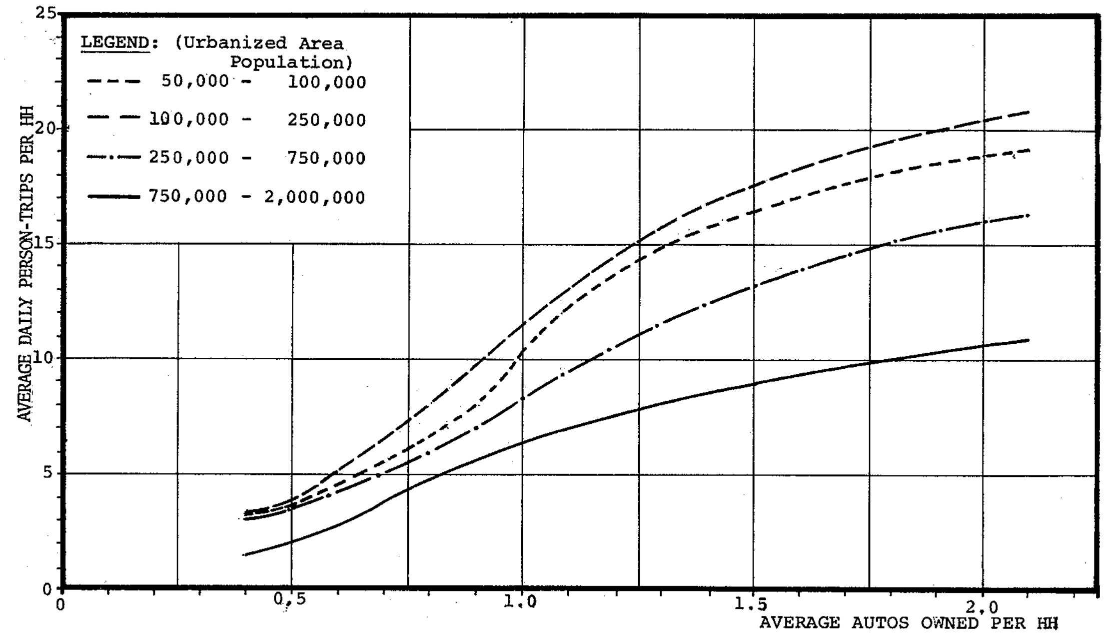


Figure 2. Average daily person-trips per household vs average autos owned per household.

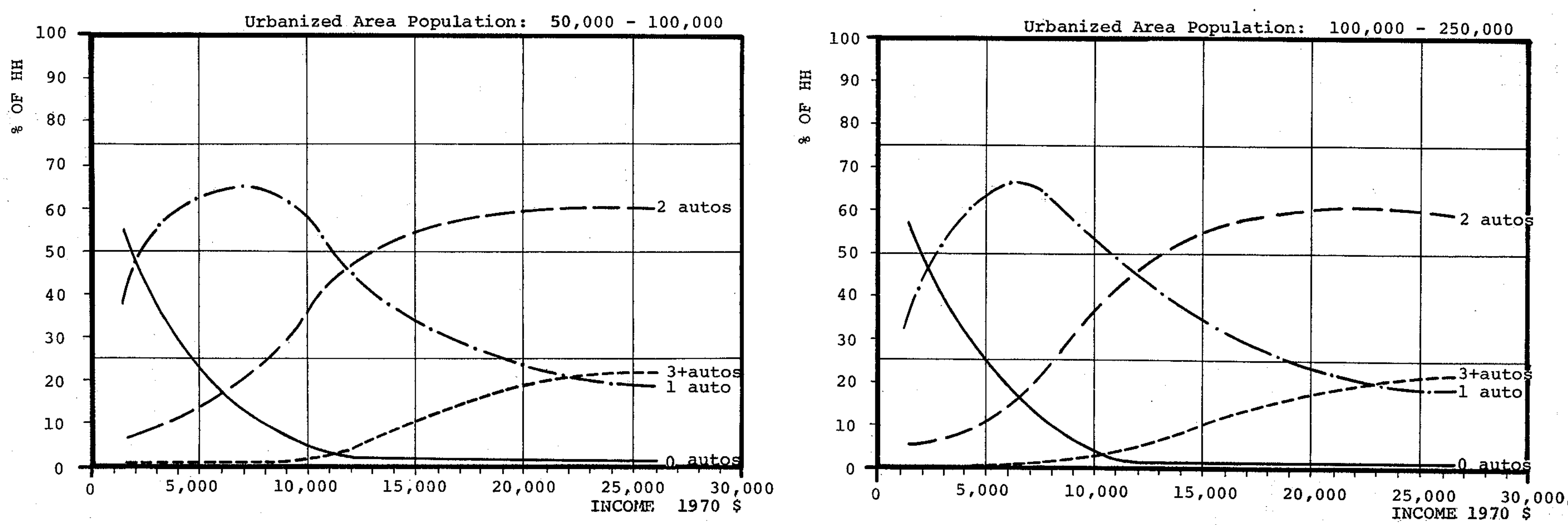


Figure 3. Percentage of households, by autos owned per household vs income, for various urban area populations.

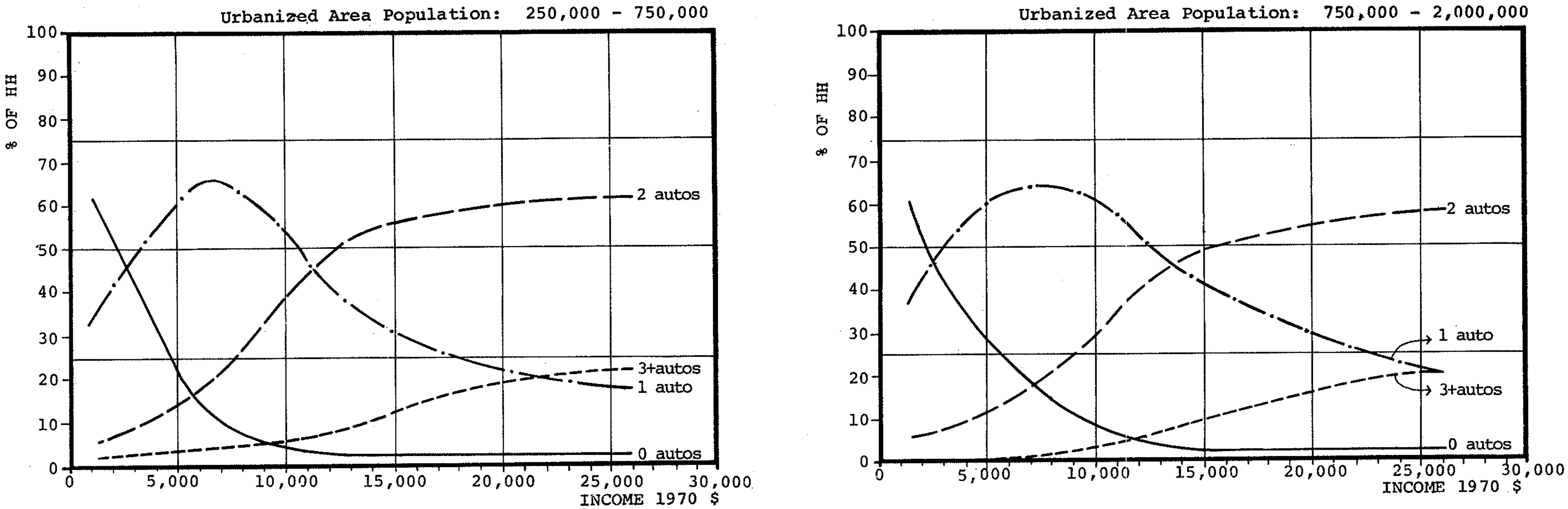


Figure 3 (continued).

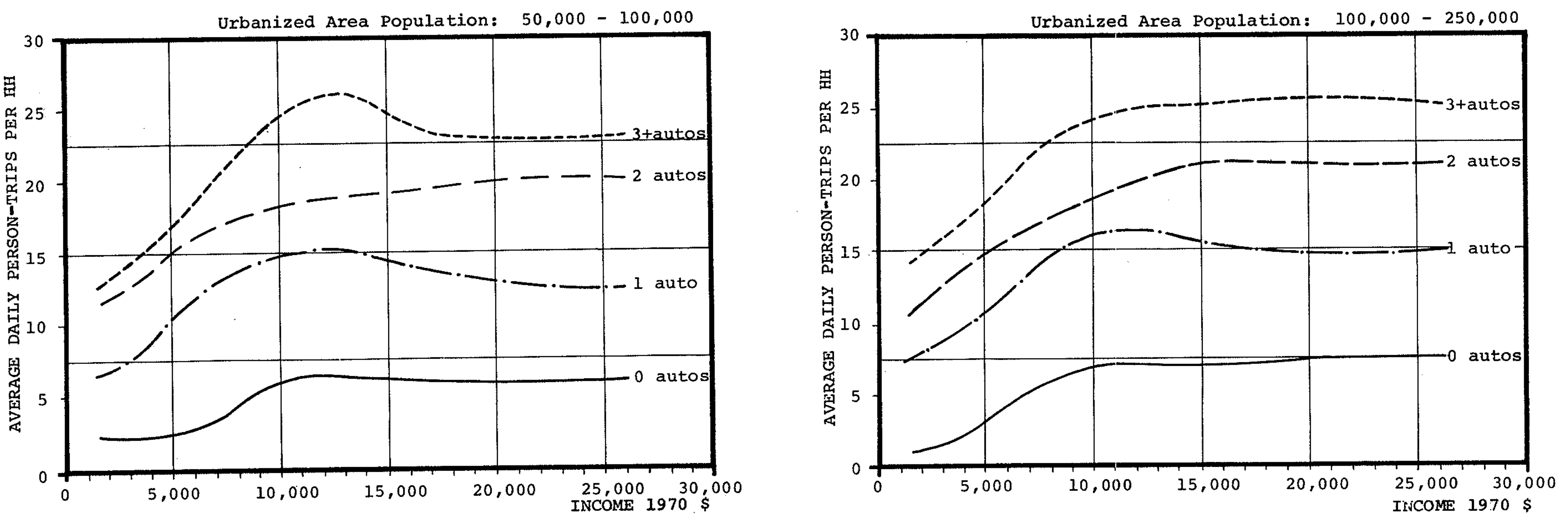


Figure 4. Average daily person-trips per household, by number of autos per household vs income, for various urban area populations.

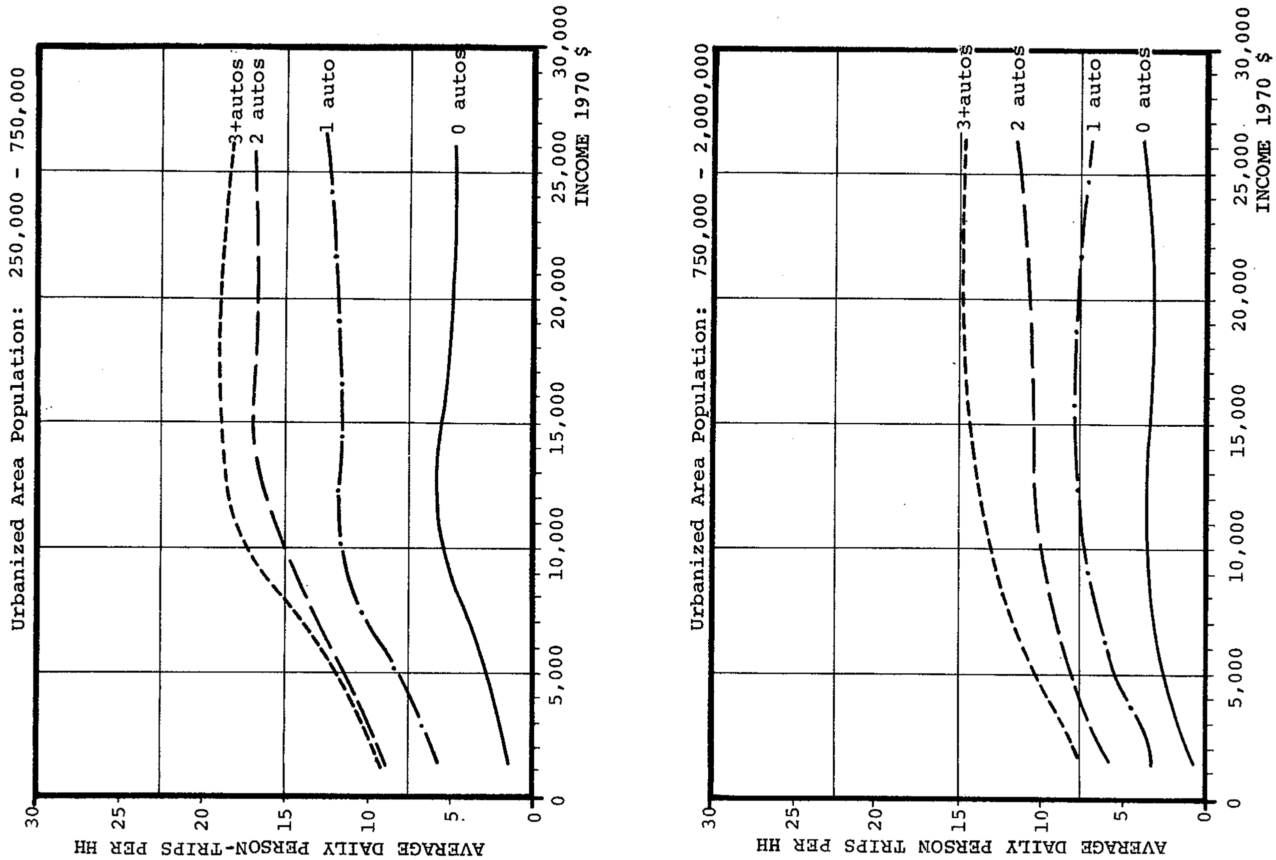


Figure 4 (continued).

Care must be taken in using trip-generation relationships developed for a region by multiple regression techniques and applying them to more specific problems at a corridor or site level when differing geographic analysis units are used. Disaggregate analysis, such as accomplished with cross classification at the household level and reflected by the material in Table 2, produces results that can be applied at any level for which land use and related characteristics can be developed. Likewise, at the nonresidential end, sufficient disaggregation is desirable to allow a detailed accounting for any specialized land uses in the area of study.

CHAPTER THREE

TRIP DISTRIBUTION

INTRODUCTION

Trip distribution is the process by which trips from one area are connected with trips from another area, thereby linking origins and destinations or productions and attractions. Inputs to the trip-distribution process include trip-generation values as may be prepared by methods described in Chapter Two, "Trip-Generation Estimation." Schematically, trip generation provides the information shown on the left-hand side of Figure 5, whereas trip distribution provides the linkage shown on the right-hand side of the figure.

Trip distribution is a significant element of the planning process because it is the trip interchanges that eventually have to be accommodated by a transportation system. The importance of trip distribution is in terms of trip length and trip orientation and the resultant magnitude of traffic and passenger volumes. The results of the trip-distribution process are often "assigned" to the highway and/or public transportation systems to determine system demand loads as related to the carrying capacity of the facilities in question.

There are many trip-distribution procedures; such procedures may be grouped into two categories: growth factor techniques and synthetic travel models.

Growth factor techniques are used to project a known trip distribution by multiplying interchange values by adjustment factors calculated at the origins and destinations of the trips. These adjustment factors are based on changes in land-use and socioeconomic characteristics of the origins and destinations. Synthetic travel models synthesize travel patterns by relating such models to characteristics of the land-use pattern and the transportation system.

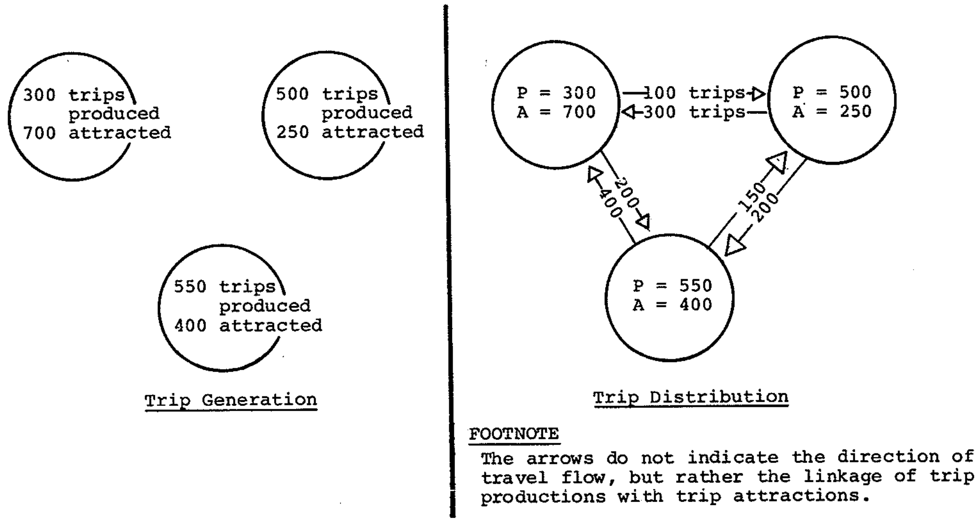


Figure 5. Diagrammatic representation of the trip-generation and trip-distribution processes.

BASIS FOR DEVELOPMENT

Most of the synthetic travel models have similar characteristics: the trip interchange is a function of the trip-producing and trip-attracting powers of the land development and of the spatial separation between them. The most widely used and best documented of the trip-distribution procedures is the Gravity Model (*23, 24*). This model, which parallels Newton's law of gravitation, is based on the assumption that all trips starting from a given area (e.g., zone) are attracted to other areas in direct proportion to the size of the attractor and in inverse proportion to the spatial separation between these areas. The spatial separation is usually measured in terms of the area-to-area travel time. Typically, gravity models are developed for from three to six trip purposes. The model calibration procedure is an iterative process in which, for each trip purpose, a set of travel time factors is developed. Generally, an inverse exponential function (i.e., $1/d^n$, where d is the total travel time between points and n is some power such as 2.0) is used for the spatial separation. The value of n varies between different urbanized areas and for different trip purposes.

A second, less widely used, travel model is the Intervening Opportunities Model developed by the Chicago Area Transportation Study (*25*). This model uses a probability concept which requires that a trip remain as short as possible, lengthening only as it fails to find an acceptable destination. All trip opportunities or destinations are considered in sequence by travel time from the zone of origin. The first opportunity considered is the one closest to the origin, and it has the basic probability of acceptance characteristic of all opportunities in the study area. The next opportunity has the same basic probability of acceptance; however, the probability of reaching the next opportunity is decreased because the trip being distributed had a chance of already having accepted the first opportunity. The procedure continues with each successive opportunity having a decreased probability of actually being reached.

For the purpose of inclusion in this guide, the Gravity Model was selected for a manual trip-distribution process based on the following considerations:

- The Gravity Model is the most widely used technique; and as such, calibration values are available from numerous applications.
- The Gravity Model is most easily understood by and explained to technicians, administrators, citizens, and the like.

Also included in this guide are distribution characteristics for several types of land uses that may be used for gross distribution of trips to the area surrounding a specific site.

Theory of the Gravity Model

The Gravity Model is mathematically expressed as:

$$T_{ij} = P_i \frac{A_j F_{ij} K_{ij}}{\sum_{j=1}^{n} A_j F_{ij} K_{ij}} \qquad (1)$$

where

$$F_{ij} = f(tij)$$

and

T_{ij} = trips produced in analysis area i, and attracted at analysis area j;
P_i = total trip production at i;
A_j = total trip attraction at j;
F_{ij} = friction factor for trip interchange ij;
K_{ij} = socioeconomic adjustment factor for interchange ij if necessary;
tij = travel time (or impedance) for interchange ij;
i = origin analysis area number, $i = 1, 2, 3 \ldots n$;
j = destination analysis area number, $j = 1, 2, 3 \ldots n$;
n = number of analysis areas.

For the manual application, K_{ij} has been discarded altogether. The Gravity Model formulation then simplifies to the following form for manual application:

$$T_{ij} = R_i A_j F_{ij} \quad (2)$$

where

$$R_i = \frac{P_i}{\sum_{j=1}^{n} A_j F_{ij}}$$

called the "production index" (a constant for each production analysis area *i*)

$A_j F_{ij}$ = the "attraction factor" for analysis area *j*

and;

$\sum_{j=1}^{n} A_j F_{ij}$ = the "accessibility index" for analysis area *i*.

Mathematically, the Gravity Model is formulated so that a production balance is maintained; in other words, the production (row) totals for each analysis area as calculated from the model equal the input productions. However, the attraction (column) totals for each analysis area output from the model will not necessarily match the desired input values. To attain an acceptable attraction balance, an iterative process is employed to adjust the calculated trip interchanges.

After each application (iteration) of the Gravity Model, the adjusted attraction totals (for each analysis area) to be used for the next iteration are calculated according to the following formula:

$$A_j^q = A_j^{q-1} \cdot \frac{A_j}{C_j^{q-1}} \quad (3)$$

where

- A_j^q = adjusted attraction factor for attraction analysis area (column) *j*, iteration *q*; for manual application only a maximum of one additional iteration is suggested;
- $A_j^{q-1} = A_j$ when $q = 1$
- C_j^{q-1} = attraction (column) total for analysis area *j*, resulting from the application of the Gravity Model during iteration $q - 1$;
- A_j = original and desired attraction total for attraction analysis area (column) *j*; this is the value developed from the trip generation step;
- *j* = attraction analysis area, $j = 1, 2 \ldots n$;
- *n* = number of analysis areas;
- *q* = iteration number, $q = 1, 2 \ldots m$.

For the manual trip-distribution procedure, two iterations are considered sufficient. For many uses, only the original application (the first iteration) with no adjustment could be considered adequate. The option of whether or not to iterate twice depends on the percent difference between the attraction totals at the end of each iteration and that originally input for each analysis area. Generally, a 5- to 10-percent difference is acceptable, depending on the degree of accuracy required.

MANUAL TRIP-DISTRIBUTION PROCEDURE

The objective of the procedure described herein is to provide the user with a trip-distribution technique that can be performed manually. The manual operation uses nothing more sophisticated than an ordinary desk calculator with an accumulating memory.

The manual procedure provided employs the widely used Gravity Model formulation discussed previously. What makes the approach different, however, is the streamlining of the various steps leading to estimation of the trip interchanges. The procedure described includes the following material:

- Short-cut calculation of area-to-area impedances.
- Distribution factors (friction factors) for urbanized areas for four population groups, and within such groups, for three trip purposes; namely, HBW, HBNW, and NHB. The urbanized area population groups for which distribution factors are provided are, as aforementioned:

50,000	to	100,000	population
100,000	to	250,000	population
250,000	to	750,000	population
750,000	to	2,000,000	population

- Simplified work sheets for entering required information and calculating trip interchanges.

Use of the manual trip-distribution procedure is illustrated with a 5-district example. It has also been manually applied for 1970 HBW trips at the 34-district level for Atlanta, Georgia, and its results compared to those output by a Gravity Model applied by computer at a detailed zonal level (525 zones aggregated to 34 districts). The home-interview survey from which the zonal computer model was calibrated was used as a benchmark for comparison.

Input Requirements

The following input information is necessary before proceeding with the distribution process.

1. A map of the study region showing the layout of the analysis areas and their centroids; boundary limits of the CBD, central city, and suburban subregions; and a highway map differentiating freeways and arterials. It is recommended that the size of the map be no larger than 1 in. : 2-mi scale and no smaller than 1 in. : 4-mi scale. A typical study area map for the Atlanta metropolitan region is shown in Figure 6.

2. Production and attraction trip ends by analysis area (for each particular trip purpose). These figures are output from the trip-generation stage and can be rounded off to the nearest 100 trips without appreciable loss in trip-interchange accuracy for most applications.

3. A travel time/distribution factor matrix. This matrix, incidentally, is triangular; that is, it is assumed that the travel time from district *i* to district *j* is the same from *j* to *i*. The matrix is produced by the procedure described as follows. The construction of such a matrix, which could be a time-consuming and cumbersome task, has been simplified through the use of the centroid-to-centroid airline distance; this airline distance is then converted to travel time and distribution factor using a series of graphs, which operate as follows: Knowing the airline distance in miles between the production and attraction district centroids and approximating the over-the-road freeway-arterial percentage mix for that particular interchange, the *total* travel time (in-vehicle time plus total origin-destination

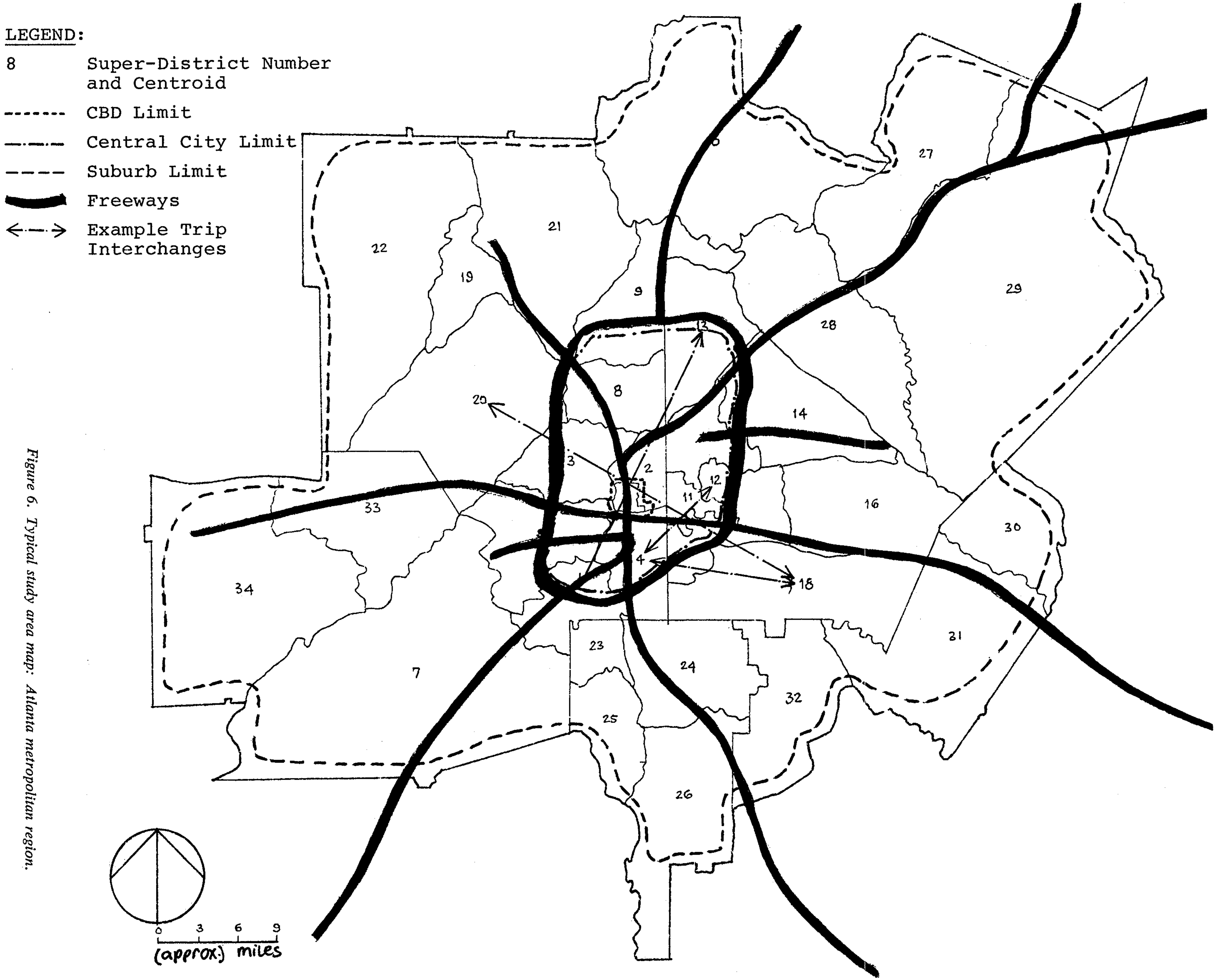


Figure 6. Typical study area map: Atlanta metropolitan region.

terminal times) and the corresponding distribution factor for any one of three purposes can be read off the graphs (Figs. 7 through 30). The derivation of these graphs is described later in this chapter.

4. Finally, a thorough knowledge of the study area and its travel behavioral patterns is obviously important and useful.

Thus, having laid out a reasonably explicit map of the study area, having derived production and attraction trip ends from the preceding trip-generation stage, and having compiled the area-to-area travel time/distribution factor matrix, the user is ready to distribute trips.

Use of Airline Distance vs. Travel Time vs. Distribution Factors Graphs

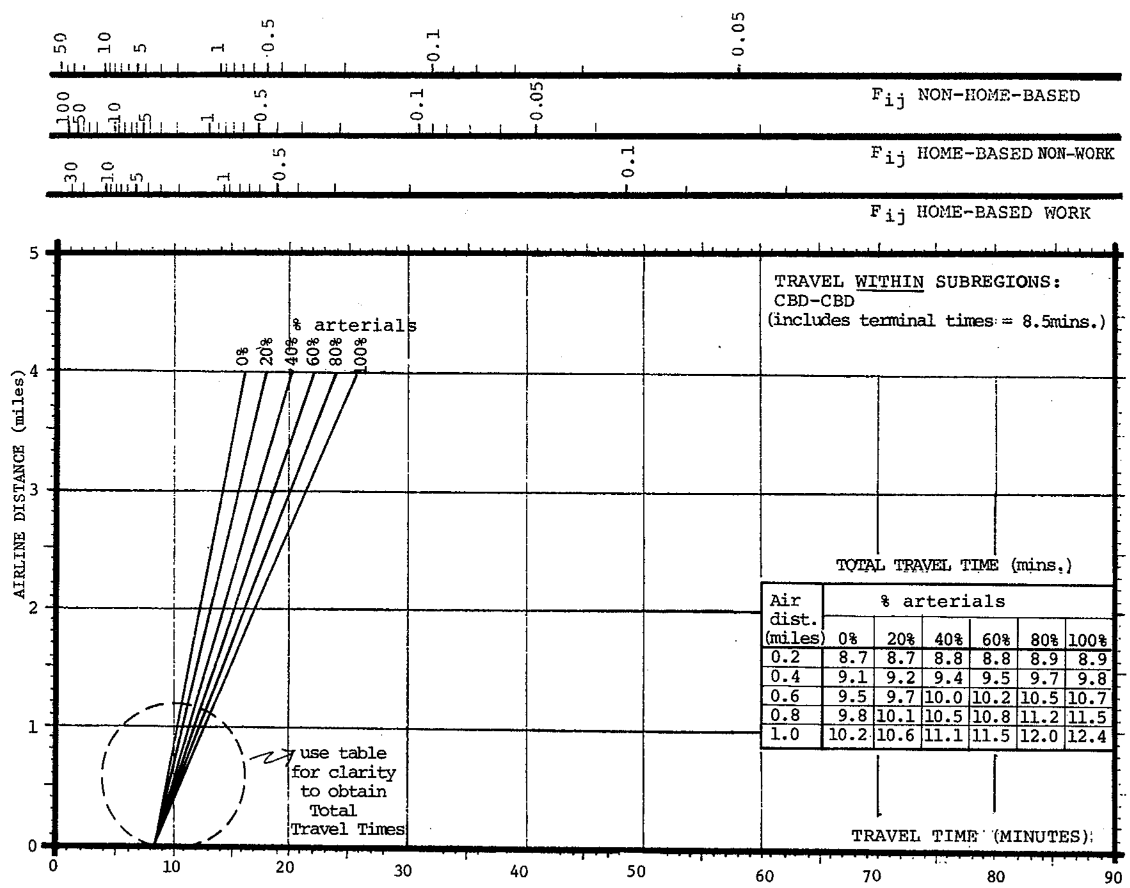
Graphs have been developed to reduce substantially the steps involved in obtaining the distribution factors (friction factors) required for the application of the distribution procedure. Rather than pick a route and calculate elapsed travel time or distance, the graphical method is based on measuring a straight-line distance (the airline distance) between the centroids of the analysis areas in question.

Two sets of graphs, as shown in Figures 7 through 30 (Figures 7 through 12, 50,000 to 100,000 pop.; Figures 13 through 18, 100,000 to 250,000 pop.; Figures 19 through 24, 250,000 to 750,000 pop.; and Figures 25 through 30, 750,000 to 2,000,000 pop.) have been developed for each urbanized area population group. The first set is used when a trip interchange occurs *within* a subregion; for example, CBD-to-CBD, or central city-to-central city, or suburb to-suburb. For such an interchange, the travel time read from the appropriate graph is the *total* travel time; that is, it includes O-D terminal times as well as in-vehicle times. O-D terminal times include walking and parking/unparking times at both ends of the trip.

For example, for an urbanized area of 750,000 to 2,000,000 population and a trip interchange within the central city from analysis area 4 to 12 (Fig. 6), the applicable graph is shown in Figure 26. Scaling the airline distance between the centroids of areas 4 and 12, the distance is found to be 7 mi to the nearest mile. Through past experience of the user, his familiarity with this particular interchange and the surrounding area, it is concluded that 20 percent of *over-the-road* travel is made on arterials (and therefore 80 percent on freeways). For such a mix of facilities, the 20-percent curve on the graph is used to generate the following parameters.

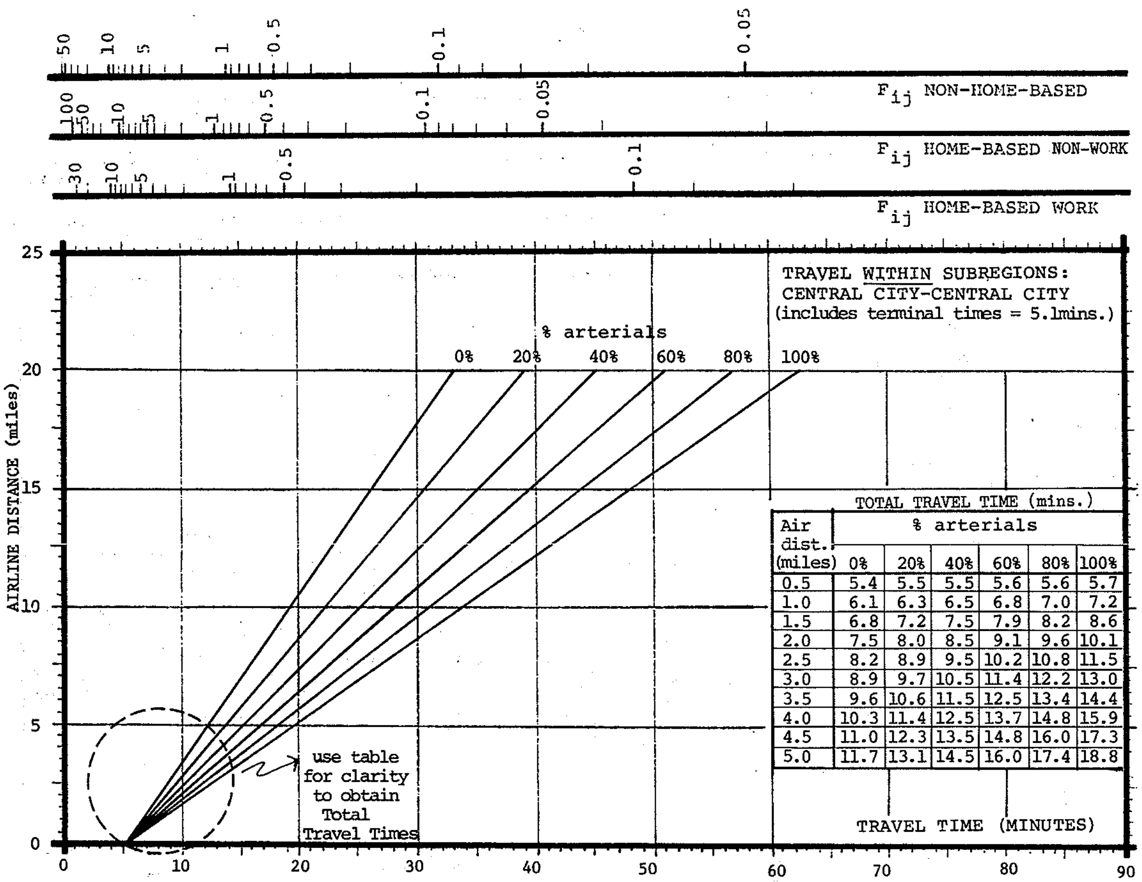
Total travel time between areas 4 and 12 = 21 min.
Corresponding distribution factor for HBW trips = 0.49
Corresponding distribution factor for HBNW trips = 0.18
Corresponding distribution factor for NHB trips = 0.22

These figures are assumed to hold true for the area 12 to area 4 interchange also.



Air dist. (miles)	% arterials 0%	20%	40%	60%	80%	100%
0.2	8.7	8.7	8.8	8.8	8.9	8.9
0.4	9.1	9.2	9.4	9.5	9.7	9.8
0.6	9.5	9.7	10.0	10.2	10.5	10.7
0.8	9.8	10.1	10.5	10.8	11.2	11.5
1.0	10.2	10.6	11.1	11.5	12.0	12.4

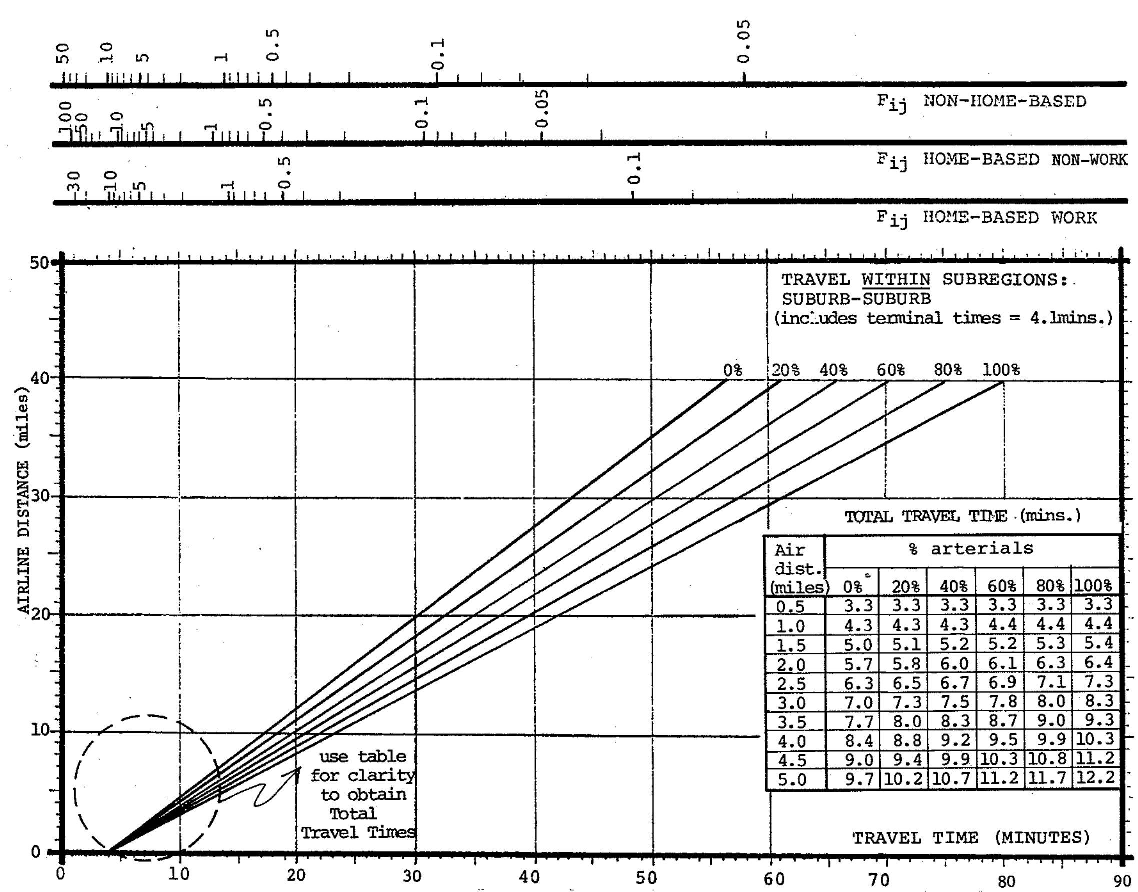
Figure 7. Airline distance vs travel time vs distribution factors, by trip purpose (CBD to CBD), in urban area of 50,000-100,000 population.



TOTAL TRAVEL TIME (mins.)

Air dist. (miles)	% arterials					
	0%	20%	40%	60%	80%	100%
0.5	5.4	5.5	5.5	5.6	5.6	5.7
1.0	6.1	6.3	6.5	6.8	7.0	7.2
1.5	6.8	7.2	7.5	7.9	8.2	8.6
2.0	7.5	8.0	8.5	9.1	9.6	10.1
2.5	8.2	8.9	9.5	10.2	10.8	11.5
3.0	8.9	9.7	10.5	11.4	12.2	13.0
3.5	9.6	10.6	11.5	12.5	13.4	14.4
4.0	10.3	11.4	12.5	13.7	14.8	15.9
4.5	11.0	12.3	13.5	14.8	16.0	17.3
5.0	11.7	13.1	14.5	16.0	17.4	18.8

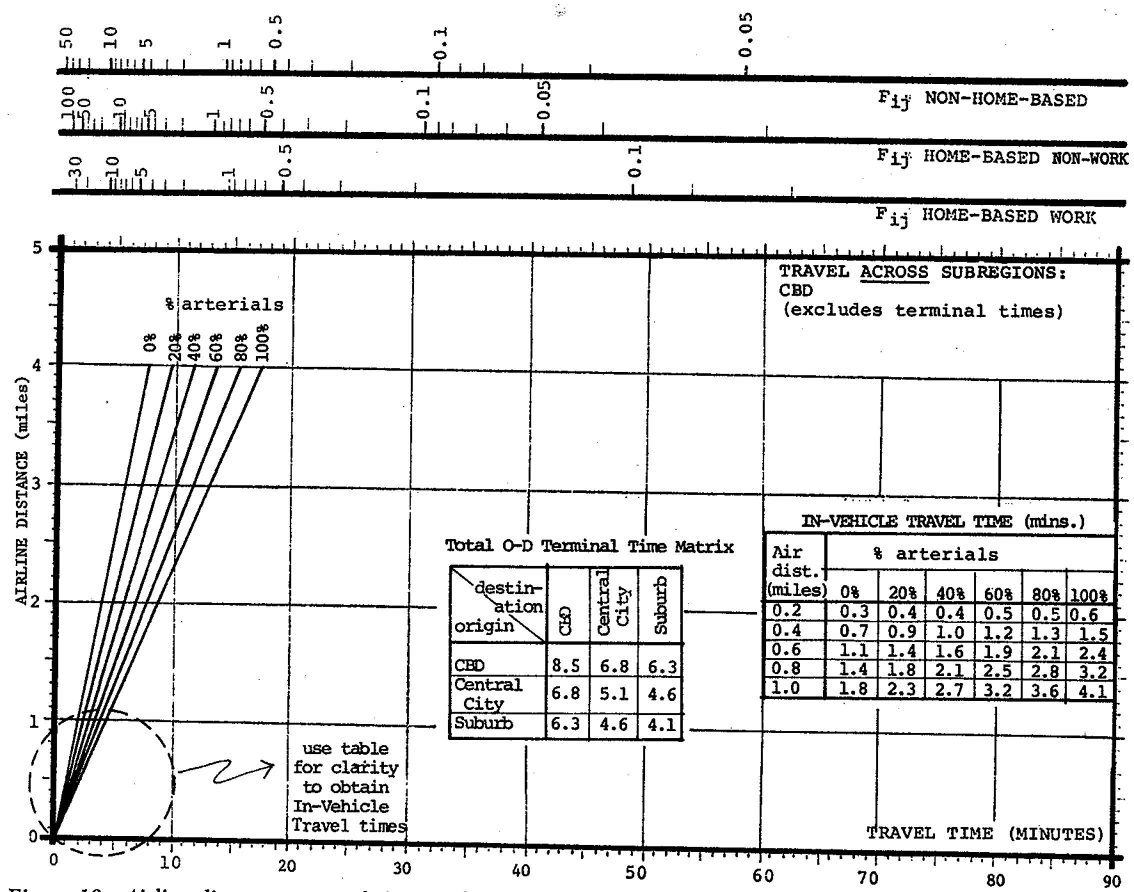
Figure 8. Airline distance vs travel time vs distribution factors, by trip purpose (central city to central city), in urban area of 50,000-100,000 population.



TOTAL TRAVEL TIME (mins.)

Air dist. (miles)	% arterials					
	0%	20%	40%	60%	80%	100%
0.5	3.3	3.3	3.3	3.3	3.3	3.3
1.0	4.3	4.3	4.3	4.4	4.4	4.4
1.5	5.0	5.1	5.2	5.2	5.3	5.4
2.0	5.7	5.8	6.0	6.1	6.3	6.4
2.5	6.3	6.5	6.7	6.9	7.1	7.3
3.0	7.0	7.3	7.5	7.8	8.0	8.3
3.5	7.7	8.0	8.3	8.7	9.0	9.3
4.0	8.4	8.8	9.2	9.5	9.9	10.3
4.5	9.0	9.4	9.9	10.3	10.8	11.2
5.0	9.7	10.2	10.7	11.2	11.7	12.2

Figure 9. Airline distance vs travel time vs distribution factors, by trip purpose (suburb to suburb), in urban area of 50,000-100,000 population.



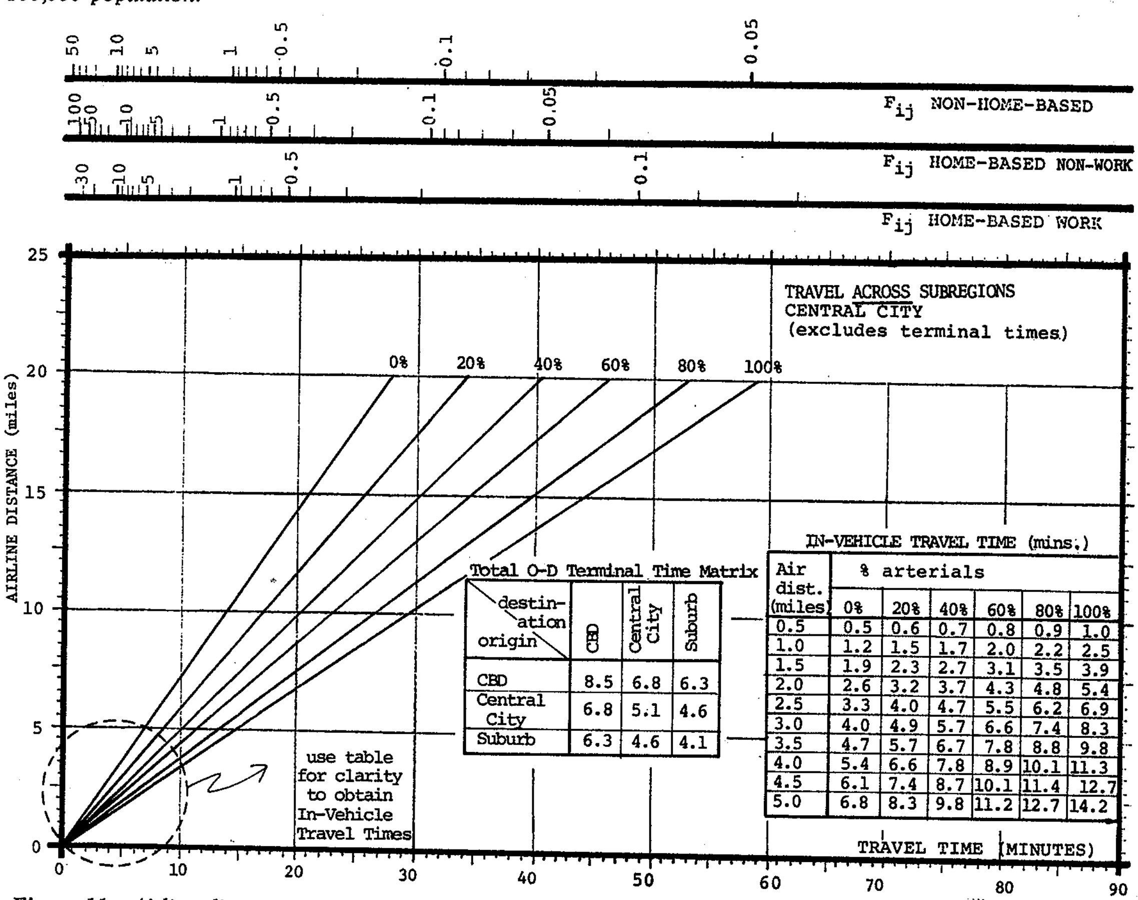
Total O-D Terminal Time Matrix

destination / origin	CBD	Central City	Suburb
CBD	8.5	6.8	6.3
Central City	6.8	5.1	4.6
Suburb	6.3	4.6	4.1

IN-VEHICLE TRAVEL TIME (mins.)

Air dist. (miles)	% arterials 0%	20%	40%	60%	80%	100%
0.2	0.3	0.4	0.4	0.5	0.5	0.6
0.4	0.7	0.9	1.0	1.2	1.3	1.5
0.6	1.1	1.4	1.6	1.9	2.1	2.4
0.8	1.4	1.8	2.1	2.5	2.8	3.2
1.0	1.8	2.3	2.7	3.2	3.6	4.1

Figure 10. Airline distance vs travel time vs distribution factors, by trip purpose (CBD), in urban area of 50,000-100,000 population.



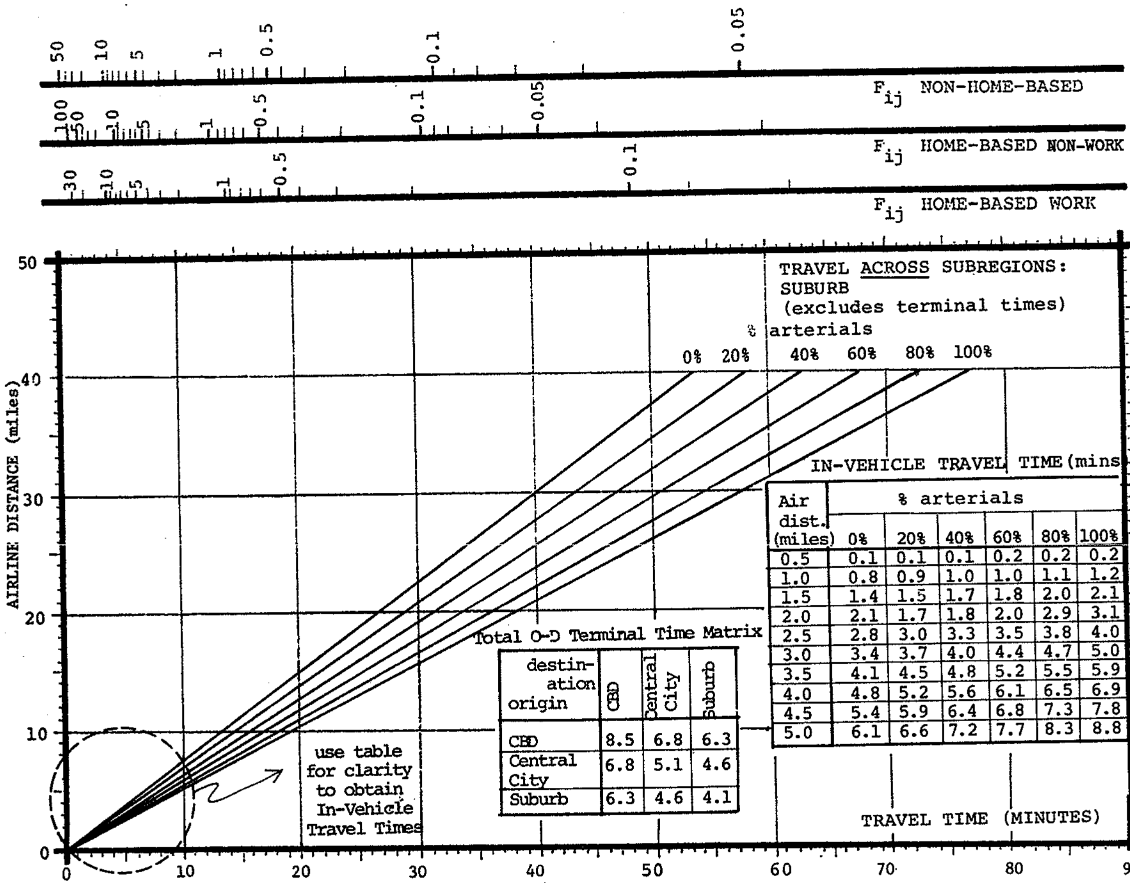
Total O-D Terminal Time Matrix

destination / origin	CBD	Central City	Suburb
CBD	8.5	6.8	6.3
Central City	6.8	5.1	4.6
Suburb	6.3	4.6	4.1

IN-VEHICLE TRAVEL TIME (mins.)

Air dist. (miles)	% arterials 0%	20%	40%	60%	80%	100%
0.5	0.5	0.6	0.7	0.8	0.9	1.0
1.0	1.2	1.5	1.7	2.0	2.2	2.5
1.5	1.9	2.3	2.7	3.1	3.5	3.9
2.0	2.6	3.2	3.7	4.3	4.8	5.4
2.5	3.3	4.0	4.7	5.5	6.2	6.9
3.0	4.0	4.9	5.7	6.6	7.4	8.3
3.5	4.7	5.7	6.7	7.8	8.8	9.8
4.0	5.4	6.6	7.8	8.9	10.1	11.3
4.5	6.1	7.4	8.7	10.1	11.4	12.7
5.0	6.8	8.3	9.8	11.2	12.7	14.2

Figure 11. Airline distance vs travel time vs distribution factors, by trip purpose (central city), in urban area of 50,000-100,000 population.



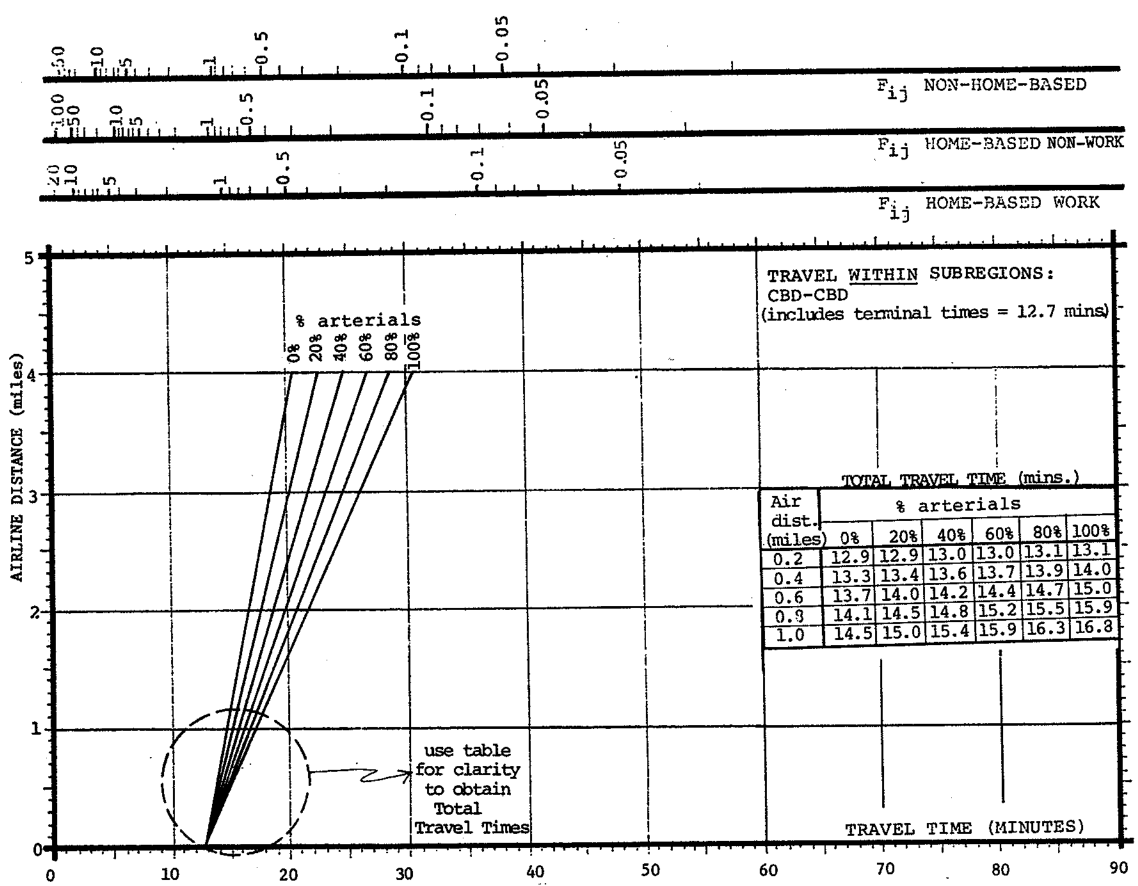
Total O-D Terminal Time Matrix

destination / origin	CBD	Central City	Suburb
CBD	8.5	6.8	6.3
Central City	6.8	5.1	4.6
Suburb	6.3	4.6	4.1

IN-VEHICLE TRAVEL TIME (mins)

Air dist. (miles)	% arterials 0%	20%	40%	60%	80%	100%
0.5	0.1	0.1	0.1	0.2	0.2	0.2
1.0	0.8	0.9	1.0	1.0	1.1	1.2
1.5	1.4	1.5	1.7	1.8	2.0	2.1
2.0	2.1	1.7	1.8	2.0	2.9	3.1
2.5	2.8	3.0	3.3	3.5	3.8	4.0
3.0	3.4	3.7	4.0	4.4	4.7	5.0
3.5	4.1	4.5	4.8	5.2	5.5	5.9
4.0	4.8	5.2	5.6	6.1	6.5	6.9
4.5	5.4	5.9	6.4	6.8	7.3	7.8
5.0	6.1	6.6	7.2	7.7	8.3	8.8

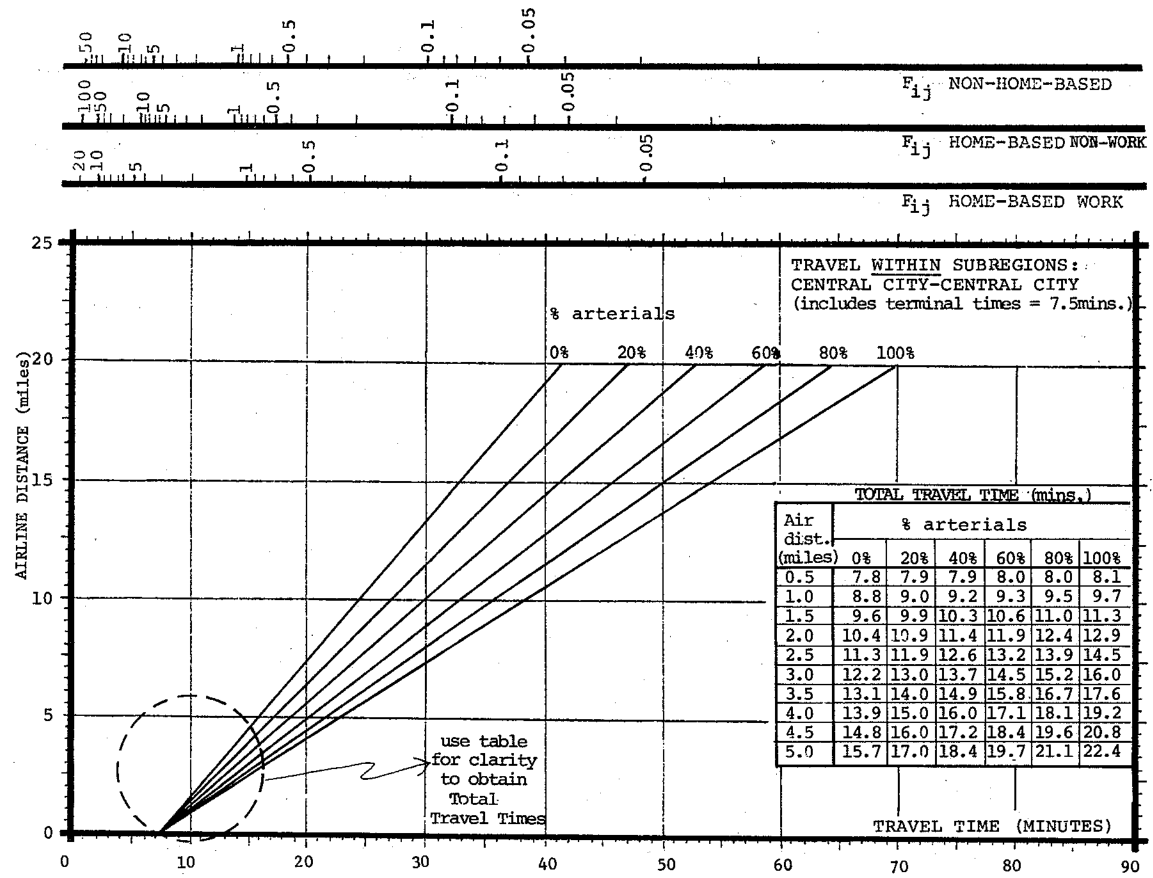
Figure 12. Airline distance vs travel time vs distribution factors, by trip purpose (suburb), in urban area of 50,000-100,000 population.



TOTAL TRAVEL TIME (mins.)

Air dist. (miles)	% arterials 0%	20%	40%	60%	80%	100%
0.2	12.9	12.9	13.0	13.0	13.1	13.1
0.4	13.3	13.4	13.6	13.7	13.9	14.0
0.6	13.7	14.0	14.2	14.4	14.7	15.0
0.8	14.1	14.5	14.8	15.2	15.5	15.9
1.0	14.5	15.0	15.4	15.9	16.3	16.8

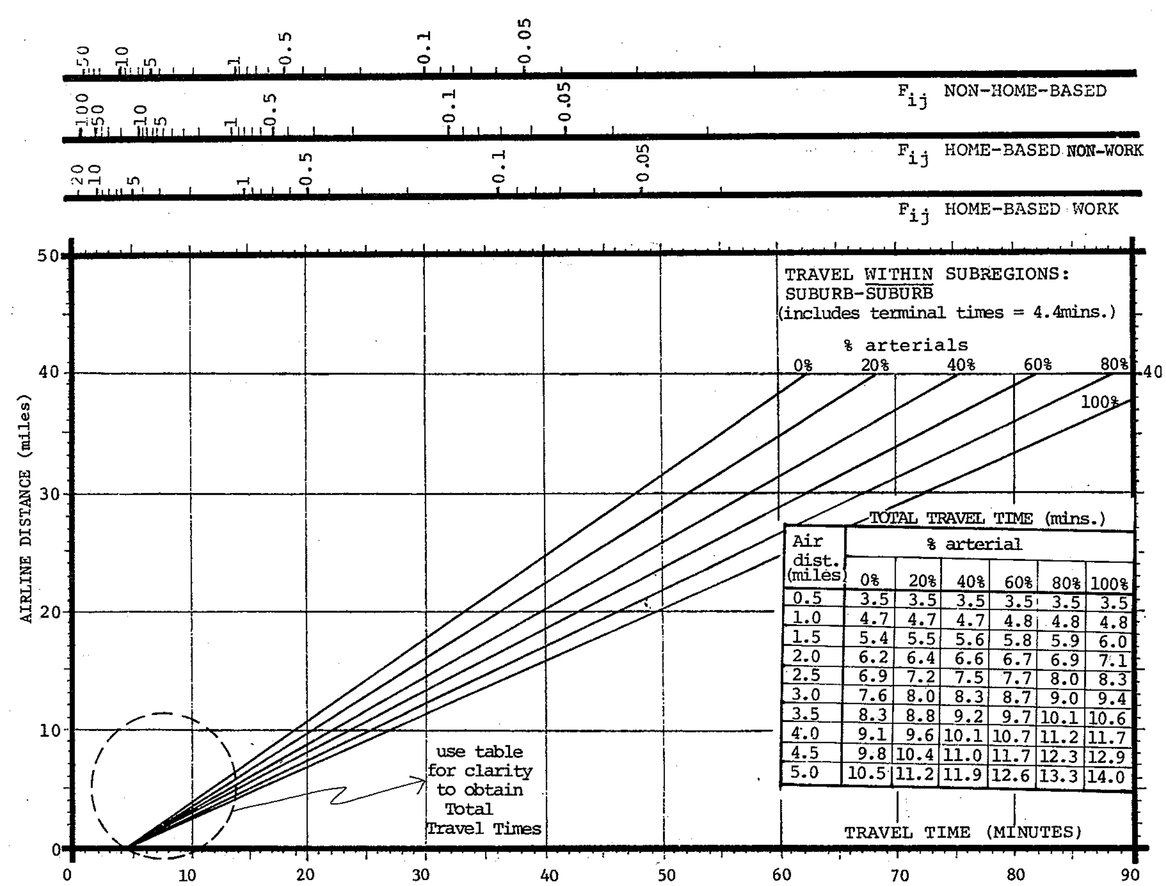
Figure 13. Airline distance vs travel time vs distribution factors, by trip purpose (CBD to CBD), in urban area of 100,000-250,000 population.



TOTAL TRAVEL TIME (mins.)

Air dist. (miles)	% arterials 0%	20%	40%	60%	80%	100%
0.5	7.8	7.9	7.9	8.0	8.0	8.1
1.0	8.8	9.0	9.2	9.3	9.5	9.7
1.5	9.6	9.9	10.3	10.6	11.0	11.3
2.0	10.4	10.9	11.4	11.9	12.4	12.9
2.5	11.3	11.9	12.6	13.2	13.9	14.5
3.0	12.2	13.0	13.7	14.5	15.2	16.0
3.5	13.1	14.0	14.9	15.8	16.7	17.6
4.0	13.9	15.0	16.0	17.1	18.1	19.2
4.5	14.8	16.0	17.2	18.4	19.6	20.8
5.0	15.7	17.0	18.4	19.7	21.1	22.4

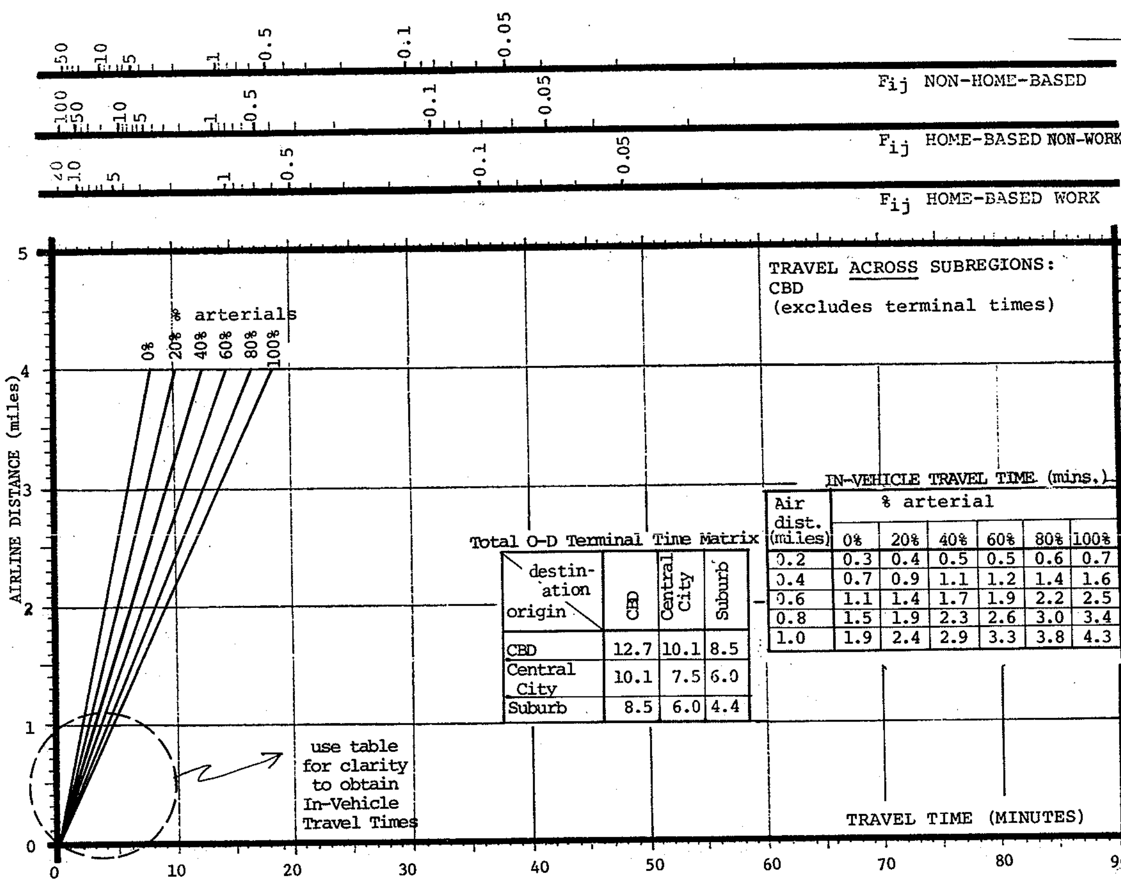
Figure 14. Airline distance vs travel time vs distribution factors, by trip purpose (central city to central city), in urban area of 100,000-250,000 population



TOTAL TRAVEL TIME (mins.)

Air dist. (miles)	% arterial 0%	20%	40%	60%	80%	100%
0.5	3.5	3.5	3.5	3.5	3.5	3.5
1.0	4.7	4.7	4.7	4.8	4.8	4.8
1.5	5.4	5.5	5.6	5.8	5.9	6.0
2.0	6.2	6.4	6.6	6.7	6.9	7.1
2.5	6.9	7.2	7.5	7.7	8.0	8.3
3.0	7.6	8.0	8.3	8.7	9.0	9.4
3.5	8.3	8.8	9.2	9.7	10.1	10.6
4.0	9.1	9.6	10.1	10.7	11.2	11.7
4.5	9.8	10.4	11.0	11.7	12.3	12.9
5.0	10.5	11.2	11.9	12.6	13.3	14.0

Figure 15. Airline distance vs travel time vs distribution factors, by trip purpose (suburb to suburb), in urban area of 100,000-250,000 population.



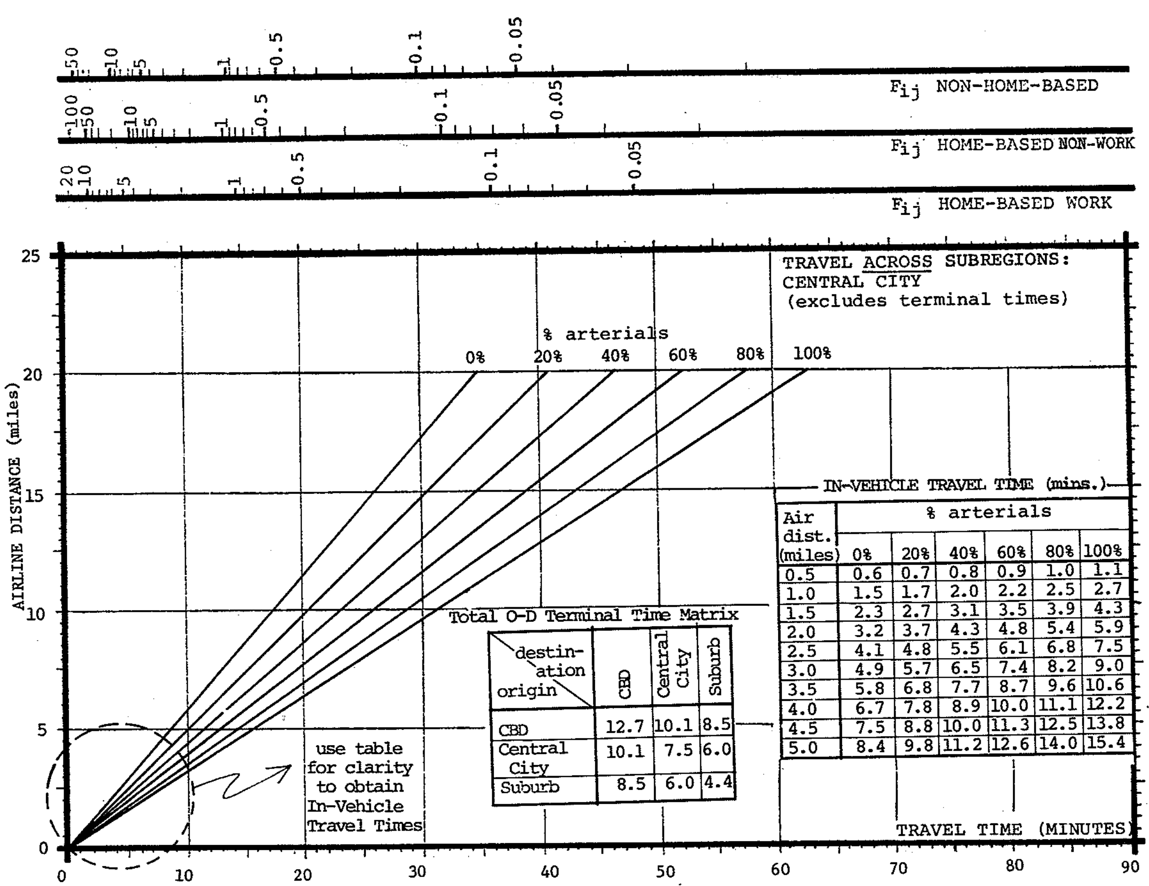
Total O-D Terminal Time Matrix

destination / origin	CBD	Central City	Suburb
CBD	12.7	10.1	8.5
Central City	10.1	7.5	6.0
Suburb	8.5	6.0	4.4

IN-VEHICLE TRAVEL TIME (mins.)

Air dist. (miles)	% arterial					
	0%	20%	40%	60%	80%	100%
0.2	0.3	0.4	0.5	0.5	0.6	0.7
0.4	0.7	0.9	1.1	1.2	1.4	1.6
0.6	1.1	1.4	1.7	1.9	2.2	2.5
0.8	1.5	1.9	2.3	2.6	3.0	3.4
1.0	1.9	2.4	2.9	3.3	3.8	4.3

Figure 16. Airline distance vs travel time vs distribution factors, by trip purpose (CBD), in urban area of 100,000-250,000 population.



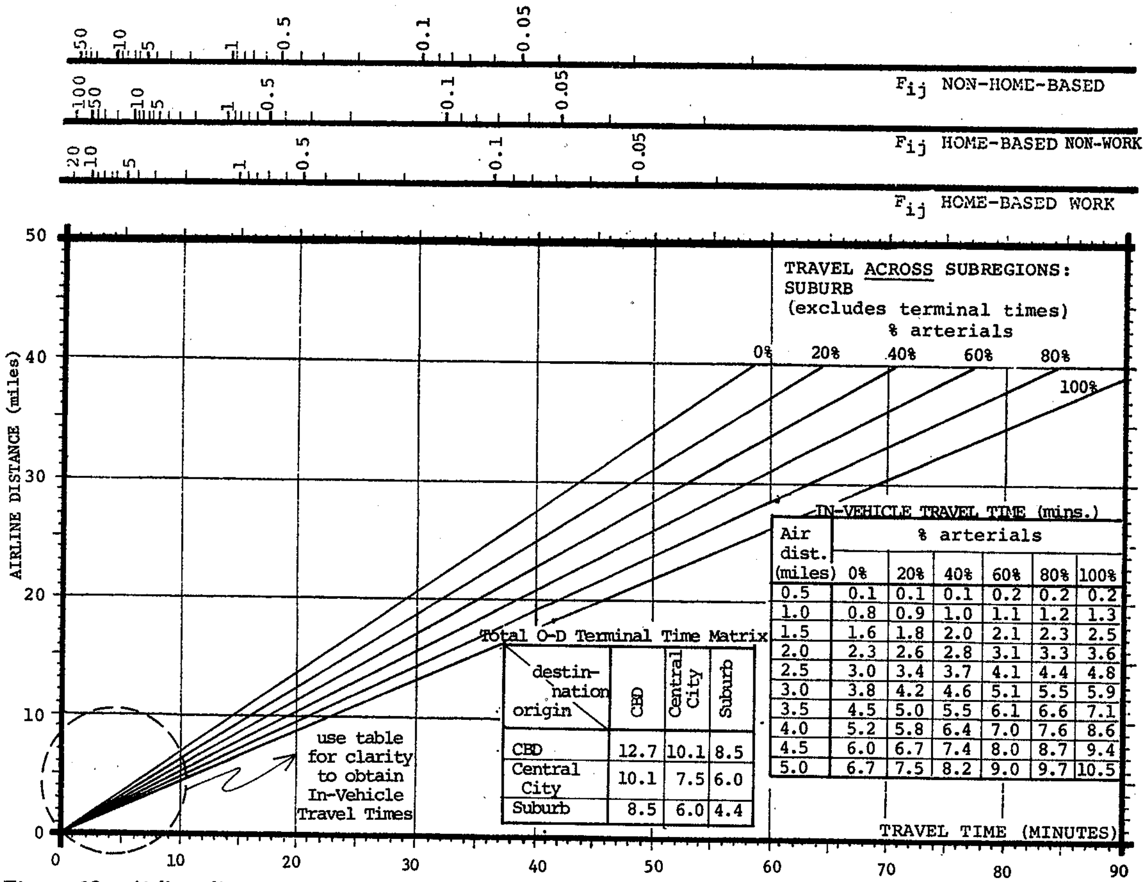
Total O-D Terminal Time Matrix

destination / origin	CBD	Central City	Suburb
CBD	12.7	10.1	8.5
Central City	10.1	7.5	6.0
Suburb	8.5	6.0	4.4

IN-VEHICLE TRAVEL TIME (mins.)

Air dist. (miles)	% arterials					
	0%	20%	40%	60%	80%	100%
0.5	0.6	0.7	0.8	0.9	1.0	1.1
1.0	1.5	1.7	2.0	2.2	2.5	2.7
1.5	2.3	2.7	3.1	3.5	3.9	4.3
2.0	3.2	3.7	4.3	4.8	5.4	5.9
2.5	4.1	4.8	5.5	6.1	6.8	7.5
3.0	4.9	5.7	6.5	7.4	8.2	9.0
3.5	5.8	6.8	7.7	8.7	9.6	10.6
4.0	6.7	7.8	8.9	10.0	11.1	12.2
4.5	7.5	8.8	10.0	11.3	12.5	13.8
5.0	8.4	9.8	11.2	12.6	14.0	15.4

Figure 17. Airline distance vs travel time vs distribution factors, by trip purpose (central city), in urban area of 100,000-250,000 population.



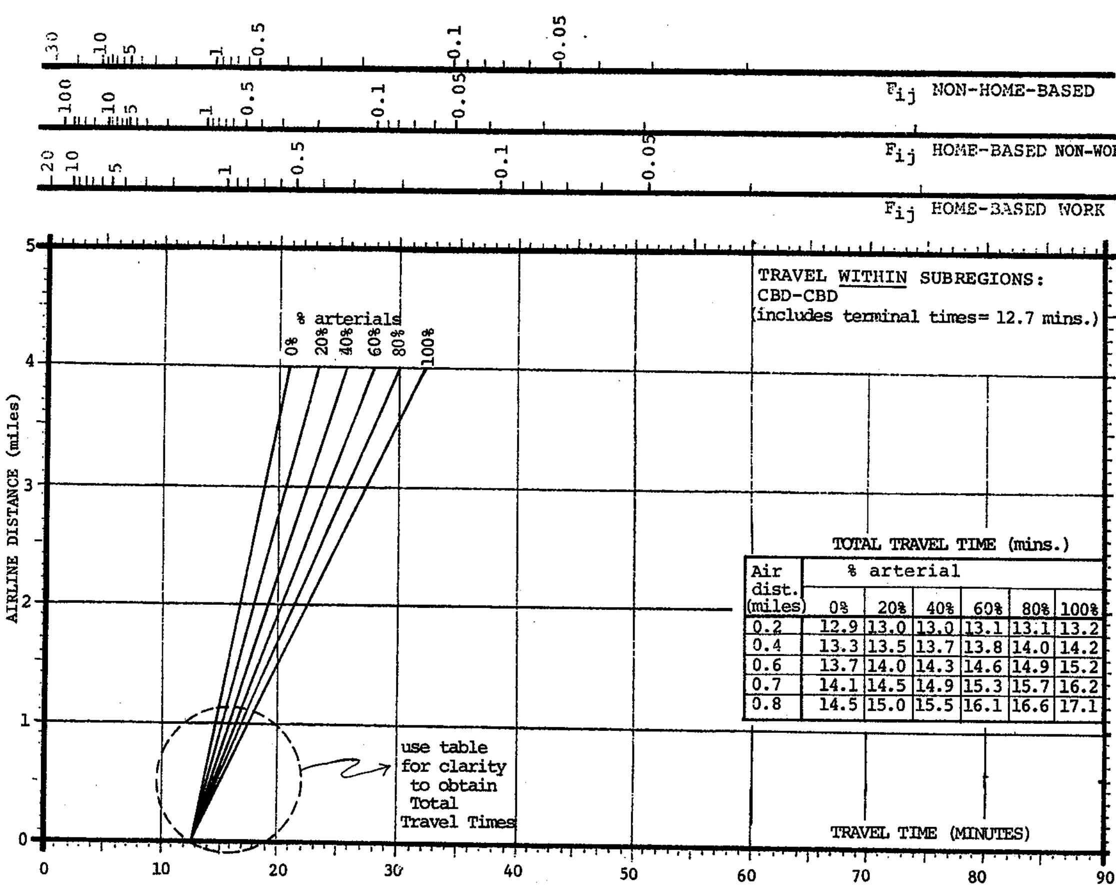
Total O-D Terminal Time Matrix

destination / origin	CBD	Central City	Suburb
CBD	12.7	10.1	8.5
Central City	10.1	7.5	6.0
Suburb	8.5	6.0	4.4

IN-VEHICLE TRAVEL TIME (mins.)

Air dist. (miles)	% arterials 0%	20%	40%	60%	80%	100%
0.5	0.1	0.1	0.1	0.2	0.2	0.2
1.0	0.8	0.9	1.0	1.1	1.2	1.3
1.5	1.6	1.8	2.0	2.1	2.3	2.5
2.0	2.3	2.6	2.8	3.1	3.3	3.6
2.5	3.0	3.4	3.7	4.1	4.4	4.8
3.0	3.8	4.2	4.6	5.1	5.5	5.9
3.5	4.5	5.0	5.5	6.1	6.6	7.1
4.0	5.2	5.8	6.4	7.0	7.6	8.6
4.5	6.0	6.7	7.4	8.0	8.7	9.4
5.0	6.7	7.5	8.2	9.0	9.7	10.5

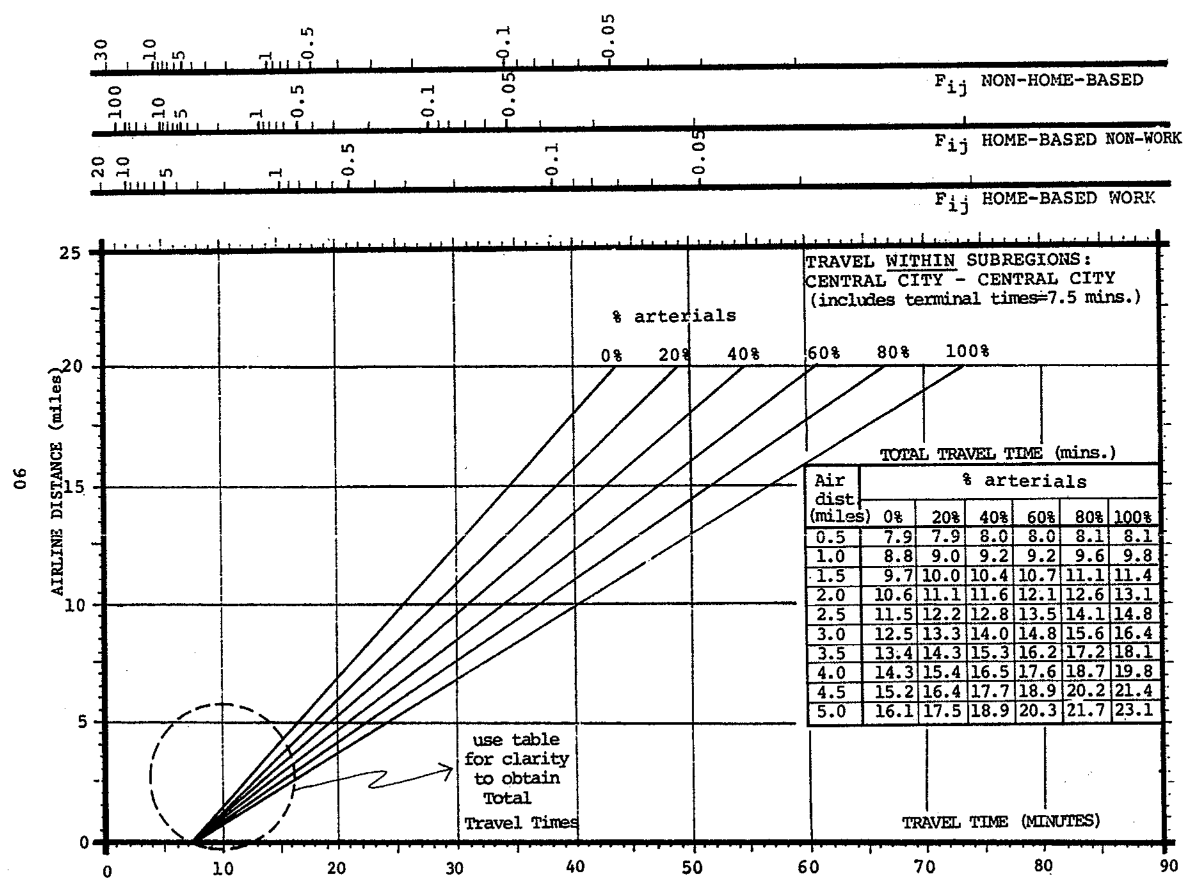
Figure 18. Airline distance vs travel time vs distribution factors, by trip purpose (suburb), in urban area of 100,000-250,000 population.



TOTAL TRAVEL TIME (mins.)

Air dist. (miles)	% arterial 0%	20%	40%	60%	80%	100%
0.2	12.9	13.0	13.0	13.1	13.1	13.2
0.4	13.3	13.5	13.7	13.8	14.0	14.2
0.6	13.7	14.0	14.3	14.6	14.9	15.2
0.7	14.1	14.5	14.9	15.3	15.7	16.2
0.8	14.5	15.0	15.5	16.1	16.6	17.1

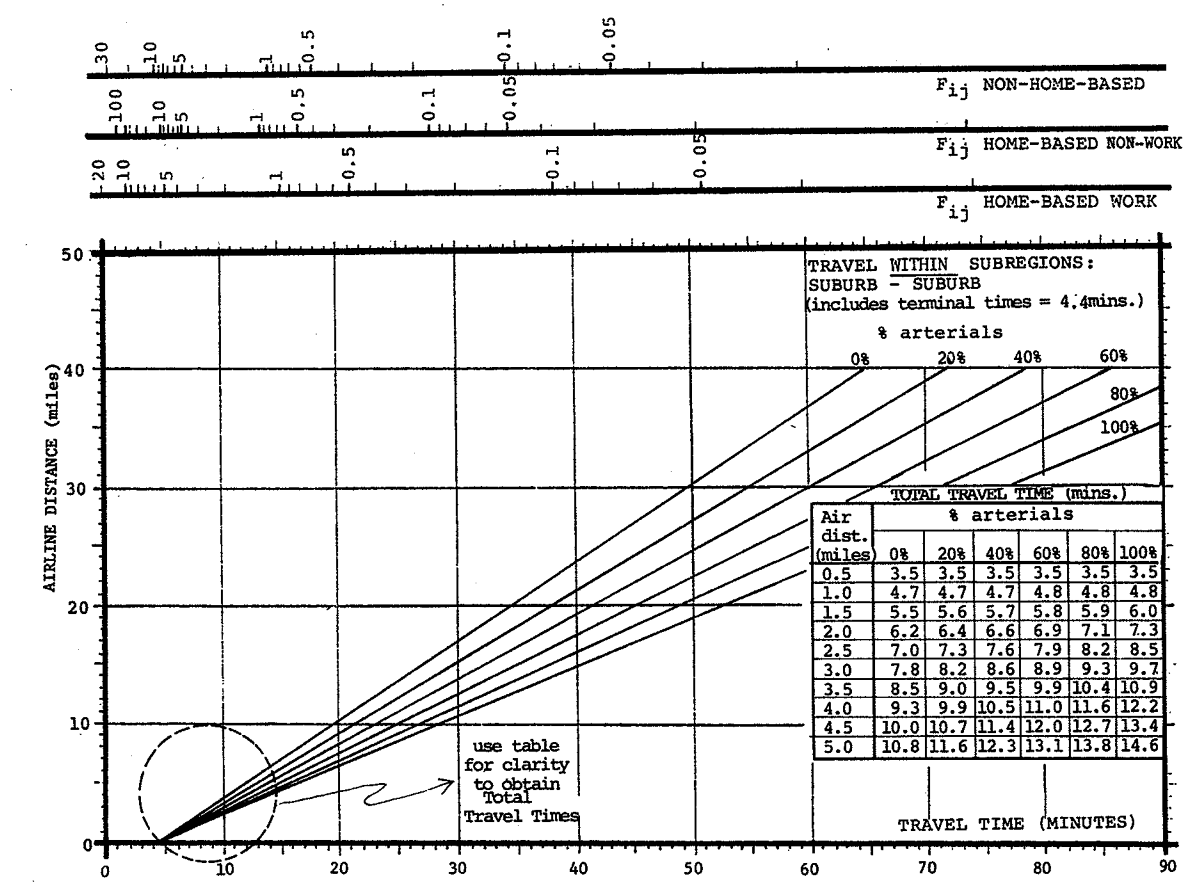
Figure 19. Airline distance vs travel time vs distribution factors, by trip purpose (CBD to CBD), in urban area of 250,000-750,000 population.



TOTAL TRAVEL TIME (mins.)

Air dist. (miles)	% arterials 0%	20%	40%	60%	80%	100%
0.5	7.9	7.9	8.0	8.0	8.1	8.1
1.0	8.8	9.0	9.2	9.2	9.6	9.8
1.5	9.7	10.0	10.4	10.7	11.1	11.4
2.0	10.6	11.1	11.6	12.1	12.6	13.1
2.5	11.5	12.2	12.8	13.5	14.1	14.8
3.0	12.5	13.3	14.0	14.8	15.6	16.4
3.5	13.4	14.3	15.3	16.2	17.2	18.1
4.0	14.3	15.4	16.5	17.6	18.7	19.8
4.5	15.2	16.4	17.7	18.9	20.2	21.4
5.0	16.1	17.5	18.9	20.3	21.7	23.1

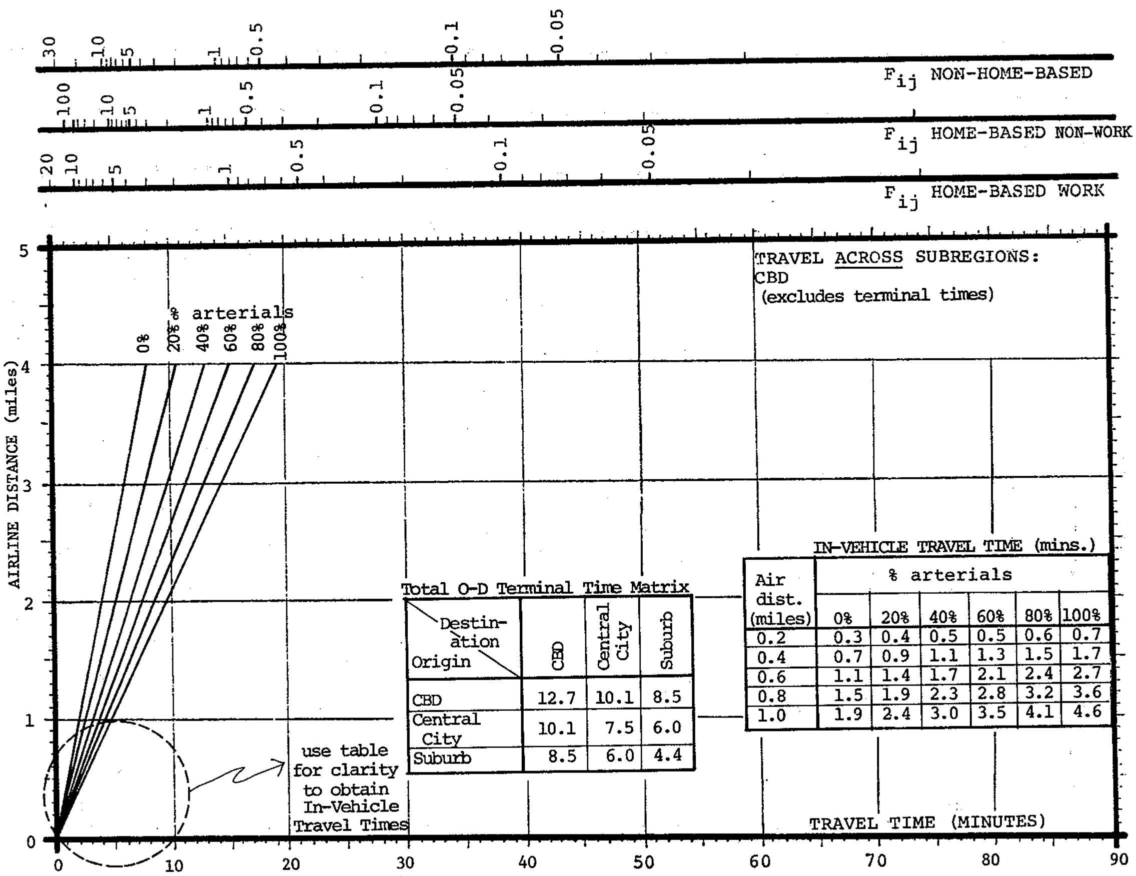
Figure 20. Airline distance vs travel time vs distribution factors, by trip purpose (central city to central city), in urban area of 250,000-750,000 population.



TOTAL TRAVEL TIME (mins.)

Air dist. (miles)	% arterials 0%	20%	40%	60%	80%	100%
0.5	3.5	3.5	3.5	3.5	3.5	3.5
1.0	4.7	4.7	4.7	4.8	4.8	4.8
1.5	5.5	5.6	5.7	5.8	5.9	6.0
2.0	6.2	6.4	6.6	6.9	7.1	7.3
2.5	7.0	7.3	7.6	7.9	8.2	8.5
3.0	7.8	8.2	8.6	8.9	9.3	9.7
3.5	8.5	9.0	9.5	9.9	10.4	10.9
4.0	9.3	9.9	10.5	11.0	11.6	12.2
4.5	10.0	10.7	11.4	12.0	12.7	13.4
5.0	10.8	11.6	12.3	13.1	13.8	14.6

Figure 21. Airline distance vs travel time vs distribution factors, by trip purpose (suburb to suburb), in urban area of 250,000-750,000 population.



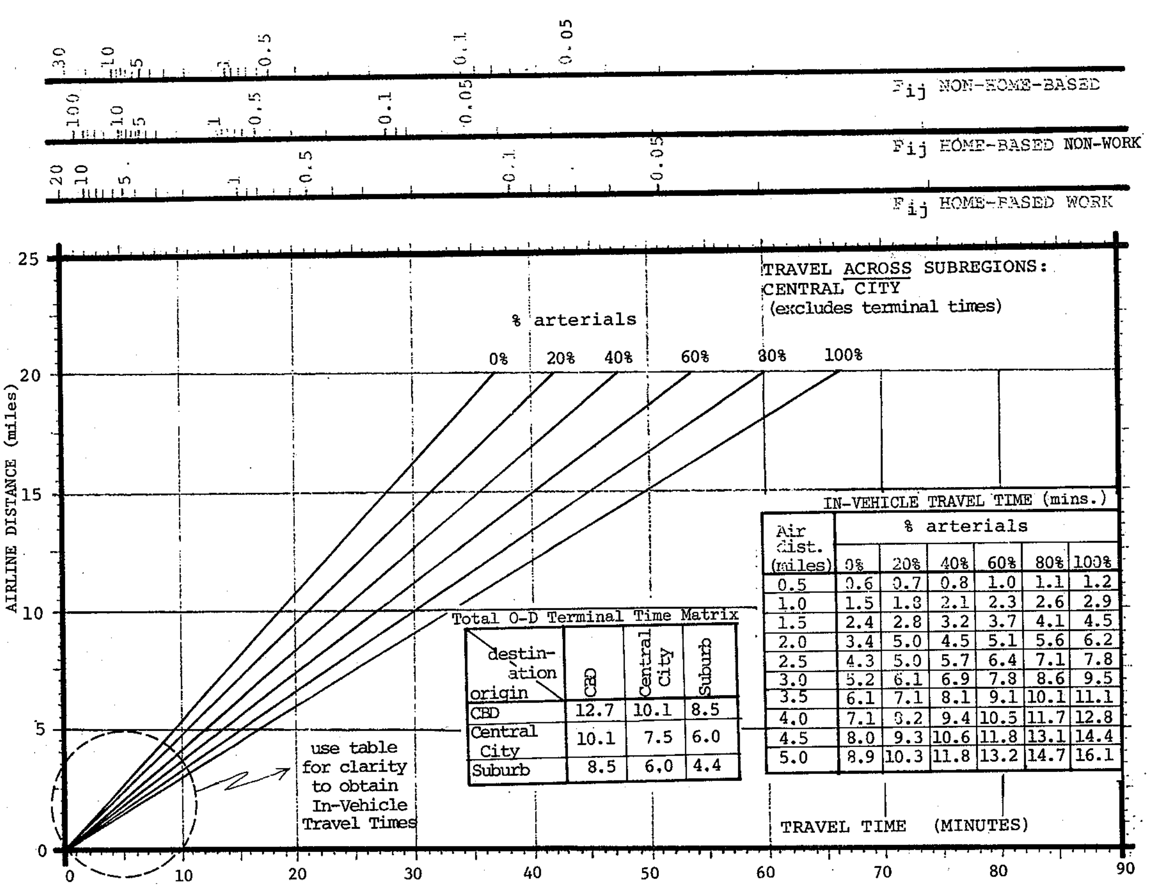
Total O-D Terminal Time Matrix

Destination / Origin	CBD	Central City	Suburb
CBD	12.7	10.1	8.5
Central City	10.1	7.5	6.0
Suburb	8.5	6.0	4.4

IN-VEHICLE TRAVEL TIME (mins.)

Air dist. (miles)	% arterials					
	0%	20%	40%	60%	80%	100%
0.2	0.3	0.4	0.5	0.5	0.6	0.7
0.4	0.7	0.9	1.1	1.3	1.5	1.7
0.6	1.1	1.4	1.7	2.1	2.4	2.7
0.8	1.5	1.9	2.3	2.8	3.2	3.6
1.0	1.9	2.4	3.0	3.5	4.1	4.6

Figure 22. Airline distance vs travel time vs distribution factors by trip purpose (CBD), in urban area of 250,000-750,000 population.



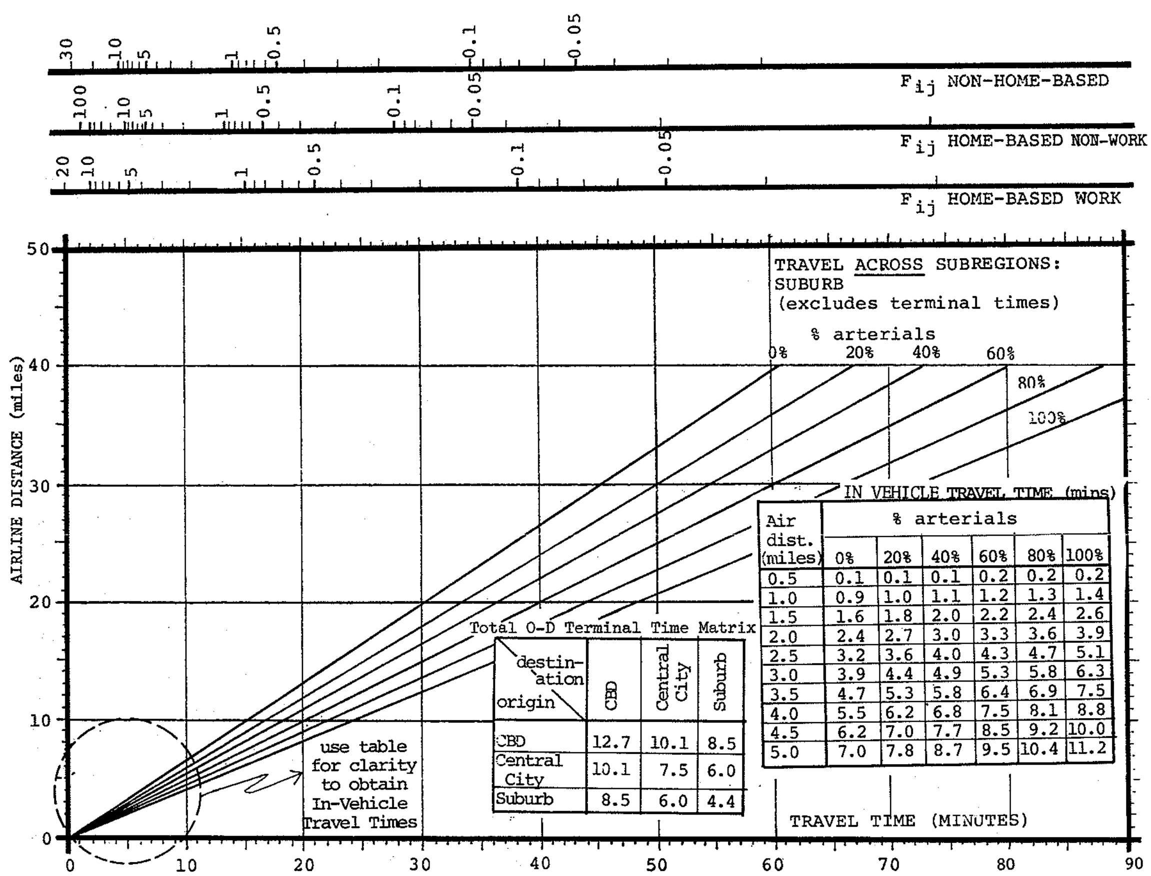
Total O-D Terminal Time Matrix

destination / origin	CBD	Central City	Suburb
CBD	12.7	10.1	8.5
Central City	10.1	7.5	6.0
Suburb	8.5	6.0	4.4

IN-VEHICLE TRAVEL TIME (mins.)

Air dist. (miles)	% arterials					
	0%	20%	40%	60%	80%	100%
0.5	0.6	0.7	0.8	1.0	1.1	1.2
1.0	1.5	1.8	2.1	2.3	2.6	2.9
1.5	2.4	2.8	3.2	3.7	4.1	4.5
2.0	3.4	5.0	4.5	5.1	5.6	6.2
2.5	4.3	5.0	5.7	6.4	7.1	7.8
3.0	5.2	6.1	6.9	7.8	8.6	9.5
3.5	6.1	7.1	8.1	9.1	10.1	11.1
4.0	7.1	8.2	9.4	10.5	11.7	12.8
4.5	8.0	9.3	10.6	11.8	13.1	14.4
5.0	8.9	10.3	11.8	13.2	14.7	16.1

Figure 23. Airline distance vs travel time vs distribution factors, by trip purpose (central city), in urban area of 250,000-750,000 population.



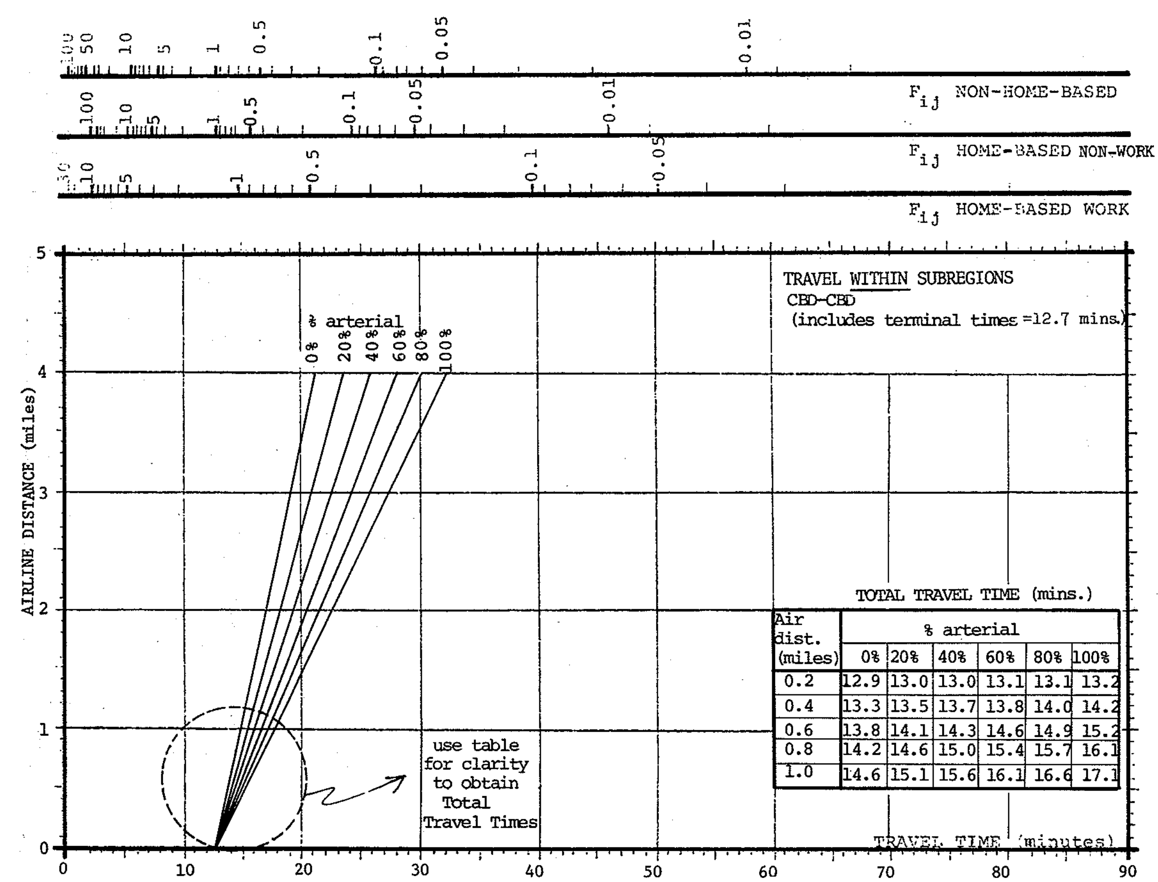
IN VEHICLE TRAVEL TIME (mins)

Air dist. (miles)	% arterials					
	0%	20%	40%	60%	80%	100%
0.5	0.1	0.1	0.1	0.2	0.2	0.2
1.0	0.9	1.0	1.1	1.2	1.3	1.4
1.5	1.6	1.8	2.0	2.2	2.4	2.6
2.0	2.4	2.7	3.0	3.3	3.6	3.9
2.5	3.2	3.6	4.0	4.3	4.7	5.1
3.0	3.9	4.4	4.9	5.3	5.8	6.3
3.5	4.7	5.3	5.8	6.4	6.9	7.5
4.0	5.5	6.2	6.8	7.5	8.1	8.8
4.5	6.2	7.0	7.7	8.5	9.2	10.0
5.0	7.0	7.8	8.7	9.5	10.4	11.2

Total O-D Terminal Time Matrix

destination / origin	CBD	Central City	Suburb
CBD	12.7	10.1	8.5
Central City	10.1	7.5	6.0
Suburb	8.5	6.0	4.4

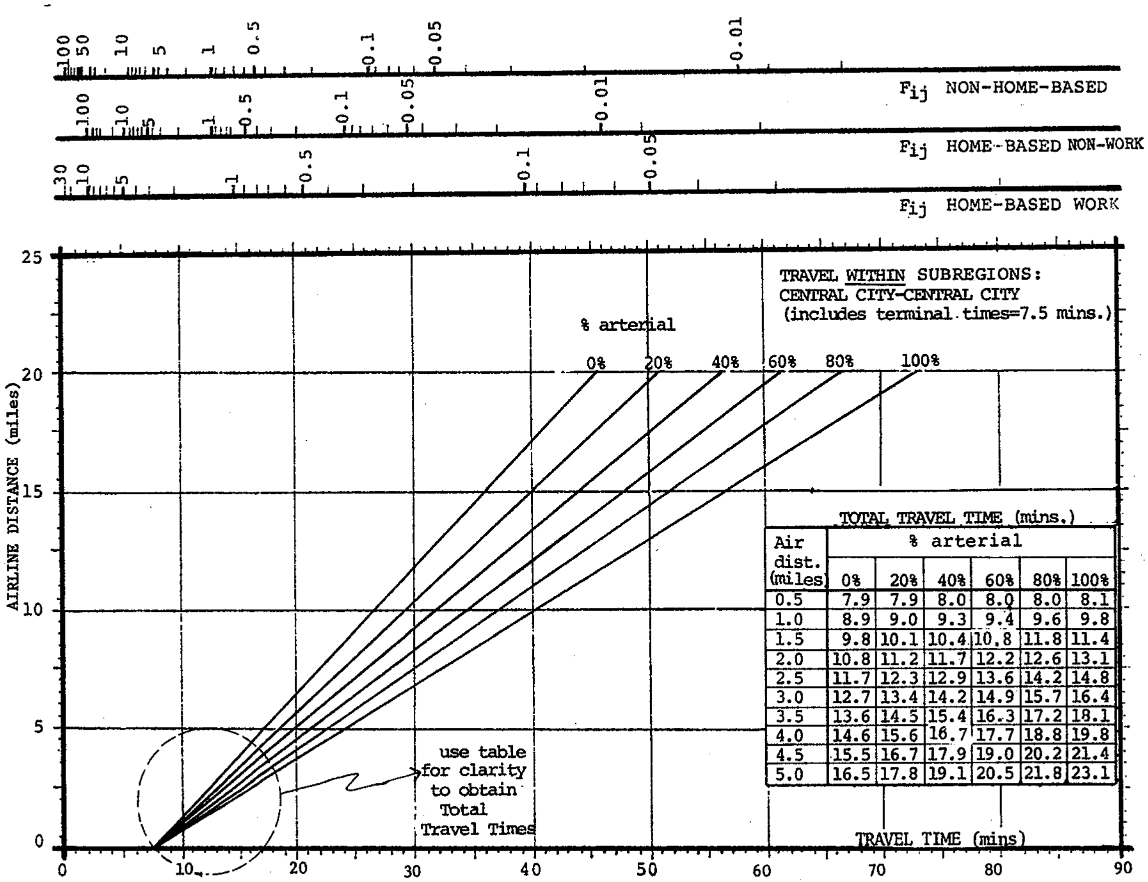
Figure 24. Airline distance vs travel time vs distribution factors, by trip purpose (suburb), in urban area of 250,000-750,000 population.



TOTAL TRAVEL TIME (mins.)

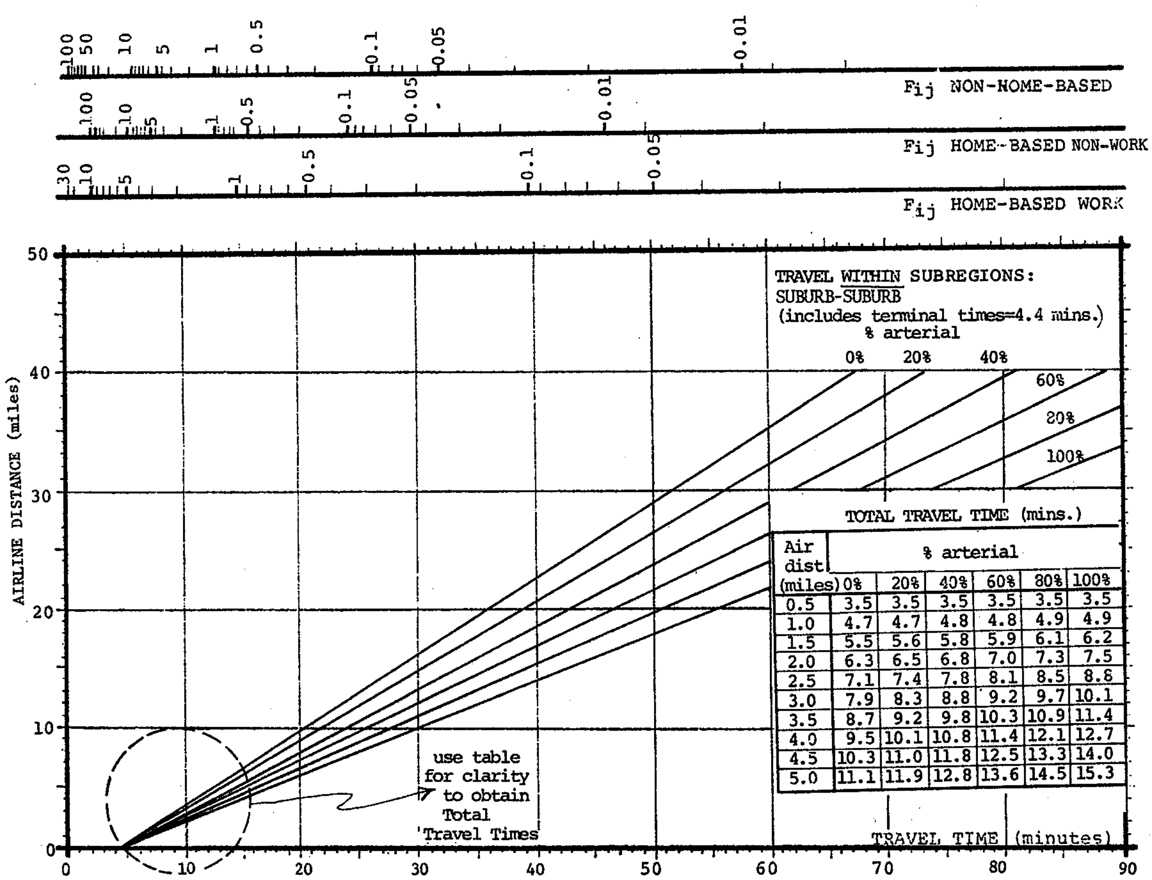
Air dist. (miles)	% arterial					
	0%	20%	40%	60%	80%	100%
0.2	12.9	13.0	13.0	13.1	13.1	13.2
0.4	13.3	13.5	13.7	13.8	14.0	14.2
0.6	13.8	14.1	14.3	14.6	14.9	15.2
0.8	14.2	14.6	15.0	15.4	15.7	16.1
1.0	14.6	15.1	15.6	16.1	16.6	17.1

Figure 25. Airline distance vs travel time vs distribution factors, by trip purpose (CBD to CBD), in urban area of 750,000-2,000,000 population.



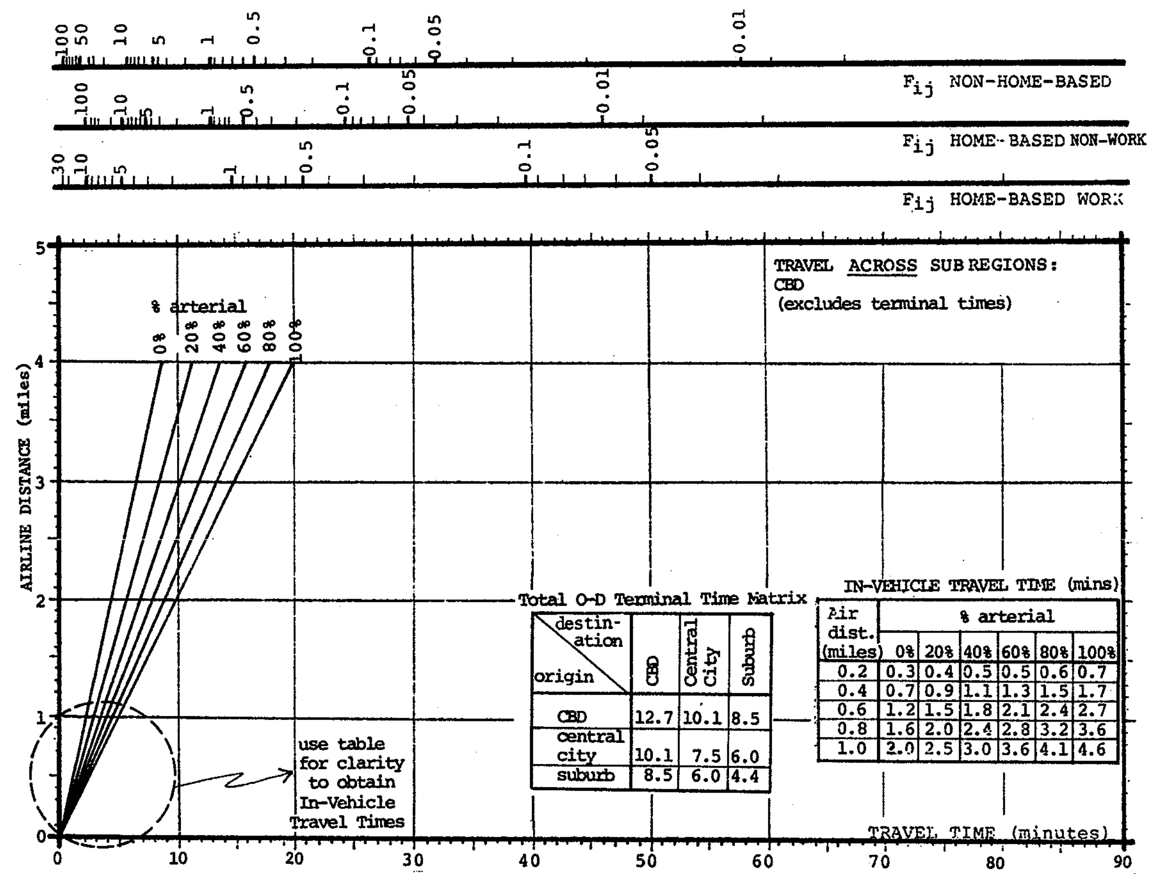
Air dist. (miles)	% arterial 0%	20%	40%	60%	80%	100%
0.5	7.9	7.9	8.0	8.0	8.0	8.1
1.0	8.9	9.0	9.3	9.4	9.6	9.8
1.5	9.8	10.1	10.4	10.8	11.8	11.4
2.0	10.8	11.2	11.7	12.2	12.6	13.1
2.5	11.7	12.3	12.9	13.6	14.2	14.8
3.0	12.7	13.4	14.2	14.9	15.7	16.4
3.5	13.6	14.5	15.4	16.3	17.2	18.1
4.0	14.6	15.6	16.7	17.7	18.8	19.8
4.5	15.5	16.7	17.9	19.0	20.2	21.4
5.0	16.5	17.8	19.1	20.5	21.8	23.1

Figure 26. Airline distance vs travel time vs distribution factors, by trip purpose (central city to central city), in urban area of 750,000-2,000,000 population.



Air dist (miles)	% arterial 0%	20%	40%	60%	80%	100%
0.5	3.5	3.5	3.5	3.5	3.5	3.5
1.0	4.7	4.7	4.8	4.8	4.9	4.9
1.5	5.5	5.6	5.8	5.9	6.1	6.2
2.0	6.3	6.5	6.8	7.0	7.3	7.5
2.5	7.1	7.4	7.8	8.1	8.5	8.8
3.0	7.9	8.3	8.8	9.2	9.7	10.1
3.5	8.7	9.2	9.8	10.3	10.9	11.4
4.0	9.5	10.1	10.8	11.4	12.1	12.7
4.5	10.3	11.0	11.8	12.5	13.3	14.0
5.0	11.1	11.9	12.8	13.6	14.5	15.3

Figure 27. Airline distance vs travel time vs distribution factors, by trip purpose (suburb to suburb), in urban area of 750,000-2,000,000 population.



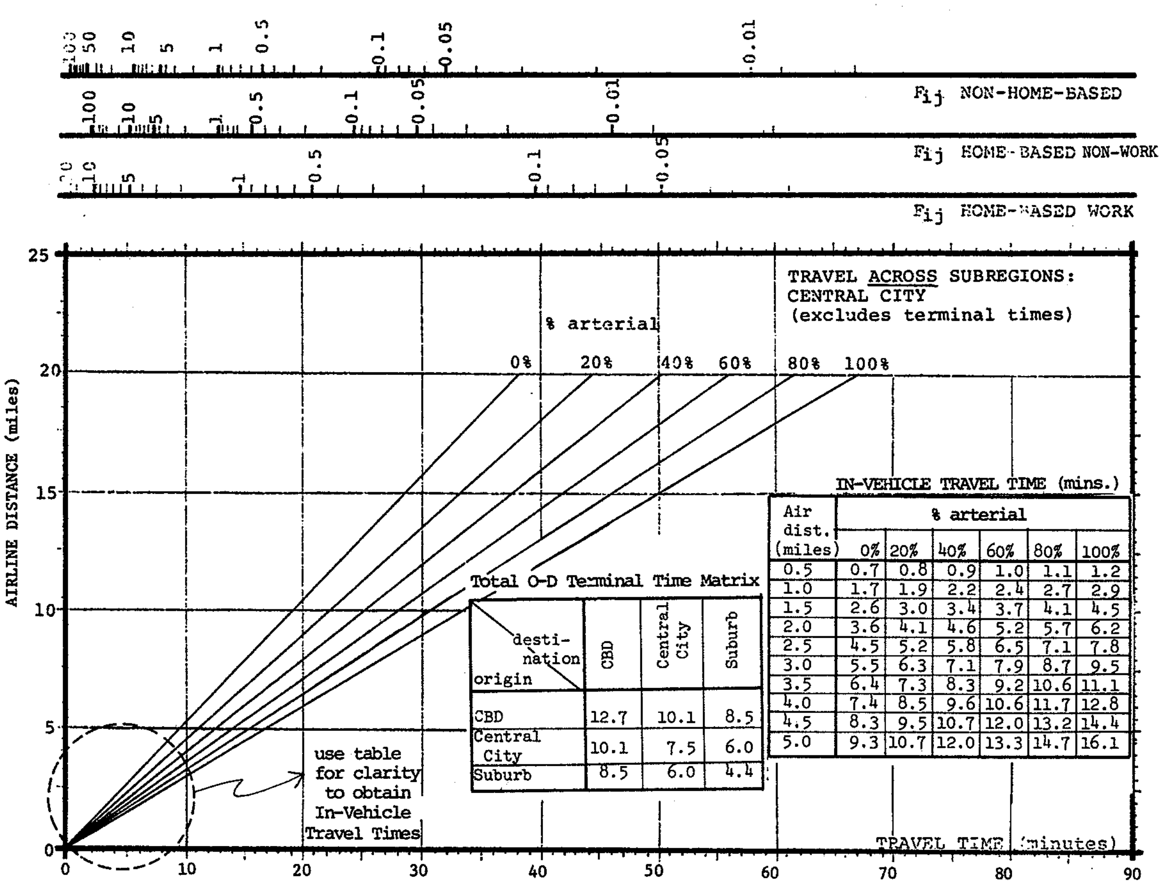
Total O-D Terminal Time Matrix

origin \ destination	CBD	Central City	Suburb
CBD	12.7	10.1	8.5
central city	10.1	7.5	6.0
suburb	8.5	6.0	4.4

IN-VEHICLE TRAVEL TIME (mins)

Air dist. (miles)	% arterial 0%	20%	40%	60%	80%	100%
0.2	0.3	0.4	0.5	0.5	0.6	0.7
0.4	0.7	0.9	1.1	1.3	1.5	1.7
0.6	1.2	1.5	1.8	2.1	2.4	2.7
0.8	1.6	2.0	2.4	2.8	3.2	3.6
1.0	2.0	2.5	3.0	3.6	4.1	4.6

Figure 28. Airline distance vs travel time vs distribution factors, by trip purpose (CBD), in urban area of 750,000-2,000,000 population.



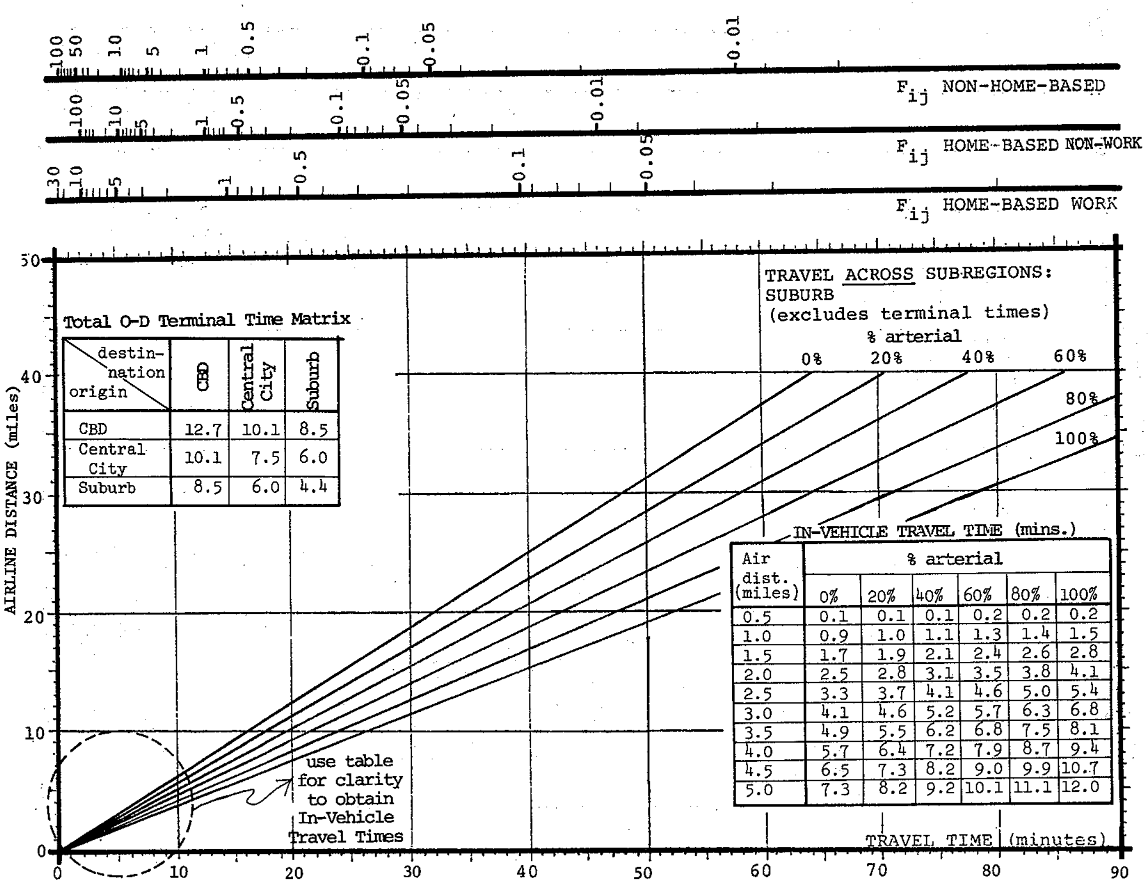
Total O-D Terminal Time Matrix

origin \ destination	CBD	Central City	Suburb
CBD	12.7	10.1	8.5
Central City	10.1	7.5	6.0
Suburb	8.5	6.0	4.4

IN-VEHICLE TRAVEL TIME (mins.)

Air dist. (miles)	% arterial 0%	20%	40%	60%	80%	100%
0.5	0.7	0.8	0.9	1.0	1.1	1.2
1.0	1.7	1.9	2.2	2.4	2.7	2.9
1.5	2.6	3.0	3.4	3.7	4.1	4.5
2.0	3.6	4.1	4.6	5.2	5.7	6.2
2.5	4.5	5.2	5.8	6.5	7.1	7.8
3.0	5.5	6.3	7.1	7.9	8.7	9.5
3.5	6.4	7.3	8.3	9.2	10.6	11.1
4.0	7.4	8.5	9.6	10.6	11.7	12.8
4.5	8.3	9.5	10.7	12.0	13.2	14.4
5.0	9.3	10.7	12.0	13.3	14.7	16.1

Figure 29. Airline distance vs travel time vs distribution factors, by trip purpose (central city), in urban area of 750,000-2,000,000 population.



Total O-D Terminal Time Matrix

origin \ destination	CBD	Central City	Suburb
CBD	12.7	10.1	8.5
Central City	10.1	7.5	6.0
Suburb	8.5	6.0	4.4

In-Vehicle Travel Time (mins.)

Air dist. (miles)	% arterial 0%	20%	40%	60%	80%	100%
0.5	0.1	0.1	0.1	0.2	0.2	0.2
1.0	0.9	1.0	1.1	1.3	1.4	1.5
1.5	1.7	1.9	2.1	2.4	2.6	2.8
2.0	2.5	2.8	3.1	3.5	3.8	4.1
2.5	3.3	3.7	4.1	4.6	5.0	5.4
3.0	4.1	4.6	5.2	5.7	6.3	6.8
3.5	4.9	5.5	6.2	6.8	7.5	8.1
4.0	5.7	6.4	7.2	7.9	8.7	9.4
4.5	6.5	7.3	8.2	9.0	9.9	10.7
5.0	7.3	8.2	9.2	10.1	11.1	12.0

Figure 30. Airline distance vs travel time vs distribution factors, by trip purpose (suburb), in urban area of 750,000-2,000,000 population.

The second set of graphs is used when the trip interchange occurs *across* subregions; for example, CBD-to-central city, or CBD-to-suburb, or central city-to-suburb, and the like. In this case, the travel time read from the graphs is the *in-vehicle* time *excluding* terminal times. Total travel time is then calculated by adding the appropriate total origin and destination terminal times shown tabulated on the second set of graphs for each urbanized area population group.

For example, for an urbanized area of 750,000 to 2,000,000 population and a trip interchange across subregions, say central city-to-suburb [i.e., from area 4 to 18 (Fig. 6)], the applicable graphs are shown in Figures 29 and 30. Scaling the airline distance between the centroids of areas 4 and 18, the total distance is found to be 11 mi, with 2 mi being the central city portion and 9 mi the suburb portion. Through an "experienced estimation," it is concluded that 5 percent of over-the-road travel of the 2-mi central city portion is made on arterials; also, 100 percent of over-the-road travel of the 9-mi suburb portion is made on arterials. For such facility mixes, the 5-percent curve (interpolated) in Figure 29 and the 100-percent curve in Figure 30 are used to generate the following parameters:

In-vehicle travel time for 2 mi central city portion = 4 min
In-vehicle travel time for 9 mi suburb portion = 24 min
Total O-D terminal times for central city-suburb combination = 6 min
Total travel time between area 4 and area 18 = 34 min
Corresponding distribution factor for HBW trips = 0.160
Corresponding distribution factor for HBNW trips = 0.029
Corresponding distribution factor for NHB trips = 0.041

These figures are assumed to hold true for the 18 to 4 interchange also.

Situations arise for interchanges where the origin and destination centroids are located within a subregion and yet the centroid-to-centroid straight line is straddled across subregions. Trip interchange from district 6 to 13 or 13 to 6 (Fig. 6), for example, has its origin and destination in the central city but crosses the CBD. For this case, the within set of curves do *not* apply; the airline distances and the in-vehicle travel times should be computed separately (for the central city and CBD portions) using the across subregion set of curves with the appropriate freeway-arterial mix percentages. The central city-to-central city terminal times are then added to obtain the total times, and the corresponding distribution factors are then obtained.

As a further illustration, a situation which entails the use of the across subregion set of curves is an O-D straight line that crosses the CBD, central city, and suburbs. For instance, the straight line between area 18 and 20 (Fig. 6) crosses three subregions, and, therefore, three in-vehicle times are accordingly read off (for the suburb, central city, and CBD portions) and then the suburb-to-suburb terminal times added.

It must be pointed out that in cases of the across sub-region travel, the distribution factor cannot be read off the graphs for each component of travel time and then summed. The total travel time must be computed first, following which any one of the appropriate graphs for an urbanized area population group is reentered, and the distribution factor (by trip purpose) corresponding to the total travel time is read off.

Note that if travel occurs entirely within a zone or district; that is, an *intra*-zonal or an *intra*-district trip, the airline distance is computed by a method described in Ref. (*23*). This method involves the measurement of airline distances from the centroid of the area of intra-travel to the centroids of all adjacent zones or districts. These airline distances are then averaged, and then the intra-area airline distance is taken as one-half of this average. The appropriate graph(s) is then entered to obtain the travel times.

Notice, however, that in the aforementioned situations, it is the airline distance between the O-D centroids that is scaled from the map, but that the freeway-arterial facility mix is determined from the actual over-the-road conditions irrespective of the magnitude differences between the airline and over-the-road distances. The graphs (Figs. 7 through 30) have been designed to accommodate these variations by using built-in factors. Note also, that in determining the freeway-arterial facility mixes, the local and collector portion of the trip is not explicitly considered simply because this factor is also allowed for in the graphs. In the preceding discussion, it has been presumed that for the study area in question, a travel time matrix is not available. Of course, if such a matrix has already been compiled, it should be used, for it will result in considerable saving in time and effort.

Constructing Airline Distance vs. Travel Time vs. Distribution Factors Graphs

Several assumptions were made in the construction of the "Airline Distance vs. Travel Time vs. Distribution Factors" graphs shown in Figures 7 through 30. These graphs will be described in detail to provide a full understanding of their development as well as to provide the user the opportunity to construct his own graphs where a more specific representation is desirable.

A circuity factor of 1.22 has been used to convert airline miles to over-the-road distance (*26*). Circuity factors vary by the topography and network layout for an urbanized area, and the 1.22 represents an average. Pittsburgh, for example, has a higher value based on the hilly terrain.

For terminal times, several urban transportation studies were reviewed and two sets of average terminal times were compiled: one for urbanized areas with more than 100,000 population and one for areas with less than 100,000 population. These terminal times are given in Table 4 and reflect the time spent walking to and from the vehicle and the time spent parking and unparking the vehicle.

The values in Table 4 represent the time spent at one end of the trip. For example, for an urbanized area with a population of and exceeding 100,000, a trip from the suburbs to the CBD would have a total O-D terminal time of 8.5 min (6.34 + 2.20).

TABLE 4

TRIP END CONDITIONS[a]

FOR URBANIZED AREAS WITH POPULATION 100,000 AND ABOVE:

	CBD	Central City	Suburb
Terminal time (mins.)	6	3	1
Local street distance (miles)	0.0625	0.1875	0.5000
Local street speed (mph)	11	15	25
Local street time (mins.)	0.34	0.75	1.20
Total terminal time[b] (terminal + local street time) (mins.)	6.34	3.75	2.20

FOR URBANIZED AREAS WITH POPULATION LESS THAN 100,000:

	CBD	Central City	Suburb
Terminal time (mins.)	4	2	1
Local street distance (miles)	0.0625	0.1875	0.5000
Local street speed (mph)	14	20	29
Local street time (mins.)	0.27	0.56	1.03
Total terminal time[b] (terminal + local street time) (mins.)	4.27	2.56	2.03

a. Source: Various urban transportation studies.
b. This time represents the total terminal time at either the origin end or the destination end of a trip. Therefore, to obtain the total O-D terminal time for a trip originating, say, in the CBD and terminating in the suburb, this time is 6.34 + 2.20 = 8.54 mins. (for an urbanized area population of 100,000 and above).

Trips were always assumed to be made using the local street system and then, if long enough, arterials; likewise, some trips would be made using freeways for a portion of the travel. Local street mileage at each end of a trip was assumed to be equal to 1/16 mi in the CBD, 3/16 mi in the remainder of the central city, and ½ mi in the suburbs, irrespective of the urbanized area population. This is based on an assumption that arterial spacing in the CBD is ¼ mi, ¾ mi in the central city, and 2 mi in the suburbs; and that the trip length on local streets at each end of a trip is ¼ the arterial street spacing. Local street speeds were assumed equal to the average speeds given in Table 4. When a trip is shorter than the local street mileage assumed, only the actual length is considered in constructing the nomographs.

For any trip, therefore, a time occurs at each end of that trip reflecting local street travel plus terminal time, and the remainder represents arterial/freeway travel time. The arterial/freeway travel time is for the total distance less the distance on local streets.

To illustrate the preceding discussion, three cases are described for an urbanized area with 750,000 to 2,000,000 population. Before reading this description, the trip-end conditions given in Table 4 and the speed values given in Table 5 should be reviewed.

For the first example, consider a trip made entirely within the central city where no freeway is available and the speed on the arterials is assumed to be 22 mph and the length of trip is measured from a map to be 3.0 airline miles. The over-the-road distance is estimated at 3.66 mi (3 × 1.22 circuity factor). Because the trip is made entirely in the central city, reference to Table 4 indicates that 0.375 mi is traveled on local streets (2 × 0.1875) and, therefore, 3.29 mi (3.66 — 0.375) is traveled on arterials. The total travel time including terminal time is calculated at 16.46 min as follows:

Arterial time $= \frac{3.29}{\text{speed} = 22} \times 60 = 8.96$ min

Local street + total O-D terminal time (Table 4) $= 7.50$ min

Total travel time $= 16.46$ min

Now, in the second case, assume that all conditions are the same but that 60 percent of the nonlocal street travel is on freeways at 38 mph and 40 percent is on other arterials.

Other arterial time $= \frac{3.29}{\text{speed} = 22} \times 60 \times 0.40 = 3.59$ min

Freeway time $= \frac{3.28}{\text{speed} = 22} \times 60 \times 0.60 = 3.11$ min

Local street + total O-D terminal time (Table 4) $= 7.50$ min

Total travel time $= 14.20$ min

For a third case, consider a trip from the suburbs to the central city. Assume that 3 mi is traveled in the suburbs and 2 mi in the central city, and that no travel is by freeway (mileage is airline distance). The time calculated would be:

Over-the-road distance in suburbs $= 3 \times 1.22 = 3.66$ mi
Distance in suburbs on local streets (Table 4) $= 0.50$ mi
Distance on arterials, difference $= 3.16$ mi
Time on local streets (Table 4) $= 1.20$ min
Time on arterials, $\frac{3.16 \times 60}{\text{speed} = 28} = 6.77$ min
Terminal time (Table 4) $= 1.00$ min
Total time suburbs $= 8.97$ min

Over-the-road distance central city $= 2 \times 1.22 = 2.44$ mi
Distance in central city on local streets (Table 4) $= 0.19$ mi
Distance on arterials, difference $= 2.25$ mi
Time on local streets (Table 4) $= 0.75$ min
Time on arterials, $\frac{2.25 \times 60}{\text{speed} = 22} = 6.14$ min
Terminal Time (Table 4) $= 3.00$ min
Total time central city $= 9.89$ min
Total travel time $= 18.86$ min

The foregoing calculations indicate that for trips entirely *within a subregion* (i.e., CBD), a table can be produced and plotted as those included in this chapter (Figures 7–9, 13–15, 19–21, and 25–27) for various freeway/arterial combinations. For trips that pass across subregions (i.e., CBD to suburb), tables and graphs expressing the amount of travel in each type area must be used and the sums added to represent total time (Figures 10–12, 16–18, 22–24, and 28–30).

TABLE 5

SPEED VALUES (MPH) BY FACILITY TYPE BY SUBREGION BY URBANIZED AREA POPULATION [a]

	SUBREGION TYPE					
	CBD		Central City		Suburb	
Urbanized Area Population	Arterial	Freeway	Arterial	Freeway	Arterial	Freeway
50,000- 100,000	17	38	25	52	38	55
100,000- 250,000	16	36	23	42	32	50
250,000- 750,000	15	36	22	40	30	48
750,000-2,000,000	15	35	22	38	28	46

a. Source: Various urban transportation studies.

Using the speed values given in Table 5, which represent averages for several cities from which speed tables were available, and the trip-end values from Table 4, the graphs shown in Figures 7 through 30 of this guide were produced.

Distribution factor curves were developed from data collected in a number of cities (*27*). These curves have been normalized to a constant scale and summarized to represent HBW, HBNW, and NHB trips. These distribution factors have been included in Figures 7 through 30 as shown.

APPLICATION OF THE MANUAL TRIP-DISTRIBUTION PROCEDURE TO REGIONWIDE ANALYSIS

Five districts in a hypothetical urbanized area of 800,000 population are to be analyzed for HBW trips. Productions and attractions for each district are provided from the trip-generation phase. The method proceeds in the following manner:

Step 1: Map of study area. Lay out a map showing the five districts, district centroids, and subregion boundaries as shown in Figure 31. It is helpful to use a map showing major arterials and freeways. A highway road map is usually suitable for this purpose.

Step 2: Enter production and attraction trip ends—P_i, A_j. These trip-end totals are entered in the trip-distribution matrix along with other identification features, such as headings, district numbers, and the like, as shown in Figure 32.

Step 3: Enter district-to-district travel times and distribution factors—t_{ij}, F_{ij}. Although only the distribution factors are to be used in the computation of trip interchanges, it is useful to enter and retain the travel times—these times will enable the user to better relate and perceive the spatial separation between the districts, see Figure 33.

Helpful aids and notes of caution:

1. Because the construction of the travel time/distribution factor matrix entails repetitive steps, it is important that the user build up and maintain some kind of "mental rhythm," particularly when a large number of interchanges is involved. This results in some time savings. Typically, one efficient approach is exemplified as follows:

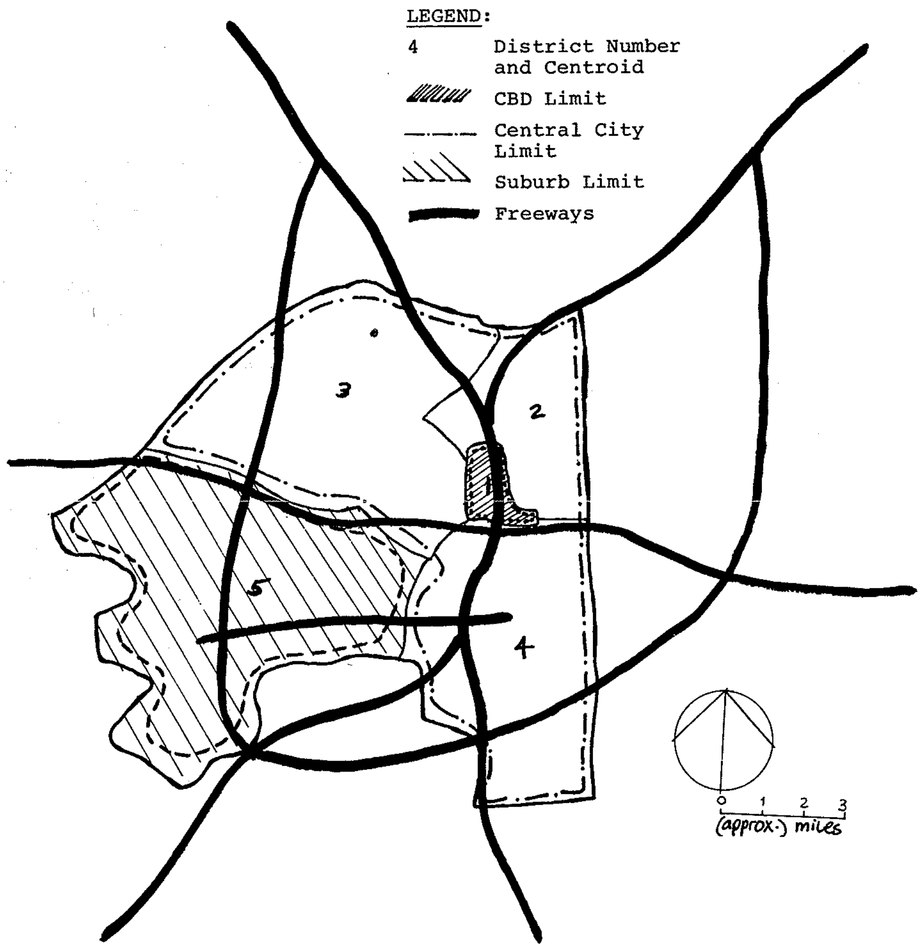


Figure 31. Step 1—Map of study area: hypothetical city.

STEPS	USER RESPONSE
(a) Identification of origin-destination subregions.	3 to 5, central city-to-suburb.
(b) Scaling of airline distance and reading off travel time from appropriate graphs.	Figure 29: 3 mi central city at 100 percent arterial . . . in-vehicle travel time = 9.6 min. Figure 30: 2 mi suburb at 100 percent arterial . . . in-vehicle travel time = 4.2 min.
(c) Total O-D terminal times.	Central city to suburb = 6.0 min.
(d) Total travel time.	9.6 + 4.2 + 6.0 = 19.8 min.
(e) Distribution factor (HBW) at 20 min.	0.56

This series of operations can be performed very easily on the desk calculator. A calculator with paper tape could prove handy in that travel time for the various portions of the trip interchange can be saved for later checking should the need arise.

2. Although the time matrix is triangular, it is helpful to enter all the interchange cells with their respective travel time and distribution factors.

3. Caution should be exercised when making judgments on the freeway-arterial percentage mix for any interchange, inasmuch as distance on a map can be visually deceptive, especially when a small map scale is used.

Step 4: Calculate attraction factors, $A_j F_{ij}$; *accessibility index,* $\sum A_j F_{ij}$; *and production index,* R_i*—iteration 1.* Except for R_i, the terms $A_j F_{ij}$ and $\sum A_j F_{ij}$ are calculated to the nearest 100 as shown in Figure 34. For example:

- Attraction factor from district $i = 3$ to district $j = 5$ is:

$$A_j F_{ij} = 8{,}000 \times 0.56 = 4{,}500$$

- Accessibility index for district $i = 3$ is:

$$\sum_{j=1}^{5} A_j F_{ij} = 21{,}200 + 5{,}600 + 18{,}200 + 4{,}000 + 4{,}500 = 53{,}500$$

- Production index for district $i = 3$ is:

$$R_i = P_i / \sum_{j=1}^{5} A_j F_{ij} = 27{,}100/53{,}500 = 0.506542$$

And so on for all rows and columns.

Helpful aids and notes of caution:

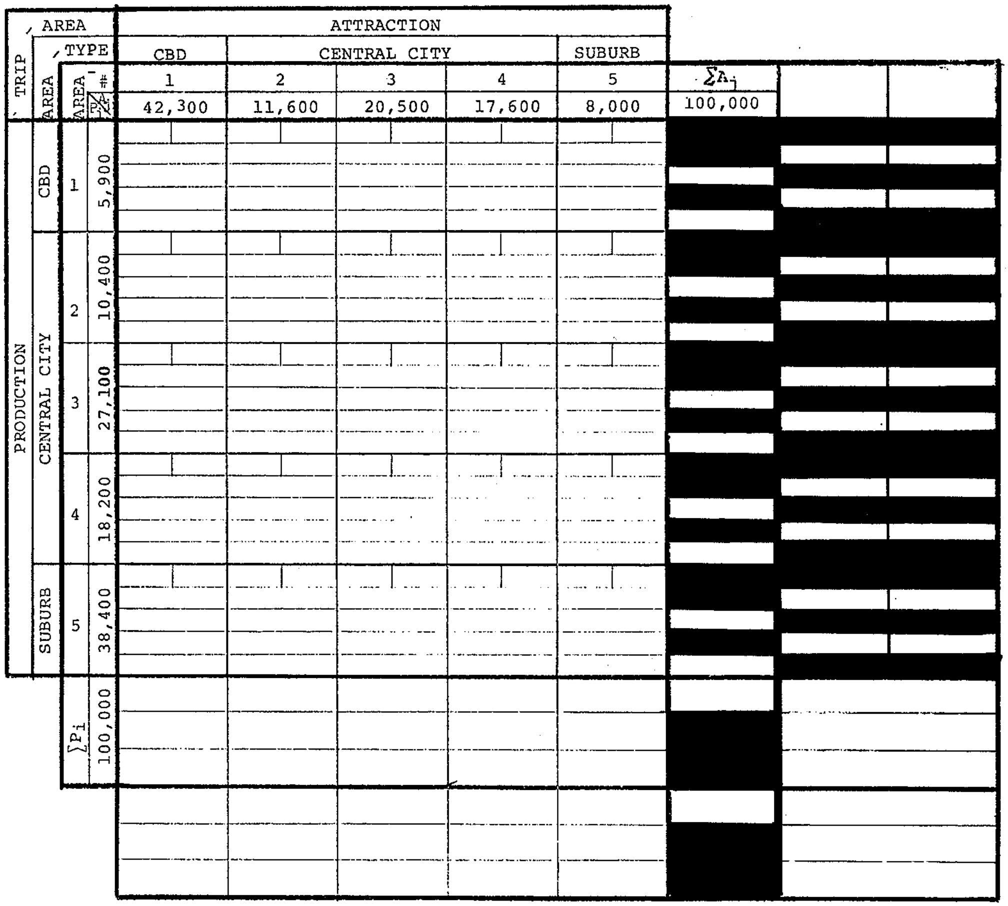


Figure 32. Step 2—Enter production and attraction trip ends.

As a time-saving measure, the attraction factors, $A_j F_{ij}$, can be computed by columns instead of rows. For instance, for column 5, the attraction, $A_j = 8{,}000$, can be stored as a constant in the desk calculator; the attraction factors, $A_j F_{ij}$'s, from $i = 1$ to 5 can be calculated by entering the respective F_{ij} in the calculator and obtaining the product.

Step 5: Calculate trip interchanges, T_{ij}*—iteration 1.* The trip interchanges are calculated using $T_{ij} = R_i A_j F_{ij}$. The production and attraction totals at the end of iteration 1 are also obtained (Fig. 34). Thus:

- Trip interchange for district $i = 3$ and district $j = 5$ is:

$$T_{ij} = R_i A_j F_{ij} = 0.506540 \times 4{,}500 = 2{,}300$$

- Production total for district $i = 3$ is:

$$P_i = \sum_{j=1}^{5} T_{ij} = 10{,}700 + 2{,}800 + 9{,}200 + 2{,}000 + 2{,}300$$
$$= 27{,}100 \text{ (which matches the desired } P_i\text{)}$$

- Attraction total for district $j = 5$ is:

$$A_j = \sum_{i=1}^{5} T_{ij} = 200 + 200 + 2{,}300 + 700 + 6{,}800$$
$$= 10{,}200$$

(Unbalanced: +28 percent difference from desired A_j)

At this point, because of the structure of the gravity model formulation which constrains the production values, the production total for each district will equal the true production trip ends. The attraction totals, however, will not necessarily match their input values. To refine the calculated interchanges, attraction totals are adjusted before application in iteration 2.

The adjustment is made using the formula described in the preceding section entitled "Theory of the Gravity Model." Thus:

- Adjusted attraction total for district $j = 5$ for use in iteration 2 is:

$$A_5^2 = A_5^1 \left(\frac{A_5}{C_5^1} \right) = 8{,}000 \times \frac{8{,}000}{10{,}200} = 6{,}300$$

And so on for all columns (Fig. 34).

Helpful aids and notes of caution:

1. A time savings can be realized by storing R_i as a constant in the calculator and then computing T_{ij} by entering $A_j F_{ij}$ for $j = 1$ to 5.
2. Production balance must exist; if not, an error may have been introduced in the preceding calculations.
3. It is wise to compute the percent differences between the attraction total at the end of iteration 1 and the desired attractions. This will indicate the magnitude of deviations.

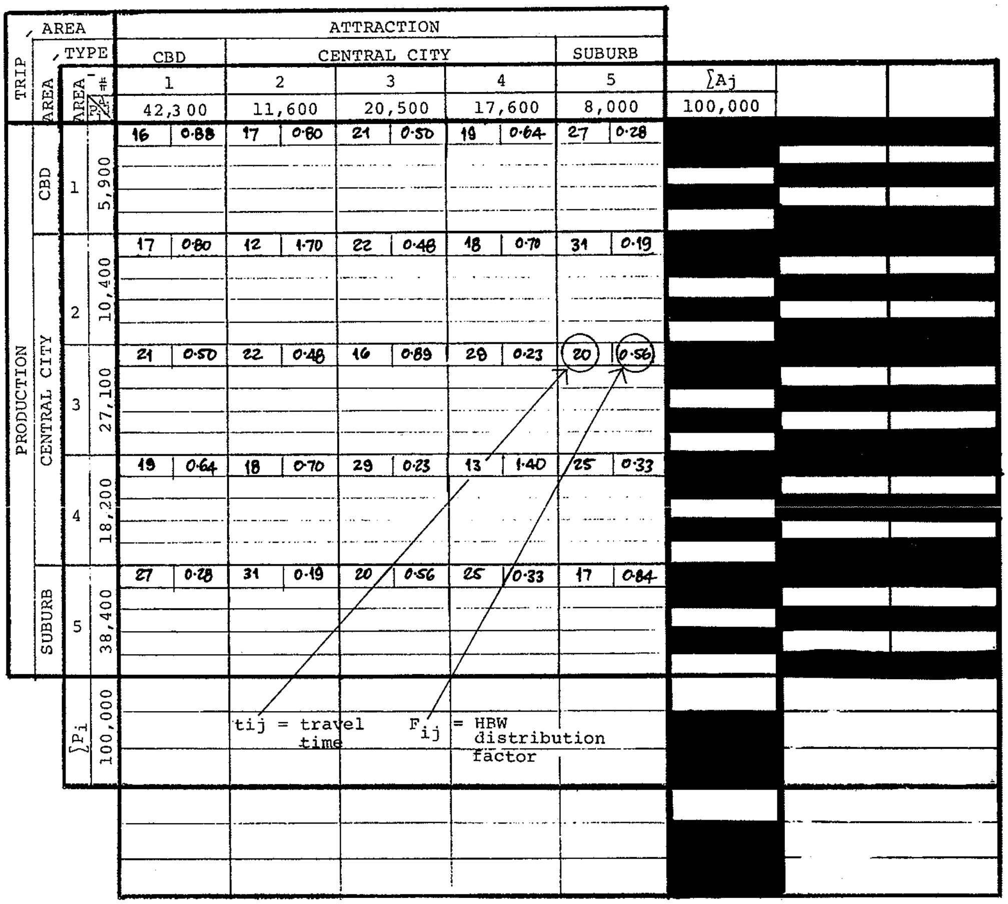


Figure 33. Step 3—Enter district-to-district travel time and distribution factors.

4. It should be noted that the trip matrix is not triangular, that is, trips from i to $j \neq$ trips from j to i; therefore, interchanges for all cells must be calculated.

Step 6: Recalculate terms as in Step 4—iteration 2. This step, as shown in Figure 35, is a repetition of Step 4, but using the adjusted attraction totals from iteration 1, thus:

- Attraction factor from district $i = 3$ to district $j = 5$ is:

$$A_j F_{ij} = 6{,}300 \times 0.56 = 3{,}500$$

- Accessibility index for district $i = 3$ is:

$$\sum_{j=1}^{5} A_j F_{ij} = 23{,}800 + 6{,}000 + 15{,}400 + 4{,}100 + 3{,}500 = 52{,}800$$

- Production index for district $i = 3$ is:

$$R_i = P_i / \sum_{j=1}^{5} A_j F_{ij} = 27{,}100/52{,}800 = 0.513258$$

And so on for all rows and columns.

Step 7: Recalculate terms as in Step 5—iteration 2. This step is a repetition of Step 5, but using the new attraction factors, $A_j F_{ij}$, and the new production index, R_i, computed in Step 6. The production and attraction totals are also calculated by rows and columns, respectively (Fig. 35). Thus:

- Trip interchange from district $i = 3$ to district $j = 5$ is:

$$T_{ij} = R_i A_j F_{ij} = 0.513258 \times 3{,}500 = 1{,}800$$

- Production total for district $i = 3$ is:

$$P_i = \sum_{j=1}^{5} T_{ij} = 12{,}200 + 3{,}100 + 7{,}900 + 2{,}100 + 1{,}800 = 27{,}100 \text{ (matches the desired } P_i)$$

- Attraction total for district $j = 5$ is:

$$A_j = \sum_{j=1}^{5} T_{ij} = 100 + 100 + 1{,}800 + 500 + 5{,}600 = 8{,}100$$

(+1 percent difference from desired A_j)

At the end of this iteration, the new attraction totals should have converged very close to the desired attraction totals. If this is not the case and it is desired that trip interchanges be defined further through an additional iteration (3), the adjusted attraction totals can be computed as follows:

- Adjusted attraction total for district $j = 5$ for use in iteration 3 (if desired) is:

$$A_5^3 = A_5^2 \left(\frac{A_5}{C_5^2} \right) = 6{,}300 \times \frac{8{,}000}{8{,}100} = 6{,}200$$

And so on for all columns. Note that at the end of iteration 2, all the attraction totals are within ±3 percent of the desired attraction totals which is sufficiently accurate in nearly all applications. Generally a third iteration is not recommended.

Finally, the average trip time (ATT) of the HBW trips can be calculated, if desired, quite simply by using:

$$ATT = \frac{\sum_{i=1}^{5} \sum_{j=1}^{5} T_{ij} \cdot t_{ij}}{\sum_{i=1}^{5} \sum_{j=1}^{5} T_{ij}} \qquad (4)$$

where

T_{ij} = trip interchanges from area i to area j;
t_{ij} = travel time for trip interchange $_{ij}$;

that is

$$ATT = \frac{(3{,}300 \times 16) + (800 \times 17) + \ldots + (6{,}200 \times 25) + (5{,}600 \times 18)}{100{,}000}$$

$$= 20.5 \text{ min.}$$

At this juncture, it is advisable to conduct a systematic check of the various calculations to confirm the validity of the figures. If no errors are detected, the 5 by 5 district trip distribution is then considered complete.

These interchanges represent the HBW trip purpose, if required; the HBNW and NHB trip interchanges can also be calculated in a similar fashion. Note, however, that for HBNW and NHB trips, the district-to-district travel times remain the same as those calculated initially; only the distribution factors will be different.

In some cases where a quick and rough trip-distribution matrix is to be developed, one need only perform the distribution computations for the HBW trips, and then factor these to arrive at the *total* (all purpose) trip distribution. Thus, the HBNW and NHB trip distributions could be avoided altogether. These "expansion" factors are discussed in Chapter Six, "Time-of-Day Characteristics," and such a method has been described in Chapter Ten, "Scenario for Site Development Impact Analysis: Boise, Idaho." The manual trip-distribution procedure described previously is shown in Figure 36.

A Case Application and Evaluation of Results

In order to investigate the capabilities and effectiveness of the manual trip-distribution procedure described in the preceding discussion, an application of the procedure was made to the 1970 home-based work travel in the Atlanta, Georgia, metropolitan area. Results from the manual procedure were compared with Atlanta's application of the PLANPAC computerized gravity model, using the Atlanta home-interview survey trip table as a base.

To provide a background of the Atlanta region, a map showing the 34 districts, and some of the transportation facilities are shown in Figure 37. Some relevant transportation data are presented as follows:

TRIP / AREA / TYPE			ATTRACTION: CBD	CENTRAL CITY			SUBURB		Accessibility index	Production index
	AREA	AREA # / P_i	1	2	3	4	5	$\sum A_j$	$\sum A_j F_{ij}$	$R_i = \frac{P_i}{\sum A_j F_{ij}}$
			42,300	11,600	20,500	17,600	8,000	100,000		
PRODUCTION CBD	1	5,900	16 / 0.88	17 / 0.80	21 / 0.50	19 / 0.64	27 / 0.28			
			37200	9300	10300	11300	2200		70300	0.083 926
			3100	800	900	900	200	5 900		
					A_jF_{ij} = attraction factor – iteration #1; T_{ij} = trip interchange – iteration #1					
PRODUCTION CENTRAL CITY	2	10,400	17 / 0.80	12 / 1.70	22 / 0.48	18 / 0.70	31 / 0.19			
			33800	19700	9800	12300	1500		77100	0.134 889
			4600	2700	1300	1700	200	10 400		
	3	27,100	21 / 0.50	22 / 0.48	16 / 0.89	29 / 0.23	20 / 0.56			
			21200	5600	18200	4000	4500		53 500	0.506 540
			10700	2800	9200	2000	2300	27 100		
	4	18,200	19 / 0.64	18 / 0.70	29 / 0.23	13 / 1.40	25 / 0.33			
			27100	8100	4700	24600	2600		67 100	0.271 236
			7400	2200	1300	6700	700	18 200		
PRODUCTION SUBURB	5	38,400	27 / 0.28	31 / 0.19	20 / 0.56	25 / 0.33	17 / 0.84			
			11800	2200	11500	5800	6700		38 000	1.010 523
			11900	2200	11600	5900	6800	38 400		
	$\sum P_i$	100,000	37700	10700	24300	17200	10200	100 000	Attraction totals at the end of Iteration #1	
			−11%	−8%	+19%	−2%	+28%		% Difference from true attractions	
			47500	12600	17300	18000	6300		Adjusted attraction totals for Iteration #2	
									Attraction totals at the end of Iteration #2	
									% Difference from true attractions	
									Adjusted attraction totals for Iteration #3	

Figure 34. Step 4—Calculate attraction factors, accessibility index, and production index: Iteration 1. Step 5—Calculate trip interchanges: Iteration 1.

AjFij = attraction factor - iteration #2
Tij = trip interchange - iteration #2

TRIP: PRODUCTION — AREA TYPE	AREA #	P_i	ATTRACTION: CBD 1 (42,300)	CENTRAL CITY 2 (11,600)	CENTRAL CITY 3 (20,500)	CENTRAL CITY 4 (17,600)	SUBURB 5 (8,000)	$\sum A_j$ (100,000)	$\sum A_j F_{ij}$	$R_i = \frac{P_i}{\sum A_j F_{ij}}$
CBD	1	5,900	16 / 0.88	17 / 0.80	21 / 0.50	19 / 0.64	27 / 0.28			
			37200	9300	10300	11300	2200		70 300	0.083 926
			3100	800	900	900	200	5 900		
			41 800	10 100	8700	11 500	1800		73 900	0.079 837
			3 300	800	700	900	100	5 900		
CENTRAL CITY	2	10,400	17 / 0.80	12 / 1.70	22 / 0.48	18 / 0.70	31 / 0.17			
			33800	19700	9800	12300	1500		77 100	0.134 889
			4600	2700	1300	1700	200	10 400		
			38 000	21 400	8 300	12 600	1100		81 400	0.127 764
			4900	2700	1 100	1600	100	10 400		
CENTRAL CITY	3	27,100	21 / 0.50	22 / 0.48	16 / 0.89	29 / 0.23	20 / 0.56			
			21 200	5600	18200	4000	4500		53 500	0.506 540
			10700	2800	9200	2000	2300	27 100		
			23800	6 000	15400	4100	3 500		52 800	0.513 258
			12 200	3 100	7900	2100	1800	27 100		
CENTRAL CITY	4	18,200	19 / 0.64	18 / 0.70	29 / 0.23	13 / 1.40	25 / 0.33			
			27 100	8100	4700	24600	2600		67 100	0.271 236
			7400	2200	1300	6700	700	18 200		
			30 400	8800	4000	25 200	2100		70 500	0.258 154
			7 800	2300	1 000	6 500	500	18 200		
SUBURB	5	38,400	27 / 0.28	31 / 0.19	20 / 0.56	25 / 0.33	18 / 0.84			
			11800	2200	11500	5800	6700		38 000	1.010 523
			11 900	2200	11600	5900	6800	38 400		
			13 300	2400	9700	5900	5300		36 600	1.049 180
			14 000	2500	10 200	6 200	5600	38 400		
$\sum P_i$		100,000	37 700	10 700	24 300	17 200	10 200	100 000	Attraction totals at the end of Iteration #1	
			-11%	-8%	+19%	-2%	+28%		% Difference from true attractions	
			47 500	12 600	17 300	18 000	6 300		Adjusted attraction totals for Iteration #2	
			42 200	11 400	20 900	17 300	8 100	100 000	Attraction totals at the end of Iteration #2	
			0%	-2%	+2%	-2%	+ 1%		% Difference from true attractions	
			47 600	12 800	17 000	18 300	6 200		Adjusted attraction * totals for Iteration #3	

* if required

Figure 35. Step 6—Recalculate attraction factors, accessibility index, and production index: Iteration 2. Step 7—Recalculate trip interchanges: Iteration 2.

- Study area: Atlanta metropolitan region.
- Study year: 1970.
- Population: 1,173,000.
- Area—CBD: 2 sq mi.
- Area—central city: 180 sq mi (approximate).
- Area—suburbs: 1,800 sq mi (approximate).
- Area—total: 2,000 sq mi (approximate).
- Number of districts: 34.
- Area of smallest district (CBD): 2 sq mi.
- Area of largest district: 260 sq mi.
- Miles of freeway (1972): 209 mi.
- Miles of arterial (1972): 678 mi.
- Miles of locals and collectors (1972): 4,752 mi.
- Total HBW productions (=attractions): 993,968 person-trips.
- Average HBW trip time: 23.05 min.

Criteria used for comparing some of the significant results of the manual procedure with the computer model (for 34 by 34 district trip distributions) are given in Table 6. These two sets of results are also compared against Atlanta's home-interview trip tables. An additional criterion used for comparison is the trip-length-frequency distribution diagram shown in Figure 38 for each of the three sets of trip interchange results.

It should also be noted that Atlanta's district-level trip interchanges output by computer were obtained by aggregating zonal interchanges. This fact adds even more credibility to the validity of the manual procedure results, the effectiveness of which is self-evident from Table 6 and Figure 38.

Resource Requirements

As described in the preceding sections, the manual trip-distribution procedure was applied to a 5-district illustrative example and a 34-district Atlanta case application for HBW work trips. For both applications, accurate time logs were compiled; each application includes the time required for the following major steps:

1. Preliminaries, organization, and bookkeeping.
2. The seven steps outlined under "Application of Manual Trip-Distribution Procedure to Regionwide Analysis," that is, map layout of study area through two iterations of the manual procedure.
3. Random checking and tests for reasonableness.

At the completion of both applications, some conclusions were drawn concerning time and cost requirements. Contrary to common belief of the intensive resource requirements of a manual application of the gravity model, it is expected that such an application can be manageable up to the 80-zone/district level. Using an ordinary electronic desk calculator with accumulating memory, the 5 by 5 illustrative example was accomplished in less than 2 person-hours and the 34 by 34 Atlanta case in less than 26 person-

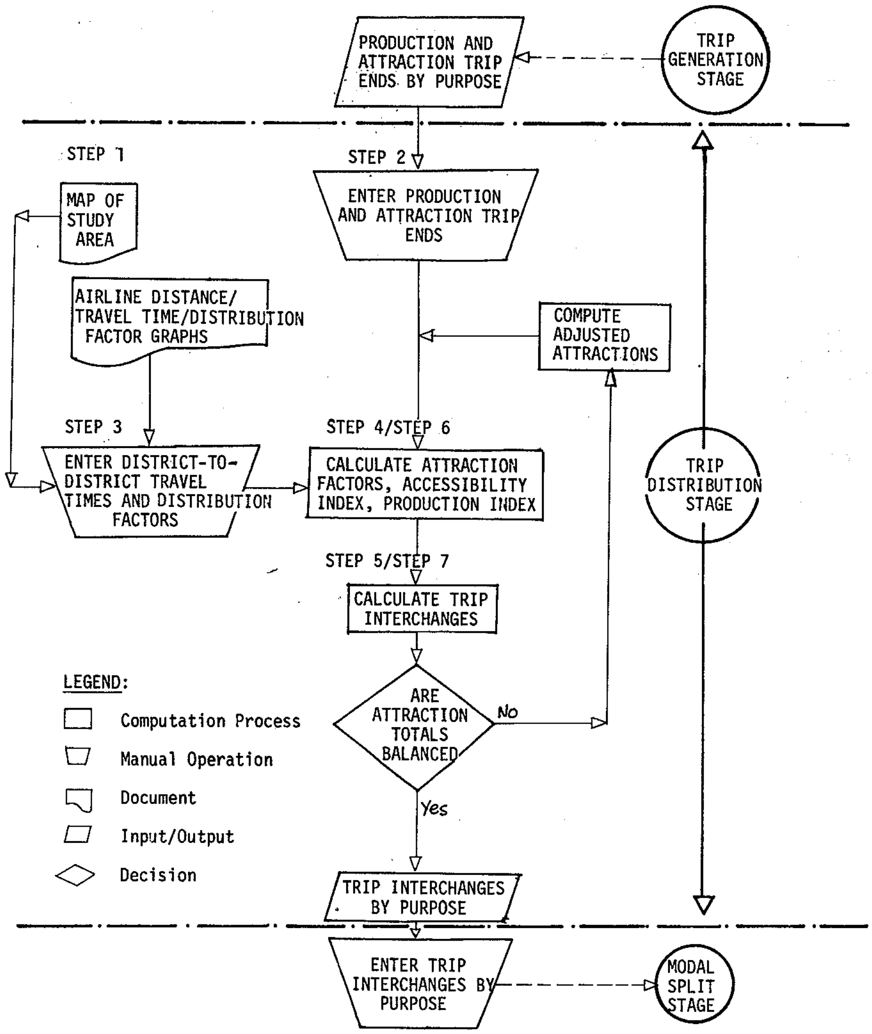


Figure 36. Summary flow chart of the manual trip-distribution procedure.

hours. These hours pertain to efforts of one transportation analyst.

It is expected that with proper supervision, a technician can accomplish the work within a similar time frame. At this point, it is uncertain and would be misleading to project how these time requirements would be affected if more than one person were assigned the task: the time requirements are not necessarily inversely proportional to the number of persons working.

In any case, these times are reasonable and acceptable for quick response, especially when comparable applications on a computer would probably require more time, money, and expertise for organization, coding, and execution. However, if testing of several alternatives is contemplated, the computer might be an asset.

Details of time requirements for the 5-district and 34-district level analyses are given in Table 7. The times presented correspond to trip distribution for the HBW trip purpose only. If distribution were to be performed also for HBNW and NHB trips, Step 2 will obviously not have to be repeated because the district-to-district travel times remain the same irrespective of trip purpose; only the distribution factor for HBW and NHB trips will have to be substituted. It is estimated, therefore, that only 15 percent of the time required for Steps 1 and 2 will be consumed for each of the subsequent purposes; the time requirements for Steps 3, 4, and 5 will remain constant for each trip purpose.

Hence, total time required to distribute HBNW (or NHB) trips for a 5-district level would be given by:

$$\frac{15}{100} \times (30 + 25) + 20 + 15 + 15 = 58 \text{ min} = 1 \text{ hr (approx.)}$$

Similarly, total time required to distribute HBNW (or NHB) trips for a 34-district level would be given by:

$$\frac{15}{100} \times (70 + 540) + 480 + 380 + 60 = 1{,}012 \text{ min} = 17 \text{ hr (approx.)}$$

It is evident from the figures given in Table 7 that an exponential mathematical relationship exists between the total time required to carry out the distribution and the number of zones/districts. This relationship is shown in Figure 39; this graph has been provided to enable the user to estimate time requirements for application of the manual trip-distribution procedure.

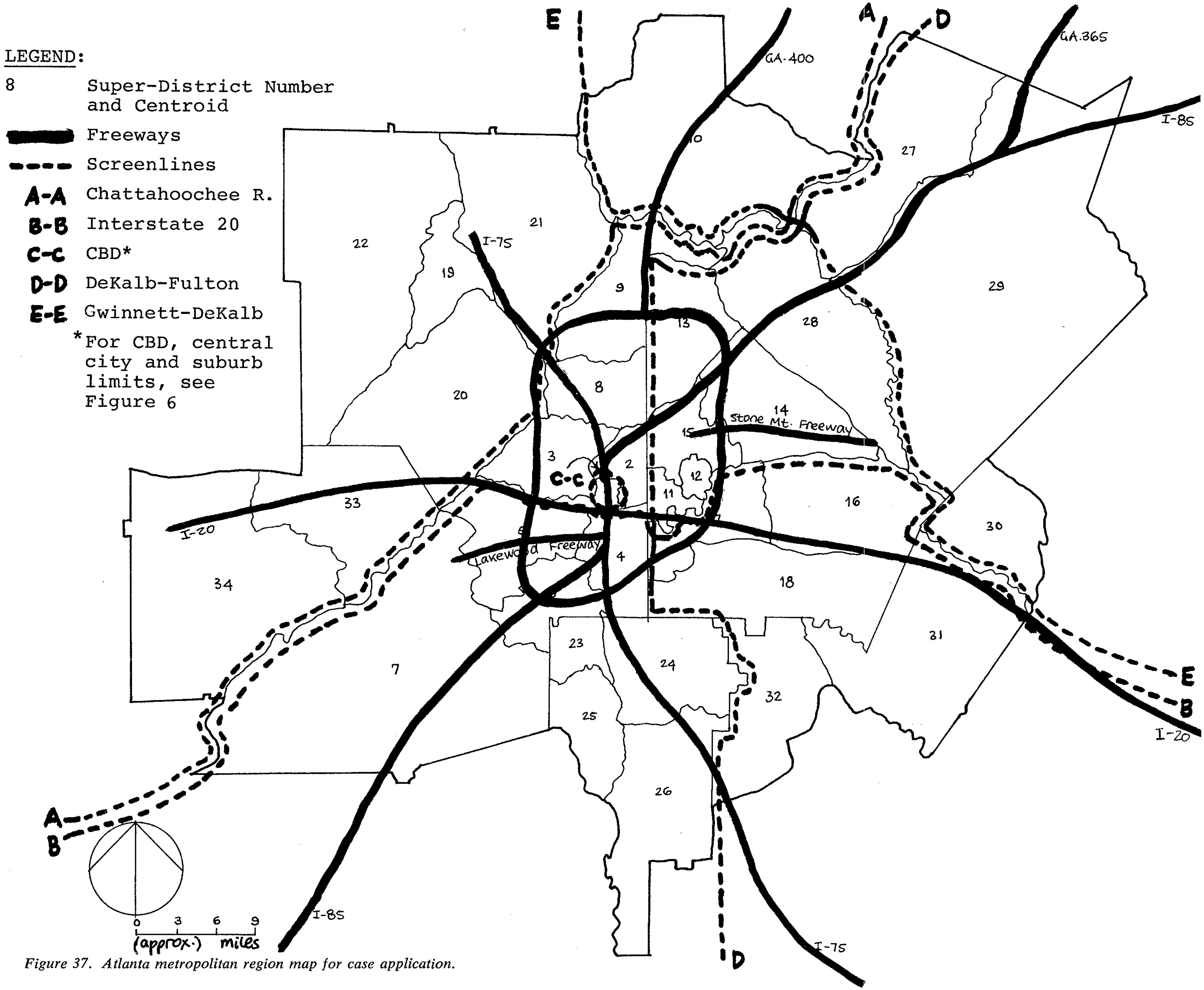


Figure 37. Atlanta metropolitan region map for case application.

TABLE 6

COMPARISON OF THE MANUAL PROCEDURE, PLANPAC GRAVITY MODEL, AND HOME-INTERVIEW SURVEY TRIP RESULTS—1970 HOME-BASED WORK PERSON-TRIPS FOR ATLANTA, GEORGIA

COMPARISON CRITERIA	MANUAL PROCEDURE	PLANPAC GRAVITY MODEL	HOME-INTERVIEW SURVEY	% DIFF(M)[a]	% DIFF(G)[a]
1. AVERAGE TRIP TIME (Mins.)	22.38	22.40	23.05	-2.9	-2.8
2. INTRAZONAL TRIPS: [b,c]					
1st highest intrazonals (13-13)	13551	19466	23289	-41.8	-16.4
2nd highest intrazonals (20-20)	25883	23607	21168	+22.3	+11.5
3rd highest intrazonals (5-5)	8747	12197	13381	-34.6	-8.8
Total intrazonals regionwide (34)[d]	195228	219853	232302	-16.0	-5.4
3. TRIP INTERCHANGES: [b,c]					
1st highest interchange (3-2)[e]	14178	13077	11714	+21.0	+11.6
2nd highest interchange (3-1)[e]	19008	14847	15634	+21.6	-5.0
3rd highest interchange (2-1)[e]	14547	11052	11346	+28.2	-2.6
Total interchanges regionwide (34x34)	993968	993968	993968	0.0	0.0
4. SCREENLINES:[f]					
A-A Chattahoochee River	137117	124803	g	g	g
B-B Interstate 20	268372	261667			
C-C CBD	135709	134735			
D-D DeKalb-Fulton	237527	241562			
E-E Gwinnett-DeKalb	37347	33282			

a. $\% \text{ DIFF(M)} = \frac{\text{Manual - Interview}}{\text{Interview}} \times 100$; $\% \text{ DIFF(G)} = \frac{\text{Gravity - Interview}}{\text{Interview}} \times 100$.
b. Highest volume person-trips with respect to home-interview survey tables.
c. Numbers in parentheses represent production and attraction district numbers respectively.
d. Excludes district 1-to-1 intrazonals due to unavailability.
e. Other than intrazonals.
f. Two-way screenline crossings.
g. Screenlines not computed.

APPLICATIONS OF THE MANUAL TRIP-DISTRIBUTION PROCEDURE TO CORRIDOR AND SITE ANALYSES

The manual trip-distribution procedure described in the preceding sections can provide trip interchange information required for site and corridor analyses. Generally, site and corridor analyses require more detailed evaluation than is required for regionwide analysis. Eighty analysis units are probably more than sufficient, however, for most site, corridor, or regional analyses.

Corridor Analysis

Two appoac'ˌes can be used to study a corridor. The first is based on having already developed a trip table on a regional basis. The second is to develop a new trip table based on the specific problem to be solved.

If a trip table is already available for a region, a proportioning process can be easily used to develop trips between smaller analysis units in the corridor of study. For the following discussion, reference should be made to Figure 40. Assume two original analysis units 1 and 8 as shown with 1,000 trips moving between them. If analysis unit 1 was split into two units with one (unit 1a) producing 4,000 of the original total of 5,000 and the second (unit lb) producing 1,000 of the total, an estimate of trips between the new zones can be calculated as follows:

$$T_{1a\text{-}8} = 1{,}000 \times \frac{4{,}000}{5{,}000} = 800 \text{ trips}$$

$$T_{1b\text{-}8} = 1{,}000 \times \frac{1{,}000}{5{,}000} = 200 \text{ trips}$$

If both original analysis units are split into smaller units, then the calculation includes proportioning based on the split at both ends as:

$$T_{1a\text{-}8} = 1{,}000 \times \frac{4{,}000}{5{,}000} \times \frac{1{,}000}{3{,}000} = 267 \text{ trips}$$

$$T_{1a\text{-}8b} = 1{,}000 \times \frac{4{,}000}{5{,}000} \times \frac{2{,}000}{3{,}000} = 533 \text{ trips}$$

$$T_{1a\text{-}8c} = 1{,}000 \times \frac{4{,}000}{5{,}000} \times \frac{0}{3{,}000} = 0 \text{ trips}$$

To generalize, then, proportioning of trips between large zones into trips between subdivisions of the original zones takes the form:

$$T_{an\text{-}bz} = T_{a\text{-}b} \times P_n \times A_z \qquad (5)$$

where

$T_{an\text{-}bz}$ = Trips produced in subdivision *n* of area *a* and attracted to subdivision *z* of area *b*;

$T_{a\text{-}b}$ = Trips produced in area *a* and attracted to area *b*;

P_n = Proportion of trip productions in subdivision *n* to total productions in area *a*.

A_z = Proportion of trip attractions in subdivision *z* to total attractions in area *b*.

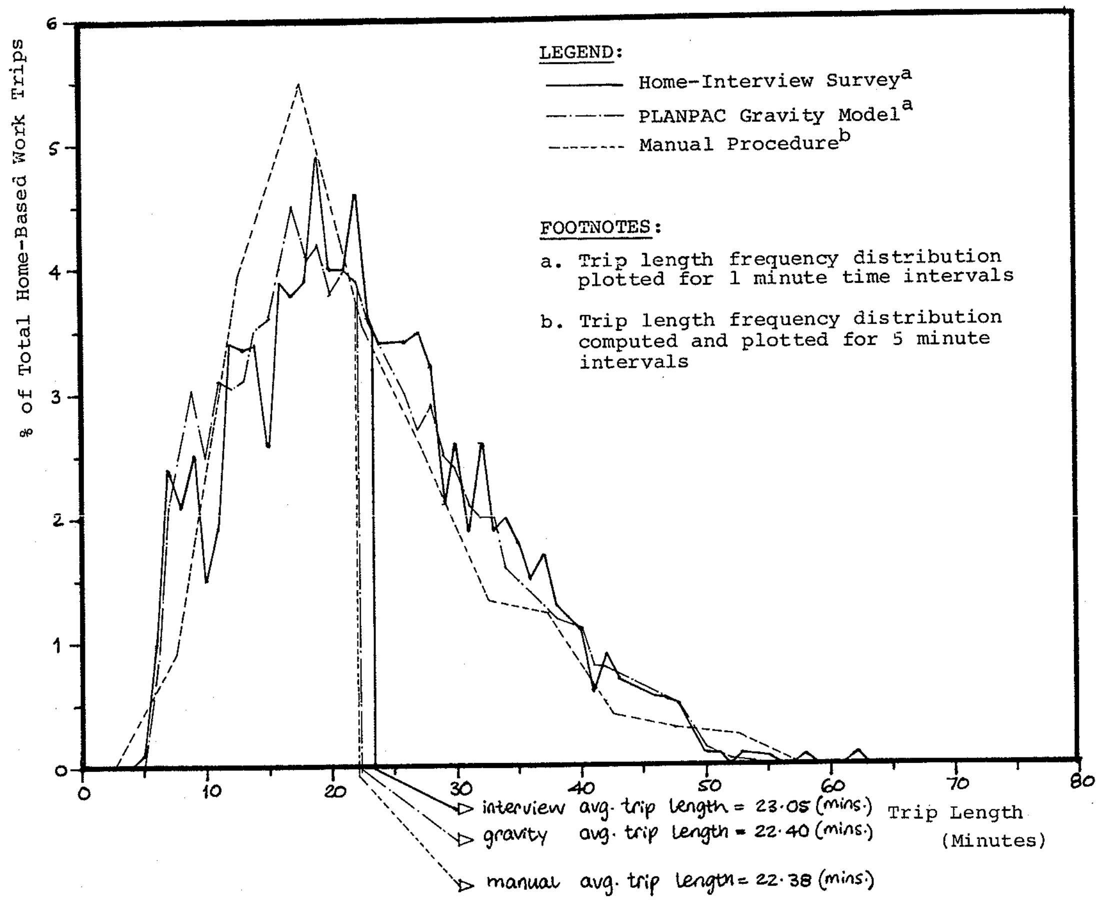


Figure 38. Trip length frequency distribution plots for manual procedure, PLANPAC gravity model, and home-interview-survey trip results.

To illustrate the organization of data to handle the type of manipulations presented in the foregoing paragraphs, reference is made to Figure 41 and the calculated trip matrix shown in Figure 42. Assume a corridor is to be studied and a more detailed set of area-to-area trips is desired in the corridor. The corridor can roughly be described by analysis areas 1, 2, and 3. Assume area 1 is to be split into two subdivisions, and areas 2 and 3 are to be split into four subdivisions, each as shown in Figure 41. The calculations can best be handled by subdividing the problem into three types of calculation: (1) trips between the subdivided areas; (2) trips from the subdivided areas to the non-subdivided areas; and (3) trips from the non-subdivided areas. Figure 42 shows the resulting computations for the original trip matrix produced as shown in Figure 35.

To illustrate a few calculations the following is offered:

$$T_{1a\text{-}2b} = T_{1\text{-}2} \times P_{1a} \times P_{2b} = 800 \times 0.50 \times 0.30 = 120 \text{ trips}$$

$$T_{1a\text{-}5} = T_{1\text{-}5} \times P_{1a} = 100 \times 0.50 = 50 \text{ trips}$$

$$T_{5\text{-}2c} = T_{5\text{-}2} \times A_{2c} = 2{,}500 \times 0.30 = 750 \text{ trips}$$

Another alternative to the foregoing procedure of modifying a trip table is to develop a completely new trip distribution employing a revised set of analysis areas. Both procedures would involve relatively fine analysis areas within the corridor of interest and relatively gross areas outside the area of interest, but would otherwise use the same gravity model trip-distribution procedures already described. It is important, however, to keep the total

TABLE 7

TIME REQUIREMENTS FOR MAJOR STEPS OF THE MANUAL TRIP-DISTRIBUTION PROCEDURE

Major Steps	Time Requirements (min.)[b]	
	5x5 Illustrative Example	34x34 Atlanta Case Application
1. Preliminaries, organization and bookkeeping[a]	30	70
2. Travel times and distribution factor matrix[a]	25	540
3. Accessibility indices/trip interchanges-Iteration #1	20	480
4. Accessibility indices/trip interchanges-Iteration #2	15	380
5. Systematic checking and tests for reasonableness	15	60
TOTAL FOR ALL STEPS	105 (1.8 hrs.)	1530 (25.5 hrs.)

a. These 2 steps need not be repeated for subsequent trip purposes.
b. Time requirements pertain to 1 experienced transportation analyst.

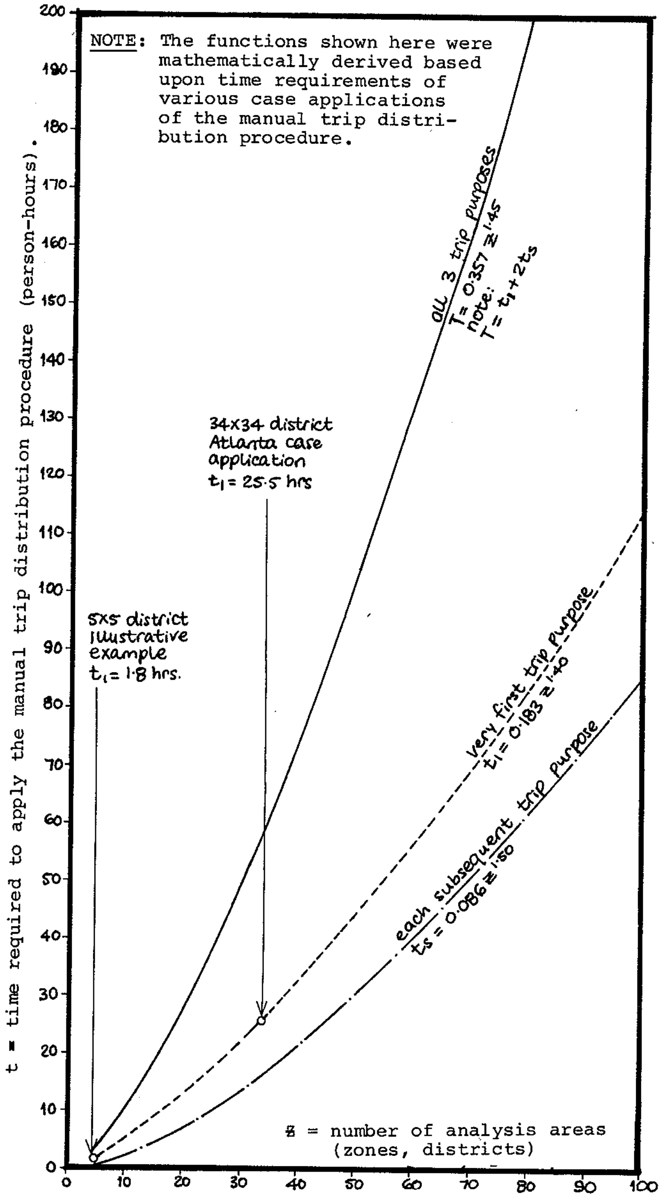


Figure 39. Time required to apply the manual trip-distribution procedure vs number of analysis areas.

number of analysis areas within manageable limits, no more than about 80 units, but more reasonably about 40 to 50 units. Figure 43 shows a possible set of subdivisions for analysis of the Fulton County transportation corridor in Atlanta.

Site Analysis

For site analysis (i.e., that of a special generator), it is often appropriate to accept some modifications to the normal gravity-model distribution process. However, such as in the example of a new employment center, one can expect to be able to distribute trips in the normal fashion with the employment center being just another attractor, where none existed previously. In applying the results of an already-developed manual trip-distribution matrix, or one produced by computer, considerable time savings will result as opposed to developing a new trip matrix for the employment center. Referring to the sample gravity model calculations shown in Figure 35, assume a major employment complex is to be built in analysis area 4 with an attraction value of 10,000 trip ends. The objective is to determine the trip interchanges associated with the development. For illustrative purposes, only production area 1 will be considered. The total accessibility index for production area 1 was 73,900 and the production index, R_i, was 0.079837 (for iteration 2) as shown in Figure 35. Because the new center is in area 4, the distribution factor (1-4) of 0.64 can be directly used to determine the addition in the accessibility index, $\Sigma A_j F_{ij}$, as follows:

$$A_j F_{ij} = 10{,}000 \times 0.64 = 6{,}400$$

The new accessibility index for area 1 would then be 80,300 (i.e., 6,400 + 73,900) and R_i would equal 0.073474. The number of trips between area 1 and the new employment center would be:

$$T_{ij} = R_i A_j F_{ij} = 0.073474 \times 10{,}000 \times 0.64$$
$$= 470 \text{ trips}$$

For this example, the trip productions in area 1 have been left unchanged. Several areas should have more trip productions because of new housing attracted by a major new employment center. The changes in travel volumes between area 1 and other areas are shown in Figure 44 where the computations outlined previously are accomplished for all attractors.

For the example given, the normal production-attraction area relationship was maintained. Where a distribution has not been developed for an entire area and a short-cut computation is desired for a new generator, the relationships between the production and attraction areas may be interchanged; that is, the production area becomes the attractor and the attraction area becomes the producer. For the example of a new employment center just described, assume that an area trip table has not been developed. Now, make the employment center the producer and the other areas the attractor. The problem would be set up as shown in Figure 45. The same answer will not be obtained by this method as was obtained previously. In the way the problem has just been handled, the production areas are competing for the new employment center trips. In the usual case, the employment center is competing with other employment centers for the production area trips. However, for a quick-response type application, the results should be useful in most cases.

Geographic Orientation of Trips Around a Site/Special Generator

Interchanging productions and attractions (i.e., by defining productions as attractions, and vice versa) provides the means for assessing the geographic orientation of travel from a site/special generator. For instance, assume a new shopping center is proposed and the impact on the surrounding street system is to be assessed. One of the initial tasks is to determine the orientation of trips using the center. If a trip table has already been developed for an area, then the method shown in Figure 44 is suggested to

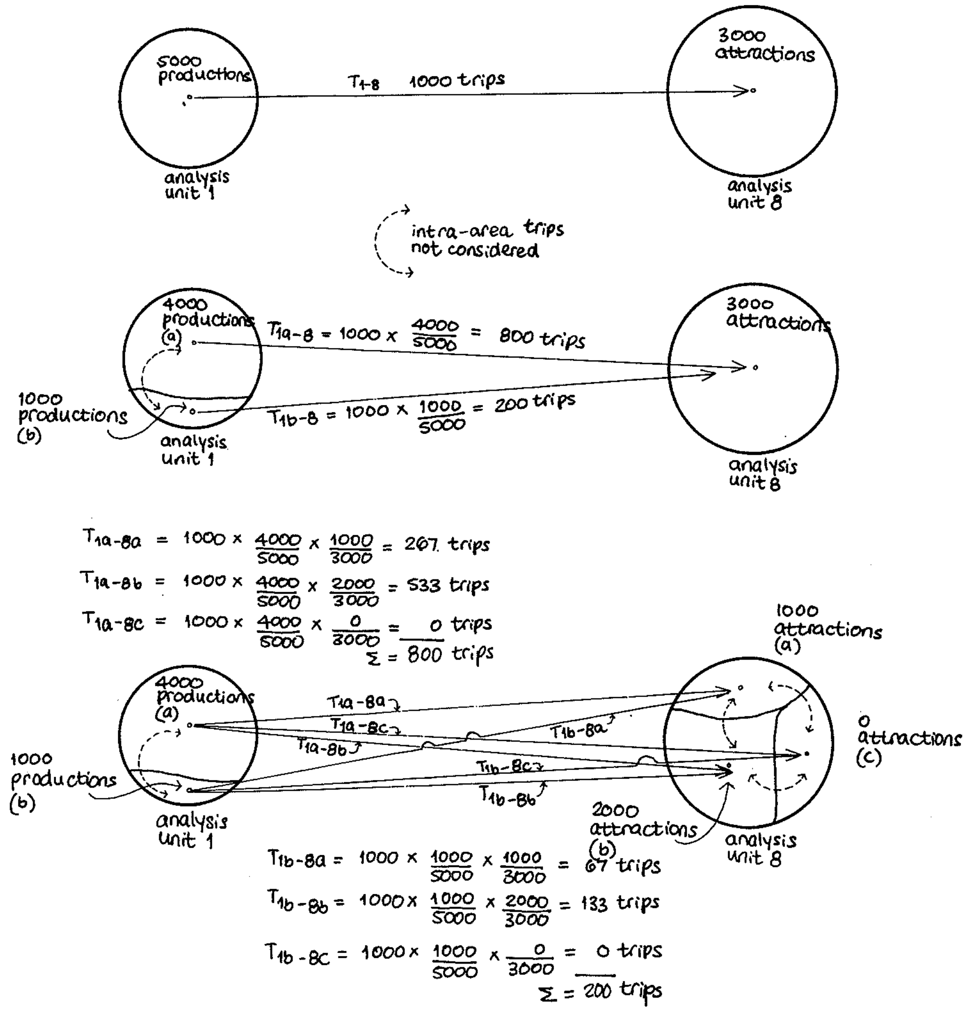


Figure 40. Proportioning of trips between large zones into trips between subdivisions of the zones.

develop the trip matrix for the center because competition from other shopping areas will enter the computation. If, however, a trip matrix has not yet been developed, then interchanging productions and attractions would be suitable.

Assume that only trips to the east are of concern inasmuch as there is excess highway capacity available in all other directions (see Fig. 46). Assume the shopping center has a ground floor area of 1,000,000 sq ft and generates 33.5 vehicle trip ends per 1,000 sq ft (see Table 1, Chapter Two) resulting in 33,500 vehicle trip ends per day. Assume these are basically shopping trips; the 33,500 becomes the production value. For this example, assume the attraction value, A, is the shopping trips to all destinations expected to be made by residents living in the ring segments shown in Figure 46.

It should be noted that the information in Tables 1, 2, and 3 in Chapter Two does not provide shopping trip attractions. An estimate of HBNW trips can be developed and should suffice inasmuch as the process will normalize the trips to the 33,500 trips associated with the shopping center.

The vehicle trips to each ring can be calculated using the manual trip-distribution procedure with the shopping center as the trip producer. For the sake of simplicity, assume that the time exponent for the gravity model is 3.00 for shopping trips and the form of the equation to be used is:

$$T_{ij} = \frac{P_i A_j \frac{1}{t^n}}{\Sigma A_j \frac{1}{t^n}} \tag{6}$$

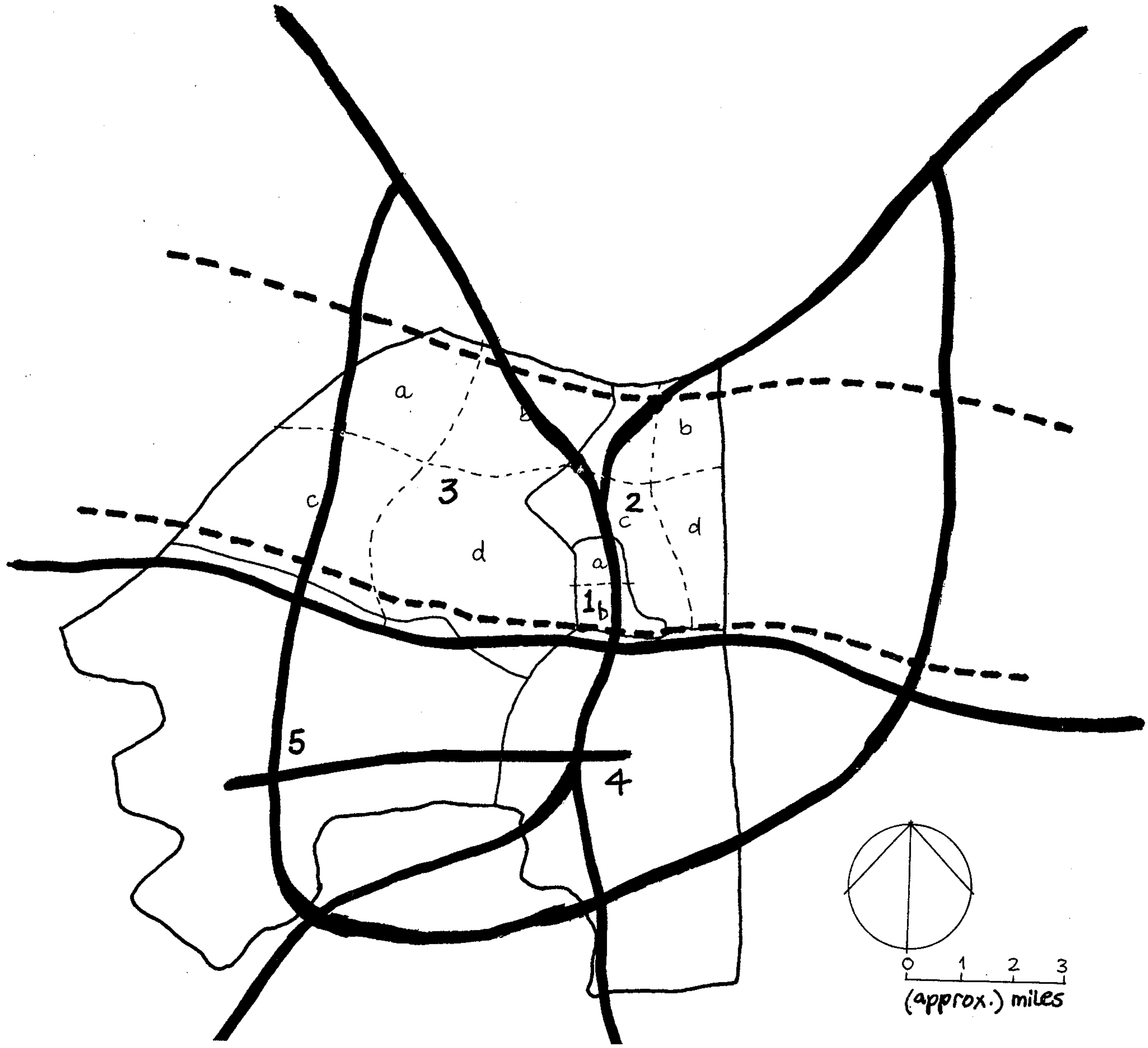
where, as before

T_{ij} = trips;
P_i = productions;
A_j = attractions;
t = time;
n = 3.00.

A table of exponents by urbanized area population and trip purpose is provided in Table 8 for use in this form of the gravity model equation (*27*). The trips to the first ring of the eastern sector would then be given by:

$$T = \frac{33{,}500 \times 2{,}000 \times \frac{1}{4^3}}{\Sigma A_j \frac{1}{t^n}} \tag{6a}$$

The value, $\dfrac{33{,}500}{\Sigma A_j \frac{1}{t^n}}$, is the production index, R_i, described previously.



LEGEND:

4 Analysis Area Number and Centroid

----a Analysis Area Subdivision, Number and Centroid

Freeways

Corridor Boundary

Figure 41. Map of hypothetical city for corridor analysis.

Using an accumulating desk calculator, the $\Sigma A_j \frac{1}{t^n}$ term (i.e., the accessibility index) can be easily calculated in a short time. For the eastern sector, this index would equal:

$$\frac{2{,}000}{4^3}+\frac{8{,}000}{6^3}+\frac{10{,}000}{9^3}+\frac{20{,}000}{15^3}+\frac{30{,}000}{20^3}=91.68$$

For the southern sector the accessibility index is 95.86; it is 20.08 for the western sector, and 48.46 for the northern sector.

Vehicle trips can be expected to "spray out" in relation to the accessibility indices calculated previously as follows:

$$T \text{ east corridor} = \frac{33{,}500 \times 91.68}{91.68 + 95.86 + 20.08 + 48.46} = 11{,}993 \text{ trips} \quad (6b)$$

Trips to the south would equal 12,540; to the west, 2,627; and to the north, 6,340. (Note that the sum of trips in all directions is 33,500.)

AREA	SUB-DIV	PROP	1 a	1 b	2 a	2 b	2 c	2 d	3 a	3 b	3 c	3 d	4	5
			.50	.50	0	.30	.30	.40	.40	.30	.10	.20	1.00	1.00
1	a	.50	825	825	0	120	120	160	140	105	35	70	450	50
1	b	.50	825	825	0	120	120	160	140	105	35	70	450	50
2	a	.20	480	480	0	162	162	216	88	66	22	44	320	40
2	b	.30	720	720	0	248	243	324	132	99	33	66	480	60
2	c	.40	960	960	0	324	324	432	176	132	44	88	640	80
2	d	.10	240	240	0	81	81	108	44	33	11	22	160	20
3	a	.50	3050	3050	0	465	465	620	1580	1185	395	790	1050	900
3	b	.20	1220	1220	0	186	186	248	632	474	1583	316	420	360
3	c	.20	1220	1220	0	186	186	248	632	474	1583	316	420	360
3	d	.10	610	610	0	93	93	124	316	237	79	158	210	180

TRIPS BETWEEN SUBDIVISIONS

TRIPS BETWEEN SUBDIVISIONS AND AREAS

TRIPS BETWEEN AREAS AND SUBDIVISIONS

AREA	SUB-DIV	PROP	1 a	1 b	2 a	2 b	2 c	2 d	3 a	3 b	3 c	3 d
			.50	.50	0	.30	.30	.40	.40	.30	.10	.20
4	4	1.00	3900	3900	0	690	690	920	400	300	100	200
5	5	1.00	700	700	0	750	750	1000	4080	1860	620	1240

Figure 42. Illustration of data organization for trip proportioning between analysis areas and subdivisions of analysis areas.

Looking at the eastern sector, vehicle trips can be studied in detail by subdividing the ring segments into zones as shown in the bottom half of Figure 46. Trips to the three subdivisions of the first ring would then be calculated as follows:

$$\text{Trips to 1} = \frac{33{,}500 \times \frac{1{,}000}{4^3}}{(91.68 + 95.86 + 20.08 + 48.46)} = 2.045 \text{ trips}$$

$$\text{Trips to 2} = \frac{33{,}500 \times \frac{500}{4^3}}{256.08} = 1{,}022 \text{ trips}$$

$$\text{Trips to 3} = \frac{33{,}500 \times \frac{500}{4^3}}{256.08} = 1{,}022 \text{ trips}$$

These detailed vehicle trip values can be used to analyze movement around the center to determine the impacts on the road system. As mentioned previously, this procedure does not consider the competition of other shopping centers included in the results when the trip productions and attractions are not interchanged. However, the approach just described will be useful for some applications and should not be overlooked.

Where a limited number of shopping centers exist, the problem does not become overly burdensome if calculations are accomplished in the normal production-to-attraction manner. For example, if there is a CBD, two shopping centers, and perhaps two to three other shopping areas worth considering when evaluating a proposed shopping center, the planner may wish to set up a trip matrix with the number of analysis areas of production equal to, for example, 30 and the number of attraction areas equal to 6 (proposed center, CBD, two existing centers, and two other shopping areas).

TRIP DISTRIBUTION USING AVAILABLE ACCESSIBILITY INDICES

Once a gravity model has been applied for some gross set of analysis areas, the results of the model can be used for analyses at a more detailed level to calculate trip interchanges for very specific land uses, for example. A key parameter in the application of the gravity model is the accessibility index of each production area. Recall that this index is the sum total of the products of the attraction trip ends for, and the distribution factors to, all the attraction areas. Mathematically, the accessibility index, X_i, for area i is given as follows:

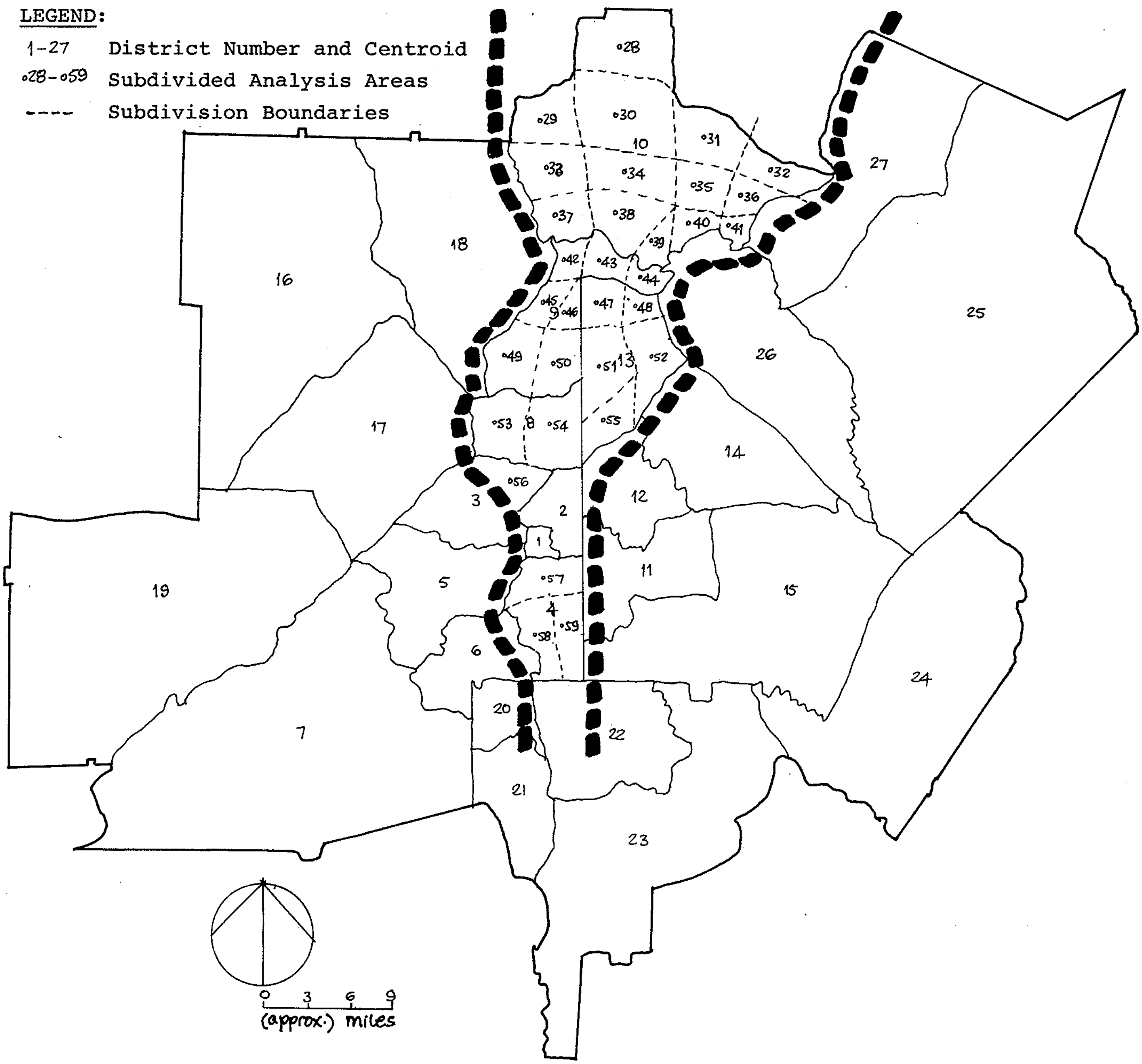


Figure 43. Atlanta metropolitan area, showing the Fulton County transportation corridor with district subdivisions.

$$X_i = \sum_{j=1}^{j} A_j F_{ij} \quad (7)$$

To illustrate the application of an accessibility index already derived for a large area (e.g., district) and now to be used for analysis of subdivisions (e.g., zones), consider the following example. For the 5 by 5 district trip-distribution matrix shown in Figure 35, the various trip parameters for production district 1 are shown diagramatically in Figure 47. Suppose that travel to *subdivisions* (three zones) of attraction district 2 is to be calculated, as shown in the upper portion of Figure 48. By assuming that the travel time from district 1 to *each* of the three zones of district 2 remains the same at 17 min, and that the accessibility index of district 1 is still 70,300, travel to the three zones can then be calculated as shown in the upper portion of Figure 48.

The preceding example can be extended even further. If travel from subdivisions (two zones) of production district 1 is to be computed, a similar method can be used. Thus, the accessibility index of district 1 remains at 70,300, and travel to the three zones of district 2 can be calculated as shown in the lower portion of Figure 48. (The user must be cautioned, however, that in addition to *inter*-area travel, *intra*-area travel must be considered. Total travel estimates can be obtained only when these two types of interchanges are accounted for. Note that in the examples illustrated in Figure 48, intra-district travel has not been calculated, but that "intras" are indicated using dashed arrows to draw attention.)

TRIP END / AREA TYPE	ATTRACTION: CBD	CENTRAL CITY				SUBURB			
AREA #	1	2	3	4	4 New Empl.	5	ΣA_j	$\Sigma A_j F_{ij}$	$R_i = \frac{P_i}{\Sigma A_j F_{ij}}$
P_i \ A_j	42,300	11,600	20,500	17,600	10,000	8,000	110,000		
PRODUCTION CBD 1 5,900	16 | 0.88	17 | 0.80	21 | 0.50	19 | 0.64	19 | 0.64	27 | 0.28			
	37200	9300	10300	11300		2200		70300	0.083926
	3100	800	900	900		200	5900		
	41800	10100	8700	11500	6400	1800		80300	0.073474
	3100	700	600	800	500	100	5900		

Figure 44. Example of calculating trips to a new analysis area by use of available trip-distribution matrix.

TRIP END / AREA TYPE	ATTRACTION: CBD	CENTRAL CITY			SUBURB			
AREA #	1	2	3	4	5	ΣA_j	$\Sigma A_j F_{ij}$	$R_i = \frac{P_i}{\Sigma A_j F_{ij}}$
P_i \ A_j	5,900	10,400	27,100	10,200	38,400	100,000		
NEW EMPL. CENTER 10,000	19 | 0.64	18 | 0.70	29 | 0.23	13 | 1.40	25 | 0.33			
	3800	7300	6200	25500	12700		55500	0.181180
	700	1300	1100	4600	2300	10000		

Figure 45. Example of interchanging production and attractions.

In actuality, the zone-to-zone travel times are not the same as those for the district-to-district interchanges because interzonal distances may be greater than or less than the interdistrict distances, depending, of course, on the spatial separation of the respective centroids. But over-all, any resultant positive or negative differences in trip interchanges will offset each other, thus providing a reasonable estimate of travel. For quick-response estimation, the technique described in the foregoing paragraphs is acceptable. Later in this section, a method is described which enables the user to develop the zonal accessibilities from the district accessibility to account for the geographical spread of zones within a district.

An interesting and useful application of the accessibility indices is the contour plot which provides a simple and convenient means for computing trip interchanges. Moreover, the contours enable the user to obtain an instant picture of regional accessibility. This concept is described herein using accessibility indices calculated in the 34-district Atlanta area case application for 1970 home-based work

TABLE 8

GRAVITY MODEL IMPEDANCE EXPONENTS BY TRIP PURPOSE AND URBANIZED AREA POPULATION [a]

TRIP PURPOSE		URBANIZED AREA POPULATION (000)[b]: 50-250	250-750	750 +	Average
HBW	- HB Work	1.99	2.08	1.94	2.00
HBNW[c]	- HB Shop	2.98	3.72	3.43	3.38
	- HB Soc.-Rec.	2.28	2.62	2.40	2.43
	- HB Other	2.94	2.94	3.26	3.05
NHB	- Non-HB	2.68	2.65	2.91	2.75

a. The gravity model impedance exponents were derived from the friction factor curves contained in Reference (27).

b. Reference (27) does not provide friction factor curves for the 4 urbanized area population groups used in this chapter (and throughout this Users Guide).

c. Reference (27) does not provide friction factor curves for the HBNW trip purpose (as used in this chapter and throughout this Users Guide), but rather for the HB Shop, HB Social-Recreational and HB Other trip purposes.

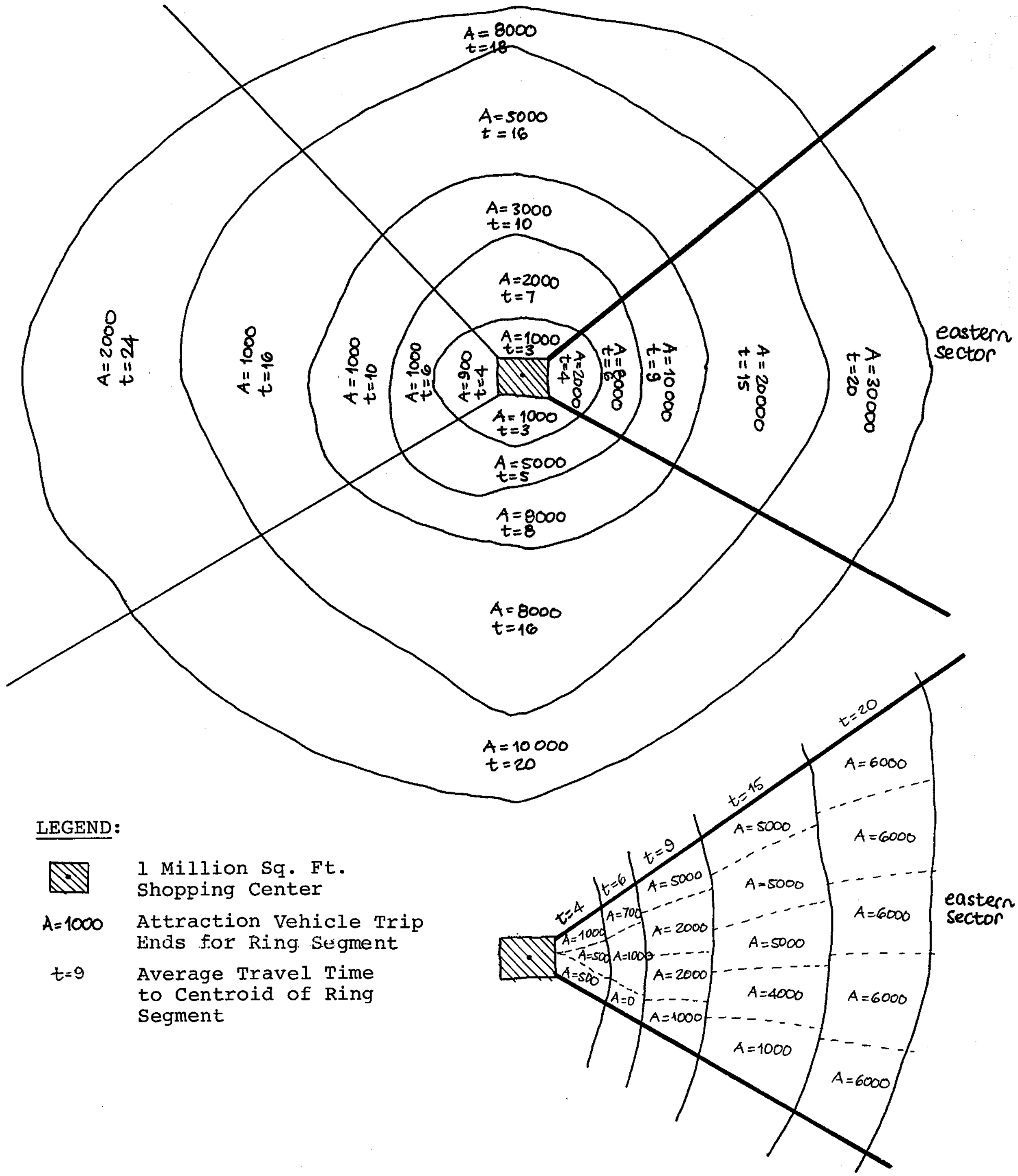


Figure 46. Computation of the geographic orientation of trips around a site/special generator.

trips. (See previous section entitled "A Case Application and Evaluation of Results.")

The 34-district indices were plotted at the centroids for each of the districts and then contours were drawn for the metropolitan region as shown in Figure 49. (In order to study the concept further, 525 *zonal* indices, corresponding to the 525 Atlanta Area Transportation Study zones, were also plotted for both home-based work and home-based shop trips. Similarly, accessibility indices were plotted for these two trip purposes for the Washington, D.C., Metropolitan Region and the Nashua, New Hampshire, area. The zonal contour plots are not included here because they were drawn on a large scale.)

It is is quite clear from the district plot shown in Figure 49 that a distinctive pattern of concentric contours forms around the CBD. The zonal home-based work contours are particularly indicative: not only do the contours emanate from the CBD, but also zones with the highest accessibilities are located at the periphery of the CBD, and those with the lowest accessibilities are located at the outlying fringes of the region. Inside the CBD, however, the accessibility index drops slightly from that of the highest value (although this is not easily discernible from Fig. 49). One other characteristic of the contours that is readily apparent in the zonal plots (but less so in the district plots) is that the contours are distorted in the vicinity of major thoroughfares, especially freeways; that is, an outward elongation of the contours exists along the freeways.

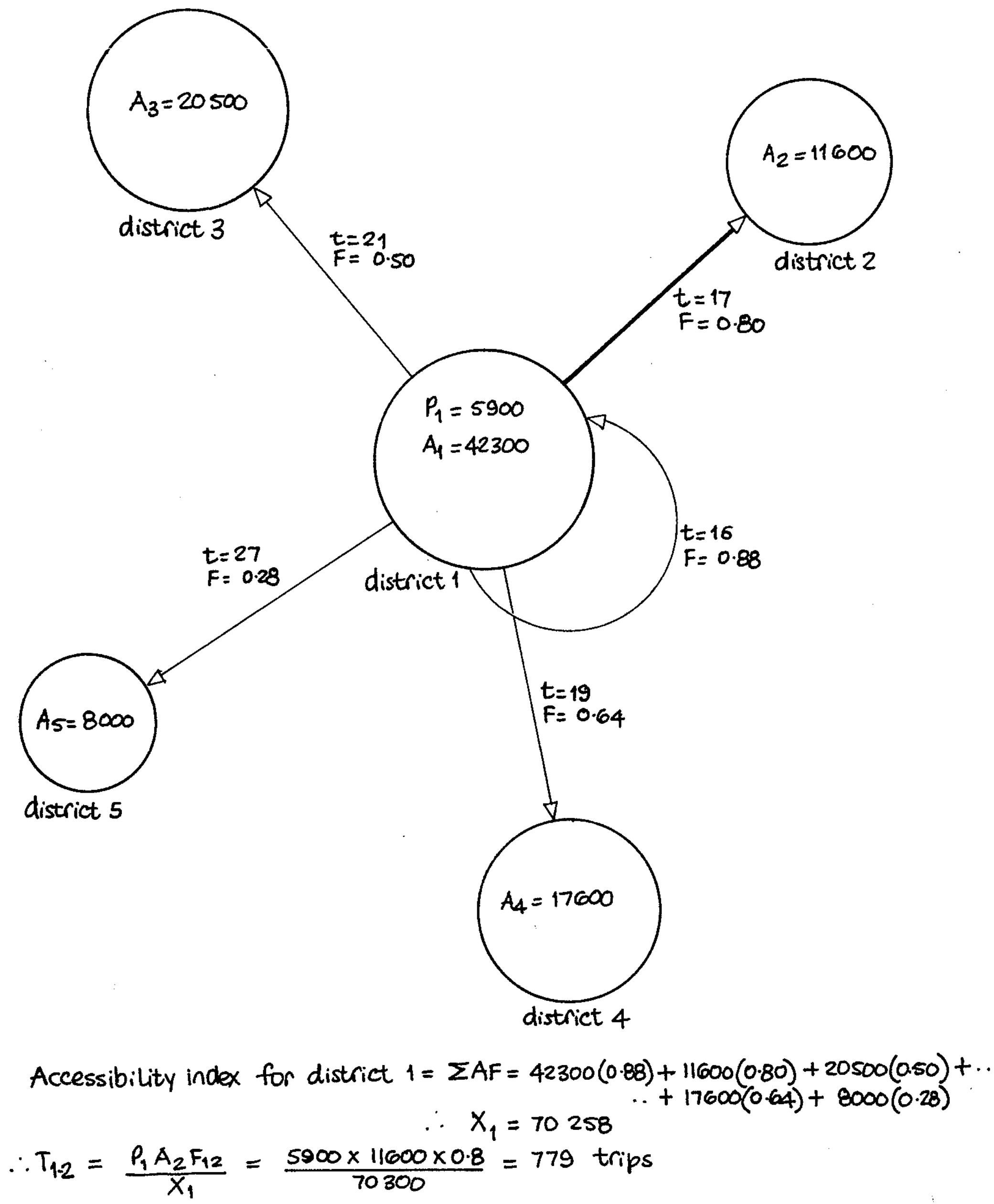


Figure 47. Diagrammatic representation of trips from District 1, as computed in trip-distribution matrix (Fig. 35).

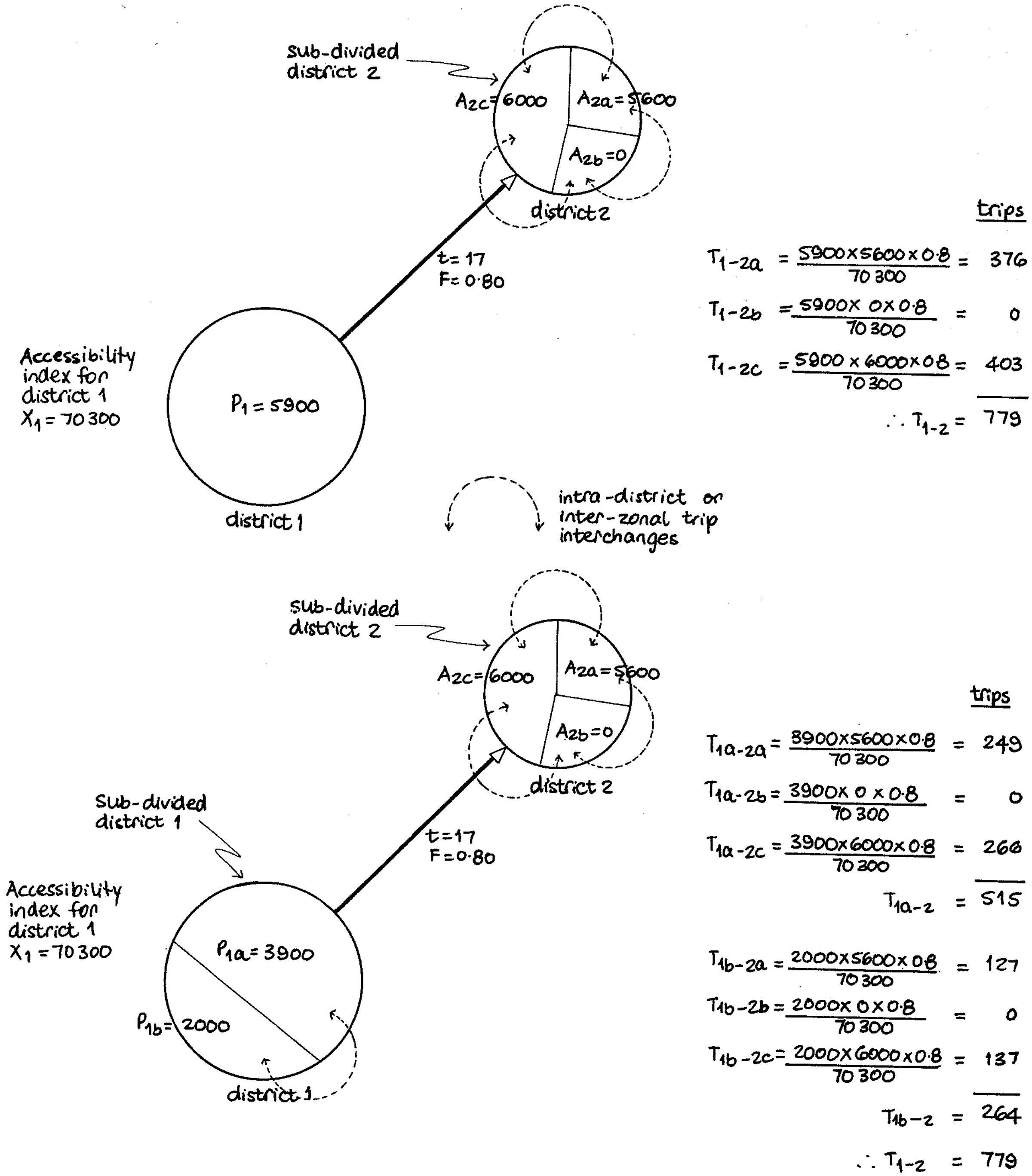


Figure 48. Use of accessibility index to calculate trip interchanges between district subdivisions (zones).

This result is in agreement with the reality that high-speed facilities increase accessibilities.

All these patterns were consistently noticeable for home-based work trips for all three cities (i.e., Atlanta, Washington, D.C., and Nashua). (Home-based shop contour plots formed irregular patterns and were deemed inconclusive for manual trip distribution.) An idea of the variations in accessibility indices can be obtained from Figure 50, which shows a typical cross-section of the contours (corresponding to cross-section SS in Fig. 49).

Earlier in the discussion, it was noted that interdistrict and interzonal travel times (and therefore the consequent accessibility indices) may vary in magnitude for similar trip interchanges. It was also pointed out that these differences might affect trip interchanges. The contour plots shown in Figure 49 enable the user to refine the district accessibilities through interpolation. (The accuracy of the interpolated values can be enhanced if a large map scale is used for the contour plots, say, 1 in. to 3 mi.) Evidence of the small differences between zonal accessibilities interpolated from the district accessibility contours and the same obtained from the calibrated gravity model are given in Table 9. (Note again that Atlanta's 34-district level accessibility indices were derived using the manual procedure, whereas

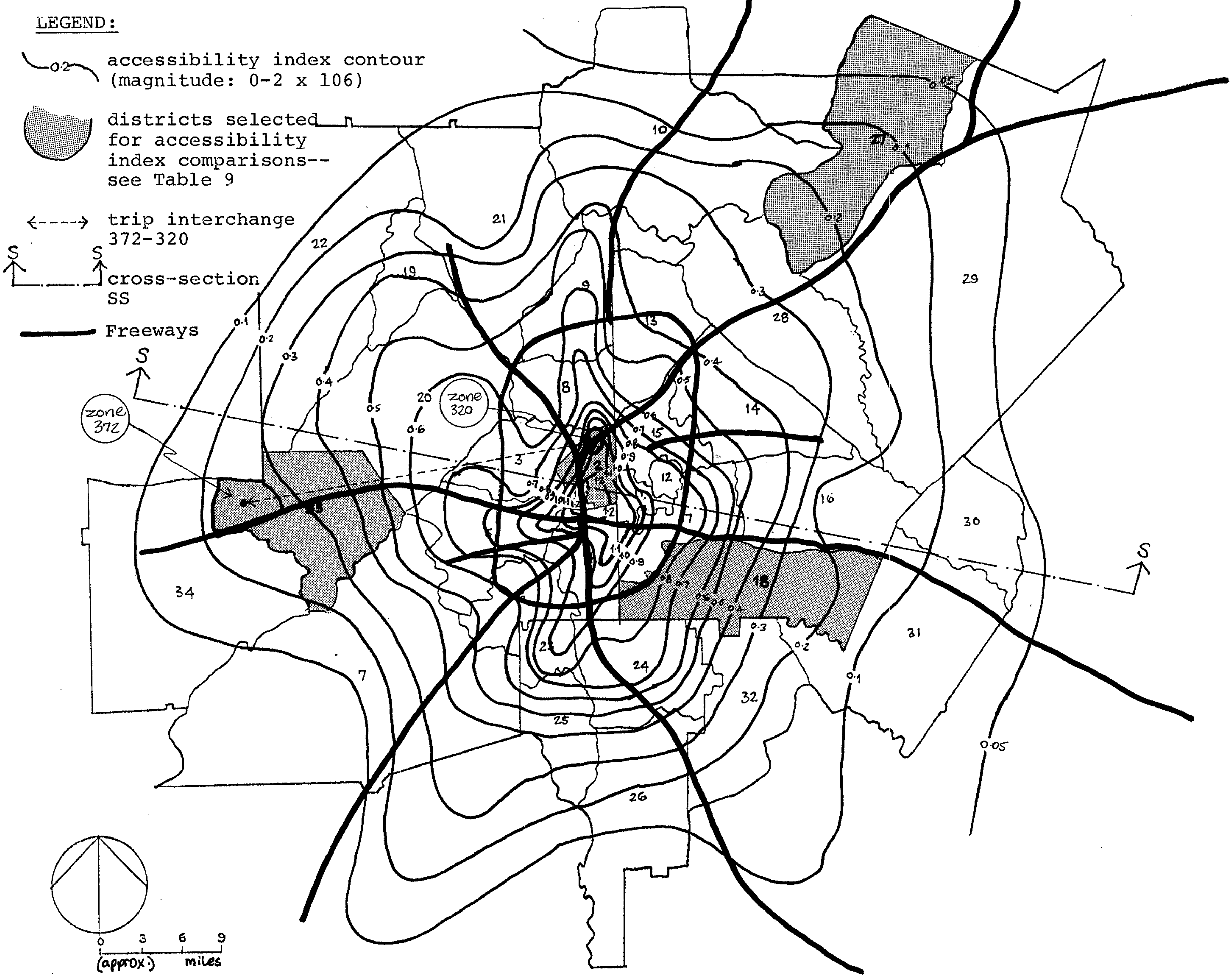


Figure 49. Atlanta metropolitan region district accessibility index contour plots for home-based work trips (index $\times 10^8$).

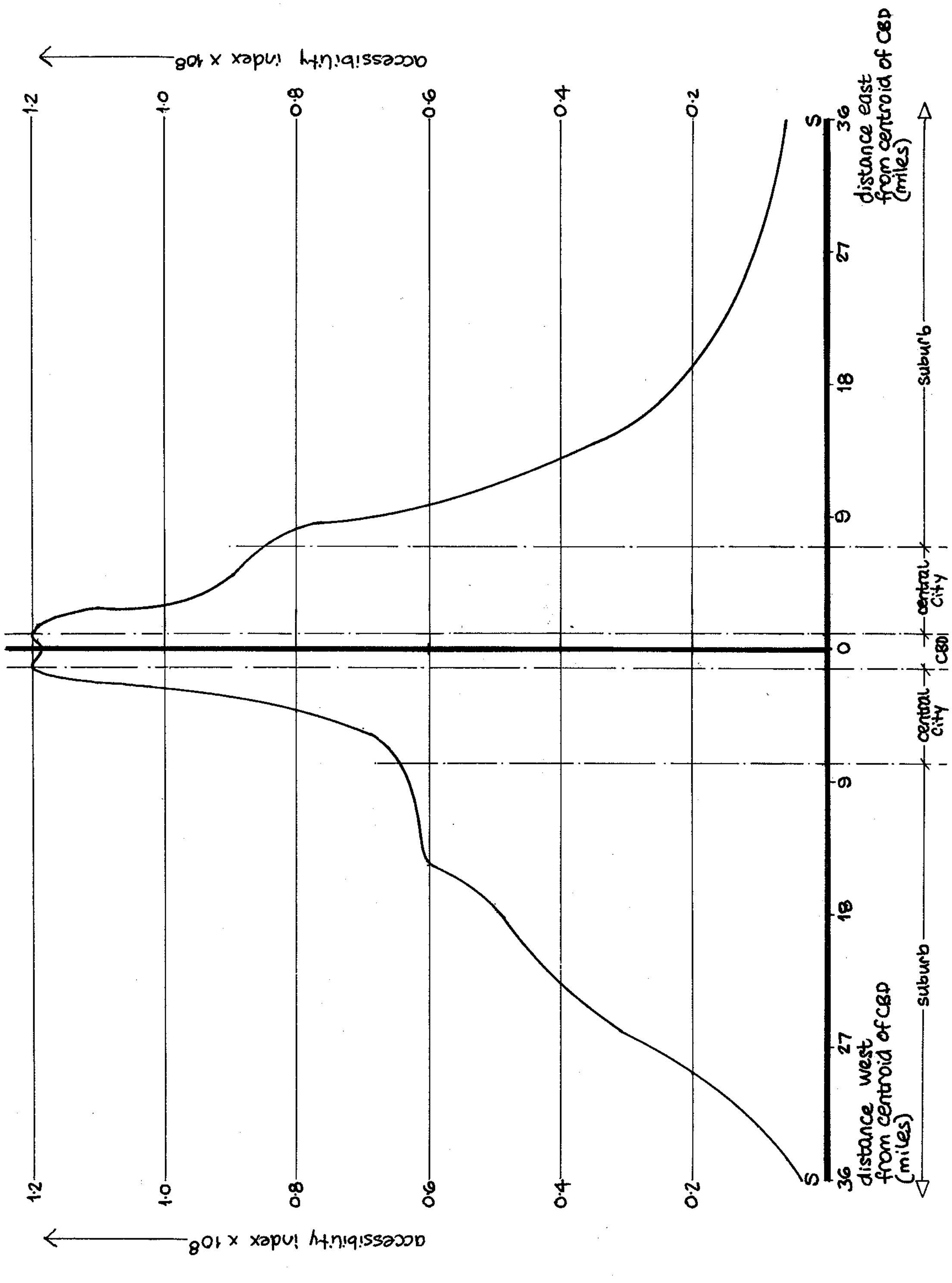


Figure 50. Cross section SS of accessibility index contour plot (Fig. 49).

the 525 zone indices were output by the computer application of the gravity model—PLANPAC). Thus, the user can pick off the accessibility index, X_i, of any zone, i, using the district accessibility index contour plot (Fig. 49). Using this index, trips, T_{ij}, between that zone and any other zone, j, can be computed from:

$$T_{ij} = \frac{P_i A_j F_{ij}}{X_i} \qquad (8)$$

Consider the following cases: in case 1, HBW trip interchanges are to be calculated between district 33 (suburb) and district 2 (central city). Variables for this trip interchange are as follows:

$P_i = P_{33}$ = 14,580 HBW production trip ends (given);
$A_j = A_2$ = 129,634 HBW attraction trip ends (given);
$t_{ij} = T_{33-2}$ = 39 min (airline distance = 18 mi; 12 mi suburb at 10 percent arterial . . . in-vehicle travel time = 20 min (Fig. 30); 6 mi central

city at 20 percent arterial . . . in-vehicle travel time = 13 min (Fig. 29); terminal times suburb to central city = 6 min; total travel time = 20 + 13 + 6 = 39 min);

$F_{ij} = F_{33\text{-}2} =$ 12 [from Atlanta's calibrated gravity model (GM)*];

$X_i = X_{33} = 0.30 \times 10^8$ (from contour plot, Fig. 49);

$$T_{ij} = T_{33\text{-}2} = \frac{14{,}580 \times 129{,}634 \times 12}{0.03 \times 10^8} = 756 \text{ person-trip interchanges.}$$

This district trip interchange agrees fairly well with that obtained from the manual procedure.

Now consider case 2, in which HBW trip interchanges are to be calculated between zones 372 (within district 33) and 320 (within district 2). Variables for this trip interchange are as follows:

$P_i = P_{372}$ = 4,361 HBW production trip ends (given);
$A_j = A_{320}$ = 6,711 HBW attraction trip ends (given);
$t_{ij} = t_{372\text{-}320}$ = 43 min (airline distance = 22.5 mi; 15 mi suburb at 10 percent arterial . . . in-vehicle travel time = 25 min (Fig. 30); 7.5 mi central city at 15 percent arterial . . . in-vehicle travel time = 16 min (Fig. 29) terminal times suburb to central city = 6 min; total travel time = 25 + 16 + 6 = 47 min);
$F_{ij} = F_{372\text{-}320}$ = 5 (from Atlanta's calibrated GM);
$X_i = X_{372} = 0.25 \times 10^8$ (Interpolated from contour plot, Fig. 49);

$$T_{ij} = T_{372\text{-}320} = \frac{4{,}361 \times 6{,}711 \times 5}{0.25 \times 10^8} = 6 \text{ person-trip interchanges.}$$

This zonal trip interchange is within 25 percent of that output by the computer application of the gravity model (PLANPAC).

Several other interchanges were similarly tested with reasonably good results. It can be seen, therefore, that the accessibility index which has to be calculated anyway as part of the manual trip-distribution procedure, can be applied (after the final iteration) as a practical and convenient tool to compute trip interchanges between either districts or zones.

TRIP-DISTRIBUTION PATTERNS FOR SELECTED SITES

Some previous work, (*2, 3*) which may prove useful for quick-response applications, has resulted in trip-distribution curves for some land-use types. These curves are provided herein for the following sites/special generators: airports; shopping centers; hospitals; universities; office buildings; and state capitol buildings, and are shown in Figures 51 through 56, respectively.

TABLE 9

COMPARISON OF SELECTED DISTRICT-LEVEL AND ZONAL-LEVEL ACCESSIBILITY INDICES FOR 1970 ATLANTA AREA HOME-BASED WORK TRIPS

DISTRICT	SAMPLE ZONES WITHIN DISTRICT	ACCESSIBILITY INDEX x 10^5	
		FROM CONTOURS[a]	FROM GRAVITY MODEL[b]
2	28	1250	1200
	65[c]	1200	970
	101	1150	920
	312	1200	1360
	320	1050	1460
18	183	650	610
	185	830	740
	430	500	440
	456[c]	370	260
	459	190	180
27	500	210	150
	501	170	160
	502[c]	120	120
	503	60	70
	505	30	40
33	372	250	230
	373[c]	330	140
	375	280	250
	376	320	270
	377	260	170

a. Interpolated from contours in Figure 49.
b. Output from calibrated gravity model (using PLANPAC).
c. Zones most representative of district centers.

To use these curves, the population by analysis area is required as well as the travel time from each analysis area to the generator. For example, looking at the airport curves in Figure 51, it can be seen that for an analysis area 10 min from an airport, about 4.7 auto driver trips per 1,000 population would be expected. Thus, for an analysis area with 150,000 population, about 70 auto driver-trips per day to the airport would be expected. As a control on the curves presented, trips from all analysis areas to a site should be calculated. The total of these should be compared against a control total based on the trip-generation characteristics of the site and the trips from each analysis area proportioned so that the totals match.

LIMITATIONS OF METHODS

Trip distribution appears to be a simple process in that it involves the proper connection of trip ends from the production area to the attraction area. The process becomes more complicated because calculated trip ends usually do not match the original trip ends derived from the trip-generation phase. This problem is commonly referred to as "trip-end imbalance"; corrective action involves iterative adjustments to the trip interchanges to achieve an acceptable state of balance. Obviously, given a large number of analysis areas (e.g., zones), several modes and

* The normalized friction factor developed was not used simply because the Atlanta calibrated set was available. Mathematically, the use of either *normalized* friction factors or actual, *calibrated* friction factors should yield approximately the same results when applied in the gravity model. This is because (1) the normalized set is merely a proportioned set of the calibrated friction factors and (2) the friction factors appear in both the numerator and denominator of the gravity model formulation.

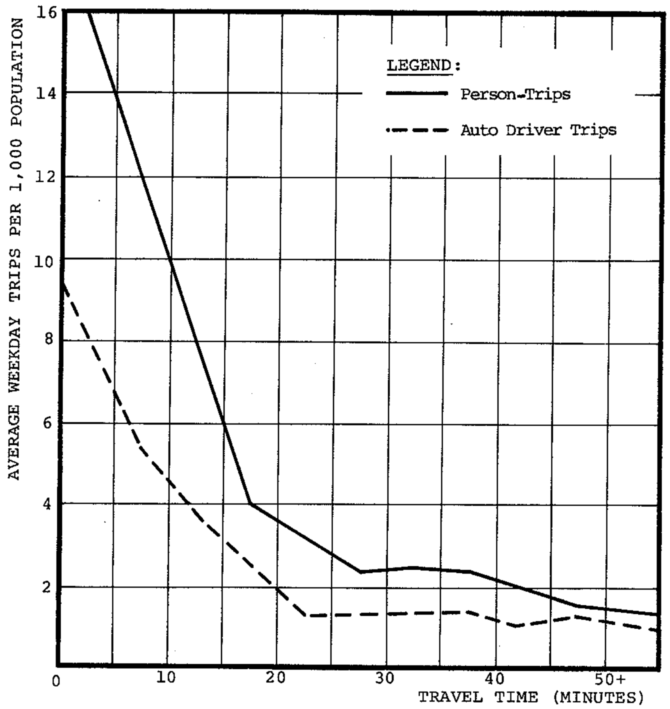


Figure 51. Trip to airports per 1,000 population (2).

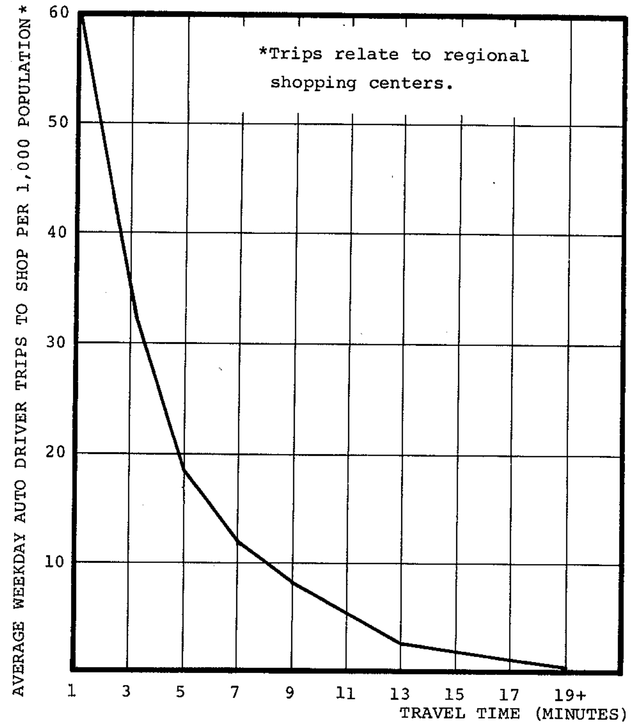


Figure 52. Composite auto driver shopping trip rates (2).

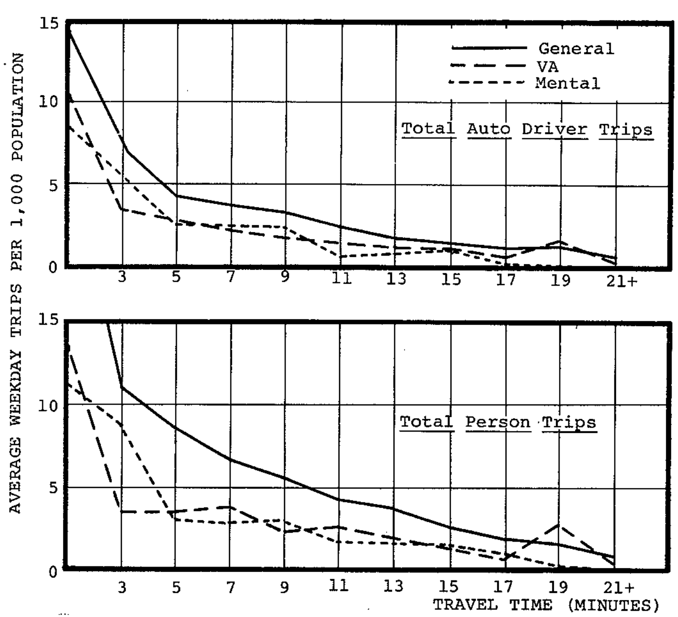


Figure 53. Trips to hospitals per 1,000 population (3).

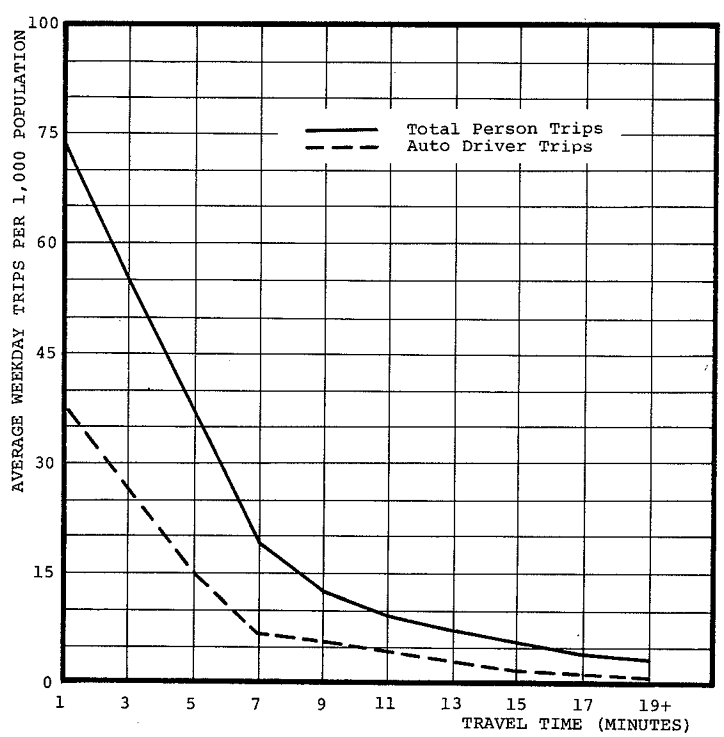


Figure 54. Trips to universities per 1,000 population (3).

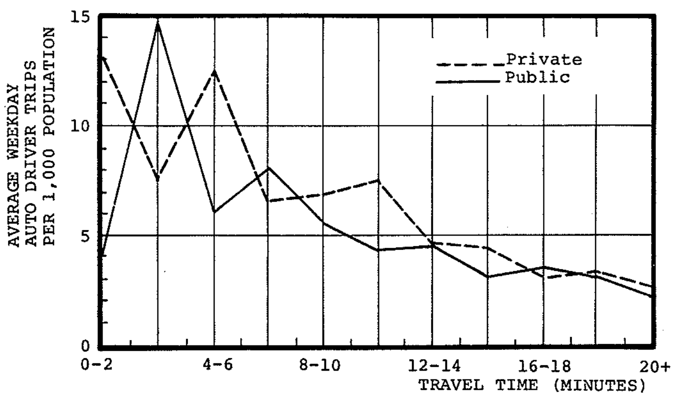


Figure 55. Auto driver trips to office buildings per 1,000 population (3).

several trip purposes, manual trip distribution becomes a lengthy, time-consuming task. However, simplification of the process renders it manageable for manual application. Such simplifications can be justified if the over-all objective of application is quick response and results that are of the correct order of magnitude.

The methods described in the foregoing paragraphs can be applied at the regionwide scale, corridor scale, or subarea level. To be applied manually, the number of analysis units must be kept at a manageable level. As has been described, the manual application should probably be limited to a maximum of about 80 analysis areas. For areawide planning, rather detailed analysis can be accomplished for areas up to about 150,000 population where a zonal basis would be used. For larger areas, "sketch" planning can be accomplished at a district level. Corridors can be studied in detail with the utilization of considerably less than 80 analysis units. Likewise, for subarea analysis many problems can be handled with considerably less than 80 analysis units.

USE OF REGIONAL MODELS

The manual procedures provided for trip distribution basically consist of simplified application of the gravity

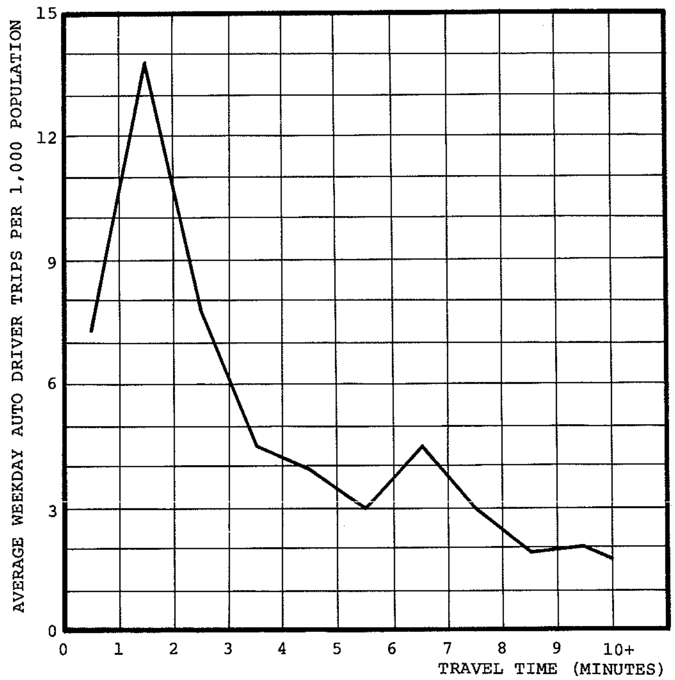


Figure 56. Auto driver trips to capitols per 1,000 population (3).

model. Where regional gravity models have been locally calibrated, such models provide much basic information that can assist in speeding up certain analysis. For example, accessibility indices available from a regional model will provide input to the procedures described for corridor and site analyses which should provide quicker and less expensive results than a computer application. Likewise, the accessibilities are useful for determining the orientation of trips around a site.

A particularly appropriate use of a locally calibrated gravity model is the distribution factors, F_{ij}, output from the model. These can be used to more specifically orient the manual method to the local area.

CHAPTER FOUR

MODE-CHOICE ANALYSIS

INTRODUCTION

The objectives of this chapter are to provide sufficient procedural materials to allow the transportation planner to determine the magnitude of travel by mode caused by varying the transit and auto system operating characteristics. It should be emphasized that the mode-choice (split) procedure deals with transit systems only at the demand-determination level and is not applicable for evaluating the extent or impact of transit capital and operating requirements. For the latter types of analyses, the user is directed to other current manual procedures such as, "Transit Corridor Analysis—A Manual Sketch Planning Technique" (*28*). However, the results obtained through application of the manual techniques contained in this user's guide can be directly applied as input to the methods described in Ref. (*28*). It should also be noted that the mode-choice procedure described herein considers fixed-route types of systems only and does not evaluate mode split for flex-route or demand-responsive types of systems. The mode-choice procedure is appropriate for use at the subarea and corridor levels, as well as for regionwide evaluations.

The major input to the mode-choice procedure is person-trip interchanges between analysis areas (e.g., zones or districts). These data may have been developed through application of the techniques described in Chapter Three, "Trip Distribution," or may have been secured from information available from other sources or developed by the transportation planning agency. If the latter is the case, a considerable amount of time can be saved by using the existing information. Other input requirements deal with characteristics of the auto and transit fares.

The level of detail at which the mode-choice procedure is applied is a function of time availability. One should not hesitate to apply the procedure to large analysis areas (e.g., districts) if time constraints are stringent.

There are two major outputs of the mode-choice analysis:

- Interchanges of transit person-trips.
- Interchanges of auto person-trips.

The transit person-trips will probably be summarized by the user to show transit travel by either large analysis areas or corridors and may be input to other transit system analyses such as those contained in Ref. (*28*).

The auto person-trips will most likely be subjected to an auto occupancy analysis (see Chapter Five) to convert the person-trips into auto-driver trips as preparation for further analysis of the highway system.

BASIS FOR DEVELOPMENT

The procedure presented here for the conduct of a mode-choice analysis has been developed from the "default model" contained in the program UMODEL of the U.S. Department of Transportation, Urban Transportation Planning System (UTPS) (*29*). The application techniques, however, have drawn upon the procedures used in Ref. (*28*).

Theory of the Mode-Choice Model

The mode-choice model contained in the UTPS program UMODEL simultaneously performs the trip-distribution and mode split functions. The mathematical form of the model is:

$$T_{ijm} = P_i \cdot \frac{A_j \cdot e^{-\theta I_{ijm}}}{\sum_j \sum_m A_j \cdot e^{-\theta I_{ijm}}} \tag{9}$$

where

T_{ijm} = trips from i to j by mode m;
P_i = productions at i (home end);
A_j = attractions at j (destination end);
e = 2.71828;
θ = a calibrated constant that varies by trip purpose;
I_{ijm} = a measure of impedance by mode m equal to: (1.0 × in-vehicle time) + (2.5 × excess time) + (trip cost)/(0.33 × income per_m in).

It can be observed from the preceding formula that the model is similar to the gravity model equation. (See Chapter Three, section entitled, "Theory of Gravity Model.") Its variance with the gravity model form is twofold:

- The model sums attractions for all (auto and transit) modes.
- The model uses impedance instead of simple travel time between an *ij* pair.

Current research of the Urban Mass Transportation Administration's (UMTA) Office of Planning Methodology and Technical Support has shown it is possible to state the impedance variable in the same form as time is displayed in the gravity model equation. That is, $e^{-\theta I}$ can be replaced with I^{-b} where I is equal to a measure of trip impedance and b is an exponent of the trip impedance, dependent on the trip purpose. Thus, substituting the expression for time, Eq. 9 becomes:

$$T_{ijm} = P_i \cdot \frac{A_j \times I^{-b}{}_{ijm}}{\sum_j \sum_m A_j \times I^{-b}{}_{ijm}} \tag{10}$$

The form of the foregoing equation is still such that distribution and mode split are accomplished simultaneously. Because trip distribution, using the procedures described in Chapter Three, is accomplished separately, it is necessary to transform Eq. 10 in a rate relationship that will assess only the market share (i.e., mode split) ratio between auto and transit trips. The transformation has been accomplished by dividing transit trips by auto trips and converting the ratio into an actual fractional market share quantity as follows:

$$r = \frac{T_{ijt}}{T_{ija}} \tag{11}$$

where

r = ratio of transit trips to auto trips;

therefore

$$ms_t = \frac{r}{1 + r} \tag{12}$$

where

ms_t = fractional market share of trips estimated to use the transit mode.

Substitution of Eq. 10 into the right-hand side of Eq. 12 yields the relationship of market share for transit to be:

$$ms_t = \frac{I_{ijt}{}^{-b}}{I_{ijt}{}^{-b} + I_{ija}{}^{-b}} \times 100 \tag{13}$$

or

$$ms_t = \frac{I_{ija}{}^{b}}{I_{ijt}{}^{b} + I_{ija}{}^{b}} \times 100 \tag{14}$$

In other words, the fractional market share for the transit mode is equal to the quotient of the auto impedance raised to a power, *b*, and the sum of the transit impedance and auto impedance each raised to a power, *b*.

As was previously discussed, Eq. 10 without the summation across modes has a form identical to that of the gravity model. It was believed that the exponent *b* would behave in a manner similar to the gravity model and that assumption has been further fortified through current research of the UMTA Office of Planning Methodology and Technical Support. It has been found that the exponent for the HBW trip purpose is near a value of 2 when calibrating with Washington, D.C., and Minneapolis-St. Paul, Minnesota, data. Consequently, the "Transit Corridor Analysis Manual" (*28*) uses an exponent value of 2 for application of the simultaneous model. A review of Table 8 in Chapter Three indicates that the b value for the HBW trip purpose is approximately 2, varying slightly with the population of the urbanized area in question.

The theory embodied in the mode-choice model (Eq. 14) was then extended to assume that the exponents for HBNW and NHB trip purposes would behave in the same manner as the exponents shown for the corresponding distribution equations; that is, $b = 3.0$ for HBNW trips and $b = 2.7$ for NHB trips. The assumption was tested using travel and impedance data from Washington, D.C., and Atlanta, Georgia.

The Washington, D.C., analysis was cursory in that the exponent was only tested for the HBW trip purpose for known impedances from 20 district pairs. The district pairs included radial and nonradial directions. Results have shown the estimation to agree with calculated values within $\pm$ 3 percent.

The Atlanta data were investigated in more depth. The algorithm in Eq. 14 was applied to impedance calculations, as specified by the variable I in Eq. 9, using time and distance quantities derived from coded highway and transit networks. The exercise was a test of only the primary algorithm—not the application procedures to be described.

Analysis of data from the Atlanta region for the HBW trip purpose is summarized in Table 10. The exponent value used (2.4) was determined by analyzing the friction factor curve for the Atlanta HBW gravity model. Similar comparisons were made for the HBW and NHB trip purposes. Results of the two latter trip purposes were equal to or exceeded the accuracy of the HBW trip purpose application.

It can be seen from Table 10 that not only is the estimate of total transit demand for the HBW purpose quite accurate, but also the demand generated in each district compares quite favorably to data collected in an on-board, origin-destination survey in 1970. Although the percentage differences for the comparison of generated and observed productions and attractions varies greatly and, in many cases, the difference is sizeable, the absolute differences are within tolerable limits. The user must also take into consideration that the model was not exposed to local calibration except for an analysis of the slope of the friction factor curve of the HBW gravity model necessary to determine the appropriate Atlanta specific b values by trip purpose.

DATA REQUIRED FOR APPLICATION

The data required for mode-choice analysis vary depending on previous work undertaken for the study area. It is recommended, where possible, that the user make every effort to take advantage of models and values that are specific to the study area. For those areas with a minimal history of transportation planning, default values have

TABLE 10

COMPARISON OF HBW TRANSIT TRIP ENDS BY DISTRICT—O-D AND SYNTHESIZED—FOR THE ATLANTA METROPOLITAN REGION

District #[a]	Origin-Destination[b]		Synthesized[c]		% Difference[d]	
	Attractions	Productions	Attractions	Productions	Attractions	Productions
1	42206	1470	43817	1728	+3.8	+17.6
2	14852	15528	17957	13100	+20.9	-15.6
3	8764	19060	5875	18007	-32.9	-5.5
4	5122	12983	5766	16042	+12.6	+23.6
5	4554	10700	3912	10792	-14.1	+0.9
6	1281	3120	3037	4078	+137.1	+30.7
7	40	383	95	648	+137.5	+69.2
8	5024	5523	3514	4354	-30.1	-21.2
9	1109	1267	641	823	-42.2	-35.0
11	1975	5880	741	4759	-62.5	-19.1
12	653	2400	568	1441	-13.0	-40.0
13	1126	2750	1137	3616	+1.0	+31.5
14	443	1165	499	930	+12.6	-20.2
15	2292	4150	2167	2723	-5.5	-34.4
16	4	82	0	312	-100.0	+280.5
17	948	3150	1014	5086	+7.0	+61.5
18	72	283	92	816	+27.8	+188.3
23	82	237	0	338	100.0	+42.6
24	205	621	580	1819	+182.9	+192.9
TOTAL	90,752	90,752	91,412	91,412	+0.7%	+0.7%

a. The Atlanta Metropolitan Region contains 34 districts; districts not listed are not served by the transit system.

b. Source: Reference (32).

c. Synthesized using the manual mode choice procedure, Eq. 14.

d. % Difference = [(Synthesized - O-D)/O-D] x 100.

been incorporated into the mode-choice procedures and can be used without further manipulation.

Input Data Elements

Table 11 lists the data elements required for application of the mode-choice procedures. The user can quickly distinguish between those input elements that must be supplied and those that are already available.

Highway Airline Distance

Highway airline distance can be obtained from several sources. If the user has utilized the trip-distribution procedures in Chapter Three, the analysis area-to-analysis area airline distances might already have been developed. If, however, the user enters the mode-choice procedures with an existing person-trip table, by purpose, (from, for example, a computer analysis) the technician will be required to scale the highway-airline distance values.

Transit Airline Distance

For analysis area pairs that have direct transit service, the highway airline distance can be used to represent transit airline distance for estimating transit demand of radially oriented trips. For area pairs where transit service is indirect, the user must exercise great caution. In those cases, the transit patron will probably be required to travel in a radial direction to a transfer point, change direction, and continue to his or her final destination. It is recommended that the transit airline distance for indirect trips be determined in components to account for indirect routing by: (a) measuring from the production analysis area centroid to the transfer point, (b) measuring the distance from the transfer point to the final destination area and, (c) summing a and b as the transit airline distance. The user will need to carefully interpret airline distance in those instances.

Some area pairs may not be accessible by transit. Those areas without service can be quickly identified using a graphic representation of the transit system routes (data element 11) and can be immediately eliminated from any further mode-choice analysis.

Transit Fare

The user will be required to supply an area-to-area transit fare matrix. If the user is studying an area with a flat fare system, this task becomes trivial in terms of the level of effort. On the other hand, a study area with an elaborate zone or graduated fare structure will require additional effort to organize the fare data between analysis areas.

Auto Operating Cost

The cost being considered is actually the out-of-pocket cost to the auto user. Over the years, mode-split models have been calibrated with a wide range of assumed values for out-of-pocket operating costs. Currently, most modeling efforts are estimating these costs to be approximately five cents per mile. Other values of cost are available to the user in the mode-choice procedures, and the final responsibility for selecting a cost rests with the analyst. It should be observed that it is possible to assess mode choice under an assumption of varying auto operating costs. For example, the user may wish to analyze the magnitude of a shift to transit if auto operating costs were to double.

Attraction-End Parking Cost

The user will be required to develop estimates of parking cost in order to use the highway impedance nomographs (shown later in this chapter). Parking costs will be necessary for each trip purpose because trip duration varies between work and nonwork purposes. As a guide, the user can assume a duration of 9 hr for the HBW trip purpose and 2 hr for the HBNW and NHB trip purposes. The parking costs shown in the highway impedance nomographs represent the full parking charge associated with a trip. For the purpose of demand analysis, it is appropriate to consider one-half of the actual parking charges associated with a round trip. The curves contained in the highway impedance nomographs represent a consideration of one-half the mid-range parking cost as described by each highway impedance nomograph. In preparing the estimates of parking cost by analysis area, the analyst is cautioned to develop the cost based on *all* available parking (free and paid) for the particular trip purpose under consideration.

Average Highway Speed

Area-to-area average highway speed can be determined from previous efforts of the user or as a special exercise using the "Airline Distance vs. Travel Time vs. Distribution Factors by Trip Purpose" graphs for the appropriate urbanized area population. (See Figs. 7 through 30 in

TABLE 11

INPUT DATA ELEMENTS REQUIRED FOR MODE-CHOICE ANALYSIS

INPUT DATA ELEMENT[a]	SOURCE	
	Default	User Supplied
1. Highway Airline Distance		X
2. Transit Airline Distance		X
3. Transit Fare		X
4. Auto Operating Cost		X
5. Attraction End Parking Cost		X
6. Average Highway Speed		X
7. Impedance Exponent (b) Values	X	
8. Median Income	X	
9. Access Time	X	
10. Person Trip Table		X
11. Graphical Display of Transit System		X

a. Input data elements 1,2,3,6 and 10 are by analysis area pairs (e.g., district-to-district).
Input data elements 5,8 and 9 are by the appropriate analysis area (e.g., data element 5 for the attraction district).
Input data elements 4 and 11 are by the study area.
Input data element 7 is by trip purpose (HBW, HBNW or NHB).

Chapter Three.) These graphs plot airline distance and travel time for a trip between subregions of a study area (i.e., CBD, central city, and suburb), and can be used to determine average auto operating speed. To determine average auto operating speed the user should:

1. Locate the appropriate "Airline Distance vs. Travel Time vs. Distribution Factors" graph.
2. Determine the mix of highway facilities (i.e., between freeways and arterials) the trip will traverse.
3. Enter the appropriate graph (Figs. 7 through 30) at the appropriate airline distance and read across to the facility mix desired and down to the travel time (add terminal time, if required).
4. Subtract from the travel time the terminal time shown for that graph and convert the new time to an operating speed using the nomograph shown in Figure 57.

Impedance Exponent, b, *Values*

Impedance exponents for the general mode-choice model (Eq. 14) are supplied for the user in the form of transit mode-choice nomographs (Figs. 74, 75, and 76 shown later in this chapter) for three trip purposes—HBW, HBNW, and NHB. They are, respectively, 2.0, 3.0, and 2.7. These values were derived from analysis of exponent values associated with gravity-model distribution factor curves for these trip purposes. As has been previously mentioned, the user can modify these default values by calculating exponents from locally calibrated gravity models and constructing new mode-choice nomographs (similar to those shown in Figs. 74, 75, and 76). If a person-trip table has already been developed by using the trip-distribution procedure described in Chapter Three, the default values for the general mode-choice model exponents should be used for mode-choice analysis.

Median Income

The mode-choice analysis procedures assume a median family income of $9,000 per year for converting travel cost items into equivalent minutes. Median income (by each analysis area) is referenced inasmuch as most land-use forecasting procedures produce the number of households within an income range. However, average household income values may be used if they are available. Income is applied to auto operating costs, parking costs, and transit fare. If the user wishes, the default impedance curves may be adjusted to take into account varying median income values. The user is cautioned, however, to gain application experience with the given analytical assumption before experimenting with procedural modifications to impedance calculations.

Access Time

Access time is that quantity of time between leaving the origin point to entering the vehicle (bus or auto) plus the time between exiting the vehicle and reaching the trip destination. For transit trips, it may also include time to transfer between transit vehicles. It is also referred to as out-of-vehicle time plus, if appropriate, in-vehicle time not associated with the line haul part of the trip. For calculating transit impedance, access time represents an important segment of the total impedance value.

Person-Trip Table

The user is required to supply an area-to-area person-trip matrix for each trip purpose (maximum of three purposes—HBW, HBNW, and NHB) to be subjected to mode-choice analysis. Trip tables may be used as developed from the trip-distribution procedure described in Chapter Three; or, the user may elect to use a computer-developed trip table if one is available. With regard to the separate application for each trip purpose, if the user desires, only mode-choice analysis for the HBW trip purpose may be conducted and then the number of transit trips derived doubled to represent annual average weekday (AAWD) transit passenger movements. (See Table 37, Chapter Six.) Other research has shown that all HBW trips approximate daily transit travel during the combined peak period for all purposes and combined period travel represents 50 percent of the AAWD transit trips. (See subsequent section entitled, "Rules of Thumb").

Graphical Display of Transit System

The user will need a graphic representation of the existing or proposed transit system to overlay the analysis area boundaries for determining those interchanges with and without transit service. Movements without transit service may be eliminated from the mode-choice analysis, and it can be assumed that all trips for those interchanges are made via auto (auto driver and auto passenger). If transit service differs significantly between the peak and off-peak periods in the specific study area, separate peak and off-peak descriptions will be required. As a general rule, the peak system applies to the HBW trip purpose travel whereas the remaining two trip purposes (i.e., HBNW and NHB) should be associated with the off-peak system.

APPLICATION OF THE MANUAL MODE-CHOICE ESTIMATION PROCEDURES

A generalized flowchart of the manual mode-choice procedure is shown in Figure 58. The procedure cycle shown in Figure 58 must be completed once for each trip purpose subjected to an analysis. There are three main steps required with application of the mode-choice procedure as follows:

Step 1: Determine auto and transit impedances. The first and most difficult task confronting the user is determining area-to-area impedances. Note: the user is directed to Figure 59, "Mode-Choice Analysis Work Sheet A," for application of the procedures. To minimize the level of effort required, it is recommended that the user compress the square person-trip table into a triangular trip table; for example, assume the travel characteristics between i and j equal j to i, and sum the trips to get a total movement between i and j. This simplification should be fully satisfactory except in localized transit service areas where inbound transit service differs markedly from outbound

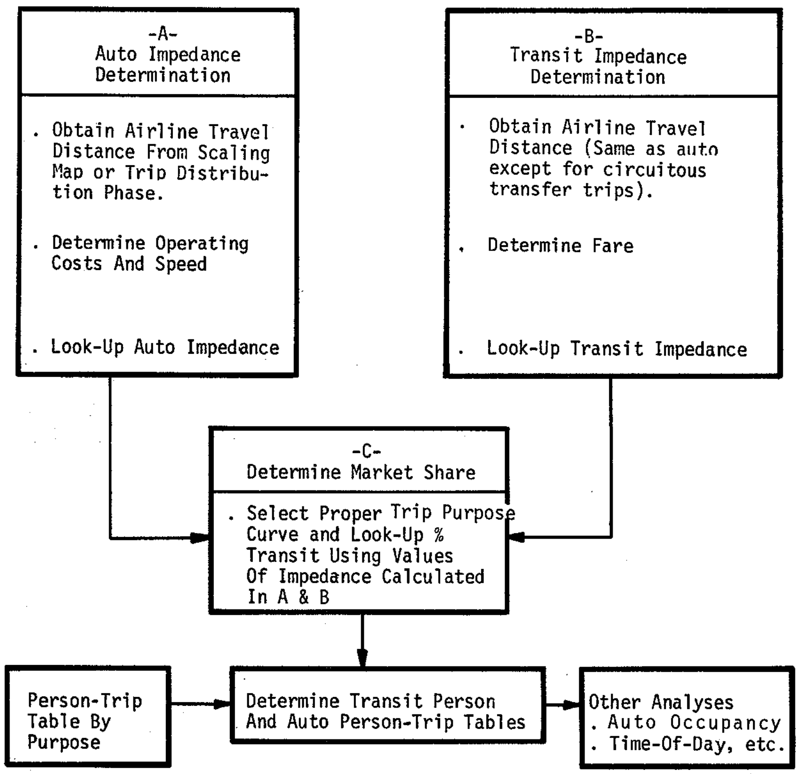


Figure 58. Flow chart of the manual mode-choice estimation procedure.

EXAMPLE

If the centroid-to-centroid airline distance between two analysis areas = 10 miles and the corresponding in-vehicle time = 30 minutes, then the average operating speed = 24 mph.

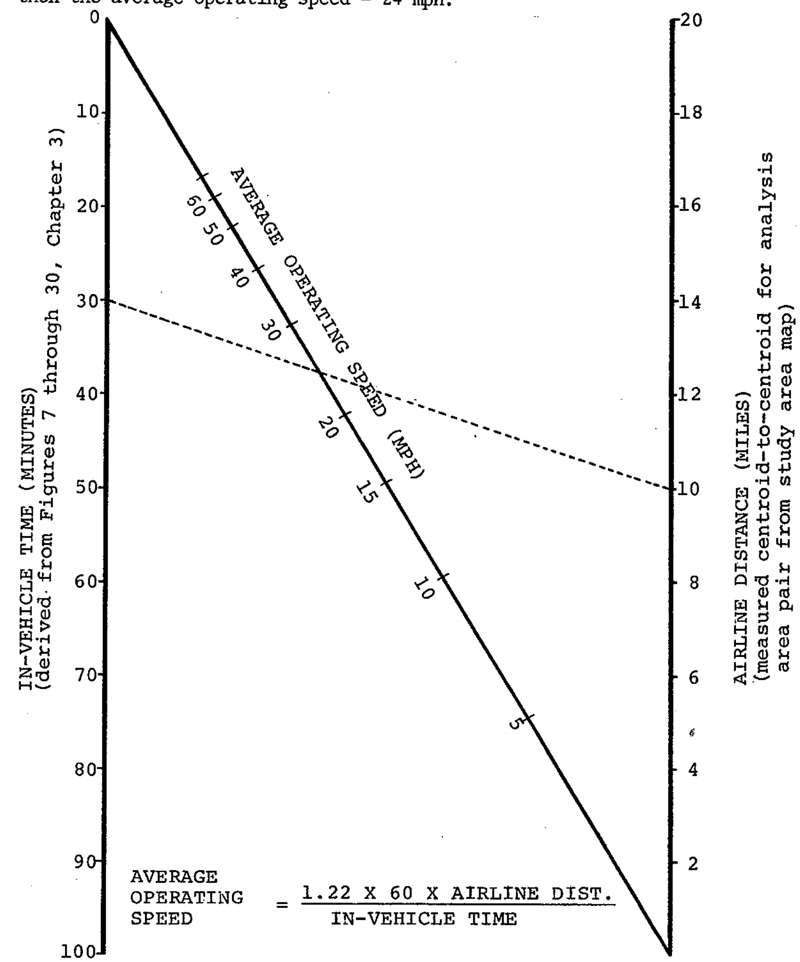


Figure 57. Nomograph for conversion of airline distance to average operating speed.

* Denotes access mode: W=walk, A=auto. Note that egress mode always assumed to be W=walk.
\+ If triangular work sheet is desired, all cells vertically below the shaded cells should be eliminated.

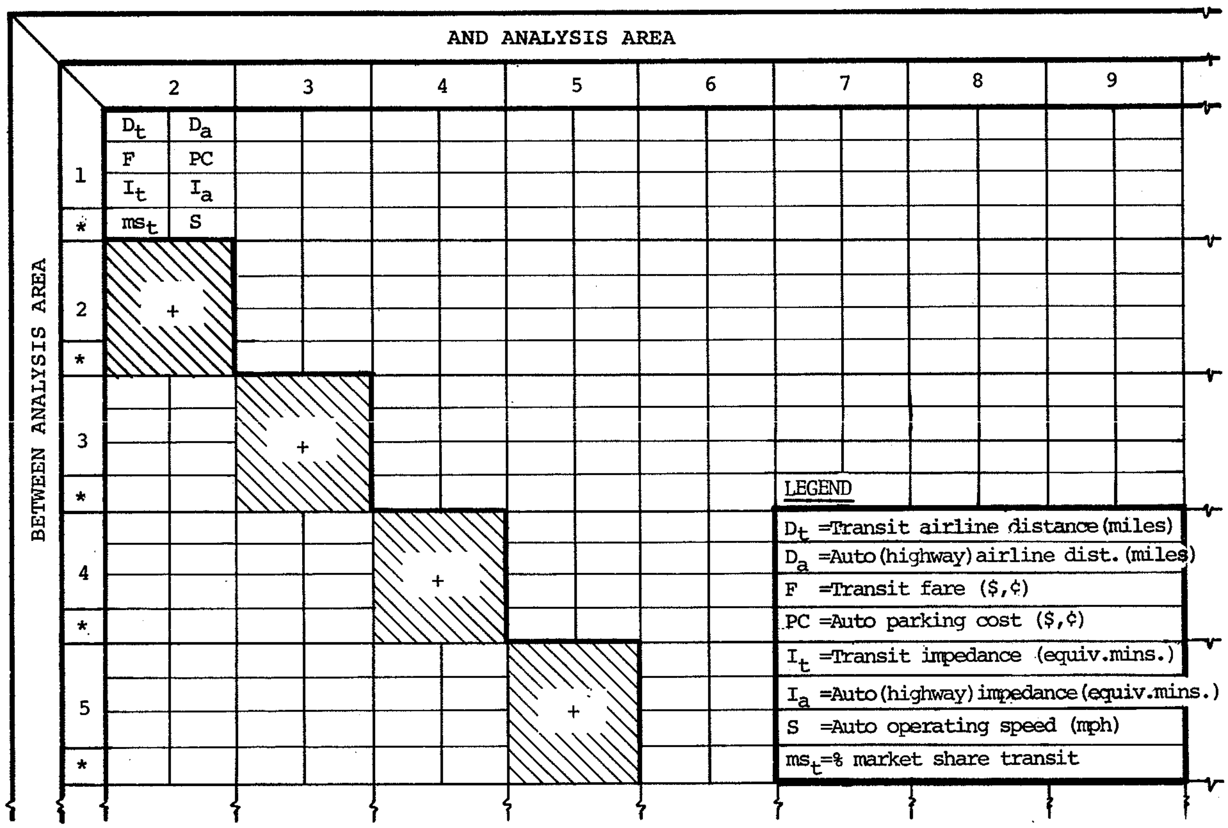


Figure 59. Mode-choice analysis work sheet A.

service. For example, where a substantial peak-commuter bus operation is provided in the peak direction, separate peak-direction and off-peak-direction calculations may be appropriate.

The analyst must supply the following information for each analysis area pair (see previous section entitled "Input Data Elements"):

INPUT	SOURCE
• Highway distance	Map of study area.
• Transit distance	Equal to highway distance except where trip requires additional trip distance due to transfer location. In those cases the airline distance is equal to the airline distance from origin to transfer point to destination.
• Highway operating speed	User judgment.
• Transit fare	Local transit system.
• Parking cost	User knowledge of study area.

Additionally, the user must determine the access mode (walk or auto) for each production analysis area. (See asterisk in Fig. 59.) It may be assumed the access mode is the same for each cell of a particular row on the analysis work sheet.

For those analysis areas without transit service, the user can simply record "0 percent" transit in the appropriate space on work sheet A, and analysis of those areas can be considered complete.

The foregoing information should be recorded on work sheet A for each analysis area pair. After doing so, the technician is prepared to determine the market share from the mode-choice nomographs (Figs. 74, 75, and 76 discussed subsequently) and prepare the modal person-trip estimates.

To determine the transit and auto impedances, the user is directed to the "Transit and Auto Total Impedance Nomographs," Figures 60 and 61 for transit, and Figures 62 through 73 for auto. The transit impedance nomographs for walk access have an assumed walking-plus-waiting time of 8 min at the production end of the trip before weighting. This assumption has been made in order to provide consistency with the "Transit Corridor Analysis Manual" (*28*). The user may desire to alter that assumption so that the nomographs can more accurately reflect changes in service levels. To change the assumption, the user should subtract 2.5 times 8 min (20 equivalent min) from the impedance quantity and add 2.5 times the desired access time. The user may wish to keep the assumed walk time (3 min) and modify the wait time to

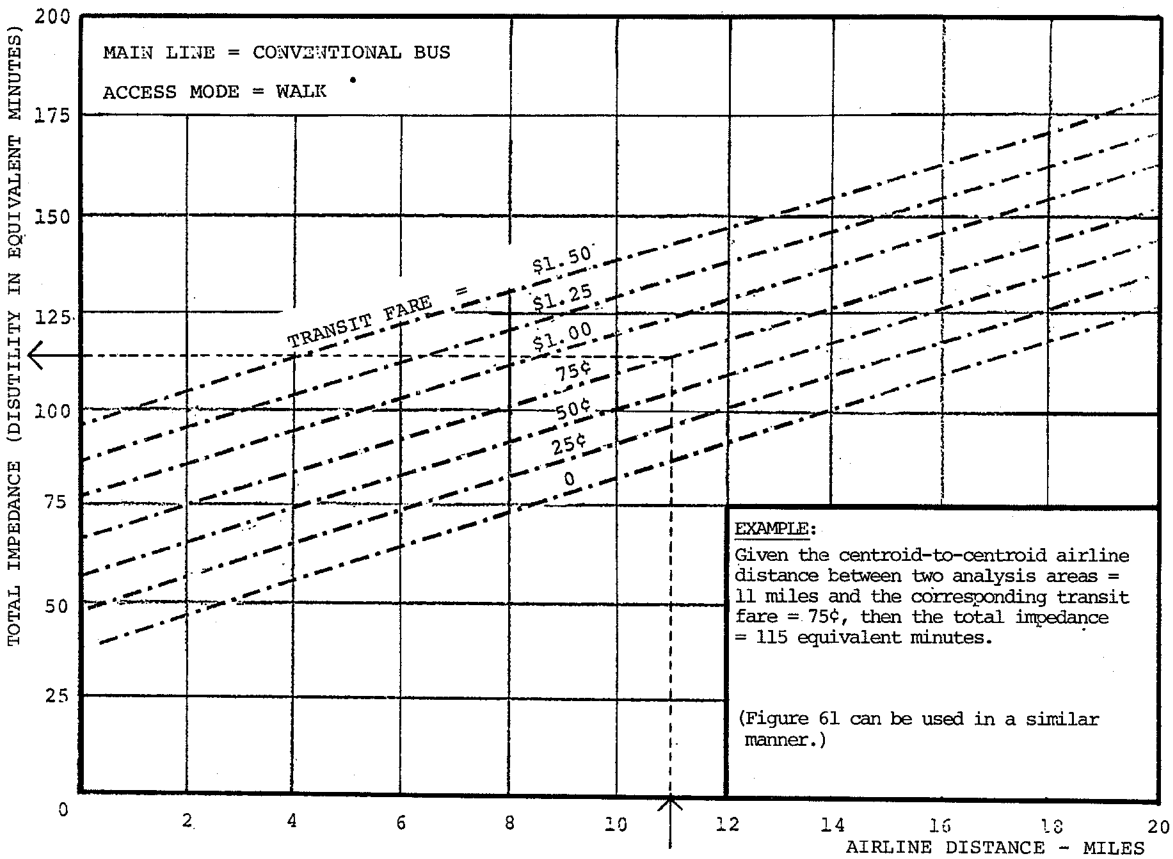


Figure 60. Nomograph for conversion of airline distance to total impedance—transit: access mode, walk (28).

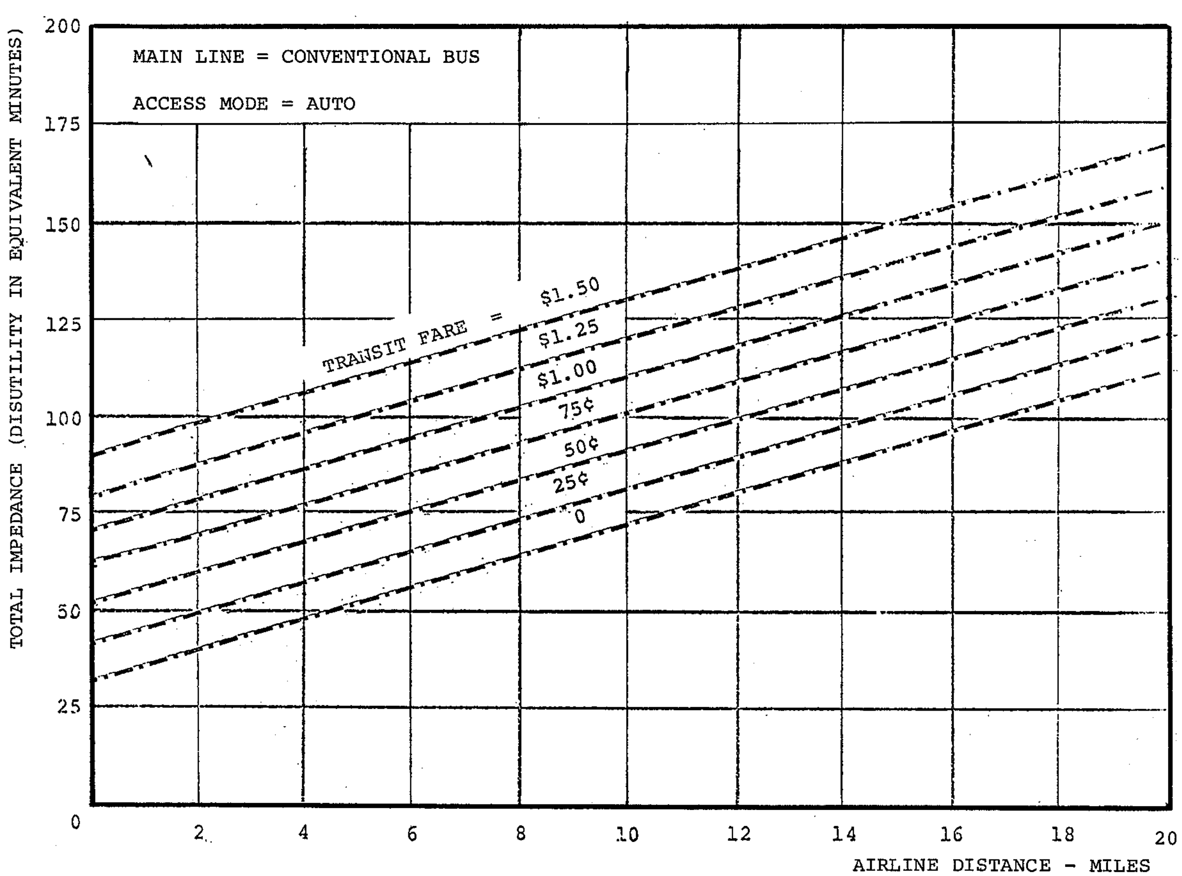


Figure 61. Nomograph for conversion of airline distance to total impedance—transit: access mode, auto (28).

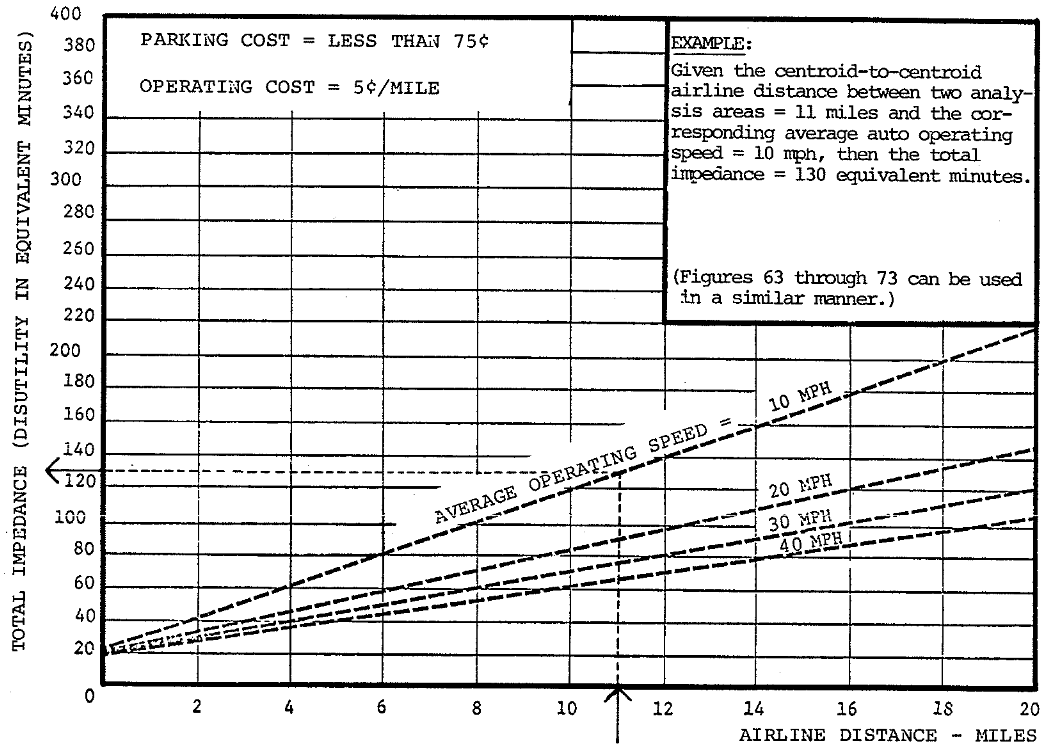


Figure 62. Nomograph for conversion of airline distance to total impedance—auto: parking cost, <$0.75; operating cost, $0.05/mi (28).

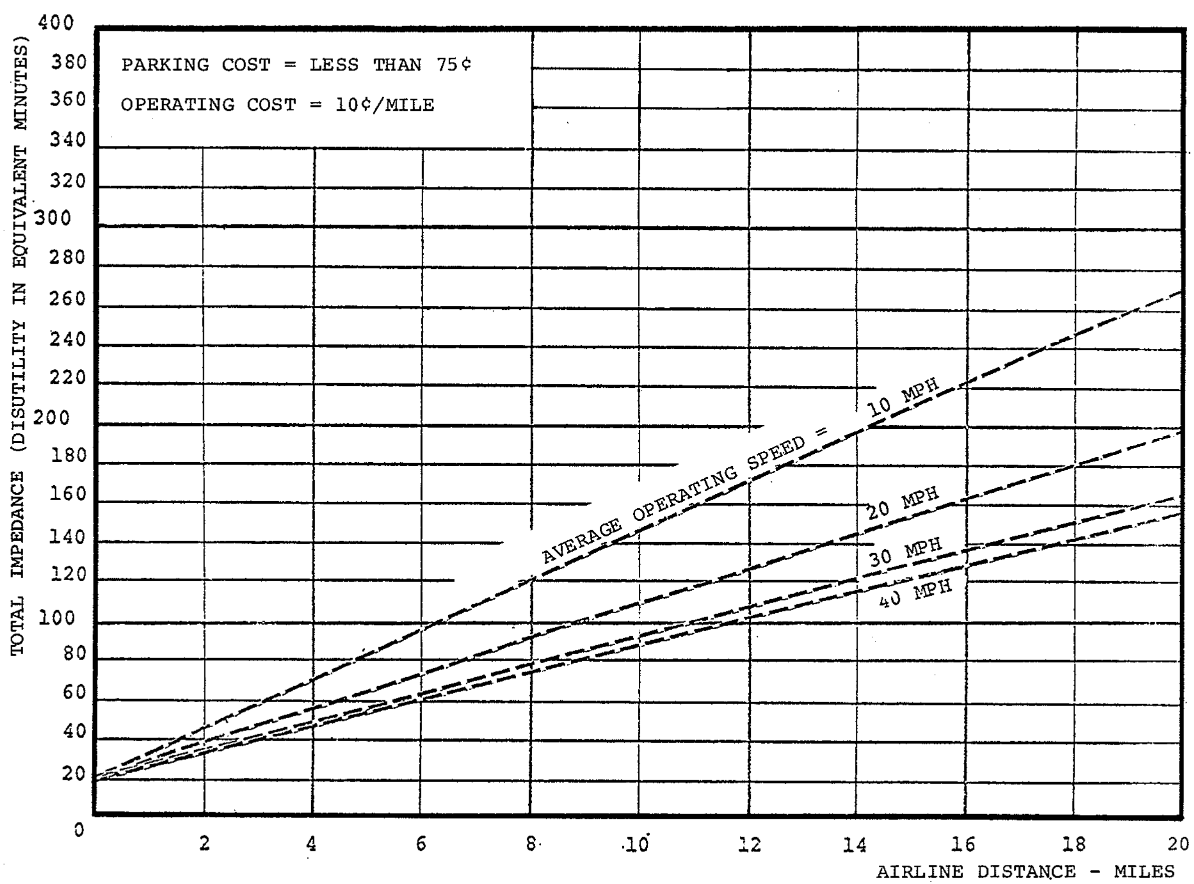


Figure 63. Nomograph for conversion of airline distance to total impedance—auto: parking cost, <$0.75; operating cost, $0.10/mi (28).

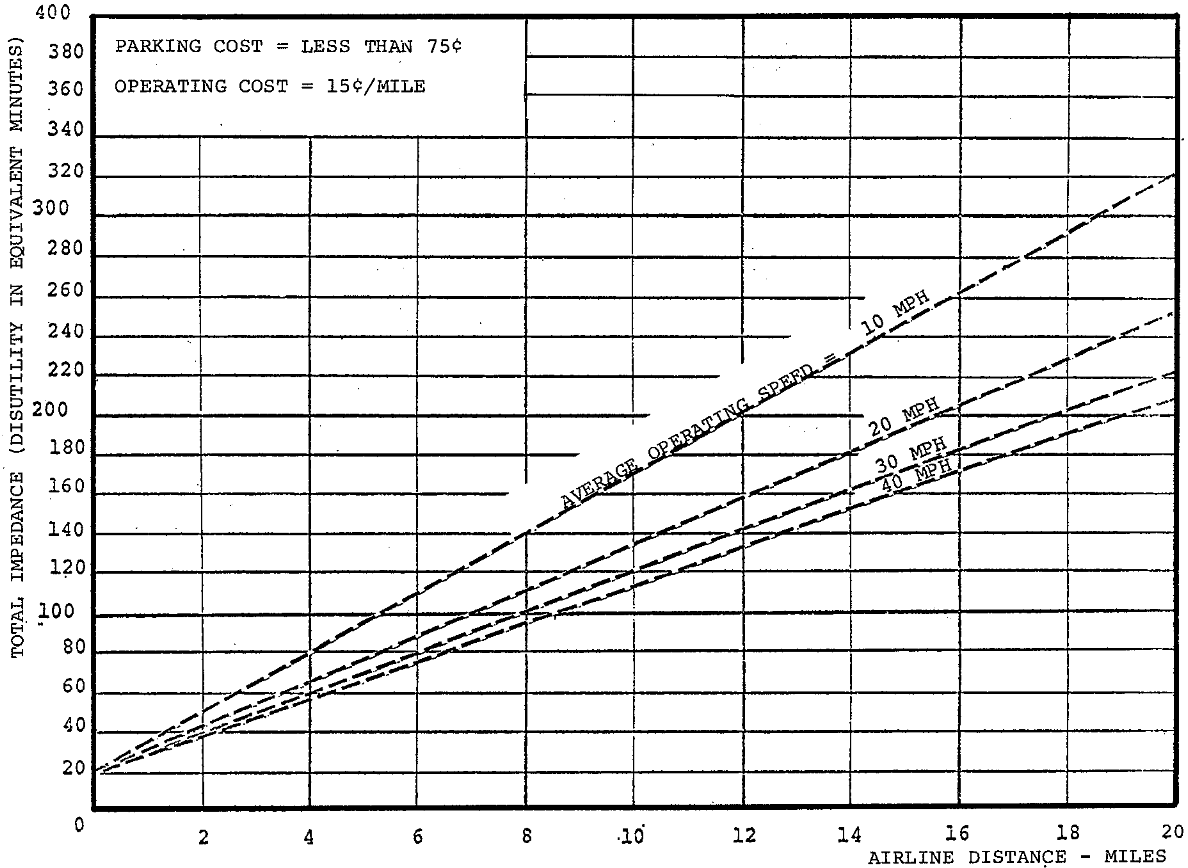


Figure 64. Nomograph for conversion of airline distance to total impedance—auto: parking cost, <$0.75; operating cost, $0.15/mi (28).

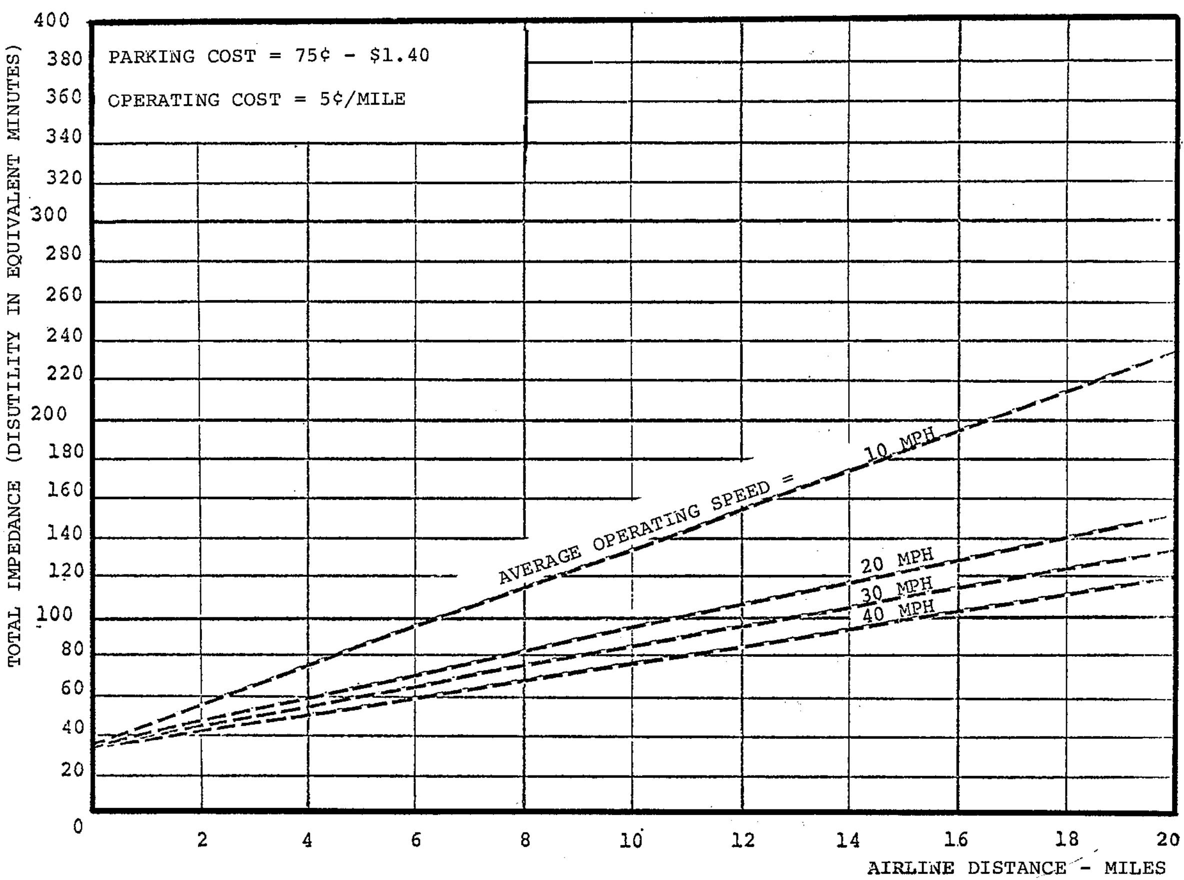


Figure 65. Nomograph for conversion of airline distance to total impedance—auto: parking cost, $0.75 to $1.40; operating cost, $0.05/mi (28).

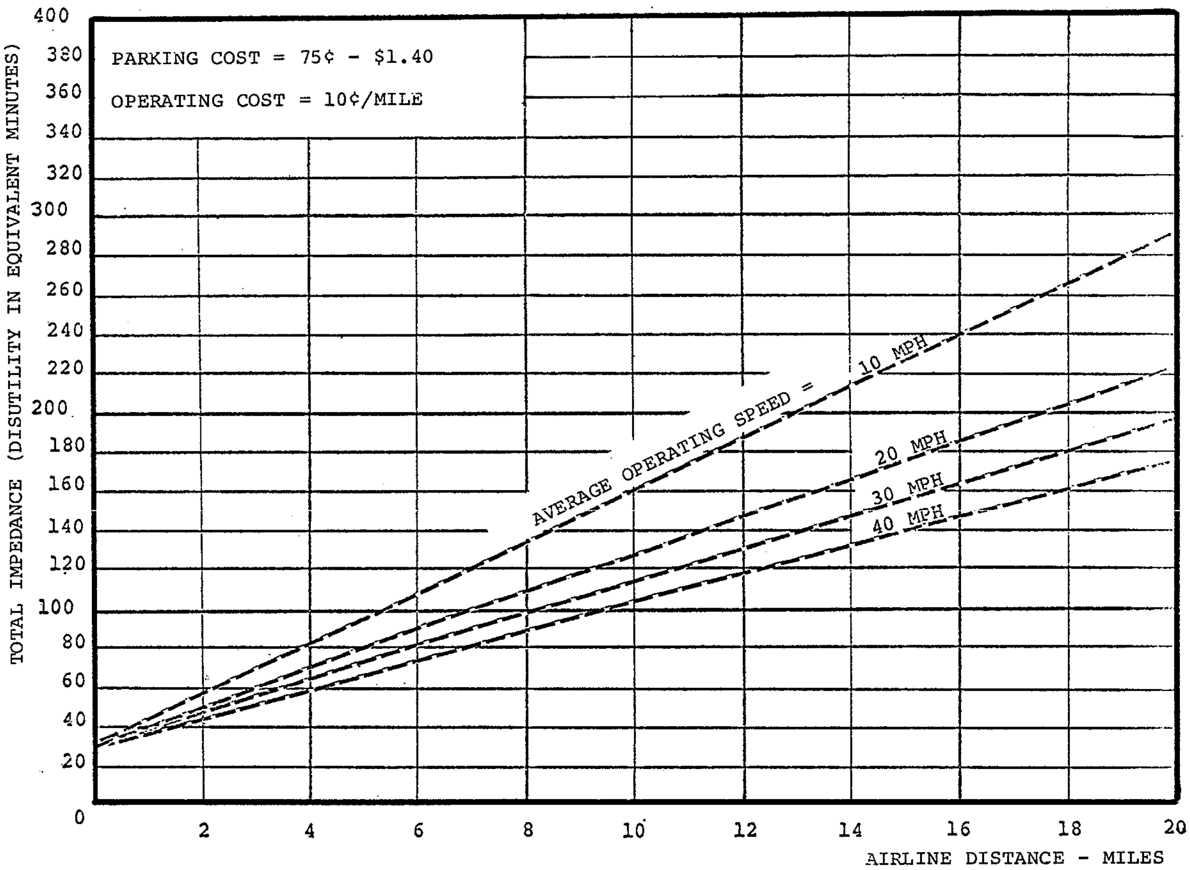


Figure 66. Nomograph for conversion of airline distance to total impedance—auto: parking cost, $0.75 to $1.40; operating cost, $0.10/mi (28).

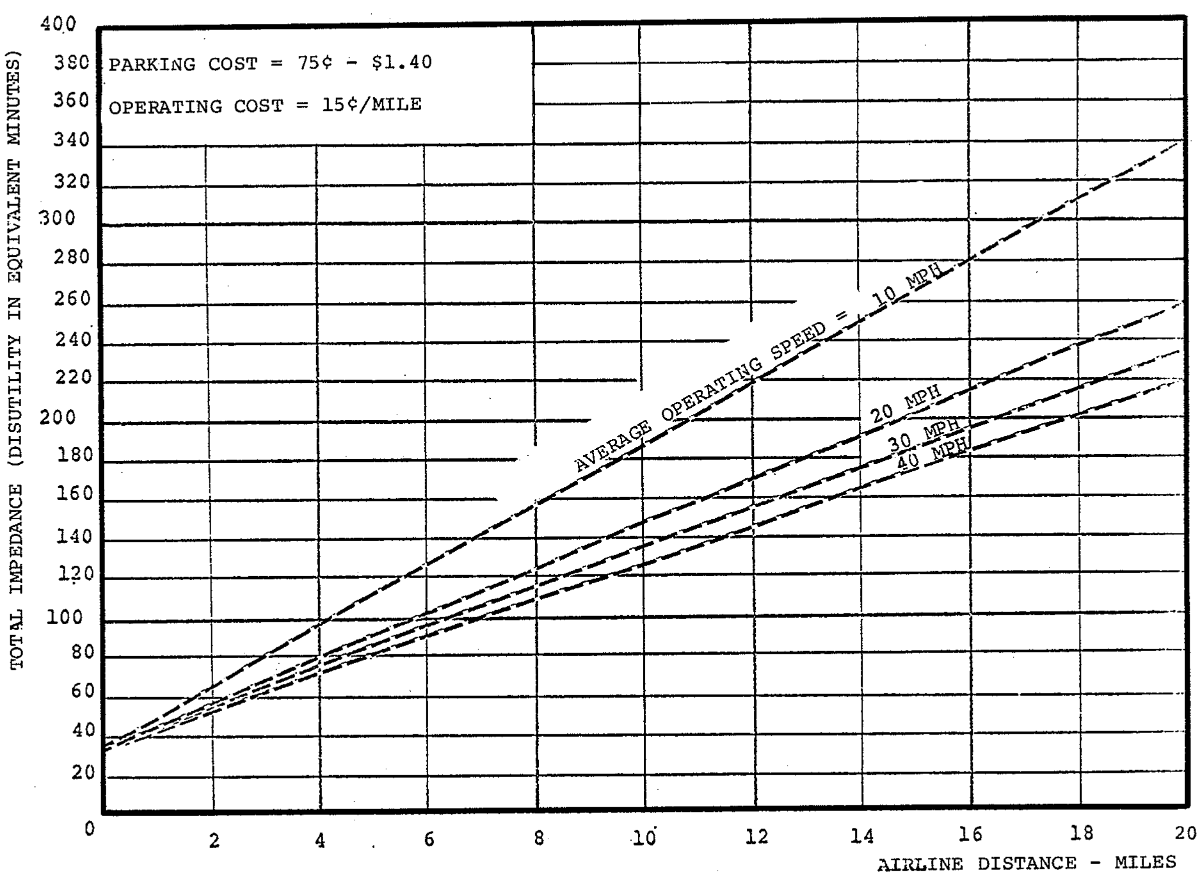


Figure 67. Nomograph for conversion of airline distance to total impedance—auto: parking cost, $0.75 to $1.40; operating cost, $0.15/mi (28).

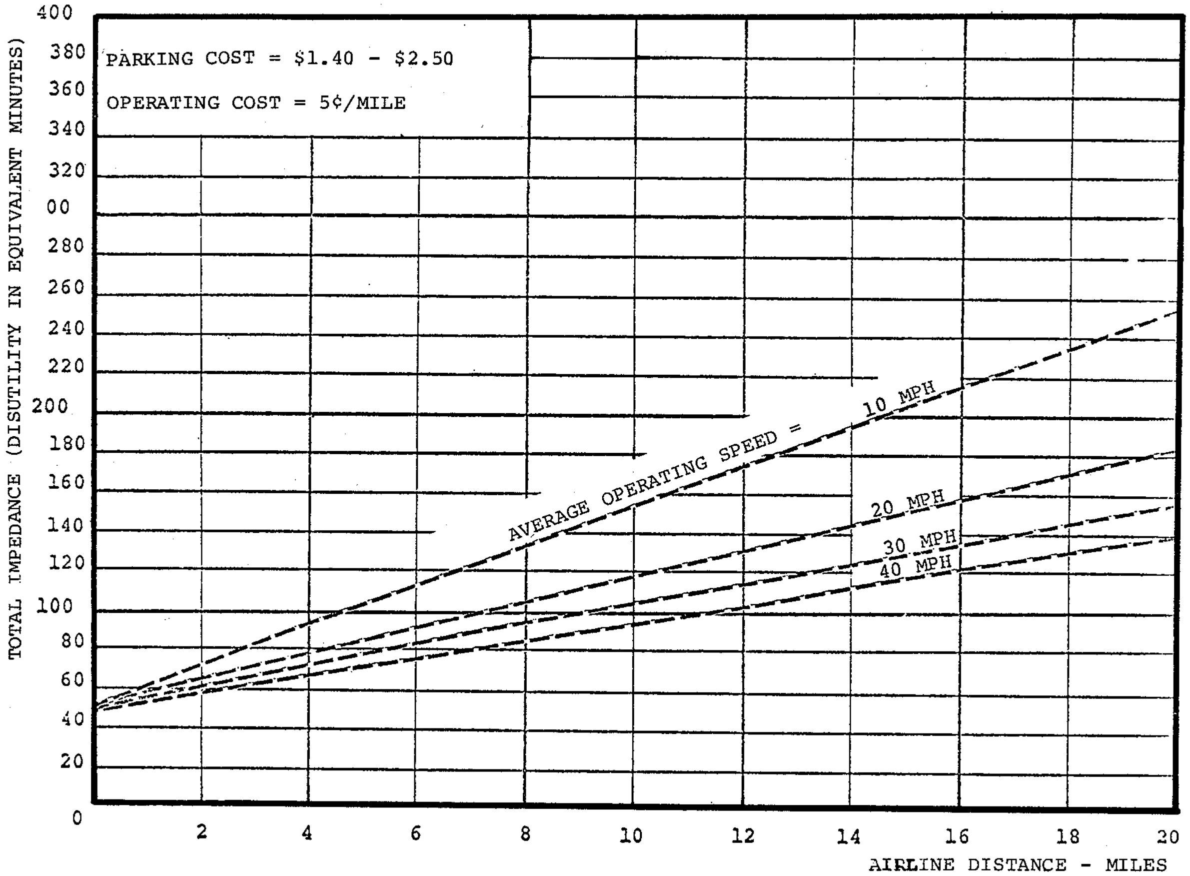


Figure 68. Nomograph for conversion of airline distance to total impedance—auto: parking cost, $1.40 to $2.50; operating cost, $0.05/mi (28).

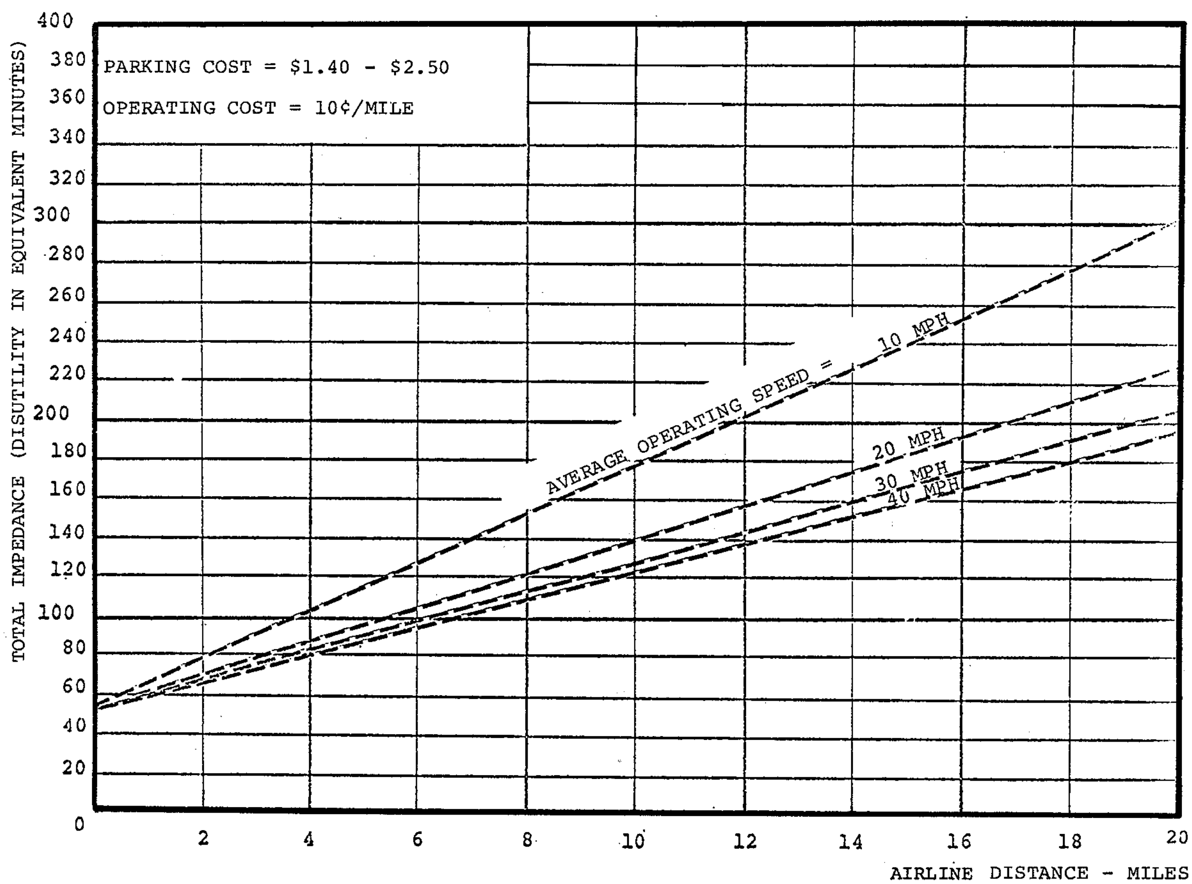


Figure 69. Nomograph for conversion of airline distance to total impedance—auto: parking cost, $1.40 to $2.50; operating cost, $0.10/mi (28).

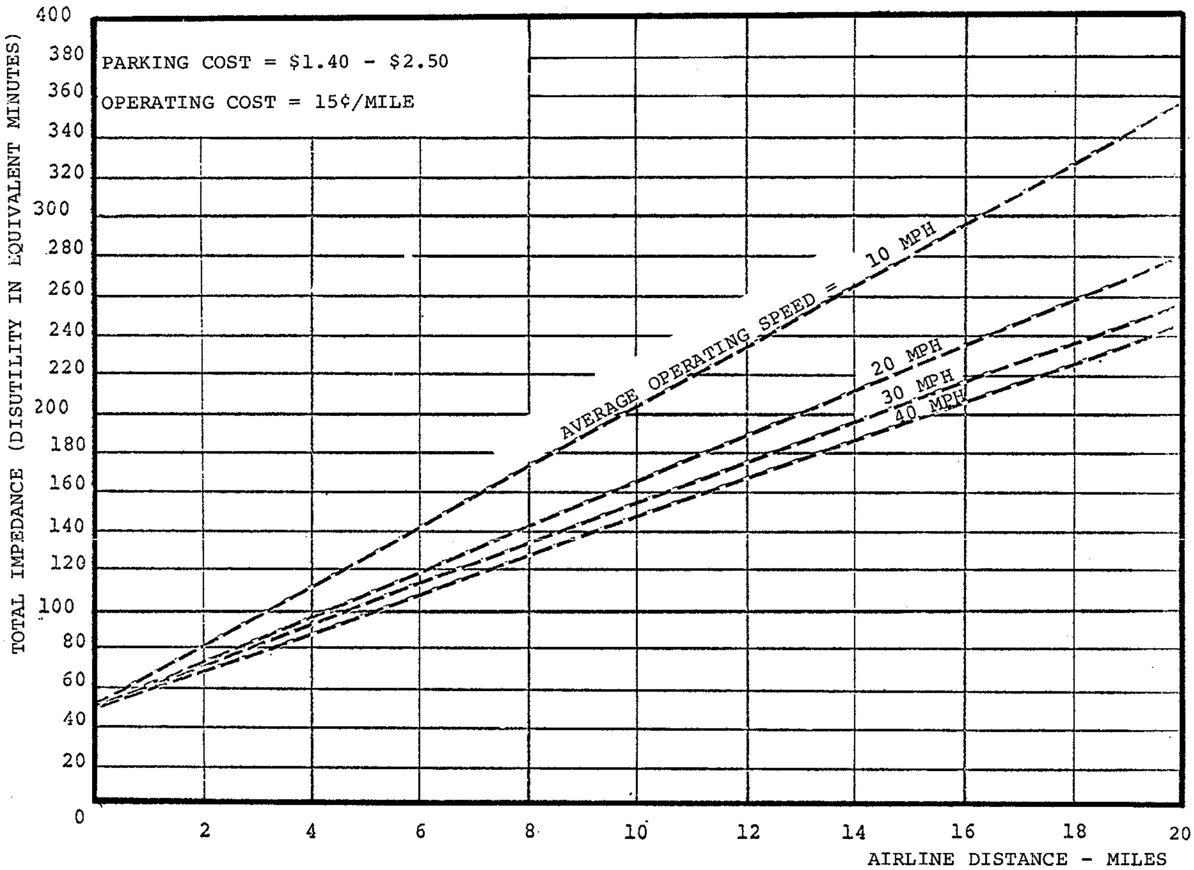


Figure 70. Nomograph for conversion of airline distance to total impedance—auto: parking cost, $1.40 to $2.50; operating cost, $0.15/mi (28).

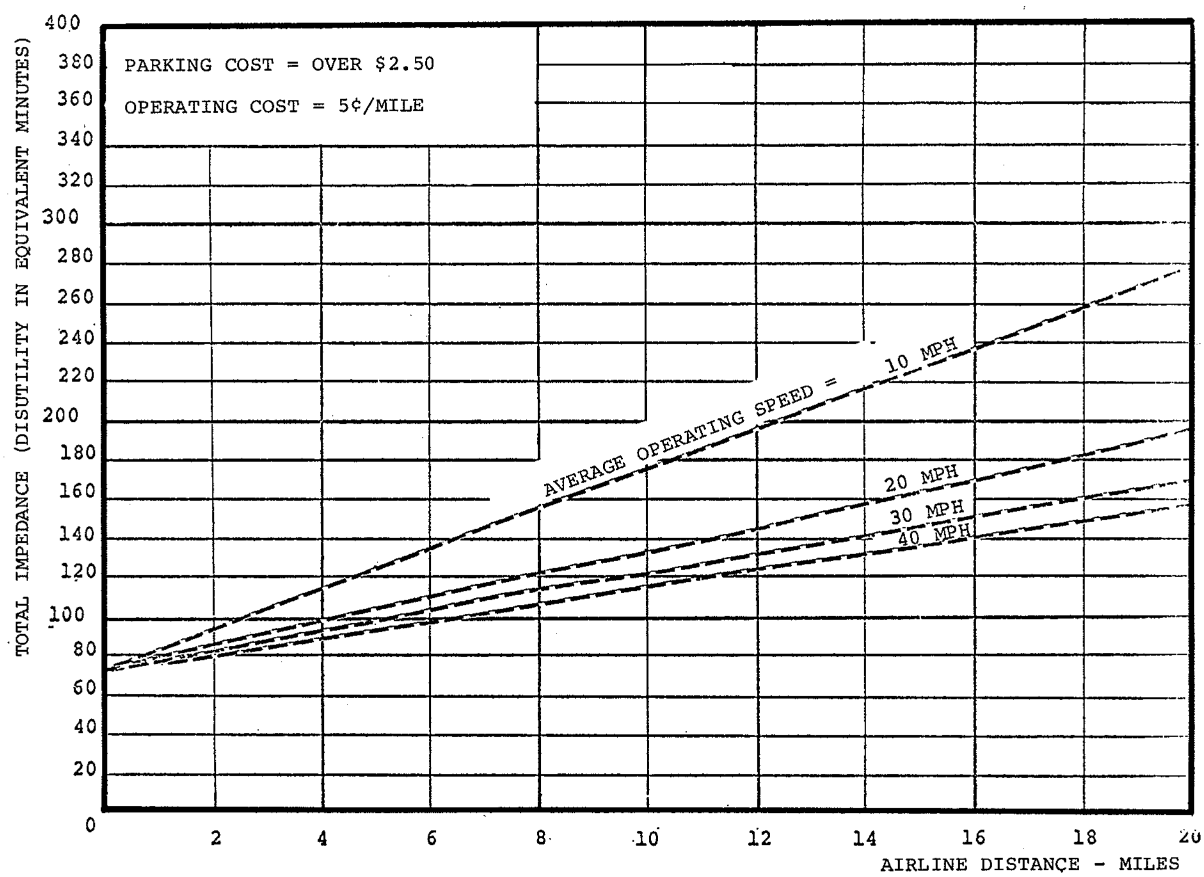


Figure 71. Nomograph for conversion of airline distance to total impedance—auto: parking cost, >$2.50; operating cost, $0.05/mi (28).

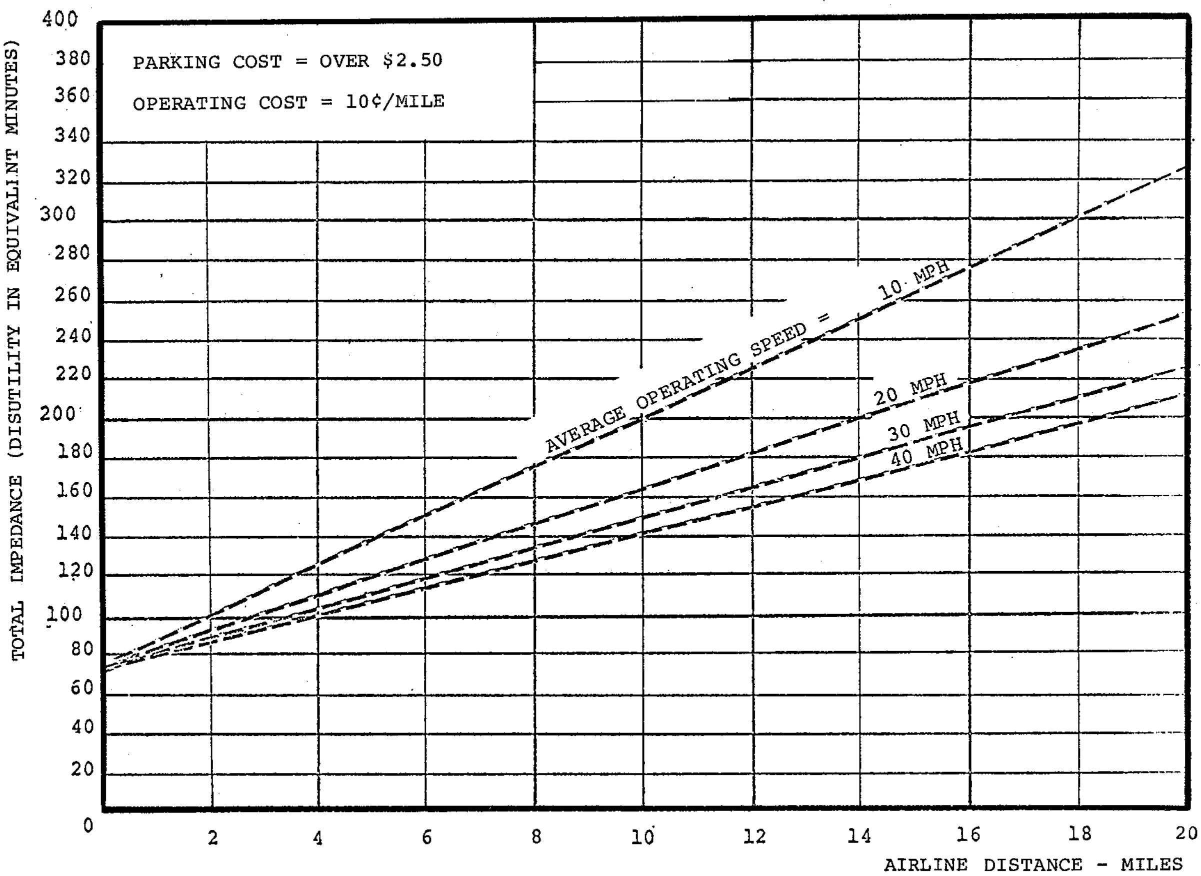


Figure 72. Nomograph for conversion of airline distance to total impedance—auto: parking cost, $1.40 to $2.50; operating cost, $0.10/mi (28).

equal one-half the headway in the analysis area. To modify the default auto access time of 3 min (Fig. 61), the user is cautioned that it is not, and should not be, weighted because it is an in-vehicle travel time. Likewise, the user may wish to adjust the default walking time at the attraction end of the trip. The default destination walk time of 3 min can be adjusted by subtracting 3 times 2.5 (7.5 equivalent min) from the impedance and adding 2.5 times the desired destination walk time.

Further modifications can be made to the impedance nomographs for transit trips requiring a transfer. These default curves assume no transit-to-transit transfer. This situation is quite common where travel occurs between two analysis areas whose path is not radial to the CBD core. It is customary to incorporate a waiting time equal to one-half the headway of the bus line being "transferred to." The user is encouraged to make these adjustments where appropriate for transit trips in order to prevent an overestimation of nonradial transit travel. As a default condition, the user can assume an additional 12.5 equivalent min (5 min unweighted transfer time) for trips of this type. When incorporating this transfer trip modification, the user can simply add the transfer penalty to the values determined from the transit impedance nomographs inasmuch as it causes a constant vertical shift to the default curves.

Two transit nomographs are provided, one for walk access, and the other for auto access; the curves within each nomograph are stratified by transit fare. Auto total impedance nomographs are categorized by out-of-pocket auto operating costs and actual parking cost at the attraction end of the trip; the curves within each nomograph are stratified by highway operating speed.

By looking up the airline distance on the appropriate nomograph and curve, the total impedance for either mode can be read off the y axis and recorded on work sheet A (i.e., I_t for transit and I_a for auto).

The user should be aware of all the assumptions that have entered into the development of the total impedance curves for transit and auto trip paths. In general, the assumptions correspond to those described in Ref. (*28*).

The assumption used in the aforementioned reference to convert highway and transit airline distance to actual miles of route was 1.27 (the circuity factor). This differs slightly from the 1.22 used in Chapter Three in the section entitled, "Constructing Airline Distance vs. Travel Time vs. Distribution Factors Graphs." However, because the ratio of impedances (auto, transit) is used when entering the mode-choice nomographs, no noticeable difference in result is obtained.

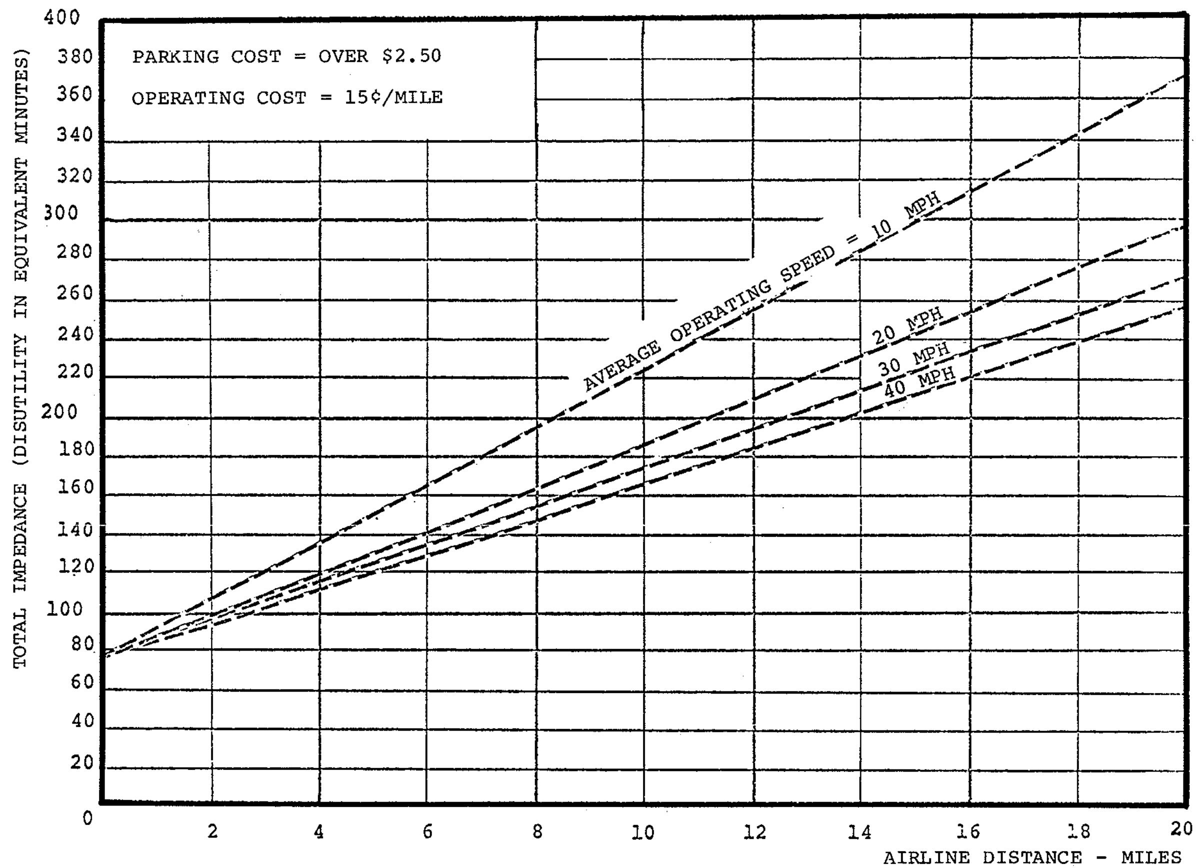


Figure 73. Nomograph for conversion of airline distance to total impedance—auto: parking cost, $1.40 to $2.50; operating cost, $0.15/mi (28).

Other assumptions are as follows:

- Parking costs:

PARKING COST STRATA ($)	VALUE REPRESENTED ($)	ONE-HALF PARKING COST ($)
0–0.75	0.37	0.185
0.75–1.40	1.07	0.535
1.41–2.50	1.95	0.975
Over 2.50	3.00	1.500

- Total auto origin and destination terminal time = 5 min or 12.5 disutility equivalent minutes.
- Average transit access times (min):

	IN-VEHICLE	OUT-OF-VEHICLE (UNWEIGHTED)			
	AUTO ACCESS	ORIGIN WALK AND WAIT		TRANSFER AND WAIT	DESTINATION WALK
Walk access	0	3	5	0	3
Auto access	3	1	0	7	3

- General impedance equation:

  Total impedance = In-vehicle time + 2.5 (out-of-vehicle time) + (costs ($)/2.5)

The user can, if so desired, develop total impedance nomographs specific to a particular study area (using the general impedance function) by substituting variables that are more representative of local conditions in that study area. The cost conversion factor (2.5) assumes an average income of $9,000 per year.

Step 2. Determine market share. The next step in determining the market share and completing work sheet A is accomplished using the mode-choice nomographs shown in Figures 74, 75, and 76. Nomographs are provided for the following trip purposes:

NOMOGRAPH	TRIP PURPOSE	EXPONENT VALUE, b
Figure 74	HBW	2.0
Figure 75	HBNW	3.0
Figure 76	NHB	2.7

Using the determined highway and transit impedance for each analysis area pair and the appropriate trip purpose mode-choice model, the user can determine the percentage of trips occurring between the analysis area pair that can be expected to use transit. To use Figure 74, 75, or 76, the appropriate nomograph is entered on both the x and y axes using the determined highway and transit impedances respectively; then, the intercept will show the percent of trips by transit, ms_t. The user will, most likely, need to interpolate between the curves supplied on the nomograph. The ms_t result should be recorded on work sheet A and work sheet B as shown in Figure 77. Work sheet A is now complete and the user can, using a calculator, proceed to complete work sheet B.

Step 3. Determine transit and auto person-trips. The compressed (triangular) person-trips for each analysis area pair of the trip purpose under investigation should be recorded on work sheet B. Multiplying the trips by the percent transit market share, ms_t, will yield the number of transit person-trips anticipated to occur between the analysis areas. Subtracting transit person-trips from the total person-trips for that particular interchange yields the number of auto person-trips for the interchange.

The completion of work sheet B finishes the mode-choice analysis for the trip purpose. Most probably the analyst will have chosen the HBW trip purpose to analyze first. If so, a decision then has to be made about the extent of further analysis of the nonwork trip purposes (i.e., HBNW and NHB trips). The analyst has two options:

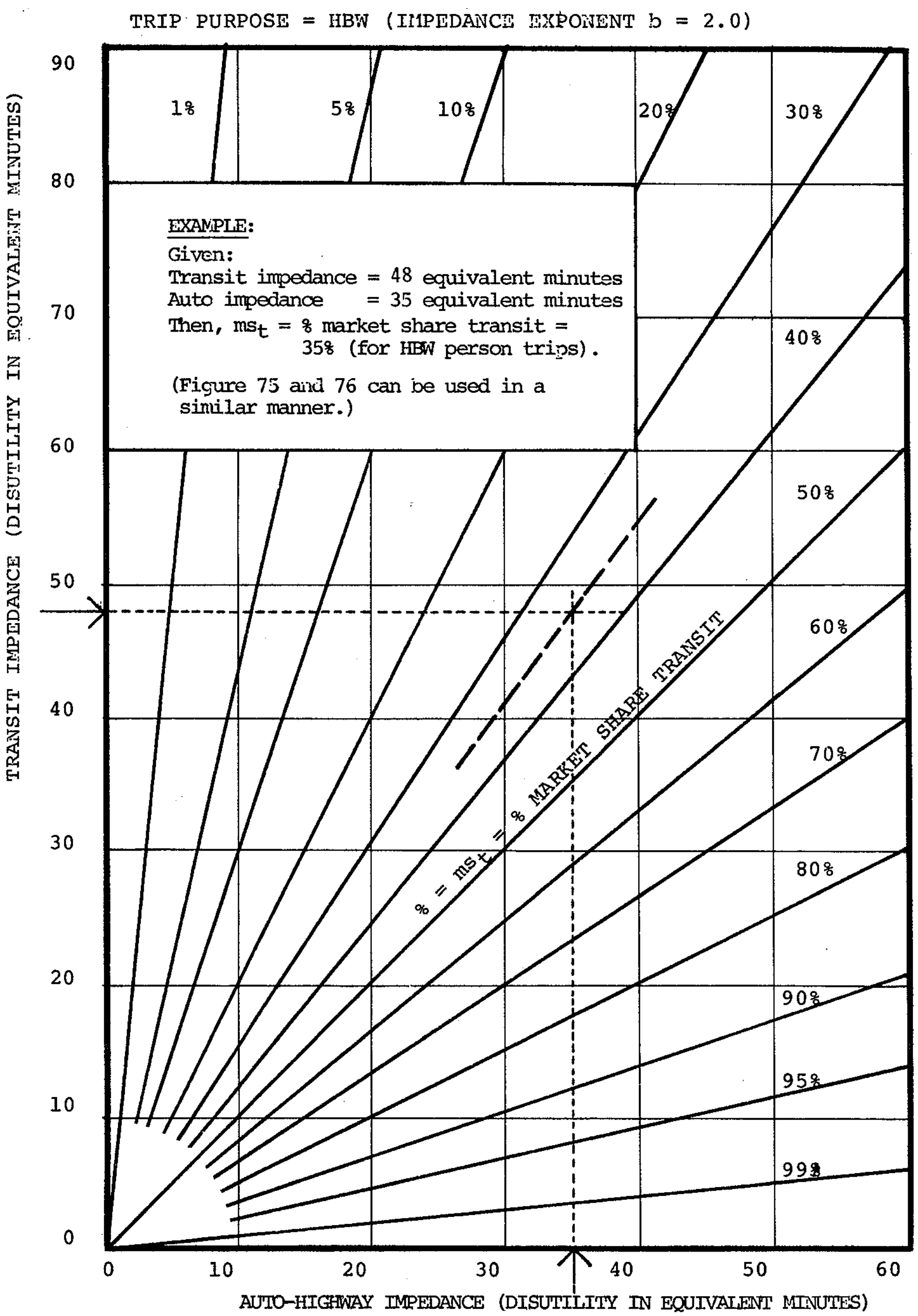


Figure 74. Mode-choice model nomograph: trip purpose, HBW.

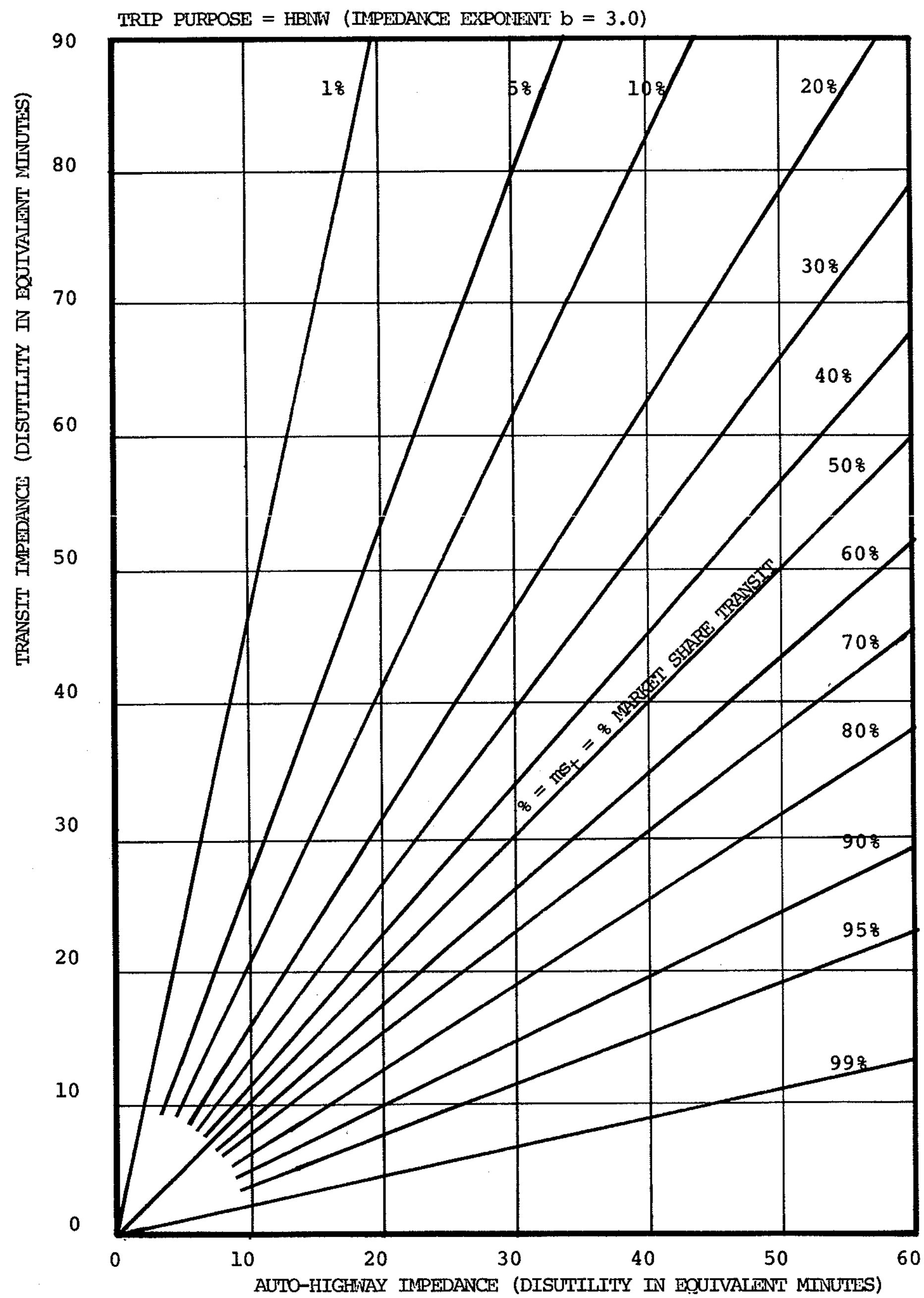


Figure 75. Mode-choice model nomograph: trip purpose, HBNW.

1. The aforementioned process may be repeated for each trip purpose (taking care to adjust input variables and to select the proper mode-choice nomograph).
2. The transit HBW trips could be assumed to represent the total movement during the peak periods, which is estimated to be 50 percent of the total transit trips for an annual average weekday (AAWD). (See Fig. 84 and Table 37 in Chapter Six.)

If the user desires to pursue transit systems analysis to determine fleet sizing and system costs, the procedures in the "Transit Corridor Analysis Manual" (*28*) should be employed.

ESTIMATING SENSITIVITY OF MODE CHOICE TO POLICY CHANGES

Today, many technicians involved in transportation planning are asked to determine the consequences of changes in fare structures, gasoline costs, and the like, and they are faced with extensive and laborious techniques in order to respond. In many cases, it seems the time required to provide an answer is so extensive that the answer is not available until after a policy decision is made. To assist the planner in reducing policy response time, several aids are included in this section for addressing quick-response situations to policy issues.

The analytical aids contained herein have been derived from the basic mode-choice model developed in the beginning of this chapter. The user may develop other relationships which are pertinent and specific to the study area and needs. The rules of thumb presented later may prove useful for many users. Should it be desirable to modify any of the information contained in the basic nomographs, the user is directed to the preceding section which describes the assumptions used.

Graph of Market Share Curves by Trip Purpose

Figure 78 shows, in combined form, the curves plotted for each of the mode choice models, that is, for HBW, HBNW, and NHB trip purposes. The market share of transit, ms_t, plotted against the impedance ratio where:

$$\text{Impedance ratio} = \frac{\text{Transit impedance}}{\text{Highway impedance}}$$

It can be seen from Figure 78 that the market share is a function of the ratio of impedances and the exponent, applied according to trip purpose, of the ratio. If a change in impedance for either the transit or highway mode can be predicted under given conditions, the change in the impedance ratio can also be determined. By observing the new impedance ratio, the user can determine a revised market share of transit.

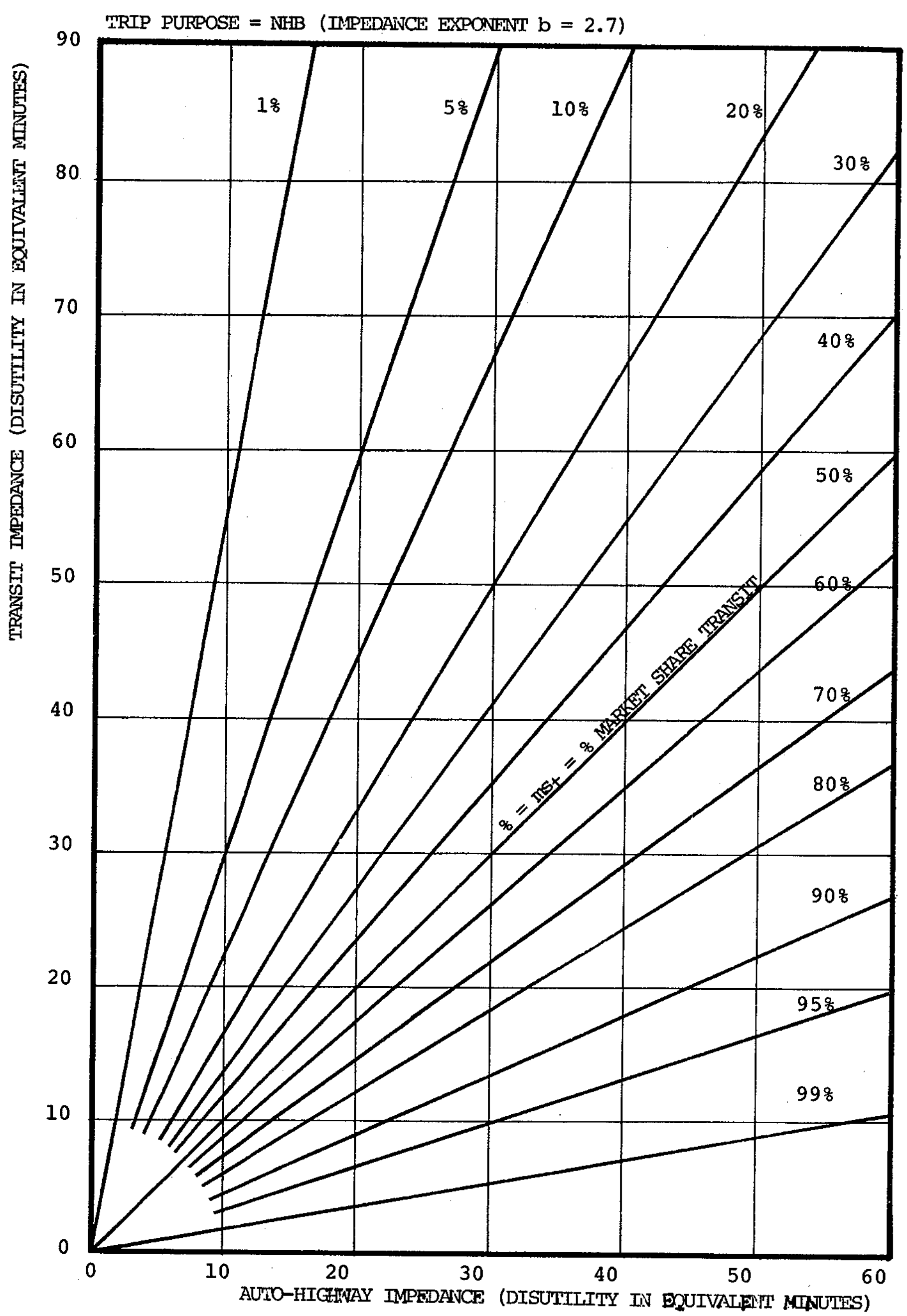


Figure 76. Mode-choice model nomograph: trip purpose, NHB.

+ If triangular work sheet is desired, all cells vertically below the shaded cells should by elimiated.

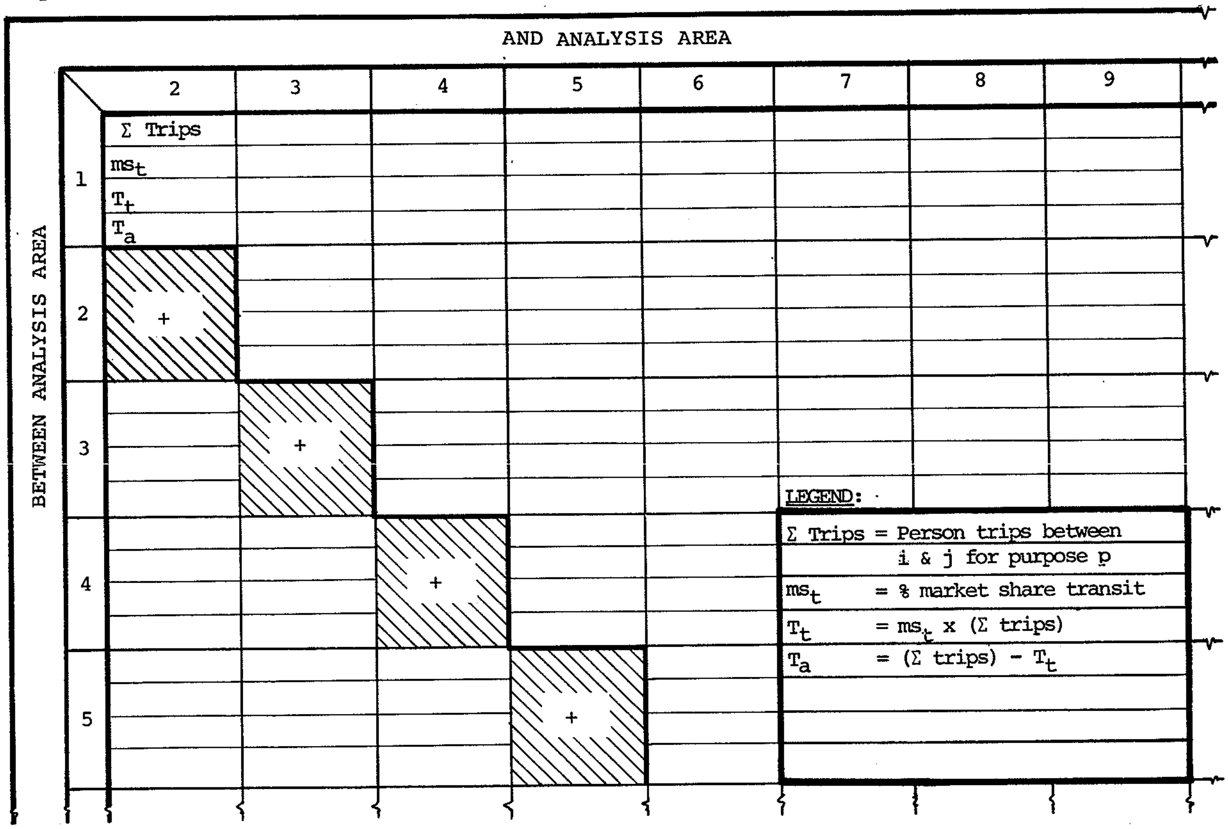


Figure 77. Mode-choice analysis work sheet B.

Graphs for Conversion of Impedance

The mode-choice model deals with three basic elements of a trip in estimating the impedance values. They are:

- In-vehicle travel time.
- Out-of-vehicle time.
- Trip costs.

The first, in-vehicle travel time, has a one-to-one correspondence with impedance. That is, the in-vehicle travel time, in minutes, is equal to the value of impedance for that component of the total impedance. The second and third items require conversion based on behavioral analysis and model calibrations from urbanized area studies.

Out-of-vehicle time is weighted by a factor of 2.5 to convert the value to an impedance quantity. In effect, the traveling individual perceives a walking or waiting minute as 2.5 × (traveling min). To assist in converting out-of-vehicle time into equivalent minutes of impedance, Figure 79 has been included. For example, if the walking time from the point of origin to the bus stop is 6 min, the user can enter Figure 79 along the *y* axis and read across to the intercepting diagonal and down to the *x* axis. The result observed, along the *x* axis, is 15 equivalent minutes of impedance.

Trip costs, in cents, must be converted to equivalent minutes in order to be additive with the other components of total impedance. Travel costs include auto operating cost, parking cost, and transit fare. The value an individual associates with his "nonworking" time has been the subject of much research. However, the assumption used in these procedures is the same as is contained in the UMTA default model which describes the value of an individual's own time equal to one-third of the value associated with an equivalent amount of working time. The transformation equation is:

$$\text{Cost in minutes} = \frac{\text{Cost (\$)}}{\tfrac{1}{3} \times \text{Annual income(\$)}/120{,}000} \qquad (15)$$

where

120,000 is a constant to convert the \$/yr to ¢/min

Figure 80 is a conversion graph for transforming costs into equivalent minutes of impedance. The graph is applicable for any type of user cost and for either highway or transit trip attributes. The graph has five income levels plotted for use in making the conversion. The dashed line represents the assumption used in the "Transit and Auto Total Impedance Nomographs" (Figs. 60 through 73) for estimating the impact of costs on trip-making decisions; it assumes a median household income of \$9,000 per year. The other four curves represent the mid-point of income ranges used in Chapter Two, "Trip-Generation Estimation," and are intended for the analyst's

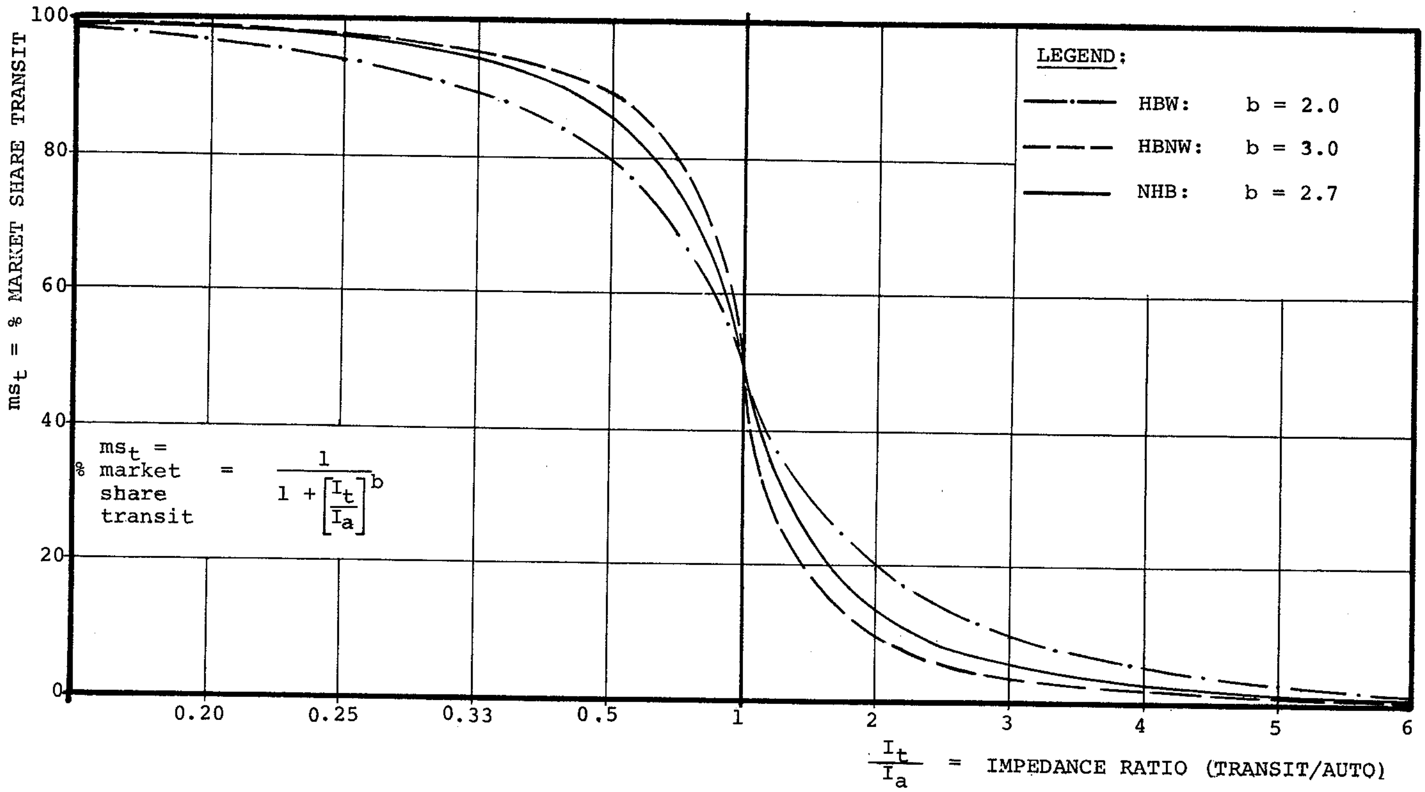


Figure 78. Market-share curves, by trip purpose.

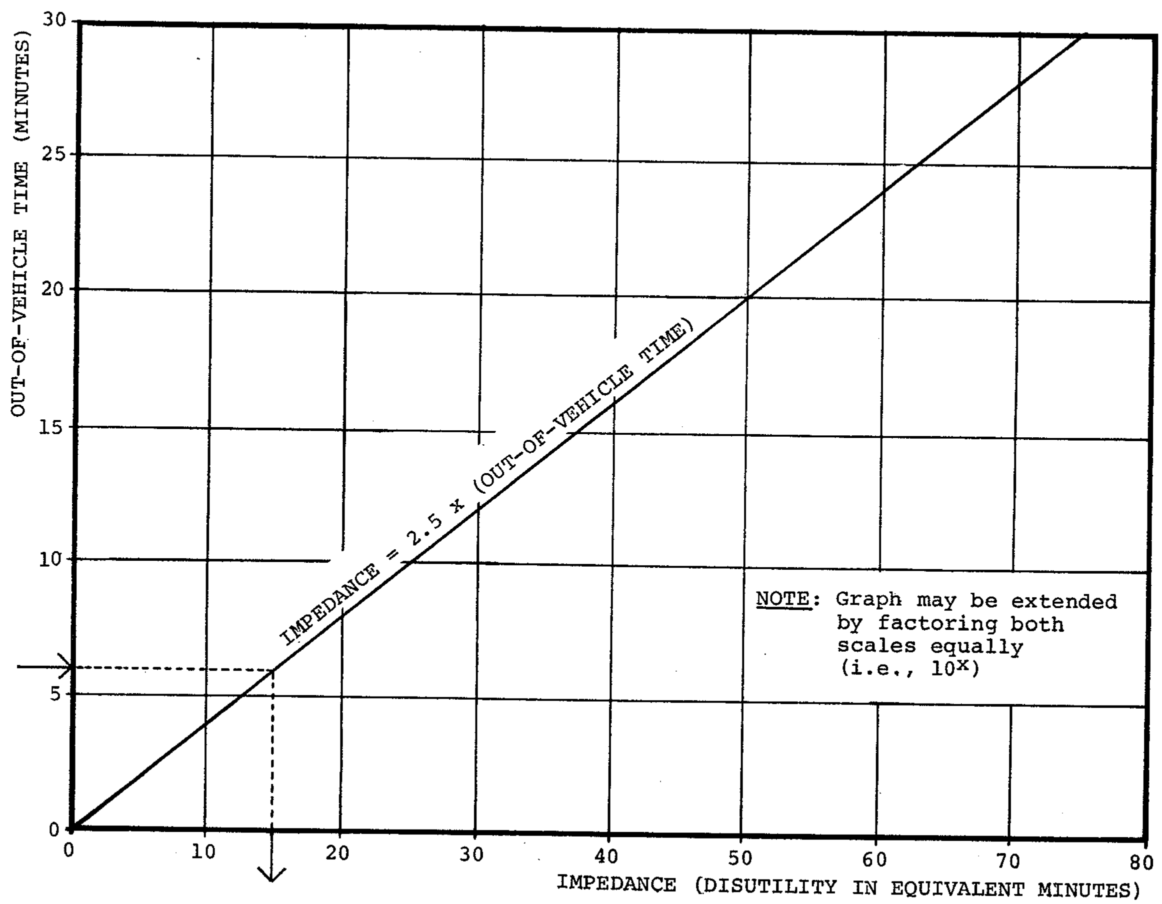


Figure 79. Graph for conversion of out-of-vehicle time to impedance.

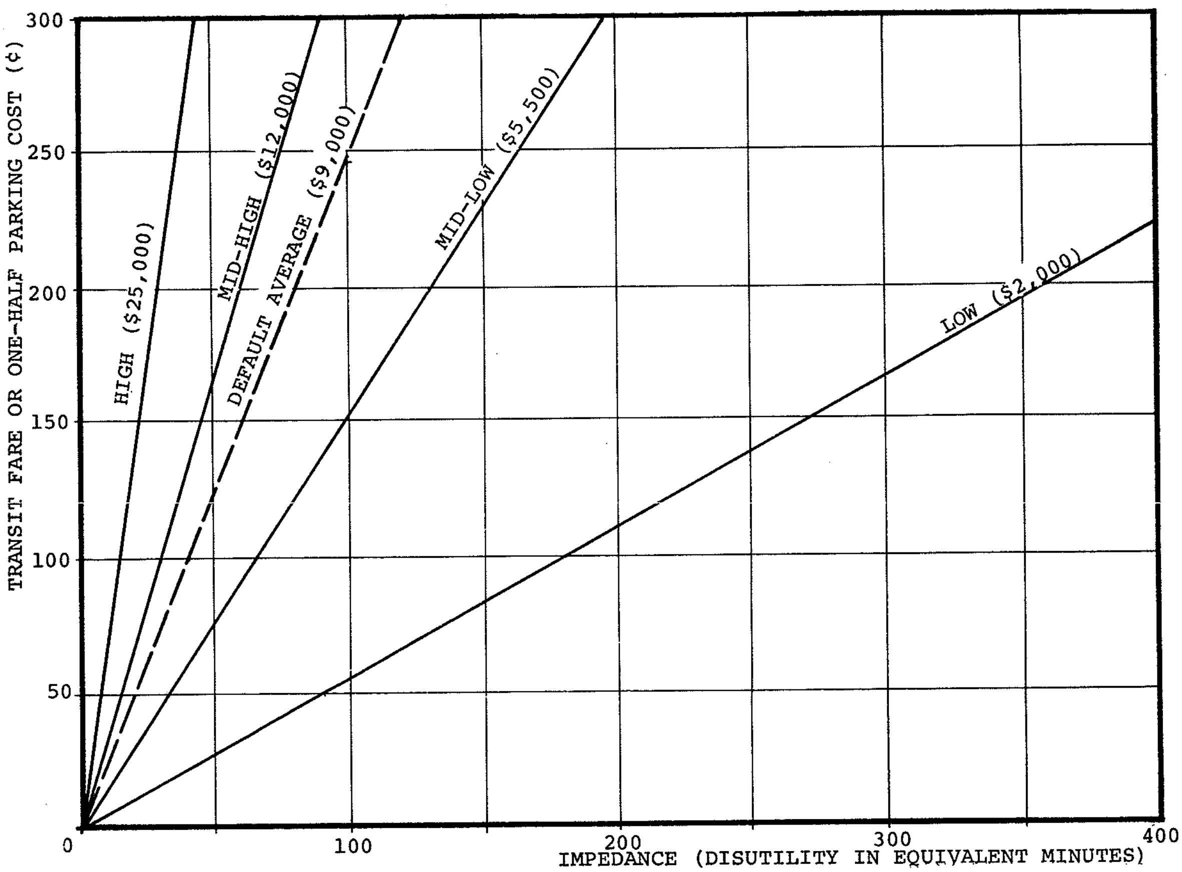


Figure 80. Graph for conversion of transit fare and auto parking cost to impedance.

use when default conditions of these procedures are to be adjusted to match known economic situations of the study area.

Nomograph for Estimating Change in Transit Patronage

Figure 81 is a key aid for quickly determining a change in transit patronage given a known split of trips between modes by purpose. The three simplified mode-choice models developed in this chapter have been combined into a single graph for use in rapidly determining mode split or change in mode split under specified policy assumptions. An application of the graph is illustrated by the following example:

Given: Two districts with the following existing impedance attributes:

Total transit impedance—95 equivalent min.
Total highway impedance—35 equivalent min.

Determine: The impact on transit patronage for HBW-related trips if transit fares were increased by $0.10.

Solution:
1. Assuming an average household income of $9,000, (in the origin district) it is determined from Figure 80 that the fare increase will add 4 equivalent minutes to the transit impedance. Thus, the revised total transit impedance will be 99 equivalent min.
2. With the known transit and highway impedance of 99 and 35, respectively, construct line 1 as shown in Figure 81.
3. At the point where line 1 intersects the reference line, construct line 2 parallel to the impedance scale lines until it intersects the HBW mode-split curve.
4. At the point line 2 intersects the HBW mode-split curve, construct line 3 perpendicular to the impedance scale lines until it intersects the percent transit scale.
5. Line 3 shows the solution; i.e., 11 percent of the HBW trips between the districts are estimated to use transit.

If desired, the analyst can obtain further information about transit travel between the two districts. Constructing other solution lines from line 2 at the points line 2 intersects the other mode-split curves will reveal that, under the same impedance conditions, HBNW percent transit is estimated to be 4 percent and NHB is estimated to be 6 percent.

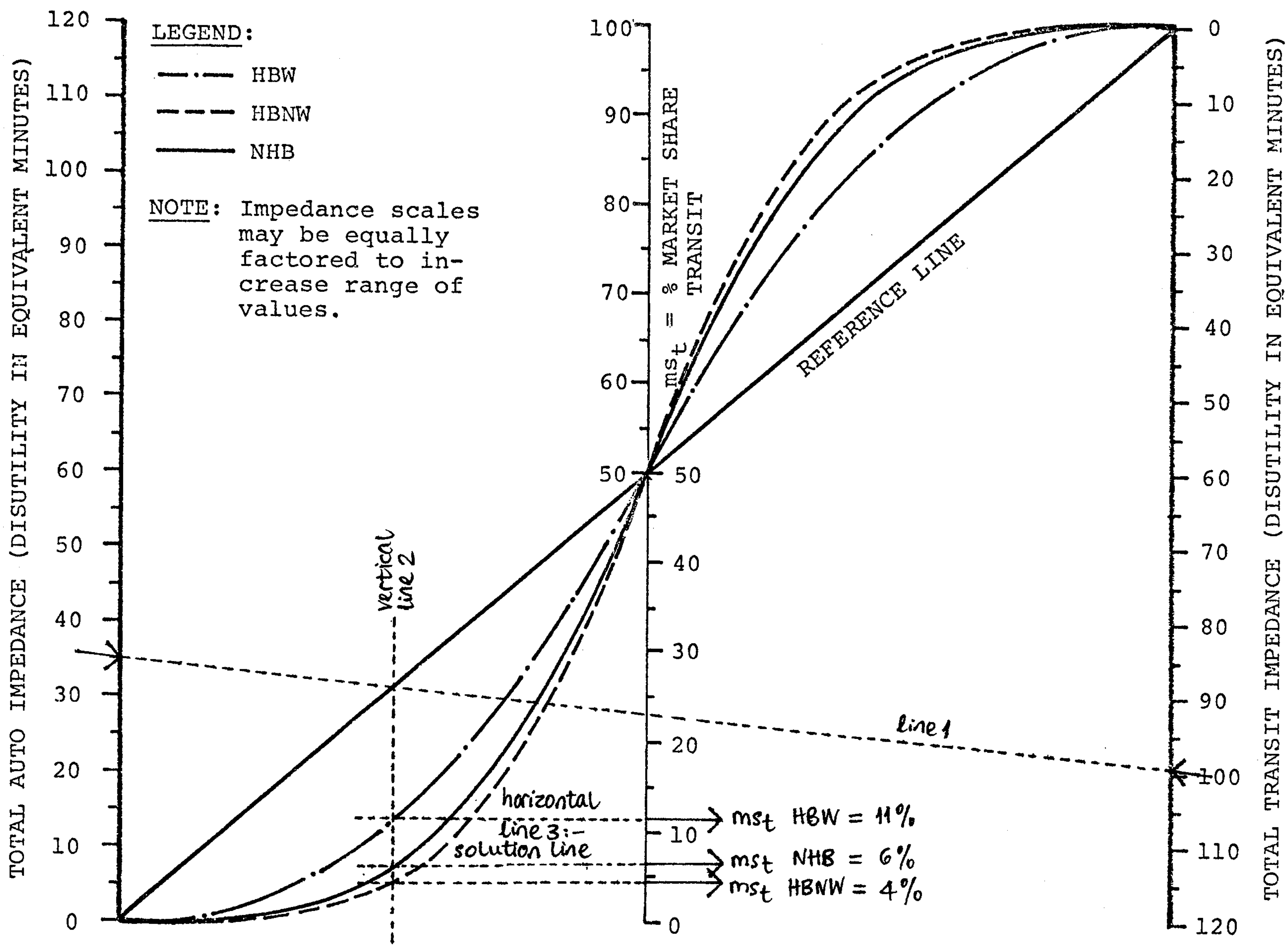


Figure 81. Nomograph for estimating change in transit patronage.

The elasticity of the fare increase can also be determined if the analyst desires to do so. A solution can be determined under the original impedance conditions of 95 and 35 equivalent minutes for transit and highway travel and compared to the preceding solution. Under the base condition, the HBW trips estimated to use transit is equal to 12 percent. Thus, the \$0.10-fare increase will have the impact of reducing the HBW transit trips by 8.3 percent; i.e., $[(11\text{-}12)/12] \times 100$.

Rules of Thumb

The intent here is not to provide analytical procedures but rather industry observations of "what's happening now," in a general sense. The user certainly should be aware that the rules are not rigid; however, their application should provide results that are of a reasonable order of magnitude.

1. A 3-percent increase in transit fare will cause a 1-percent decrease in transit ridership and, conversely, a 3-percent decrease in transit fare will cause a 1-percent increase in transit ridership.
2. The following residential transit trip-generation rates apply to an area described by ¼ mile on each side of a transit line (also see Table 1, Chapter two):

INCOME	RESIDENTIAL DENSITY	RATE
High and middle	≥ 5 DU/acre	0.75 trip/DU
High and middle	< 5 DU/acre	0.40 trip/DU
Low	All	1.00 trip/DU

3. The following represent average patronage estimates per hour of operation by area:

AREA	REVENUE PASSENGERS/HR/VEH
CBD	30
Central city-line haul	24
Suburbs-line haul	20
Suburbs-local	9

AN EXAMPLE APPLICATION

The mode-choice model can be applied to many analysis levels for varying conditions in addition to the full-scale regional case. The following example describes how an analyst, having knowledge of the existing travel, might determine the impact of an operating policy in a corridor:

Given: A transportation planner has an HBW person-trip table and knows the following information about travel between areas within the corridor and the CBD.

Transit fare	= \$0.25
CBD parking charge	= \$0.70/day
Auto operating cost	= \$0.5/mi
Auto operating speed	= 30 mph
Assumed household income	= \$9,000/year (default)

Determine: The transit headway necessary to get 30 percent of the north corridor HBW trips to and from the CBD on transit.

Solution: 1. Figure 82 shows the corridor under consideration that includes analysis districts 1, 2, 3, and the CBD. All districts are assumed to have transit service. With the foregoing information and the appropriate "Auto Total Impedance Nomograph" (Fig. 62), the district-to-district auto impedances are found to be:

DISTRICT PAIRS	ONE-WAY AIRLINE MILEAGE	AUTO IMPEDANCE (EQUIV. MIN)
1 – CBD	D1 = 1.3	29
2 – CBD	D2 = 2.0	31
3 – CBD	D3 = 2.9	35

2. With a known (desired) mode split of 30 percent, the mode-choice nomograph for HBW trip purpose (Fig. 74) and the district auto impedance can be used to determine the transit impedance necessary to achieve the desired condition. They are:

DISTRICT PAIRS	ONE-WAY AIRLINE MILEAGE	TRANSIT IMPEDANCE (EQUIV. MIN)
1 – CBD	D1 = 1.3	45
2 – CBD	D2 = 2.0	47
3 – CBD	D3 = 2.9	54

For the example, it will be assumed that district 2, as the mid-area, represents the corridor. In application each district should be evaluated individually.

3. Using the transit impedance results from Step 2, the headway necessary to get 30 percent of the workers to use transit can be predicted as follows:

Transit impedance = 47 equivalent min

also

Transit impedance = (in-vehicle time) + 2.5 (out-of-vehicle time) + (costs (\$)/2.5)

Using Figure 57 (assuming a 15-mph bus operating speed), in-vehicle time is equal to 10 min for an airline distance of 2.0 miles.

Therefore

$$47 = 10 + 2.5 \text{ (out-of-vehicle time)} + (25/2.5)$$

or

Out-of-vehicle time = 27/2.5
Out-of-vehicle time = walk
+ wait time
(assuming transfers are not involved)

The model default values assume walk time equals 6 min (3 min at origin + 3 min at destination). Then

2.5 (wait time) = 27 − 2.5(6) = 12

and

Wait time = 4.8 min

4. Conclusion: If it is assumed then, as many transit planners do, that the aver-

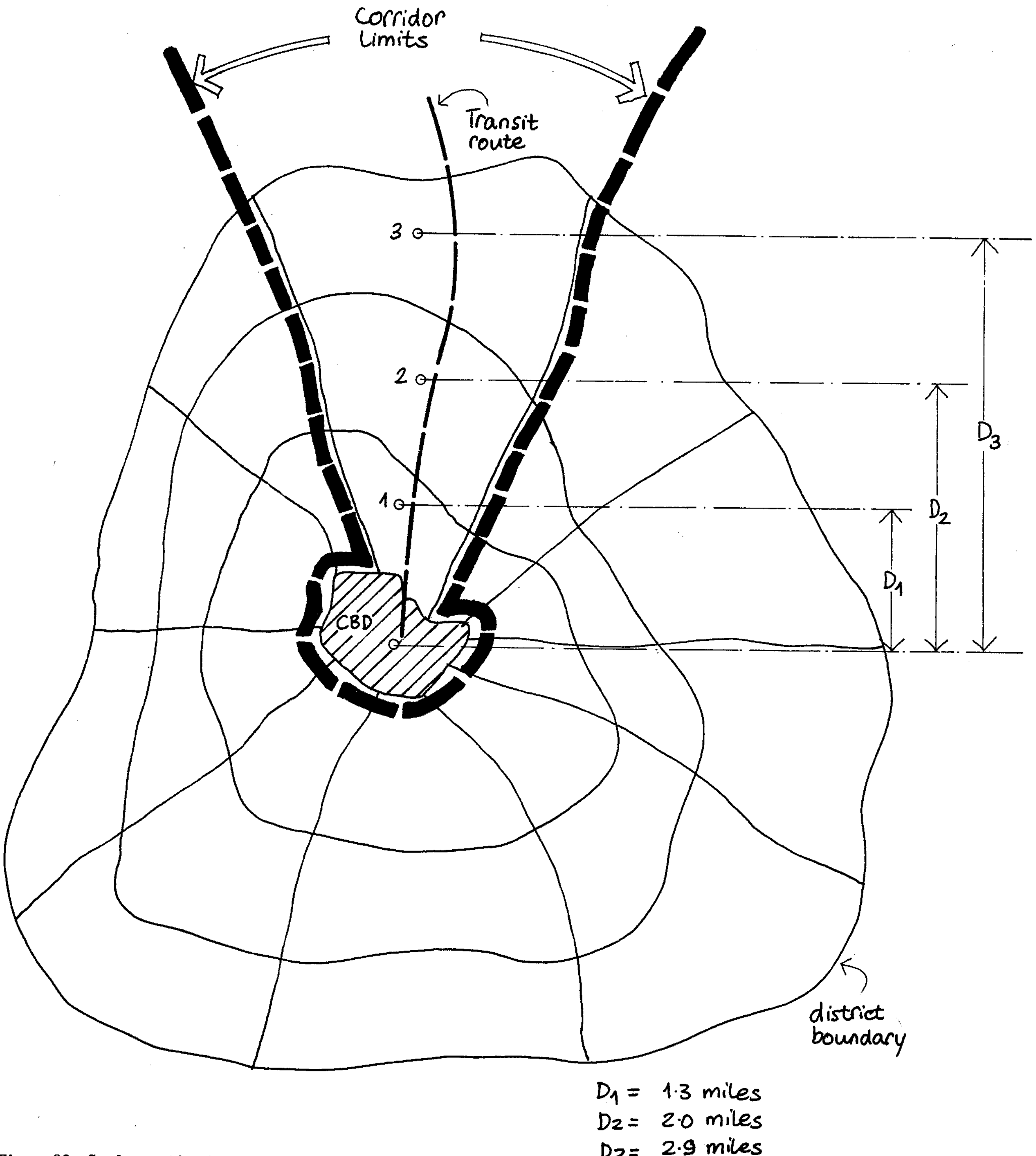


Figure 82. Study corridor for example application.

age wait time is equal to one-half the headway; then, a headway of approximately 10 min is necessary, under the given conditions, to get 30 percent of the HBW trip between district 2 and the CBD to use transit.

FEATURES AND LIMITATIONS

The user should be aware of how the mode-choice model functions in terms of elasticity. The model, as shown in Eq. 14 can be further simplified by dividing the right-hand side by $1/I_a{}^b$ to obtain (for any *ij* pair):

$$ms_t = \frac{1}{1 + \left[\frac{I_t{}^b}{I_a{}^b}\right]} \qquad (16)$$

or,

$$ms_t = \frac{1}{1 + \left[\frac{I_t}{I_a}\right]^b} \qquad (17)$$

Thus, the market share is dependent on a ratio of the impedance for each mode. The user should note that predicting changes in the market share *is* dependent on the *absolute* magnitude of modal impedance. Obviously, the degree of change observed in the ratio is related to the degree of change in either its numerator or denominator.

The mode-choice procedures have many internal features that are desirable for testing policy alternatives as well as conducting areawide planning. Their sensitivity varies according to the form in which they are applied. Sensitivity is primarily governed by the impedance nomograph. For example:

1. If the user applies the default nomographs (Figs. 60 through 73) with their inherent assumptions regarding service levels and income, the procedures will not be sensitive to varying levels of transportation. That is, if the analyst wishes to evaluate significant increases to the transit service, it will be necessary to vary the wait times and to create other appropriate nomographs. On the other hand, the user can invoke varying service and economic test conditions to provide the desired sensitivity by developing other impedance nomographs.

2. Application of the procedures to address subarea policy questions, such as to determine shifts in mode choice because of specific policy alternatives, has shown they respond well to operating and cost variations.

3. If the user has existing gravity-model calibrations, the mode choice models can be easily calibrated from the friction-factor curves.

As with any procedure, the mode-choice models, in application, should be checked against a known universe of mode split to fortify the user's confidence that the models are producing reasonable results. It is recommended the models be applied to current operating conditions and compared to transit patronage information from the local transit operator. For those areas using the models where transit service does not currently exist, the user can only judge the reasonableness of the results obtained from the model.

Application of the models to nonscheduled transit services (demand-responsive) is *not* recommended. Applications where special services exist (such as club buses, express-only service, etc.) should be made with caution. To apply the procedures for nonscheduled types of operations would require the user to develop surrogate representations of system operating conditions such as wait time, walk time, and in-vehicle operating time. Existing experience with demand-operating conditions is limited and has not produced modeling procedures that can be quickly interchanged between areas.

Use of Local Models

The user may have available an existing mode-choice model that has been calibrated for the study area in question. In those cases it is probably desirable to use the local models. Generally, all types of mode-choice models can be reduced to a graphic form whether they are:

- Trip end.
- Trip interchange.
- Marginal disutility.
- Diversion.
- Other.

Some models, such as marginal disutility, require an impedance calculation similar to that described by the procedures, and the user can make necessary adjustments to accommodate locally calibrated models. Using local impedance expressions, impedance nomographs similar to those shown in Figures 60 through 73 can be developed.

Historically, a problem of mode choice models is their insensitivity to system variability. The user should investigate the model for sensitivity to system changes and determine if it will adequately respond to policy alternatives. The user may wish to employ the procedures contained in this chapter instead of local models if the local models lack a sensitivity to system change because of limitations of the model structure.

CHAPTER FIVE

AUTOMOBILE-OCCUPANCY CHARACTERISTICS

INTRODUCTION

The most commonly used modeling approach employed by urban transportation planners is to generate total person-trips, and then distribute and split these trips into auto and transit modes. Auto-occupancy factors are then applied to the auto person-trip dataset to produce vehicle trips for use in the traffic-assignment process. The importance of auto occupancy in this process becomes apparent when it is considered that a slight error in the auto-occupancy rates (e.g., 1.36 vs. 1.50 or about 10 percent) translates into a difference of more than 10,000 vehicles per day on a high-volume facility.

Unfortunately, however, investigation indicates that relatively little attention has been given to the development of procedures to determine auto occupancy. It appears to be common practice to develop auto occupancy factors by trip purpose from base-year data and to use this one set of factors for all subsequent planning efforts.

Recently, auto occupancy considerations have begun to receive greater attention in the urban planning process. This attention is to a large extent the result of programs initiated, such as ride-sharing and the exclusive use or preferential treatment of transportation facilities to serve high-occupancy vehicles, to conserve energy and improve air quality. Many transportation planners are beginning to view auto occupancy as an input policy variable to the planning process rather than as an output of the process.

An effort was undertaken to assimilate and analyze available data relative to auto occupancy to determine auto-occupancy values, and to develop some insight into the variation of auto occupancy with other factors. Tables for estimating auto occupancy by urbanized area population, trip purpose, time of day, trip length, land-use at destination, and income and parking cost have been provided to assist in responding to auto-occupancy questions.

BASIS FOR DEVELOPMENT

This section describes the data sources utilized and the analyses performed to provide estimates of automobile occupancy.

Three major data sources were used in the development of these estimating procedures: The "Nationwide Personal Transportation Study" (*33, 34*); a report entitled, "An Analysis of Urban Travel by Time of Day" (*36*); and numerous urban transportation study reports.

In many instances, the available data sources were either incomplete or incompatible in terms of data stratification, over-all findings, or year of data. For these reasons, manipulation of the base data was required to produce the results contained herein. To the extent possible, these manipulations are described to assist the user in developing an appreciation for the strengths and weaknesses of the estimating procedures.

FEATURES AND LIMITATIONS

In an effort to develop an auto-occupancy estimating procedure usable in urbanized areas of varying population, investigation was undertaken to determine if auto occupancy (either total or by trip purpose) varies with the population of an area, by time-of-day, trip length, and the like.

Variation in Auto Occupancy by Urbanized Area Population and by Trip Purpose

The "Nationwide Personal Transportation Study" (NPTS), concludes that auto occupancy does *not* vary with city size:

> The size of the standard metropolitan statistical area has no clear relationship to occupancy rates. Although there does appear to be some difference between incorporated and unincorporated areas, this difference may be due to statistical inference (*33*).

As a check for this conclusion, information relative to auto occupancy was compiled following a review of numerous urban transportation study reports. The data were subsequently used to construct lines of best fit for each individual trip purpose and for total trips. The findings of the review led to several conclusions that should be noted: (1) the variation in auto-occupancy rates by trip purpose is quite insignificant over the range of urbanized area populations to which the results of this study will most often be applied; and (2) it is possible to develop average auto-occupancy rates by trip purpose for selected urbanized area population groups.

Such values reflect average auto-occupancy rates as of approximately 1963 (average base-year of available data). Investigation was therefore undertaken to identify trends in auto occupancy over a period of time. The NPTS was of no help in this regard because data presented in that publication are for only one point in time. However, information compiled following review of numerous urban study reports provided some insight into the change in auto occupancy over a period of time.

The information gathered and analyzed suggests that: (1) total, home-based work (HBW) and home-based nonwork (HBNW) trip purpose auto-occupancy rates are increasing at about the same order of magnitude; (2) the auto-occupancy rate for home-based (HB) social-recreational trips is increasing at a faster rate; and (3) HB shop and nonhome-based (NHB) auto-occupancy rates are decreasing. In view of the lack of data beyond 1965, it was concluded that the most reasonable method of updating the auto-occupancy values to 1976 would be to apply the trend associated with the total trip purpose to all purposes with the exception of the HB social-recreational purpose where a greater increase seems justified.

The application of these trends yields the auto-occupancy rates by urbanized area population and trip purpose given in Table 12.

Variation in Auto Occupancy by Time of Day

The preceding section explained the development of average auto-occupancy values by urbanized area population and trip purpose for 1976. These values reflect *average daily* auto occupancy rates.

Investigation was undertaken to determine if auto occupancy by trip purpose varies by time of day. Review of available information yielded some insight; that is, only three of the availiable documents (*33, 34, 36*) had investigated auto occupancy to this extent and support the premise that auto occupancy does vary by time of day and by trip purpose significantly enough to be considered. Work was therefore undertaken to develop the information given in Table 13.

The method employed was as follows: The variation in auto occupancy by trip purpose was used to construct a table of auto-occupancy values by hour-period for HBW, HBNW, NHB, and all-purpose trips for St. Louis, Missouri. This table was then adjusted to reflect 1976 national average auto-occupancy rates rather than the St. Louis rates, by multiplying entries in the table by the national to St. Louis-occupancy rate ratios. The HBNW trip purpose was subsequently disaggregated into HB shop- and HB social-recreational trip purposes. The occupancy rates for the HB other-trip purpose were then entered using HBNW information on the assumption that this group of trips best represents the HB other-trip purpose. Finally, the auto-occupancy rates by trip purpose by hour-period were converted to the adjustment factors given in Table 13.

Variation in Auto Occupancy by Trip Length

Thus far, it has been shown that auto-occupancy rates vary by trip purpose and by time of day. In addition, information reported in Ref. (*33, 34,* and *36*) indicated that auto occupancy is also a function of trip length in terms of time or distance. For example, a line of best fit to the data given in Ref. (*36*) indicates that:

$$\text{Total auto occupancy} = 1.37 + 0.0062 \times (\text{Trip time in min})$$

These data (reflecting conditions in St. Louis as of 1965) indicate that the average auto occupancy for all trips of 25 min duration is about 1.53, and for all trips of 50 min duration the average auto occupancy is about 1.84.

In this chapter, trip length in distance rather than time is reported to eliminate the differences in level of service provided in different urbanized areas. Information given in the Nationwide Personal Transportation Study (*33*) was used to develop a set of auto-occupancy trip-length adjustment factors, modified to reflect 1976 average-occupancy factors and selected trip purposes. The resultant calculations are given in Table 14.

The auto-occupancy rates given in Table 12 may be cumulatively adjusted by the factors given in Tables 13 and 14. For example, a HBW trip for an urbanized area in the 50,000 to 100,000-population group has associated with it an auto-occupancy rate of 1.38 (Table 12). If this trip occurs at 8 AM, this rate would be adjusted downward by 0.11 (Table 13) to 1.27. If, in addition, the trip length is 20 mi, the occupancy rate would be raised by 0.10 (Table 14) to 1.37. (Similar adjustments can be made to the auto-occupancy rates contained in Tables 15 and 16.)

Variation in Auto Occupancy by Income Level and Parking Cost

In addition to the variables discussed thus far, it is intuitively known that auto occupancy is a function of the income level of the trip-maker and of parking cost at the destination of a trip; that is, the auto occupancy of low income trip-makers is higher than for similar trips by high income trip-makers, and the auto occupancy for trips to high parking cost areas is higher than for comparable trips to low parking cost areas.

This basic relationship between auto occupancy and the economics of travel is extremely important, but often neglected in the planning process. In particular, the use of average auto-occupancy rates by trip purpose will tend to overestimate vehicular trips to areas of high parking cost and underestimate vehicular trips to areas where parking costs are either low or nonexistent.

As part of this user's guide, generalized relationships between auto occupancy and parking cost and income level are provided to assist the user in assessing the effects of such variables. A set of relationships developed for the Minneapolis-St. Paul, Minnesota, area were used as a basis for the material provided. This information was subsequently updated to 1976 on the basis of the relationship between the average HBW and HBNW auto occupancy-rates developed. The results are given in Table 15, for HBW and HBNW trips. In Table 15, both income level and parking cost are stratified into non-quantitative groupings. This method of stratification was employed to allow each user to employ locally available information. However, if local quantitative data on auto-occupancy response to income and parking cost are lacking, the following guidelines may be employed:

QUALITATIVE DESCRIPTOR	INCOME LEVEL ($)	PARKING COST ($)
Very High	31,000 and above	4.25
High	23,000–30,999	3.50
High Average	16,000–22,999	2.75
Low Average	11,000–15,999	2.00
Low	6,000–10,999	1.25
Very Low	Under 6,000	0.50

Variation in Auto Occupancy by Land Use at Destination

It may be desired to estimate auto occupancy knowing only the characteristics of the destination end of the trip; for example, what will be the average auto occupancy to a proposed shopping center? Investigation was therefore

TABLE 12

AVERAGE DAILY AUTO-OCCUPANCY RATES (1976) BY URBANIZED AREA POPULATION AND TRIP PURPOSE [a]

URBANIZED AREA POPULATION	TRIP PURPOSE						
	HBW	HB Shop	HB Soc-Rec	HB Other	HBNW[b]	NHB	All Purposes[c]
50,000 - 100,000	1.38	1.57	2.31	1.52	1.82	1.43	1.50
100,000 - 250,000	1.37	1.57	2.31	1.52	1.81	1.43	1.50
250,000 - 750,000	1.35	1.57	2.30	1.52	1.77	1.43	1.50
750,000 - 2,000,000	1.33	1.58	2.29	1.51	1.74	1.43	1.51

a. Source: References (33, 34).
b. Weighted average of auto occupancy rates for HB Shop, HB Social-Recreational and HB Other trip purposes.
c. Weighted average of auto occupancy rates for all trip purposes.

TABLE 13

AUTO-OCCUPANCY RATE ADJUSTMENT FACTORS BY TIME OF DAY [a]

HOUR PERIOD BEGINNING	ADJUSTMENT FACTORS BY TRIP PURPOSE[b]						
	HBW	HB Shop	HB Soc.-Rec.	HB Other	HBNW[c]	NHB	All Purposes[d]
12 mid-night	-0.05	e	-0.01	+0.07	+0.06	-0.10	0
1	-0.07	e	e	+0.05	+0.05	-0.12	-0.06
2	-0.14	e	e	+0.08	+0.08	-0.20	-0.09
3	-0.11	e	e	+0.06	+0.06	-0.20	-0.09
4	-0.08	e	e	+0.07	+0.07	-0.20	-0.11
5	0	e	e	+0.05	+0.05	-0.21	-0.15
6	+0.05	e	e	-0.19	-0.19	-0.19	-0.22
7	+0.03	e	e	-0.25	-0.25	-0.19	-0.23
8	-0.11	-0.24	-0.20	-0.23	-0.22	-0.28	-0.26
9	-0.13	-0.16	-0.30	-0.17	-0.21	-0.24	-0.13
10	-0.12	-0.16	0	-0.13	-0.09	-0.22	-0.05
11	-0.14	-0.08	-0.20	-0.12	-0.14	-0.19	-0.03
12 noon	-0.11	-0.08	0	-0.06	-0.04	-0.18	-0.03
1	-0.11	-0.08	-0.10	-0.12	-0.10	-0.09	0
2	-0.07	0	-0.10	-0.10	-0.07	-0.11	-0.02
3	+0.03	+0.08	-0.10	-0.07	-0.04	-0.08	-0.05
4	+0.04	-0.08	0	-0.08	-0.05	-0.09	-0.12
5	+0.03	+0.08	0	-0.05	0	-0.10	-0.05
6	-0.08	+0.08	0	+0.02	+0.03	+0.17	+0.03
7	-0.03	+0.16	0	+0.17	+0.11	+0.33	+0.32
8	-0.04	+0.24	+0.10	+0.14	+0.15	+0.33	+0.29
9	-0.05	+0.16	+0.10	+0.19	+0.15	+0.31	+0.29
10	-0.05	-0.08	+0.30	+0.18	+0.15	+0.26	+0.22
11	0	e	+0.20	+0.19	+0.19	+0.27	+0.20

a. Source: References (33, 34, 36).
b. The adjustment factors are to be applied additively to the auto occupancy rates from Table 12.
c. Weighted average of adjustment factors for HB Shop, HB Social-Recreational and HB Other trip purposes.
d. Weighted average of adjustment factors for all trip purposes.
e. Trip data scarce for these hours/purposes, therefore, not sufficient for analysis.

TABLE 14

AUTO-OCCUPANCY RATE ADJUSTMENT FACTORS BY TRIP DISTANCE [a]

ONE-WAY TRIP LENGTH (MILES)	ADJUSTMENT FACTORS BY TRIP PURPOSE[b] HBW	HB Shop	HB Soc.-Rec.	HB Other	HBNW[c]	NHB	All Purposes[d]
Less than 1/2	-0.10	-0.24	-0.20	-0.08	-0.16	-0.08	-0.08
1	0	-0.16	-0.27	-0.03	-0.14	-0.03	0
2	0	-0.08	-0.14	+0.02	-0.06	+0.02	+0.08
3	-0.10	0	-0.04	+0.01	-0.04	+0.01	0
4	-0.10	0	-0.15	-0.01	-0.15	-0.01	0
5	0	+0.08	+0.06	+0.06	+0.06	+0.06	+0.08
6	0	+0.08	+0.02	-0.09	+0.02	-0.08	0
7	0	+0.16	+0.05	+0.02	+0.05	+0.02	+0.08
8 - 10	0	+0.16	-0.04	+0.10	-0.04	+0.09	0
11 - 15	0	+0.39	-0.01	+0.10	-0.01	+0.09	0
16 - 20	+0.10	+0.24	+0.08	+0.01	+0.08	+0.01	0
21 - 30	+0.29	+0.47	+0.29	+0.03	+0.29	+0.03	+0.16
31 - 40	+0.10	+0.08	+0.21	+0.41	+0.21	+0.39	+0.32
41 and over	+0.19	+0.39	+0.63	+0.37	+0.63	+0.35	+0.55

a. Source: References (33, 34, 36).
b. The adjustment factors are to be applied additively to the auto occupancy rates from Table 12. Some of the variations in the adjustment factors presented here are probably due to the statistical inadequacy of the dataset from which the factors were derived.
c. Weighted average of adjustment factors for HB Shop, HB Social-Recreational and HB Other trip purposes.
d. Weighted average of adjustment factors for all trip purposes.
* Trip data scarce for these hours/purposes, therefore, not sufficient for analysis.

undertaken to develop auto-occupancy rates by land-use category. As in other efforts, limited data were available; however, a dataset was developed that was felt to be adequate for use in developing reasonable estimates of auto occupancy by major land-use category. This dataset was subsequently updated to 1976 on the basis of information previously discussed and the results are given in Table 16.

DATA REQUIREMENTS AND EXAMPLE PROBLEMS

The goal of this chapter is to provide simplified procedures to assist the user in developing answers related to auto-occupancy in relatively rapid order. In the development of auto-occupancy parameters, considerable care was taken to minimize necessary data acquisition for application and yet produce reasonable estimates. For example, one procedure investigated that required trip-interchange density and zonal land-area measurements was excluded because of the work necessitated in its application.

Following are several example problems designed to illustrate how the procedures developed can be employed to provide reasonable estimates of auto occupancy given limited information with which to work.

Problem 1: What are reasonable values for all-purpose trip auto occupancy and HBW-trip auto occupancy in an urbanized area of 275,000 population?

TABLE 15

AVERAGE DAILY AUTO-OCCUPANCY RATES (1976) BY INCOME LEVEL OF TRIP-MAKER AND PARKING COST AT TRIP DESTINATION

HBW TRIPS

INCOME LEVEL OF TRIP-MAKER	PARKING COST AT TRIP DESTINATION VERY LOW	LOW	LOW AVERAGE	HIGH AVERAGE	HIGH	VERY HIGH
Very High	1.09	1.09	1.10	1.13	1.38	1.70
High	1.17	1.17	1.20	1.23	1.52	1.88
High Average	1.28	1.28	1.31	1.31	1.66	2.05
Low Average	1.32	1.32	1.36	1.40	1.71	2.11
Low	1.38	1.39	1.42	1.46	1.80	2.21
Very Low	1.44	1.46	1.49	1.53	1.89	2.32

HBNW TRIPS

INCOME LEVEL OF TRIP-MAKER	PARKING COST AT TRIP DESTINATION VERY LOW	LOW	LOW AVERAGE	HIGH AVERAGE	HIGH	VERY HIGH
Very High	1.31	1.31	1.33	1.36	1.66	2.05
High	1.41	1.41	1.45	1.49	1.84	2.28
High Average	1.54	1.54	1.59	1.59	2.00	2.48
Low Average	1.60	1.60	1.64	1.68	2.06	2.55
Low	1.66	1.67	1.72	1.76	2.17	2.67
Very Low	1.74	1.76	1.79	1.85	2.28	2.80

Source: Transportation data from Minneapolis-St. Paul, MN. and references (33, 34).

TABLE 16

AVERAGE DAILY AUTO-OCCUPANCY RATES (1976) BY URBANIZED AREA POPULATION AND LAND USE AT TRIP DESTINATION [a]

URBANIZED AREA POPULATION	LAND-USE AT TRIP DESTINATION					
	RESIDENTIAL	COMMERCIAL	MANU-FACTURING	TRANSPORTATION FACILITIES	PUBLIC BUILDINGS	OPEN SPACE
50,000 - 100,000	1.54	1.39	1.35	1.30	1.72	1.84
100,000 - 250,000	1.56	1.42	1.34	1.31	1.72	1.89
250,000 - 750,000	1.58	1.45	1.33	1.31	1.73	1.94
750,000 - 2,000,000	1.61	1.49	1.32	1.32	1.73	1.98

a. The auto occupancy rates may vary by the location of the land-use, i.e, in the CBD, central city or suburb, and therefore, by parking costs and employment densities. The rates may also vary by the level of service of transit provided and the existence of any ride-share programs.

Solution 1: Table 12 indicates that for an urbanized area of 250,000 to 750,000 population, the auto-occupancy rates for total trips and HBW trips in 1976 are 1.50 and 1.35 persons per vehicle, respectively.

Problem 2: A new shopping center is under construction in an urbanized area of 225,000 population. It is estimated that the center will generate 10,000 auto person-trips per day, and that 18 percent of such trips will occur during the period 8 PM to 9 PM. How many vehicle trips can be anticipated during this peak hour?

Solution 2: Table 12 indicates that the average auto occupancy for the purpose of HB shopping in an urbanized area of 225,000 population is about 1.57. Table 13 indicates that an adjustment factor of +0.24 should be used during the period 8 PM to 9 PM. The number of vehicle trips to be anticipated is therefore, 994; i.e.,

$$\text{Vehicle trps 8 PM to 9 PM} = \frac{10{,}000 \text{ person-trips} \times 0.18}{1.57 + 0.24} = 994$$

Problem 3: A new manufacturing plant is to be built in a small community of 60,000. What is a reasonable estimate of the auto occupancy of vehicles destined to this facility?

Solution 3: Table 16 indicates that a value of 1.35 is a reasonable auto-occupancy value to use for trips destined to manufacturing facilities in small urban areas.

Usefulness of Regionally Developed Models

The application of the auto-occupancy estimating procedures developed through some example problems attempts to demonstrate how the user can quickly calculate reasonable values for auto-occupancy under varying conditions knowing little more than the population of the study area. It should be noted, however, that many problems facing urban planners are quite complex and require more sophisticated estimating procedures than those outlined herein. One example would be the impact of an exclusive car pool-bus lane on air quality—a problem that requires an estimate of the shift of persons from the automobile to public transit, and from low- to high-occupancy vehicles in a corridor as a result of a change in travel time. In cases such as this, the usefulness of regionally calibrated policy-sensitive models cannot be overstated.

In addition, regionally developed information can play an important role in the refinement of the average nationwide information presented herein. For example, a simple table of auto-occupancy rates by trip purpose reflecting conditions specific to the user's study area could be used in place of Table 12 rates as a more accurate starting point in the estimation process. Other local information (if available), such as auto occupancy by time of day, by land-use category, and the like, could also be used to refine the tables developed herein. In summary, if similar information is available for the user's study area from the local regional planning organization, it should be used. Lacking such information, however, the procedures documented herein can be applied to develop, quickly and economically, reasonable answers to a diverse set of questions relative to auto occupancy.

CHAPTER SIX

TIME-OF-DAY CHARACTERISTICS

INTRODUCTION

The purpose of this chapter is to provide tables to allow determination of hourly travel from estimates of total daily travel. The material provided allows accomplishing this task on either a trip basis or a facility basis. Other information is included to estimate total automobile vehicle travel if automobile trip estimates are available for only internal area residents. Material is provided in this chapter for both automobile travel and transit travel. The data are also extremely useful in converting daily work trips from census information to peak-hour all-purpose trips. The techniques used for vehicle travel are different from those used for transit time-of-day analysis and, therefore, their respective discussions are independent.

Many of the procedures and methods included in this user's guide are based on 24-hr conditions. For analysis of particular highway facilities, transit services and other related work, peak-hour or specific-hour demand estimation is often required.

Studies for special time periods are generally required to analyze system requirements. System extent is based on loading, or sometimes overloading, during limited periods of time during the day—the peak time period. The cause of the critical demand usually is a summation of smaller demands that are generally defined by purpose of trip. For general highway traffic, the critical peak hour most often occurs during the afternoon between 4 PM and 6 PM when people are returning from work, going shopping, completing recreational trips, and the like. However, critical traffic movements may occur at other times, particularly during the morning hours of peak commutation.

BASIS FOR DEVELOPMENT

Time-of-day analyses are used for several types of studies, and, since the introduction of Transportation Systems Management (TSM) requirements, are becoming a more critical part of the over-all transportation planning process. Some examples of time-sensitive studies are:

- Traffic-Impact Studies. Analyses to determine the impact a specific residential, commercial, or mixed development has on the area transportation system.
- Trip-Accumulation Studies. Analyses usually done to determine the peak accumulation of vehicles for parking studies, taking into account the mix of trip purposes involved.
- Highway Volume/Capacity Studies. Evaluations using peak factors (essentially the type of information provided later in this chapter) to determine peak-loading conditions in vehicles per hour (VPH) for highway traffic assignment and determination of capacity requirements.
- TSM Studies. Studies which specifically address transportation solutions for the critical peak period, generally in the form of traffic engineering or operations improvements.

Transit use is highly oriented about the AM and PM peak periods with lesser amounts of travel at other times. The differences between auto and transit use are most visible during the evening hours when many trips are made for social and shopping purposes. Compared to auto trips, very few evening trips are made via transit. Also, the peak hour for transit travel probably will occur during the AM peak period—caused by a concentrated arrival of work trips—whereas the peak hour for auto-related trips will occur during the PM peak period.

There are also impacts on the transportation system from demands that are partially or totally unrelated to residential or commercial development within the subject study area. Those demands constitute trips defined as internal-external and external-external trips. External travel, or travel using the transportation network of a study area but having neither an origin nor a destination within the area, has been difficult to address in the manual techniques provided in this user's guide. Procedures and factors to solve the problem are discussed later in this chapter.

These procedures are based on observed vehicle-miles of travel (VMT). VMT represents the product determined when a given trip is multiplied by its trip length (distance) and, as such, is truly a measure of travel and not a measure of the distribution of trips during a 24-hr period. In real-life situations the trip length may vary, within a given trip purpose, over the 24-hr period. However, within the context of acceptable transportation planning procedures, such as trip-distribution modeling, the VMT distribution can be used to approximate the distribution of trips by trip purpose.

Figure 83 shows the relationship of external travel to the internal auto driver travel for urbanized areas of differing populations. The graph shows the ratio of total vehicle travel to internal auto driver travel versus the hour of day (*36*). It can be seen that the impact of external travel diminishes as the urbanized area population increases. This is a significant point. The demands for local transportation system facilities is more dependent on external travel for smaller urbanized areas than it is for larger urbanized areas. The analyst should not overlook the importance of external travel on determining facility adequacy or requirements. There are, however, many types of analysis where external travel can be neglected.

Vehicle Travel

Time-of-day analysis will most probably be undertaken at one of two points: (a) just after application of the auto-occupancy procedures to isolate a market segment for further analysis; or (b) after assignment of 24-hr travel in preparation for a capacity analysis. The general organization of the charts provided is by the four urbanized area population groups used consistently throughout this user's guide. Each set of charts (by urbanized area population) is further stratified to present data to:

- Analyze auto driver travel by trip purpose.
- Analyze total vehicle travel (including trucks).
- Determine total vehicle travel (including trucks) by time period or in aggregate from internal auto driver trips.
- Determine trip volume by route type, by subregion, and by orientation to study area core.
- Determine directional split of travel by route type, by subregion, and by orientation to study area core.

The tables have been developed by sampling directional vehicle travel observations for urbanized areas within each population group and averaging the weighted

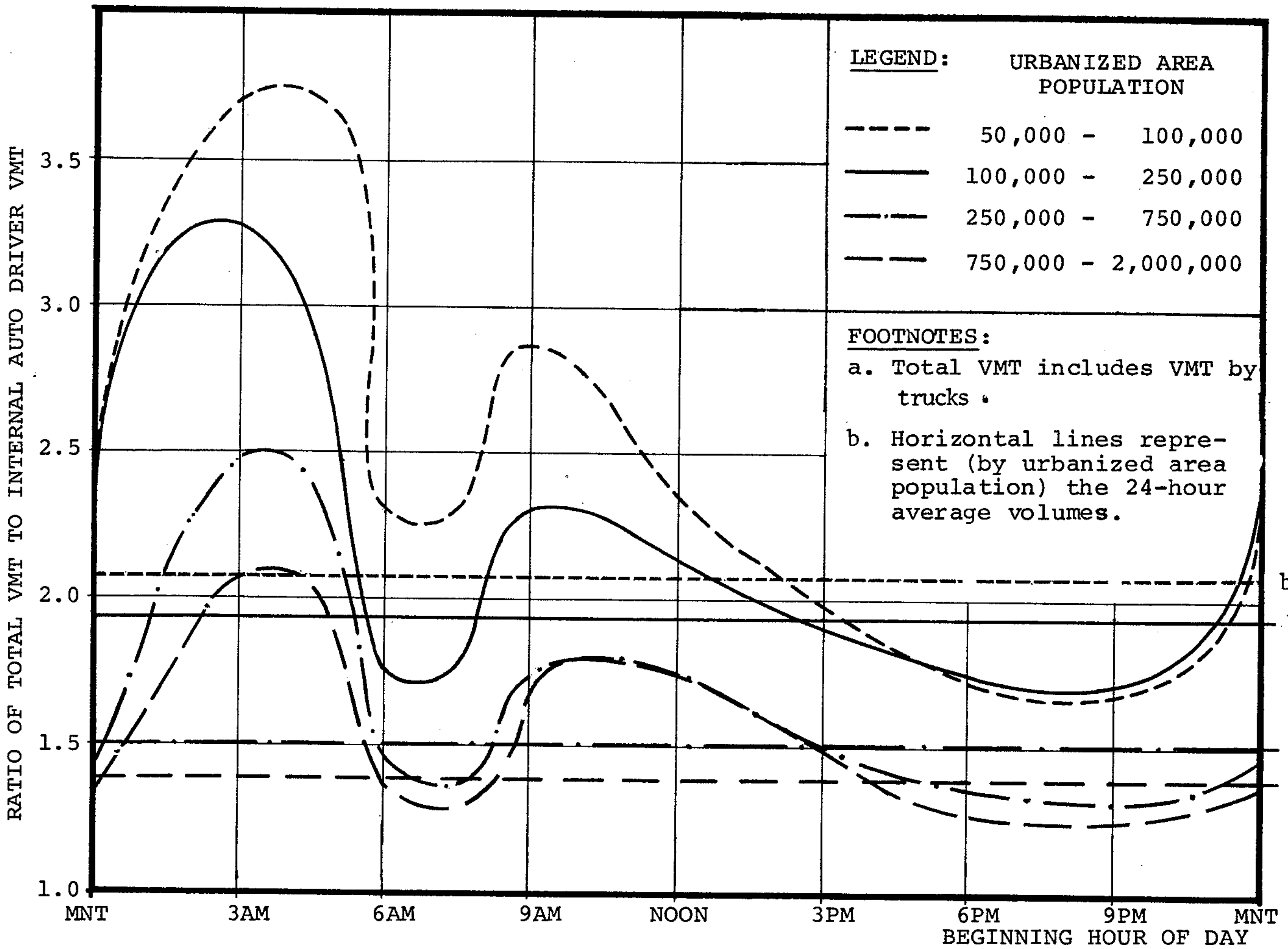


Figure 83. Distribution of total vehicle and internal auto driver trip ratios by time of day[a] (36).

results of distributions found for each study area. Data from nine urbanized area transportation studies were utilized in the preparation of these travel distributions by time-of-day. The study areas (within each of the four urbanized area population groups) are as follows:

POP. GROUP	URBANIZED AREA
50,000 to 100,000	Stockton, Calif. Manchester, N. H.
100,000 to 250,000	Colorado Springs, Colo. Fall River, Mass.
250,000 to 750,000	Louisville, Ky. Oklahoma City, Okla.
750,000 to 2,000,000	Boston, Mass. St. Louis, Mo. Seattle, Wash.

Much of the information was obtained primarily from the findings of *An Analysis of Urban Travel by Time of Day*, (*36*), which is the most current report available for use in the preparation of this chapter.

A major problem in the preparation of many of the travel-estimation procedures contained herein was the handling of external travel. The time-of-day information provides one technique to the user to address the external travel issue. Another is found in Chapter Two, "Trip-Generation Estimation." It has been possible to develop a relationship between the quantity of total travel (internal plus external) and internal auto driver travel. The user is cautioned in using the charts for these purposes in that the total vehicle factors represent average conditions and the ratio of external to internal travel can vary considerably from area to area. These characteristics are dependent on many influences that are completely external to the study area.

Transit Travel

A search of available information describing the distribution of transit travel by time-of-day has shown that little variability exists between urbanized area population and transit use, provided the area has bus transit service for the full day. A full day comprises AM and PM peaks, base (midday) service, and evening service. A paradox was also noted during the search—transit properties collect a multitude of information by time-of-day and by route for developing and adjusting schedules. However, for the most part, the information is not summarized for the system by time-of-day. Most summarization completed was found to be for special purposes such as transit or transportation system studies (*37, 38*).

TIME-OF-DAY TABLES AND EXAMPLES OF USE

This section discusses the various time-of-day distribution tables and presents applicational examples. The tables have been organized as follows with respect to the four urbanized area population groups:

50,000 to	100,000 pop.	Tables	17 through	21
100,000 to	250,000 pop.	Tables	22 through	26
250,000 to	750,000 pop.	Tables	27 through	31
750,000 to	2,000,000 pop.	Tables	32 through	36

The following discussion focuses on urbanized areas of 750,000 to 2,000,000 population (Tables 32 through 36 only).

Hourly Distribution of Internal Auto Driver Travel by Trip Purpose (Table 32)

Data are provided for three trip purposes and for "all purposes." The trip purposes—HBW, HBNW, and NHB—are consistent with other procedural directions contained in this user's guide. The user will find these factors helpful for analyzing travel to special generators or for assessing the impact of residential development by time period. The user might employ the factors for developing special-purpose trip tables such as peak-hour trip tables.

Hourly Distribution of Internal Auto Driver and Total Vehicle Travel (Table 33)

The "Percent Internal Auto Drivers" factors in Table 33 are identical to the "All Purposes" factors in Table 32. The second data column provides a distribution of total vehicle activity (including trucks) for an average day. The third data column relates total vehicle movement to that of internal auto drivers. It is, at best, an approximation that should be used with caution, and at that, only if the analyst has neither local information nor an area-specific procedure for developing total vehicular movement. The ratio might be used in the following type of problem:

Given: The total internal auto driver travel along a route within a corridor has been estimated to be 20,000 trips per day.

Determine: 1. The total vehicular travel along the route between noon and 1 PM.
2. The total vehicle average daily traffic (ADT).

Solution: From Table 33:
Percent internal auto drivers from 12 PM to 1 PM = 4.0
Ratio of internal auto driver to total vehicular travel = 1.65
Percent total vehicle travel from 12 PM to 1 PM = 4.6

Internal auto driver travel between 12 PM and 1 PM = 20,000 × 0.04 = 800 vehicles
Therefore vehicles between 12 PM and 1 PM = 800 × 1.65 = 1,320 vehicles
Therefore total vehicle ADT

$$= \frac{1,320}{0.046} = 28,696 \text{ vehicles}$$

Note: If the user had elected to determine ADT using a daily factor of 1.44, the result would have been ADT = 28,800. (Error owing to rounding of factors.)

Hourly Distribution of Total Travel by Facility Type (Tables 34 through 36).

The remaining three tables (for each urbanized area population group) describe, for an average day, the travel distributions expected to occur on three types or functional classes of facilities. The total travel includes internal-internal, internal-external, external-external, and trucks. The classes of facilities are:

- Expressways/Freeways.
- Arterials.
- Collectors.

The tables further specify the characteristics of travel by time-of-day according to location (i.e., subregions) within the study region and orientation to the core area. The tables recognize a trilevel stratification of the urbanized area—central business district (CBD), central city, and suburb—which corresponds to the geographic notation used in Chapter Three, "Trip Distribution," and throughout this user's guide. The percent ADT values have been rounded to the nearest ½ of one percent and the percent directional split (DIR SPLT) has been rounded to the nearest two percent.

The tables also recognize that facility orientation can impact the daily distribution of travel. Primarily, the impact is caused by a difference in intensity of use during the peak periods. Facilities transverse to the radial direction of flow are likely to experience a smaller proportion of total daily traffic during the peak periods than facilities oriented in the major flow directions. The user should note that, in some cases, the directional split of traffic is greater for crosstown travel than for radial traffic flows. This is partially because of the characteristics of the urbanized areas sampled, and because certain major crosstown facilities function as collectors for urban radial freeways. It should be noted also that it is not always appropriate to have a segregation of facility orientation by subregion. Tables 34 through 36 and others show a single category, "All Orientations," for facilities within the CBD. Once the major attraction area has been reached, all directions become "radial" travel.

Within the body of each table, two types of information are presented:

- Distribution of travel by hour-of-day (percent ADT).
- Directional split of travel by hour-of-day (DIR SPLT).

TABLE 17

HOURLY DISTRIBUTION OF INTERNAL AUTO DRIVER TRAVEL BY TRIP PURPOSES: URBANIZED AREA POPULATION, 50,000-100,000

	PERCENT TRAVEL			
Hour	HBW	HBNW	NHB	All Purposes
24-1	0.4	0.7	0.7	0.7
1-2	0.2	0.3	0.2	0.2
2-3	0.0	0.0	0.0	0.0
3-4	0.2	0.1	0.0	0.1
4-5	0.4	0.0	0.1	0.1
5-6	2.7	0.5	0.4	1.0
6-7	7.9	2.0	1.5	3.2
7-8	19.2	5.8	6.6	8.9
8-9	9.2	3.4	4.0	4.1
9-10	3.0	3.0	3.6	3.2
10-11	0.7	4.4	5.6	3.9
11-12	0.6	4.4	6.3	4.1
12-13	2.1	4.0	10.2	5.2
13-14	2.0	4.8	7.2	4.8
14-15	3.8	4.2	6.9	4.9
15-16	6.3	6.2	8.0	6.7
16-17	13.7	8.1	8.0	9.3
17-18	12.4	8.0	6.2	8.5
18-19	3.7	8.5	4.7	6.4
19-20	2.3	11.2	6.3	7.9
20-21	1.6	7.9	5.8	5.9
21-22	3.0	6.0	3.9	4.8
22-23	2.8	3.9	2.4	3.2
23-24	1.9	2.5	1.5	2.1
	100.0	100.0	100.0	100.0

Source: Reference (36) and nine urbanized area studies.

TABLE 18

HOURLY DISTRIBUTION OF INTERNAL AUTO DRIVER AND TOTAL VEHICLE TRAVEL: URBANIZED AREA POPULATION, 50,000-100,000 [a]

Hour	Percent Internal Auto Drivers	Percent Total Vehicles (INT + EXT)	Ratio Of Total Vehicles To INT Auto Drivers
24-1	0.7	0.7	2.25
1-2	0.2	0.3	3.08
2-3	0.0	0.2	3.52
3-4	0.1	0.2	3.63
4-5	0.1	0.2	3.93
5-6	1.0	1.1	2.29
6-7	3.2	4.0	2.63
7-8	8.9	9.2	2.13
8-9	4.9	5.8	2.49
9-10	3.2	4.5	2.95
10-11	3.9	5.1	2.72
11-12	4.1	4.9	2.50
12-13	5.2	5.4	2.12
13-14	4.8	5.7	2.47
14-15	4.9	5.2	2.21
15-16	6.7	6.4	1.98
16-17	9.3	8.9	1.87
17-18	8.5	7.7	1.88
18-19	6.4	5.8	1.60
19-20	7.9	6.1	1.59
20-21	5.9	4.5	1.65
21-22	4.8	3.8	1.74
22-23	3.2	2.7	1.82
23-24	2.1	1.8	1.82
	100.0	100.0	2.08[b]

a. Source: Reference (36) and nine urbanized area studies.

b. Represents weighted average for determining ADT total VMT from total internal auto driver travel.

The first type is similar to that of previous tables describing distribution of travel by time-of-day. The second directional split is necessary for investigating volume/capacity conditions for specified time periods on a facility. Directional split in the context of these procedures is defined as the percentage of hourly traffic occurring in the direction associated with the major flow of the morning peak period. Normally, the major morning flow is oriented toward the CBD.

Use of these tables is demonstrated by the following problem:

Given: An arterial roadway, defined as being within the central city subregion of an urbanized area of 1,000,000 population, has an ADT of 25,000 vehicles. The facility is oriented radially to the CBD.

Determine: The amount of traffic expected between 5 PM and 6 PM in the PM peak direction.

Solution: From Table 35:

Percent travel between 5 PM and 6 PM = 8.0%

Directional split = 36.0%

Total traffic between 5 PM and 6 PM = 25,000 × 0.08 = 2,000

Percent travel in PM peak direction = 100 − 36 = 64%

Therefore traffic during 5 PM to 6 PM (1700-1800 hr) in peak direction = 2,000 × 0.64 = 1,280 vehicles

At this point, the user could proceed with a capacity analysis of the arterial for the specified hour knowing the predicted volume of the facility is 1,280 vehicles.

Transit Hourly Distributions

Most analyses of time-of-day distribution of transit volumes center about a peak period or specific segments of the peak period. It is, of course, the peak-period volume

TABLE 19

HOURLY DISTRIBUTION OF TOTAL TRAVEL ON EXPRESSWAYS/FREEWAYS: URBANIZED AREA POPULATION, 50,000-100,000[a]

HOUR	DISTRIBUTION & ORIENTATION BY SUBREGION						HOUR
	CBD & Central City				Suburb		
	Radial		X-Town		All Orientations		
	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	
24-1	1.0	26	1.5	48	1.5	60	24
1-2	0.5	28	1.0	46	1.0	66	1
2-3	0.5	34	1.0	46	0.5	52	2
3-4	0.5	38	1.0	44	0.5	54	3
4-5	0.5	54	1.0	44	0.5	34	4
5-6	2.5	62	2.0	48	1.5	24	5
6-7	5.5	60	4.0	52	3.5	26	6
7-8	7.0	56	7.0	62	6.5	40	7
8-9	5.5	56	5.0	48	5.0	52	8
9-10	5.5	50	5.0	46	5.0	58	9
10-11	5.5	48	5.5	48	5.0	62	10
11-12	5.5	50	5.5	48	5.0	62	11
12-13	5.0	50	5.5	48	5.0	56	12
13-14	5.5	54	5.0	48	6.5	56	13
14-15	6.0	54	5.5	48	6.5	54	14
15-16	6.5	56	7.0	46	7.0	54	15
16-17	8.5	40	7.5	42	8.0	50	16
17-18	7.0	40	7.0	38	8.5	50	17
18-19	6.0	42	5.5	44	7.0	36	18
19-20	4.5	44	4.5	42	5.0	40	19
20-21	3.5	48	4.0	44	3.5	42	20
21-22	3.0	48	3.5	46	3.0	46	21
22-23	2.5	46	3.0	50	2.5	44	22
23-24	2.0	34	2.5	52	2.0	54	23
	100.0		100.0		100.0		

a. Source: Reference (36) and nine urbanized area studies.
b. % in a.m. peak direction.

TABLE 21

HOURLY DISTRIBUTION OF TOTAL TRAVEL ON COLLECTORS: URBANIZED AREA POPULATION, 50,000-100,000[a]

HOUR	DISTRIBUTION & ORIENTATION BY SUBREGION				HOUR
	Central City		Suburb		
	All Orientations		All Orientations		
	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	
24-1	0.5	38	1.0	52	24
1-2	0.5	40	1.0	48	1
2-3	0.0	34	1.0	46	2
3-4	0.0	42	0.5	58	3
4-5	0.0	54	1.0	42	4
5-6	0.5	66	2.0	46	5
6-7	1.5	78	3.0	60	6
7-8	7.0	70	6.0	70	7
8-9	2.5	58	4.5	56	8
9-10	1.5	52	4.0	56	9
10-11	1.0	52	5.0	62	10
11-12	2.0	50	5.0	46	11
12-13	2.0	50	5.0	50	12
13-14	2.0	52	6.0	46	13
14-15	4.5	38	6.5	44	14
15-16	15.5	34	7.0	48	15
16-17	20.0	46	9.0	46	16
17-18	13.0	46	8.5	40	17
18-19	7.5	48	6.5	48	18
19-20	11.0	48	5.5	44	19
20-21	4.0	46	4.0	42	20
21-22	1.5	52	3.5	42	21
22-23	1.5	56	2.5	46	22
23-24	0.5	40	2.0	52	23
	100.0		100.0		

a. Source: Reference (36) and nine urbanized area studies.
b. % in a.m. peak direction.

TABLE 20

HOURLY DISTRIBUTION OF TOTAL TRAVEL ON ARTERIALS: URBANIZED AREA POPULATION, 50,000-100,000[a]

HOUR	DISTRIBUTION & ORIENTATION BY SUBREGION										HOUR
	CBD		Central City				Suburb				
	All Orientations		Radial		X-Town		Radial		X-Town		
	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	
24-1	1.0	50	1.0	50	1.0	46	1.0	54	1.0	56	24
1-2	0.5	50	0.5	52	0.5	42	0.5	60	0.5	66	1
2-3	0.5	50	0.5	54	0.5	34	0.5	52	0.5	62	2
3-4	0.5	-	0.0	50	0.0	56	0.5	52	0.0	52	3
4-5	0.5	54	0.5	56	0.0	58	0.5	52	0.5	46	4
5-6	1.0	58	1.0	58	1.0	62	1.0	52	1.0	44	5
6-7	2.5	60	3.5	58	3.0	58	3.5	56	3.5	66	6
7-8	6.0	62	7.0	58	6.5	60	6.5	56	8.0	54	7
8-9	6.0	64	4.5	56	4.0	54	4.5	54	5.0	50	8
9-10	7.0	60	4.5	54	4.0	50	4.5	52	4.5	44	9
10-11	6.0	54	4.5	52	4.5	48	5.0	50	5.0	48	10
11-12	6.0	56	5.0	50	5.0	46	5.0	50	5.0	52	11
12-13	6.0	56	5.5	50	5.5	48	6.0	52	5.0	50	12
13-14	6.0	52	5.5	50	5.5	50	6.0	52	5.5	44	13
14-15	6.5	52	6.0	50	6.0	48	6.0	50	6.0	48	14
15-16	6.5	50	6.5	46	7.0	46	6.0	48	7.0	52	15
16-17	6.5	44	8.0	48	8.5	44	8.0	46	9.0	50	16
17-18	6.0	42	7.5	46	7.5	44	7.5	46	7.5	46	17
18-19	5.5	50	7.0	50	7.0	50	6.5	52	6.5	46	18
19-20	5.5	52	6.0	50	7.5	50	6.0	54	5.5	54	19
20-21	4.5	48	5.0	48	6.0	46	5.0	50	4.5	44	20
21-22	4.5	46	4.5	44	4.5	48	4.0	50	4.0	50	21
22-23	3.5	50	3.5	48	3.0	52	3.5	50	3.0	56	22
23-24	2.0	50	2.5	48	2.0	46	2.5	52	2.0	58	23
	100.0		100.0		100.0		100.0		100.0		

a. Source: Reference (36) and nine urbanized area studies.
b. % in a.m. peak direction.

TABLE 23

HOURLY DISTRIBUTION OF INTERNAL AUTO DRIVER AND TOTAL VEHICLE TRAVEL: URBANIZED AREA POPULATION, 100,000-250,000

Hour	Percent Internal Auto Drivers	Percent Total Vehicles (INT + EXT)	Ratio Of Total Vehicles To INT Auto Drivers
24-1	0.8	1.0	2.34
1-2	0.4	0.6	2.60
2-3	0.2	0.4	3.41
3-4	0.1	0.3	4.39
4-5	0.4	0.5	2.81
5-6	1.0	1.1	2.35
6-7	4.3	3.9	1.76
7-8	8.2	6.9	1.63
8-9	4.6	5.4	2.27
9-10	4.1	4.8	2.31
10-11	4.7	5.3	2.22
11-12	4.9	5.7	2.22
12-13	6.3	6.2	1.90
13-14	5.4	5.8	2.08
14-15	5.8	6.2	2.07
15-16	7.2	7.2	1.93
16-17	9.9	9.4	1.84
17-18	9.5	9.0	1.83
18-19	5.7	5.8	1.97
19-20	5.4	4.9	1.76
20-21	4.1	3.3	1.57
21-22	3.0	2.6	1.65
22-23	2.2	2.1	1.80
23-24	1.8	1.6	1.74
	100.0	100.0	1.94[b]

a. Source: Reference (36) and nine urbanized area studies.

b. Represents weighted average for determining ADT total VMT from total internal auto driver travel.

TABLE 22

HOURLY DISTRIBUTION OF INTERNAL AUTO DRIVER TRAVEL BY TRIP PURPOSE: URBANIZED AREA POPULATION, 100,000-250,000

	PERCENT TRAVEL			
Hour	HBW	HBNW	NHB	All Purposes
24-1	0.8	0.9	0.5	0.8
1-2	0.4	0.5	0.2	0.4
2-3	0.3	0.2	0.2	0.2
3-4	0.2	0.1	0.1	0.1
4-5	0.9	0.1	0.1	0.4
5-6	2.5	0.3	0.2	1.0
6-7	11.7	1.2	0.6	4.3
7-8	19.5	3.5	2.7	8.2
8-9	6.9	3.7	3.2	4.6
9-10	2.5	4.5	5.3	4.1
10-11	1.1	5.6	7.7	4.7
11-12	1.3	5.8	8.3	4.9
12-13	2.8	5.8	12.4	6.3
13-14	1.8	6.0	9.3	5.4
14-15	2.8	6.4	8.9	5.8
15-16	6.2	7.2	8.8	7.2
16-17	13.9	7.8	8.7	9.9
17-18	12.8	8.9	6.2	9.5
18-19	3.8	7.9	3.4	5.7
19-20	2.0	7.9	4.7	5.4
20-21	1.3	6.1	3.7	4.1
21-22	1.4	4.4	2.1	3.0
22-23	1.4	3.0	1.6	2.2
23-24	1.7	2.2	1.1	1.8
	100.0	100.0	100.0	100.0

Source: Reference (36) and nine urbanized area studies.

TABLE 24

HOURLY DISTRIBUTION OF TOTAL TRAVEL ON EXPRESSWAYS/FREEWAYS: URBANIZED AREA POPULATION, 100,000-250,000 [a]

HOUR	DISTRIBUTION & ORIENTATION BY SUBREGION										HOUR
	CBD		Central City				Suburb				
	All Orientations		Radial		X-Town		Radial		X-Town		
	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	
24-1	1.5	46	1.0	26	1.5	48	2.0	52	2.0	50	24
1-2	1.0	50	0.5	28	1.0	46	1.5	50	1.5	48	1
2-3	1.0	50	0.5	34	1.0	46	1.0	44	0.5	44	2
3-4	1.0	54	0.5	38	1.0	44	1.0	48	0.5	48	3
4-5	1.0	56	0.5	54	1.0	44	1.0	50	0.5	52	4
5-6	3.0	66	2.5	62	2.0	48	2.0	54	1.0	64	5
6-7	5.5	62	5.5	60	4.0	52	3.5	58	5.5	64	6
7-8	7.5	64	7.0	56	7.0	62	5.5	64	10.0	56	7
8-9	6.0	64	5.5	56	5.0	48	6.0	60	6.0	64	8
9-10	5.0	60	5.5	50	5.0	46	5.5	54	4.5	54	9
10-11	5.0	56	5.5	48	5.5	48	6.0	54	4.0	52	10
11-12	4.5	54	5.5	50	5.5	48	6.0	50	4.0	50	11
12-13	4.5	54	5.0	50	5.5	48	6.0	50	4.0	50	12
13-14	4.5	56	5.5	50	5.0	48	6.0	50	4.0	50	13
14-15	5.5	52	6.0	54	5.5	48	6.0	50	4.5	54	14
15-16	7.0	50	6.5	46	7.0	46	6.0	54	7.5	50	15
16-17	8.5	46	8.5	40	7.5	42	7.0	44	10.0	46	16
17-18	7.5	44	7.0	40	7.0	38	7.0	40	9.0	42	17
18-19	5.0	52	6.0	42	5.5	44	6.0	40	5.5	48	18
19-20	4.5	54	4.5	44	4.5	42	4.0	48	4.5	48	19
20-21	3.5	52	3.5	48	4.0	44	3.5	46	3.5	50	20
21-22	3.0	48	3.0	48	3.5	46	3.0	48	3.0	50	21
22-23	2.5	50	2.5	46	3.0	50	2.5	52	2.5	50	22
23-24	2.0	48	2.0	34	2.5	52	2.0	54	2.0	50	23
	100.0		100.0		100.0		100.0		100.0		

a. Source: Reference (36) and nine urbanized area studies.
b. % in a.m. peak direction.

TABLE 25

HOURLY DISTRIBUTION OF TOTAL TRAVEL ON ARTERIALS: URBANIZED AREA POPULATION, 100,000-250,000

HOUR	DISTRIBUTION & ORIENTATION BY SUBREGION										HOUR
	CBD		Central City				Suburb				
	All Orientations		Radial		X-Town		Radial		X-Town		
	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	
24-1	1.0	38	1.0	40	1.0	44	1.0	50	1.0	44	24
1-2	0.5	40	0.5	44	0.5	44	0.5	50	0.5	50	1
2-3	0.5	34	0.5	42	0.5	46	0.5	50	0.5	42	2
3-4	0.5	42	0.5	48	0.5	48	0.0	50	0.5	52	3
4-5	0.5	54	0.5	52	0.5	54	0.5	50	0.5	48	4
5-6	1.0	66	1.0	64	1.0	54	1.0	62	1.0	66	5
6-7	4.0	78	3.0	70	3.0	58	2.5	66	2.5	66	6
7-8	8.0	70	7.0	68	7.5	56	7.0	74	7.5	68	7
8-9	7.0	58	5.5	58	5.5	56	6.0	66	6.0	52	8
9-10	6.0	52	5.0	52	5.0	54	5.0	56	4.5	50	9
10-11	6.0	52	5.0	50	5.5	54	5.0	54	4.5	48	10
11-12	6.5	50	5.5	48	5.5	50	5.5	50	5.5	48	11
12-13	6.5	50	6.0	50	6.0	50	6.0	48	5.5	52	12
13-14	6.5	52	6.0	50	5.5	50	6.0	50	5.5	50	13
14-15	5.5	38	6.5	52	6.5	50	6.0	50	5.5	50	14
15-16	6.0	34	7.5	48	7.5	46	7.0	48	6.5	50	15
16-17	8.0	46	8.5	42	8.0	46	8.0	42	7.5	46	16
17-18	7.5	46	8.0	38	7.5	46	8.5	36	9.0	36	17
18-19	4.5	48	5.5	44	6.0	50	6.5	42	6.5	42	18
19-20	4.0	48	5.0	48	5.0	48	5.5	48	5.5	44	19
20-21	3.5	46	4.0	48	4.0	48	4.0	48	5.0	46	20
21-22	3.0	52	3.5	54	3.5	46	3.5	44	4.0	50	21
22-23	2.0	56	2.5	46	2.5	48	2.5	48	3.0	48	22
23-24	1.5	40	2.0	48	2.0	48	2.0	50	2.0	46	23
	100.0		100.0		100.0		100.0		100.0		

a. Source: Reference (36) and nine urbanized area studies.
b. % in a.m. peak direction.

TABLE 26

HOURLY DISTRIBUTION OF TOTAL TRAVEL ON COLLECTORS: URBANIZED AREA POPULATION, 100,000-250,000

HOUR	DISTRIBUTION & ORIENTATION BY SUBREGION				HOUR
	Central City		Suburb		
	All Orientations		All Orientations		
	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	
24-1	0.5	38	1.0	50	24
1-2	0.5	40	0.5	50	1
2-3	0.0	34	0.5	50	2
3-4	0.0	42	0.0	50	3
4-5	0.0	54	0.0	50	4
5-6	0.5	66	1.0	20	5
6-7	1.5	78	3.5	24	6
7-8	7.0	70	10.5	40	7
8-9	2.5	58	7.5	66	8
9-10	1.5	52	4.5	58	9
10-11	1.0	52	4.5	50	10
11-12	2.0	50	5.0	46	11
12-13	2.0	50	6.0	48	12
13-14	2.0	52	6.0	42	13
14-15	4.5	38	4.5	46	14
15-16	15.5	34	3.5	20	15
16-17	20.0	46	9.0	54	16
17-18	13.0	46	6.5	48	17
18-19	7.5	48	65	48	18
19-20	11.0	48	6.0	48	19
20-21	4.0	46	4.5	50	20
21-22	1.5	52	4.0	50	21
22-23	1.5	56	3.0	50	22
23-24	0.5	40	2.0	50	23
	100.0		100.0		

a. Source: Reference (36) and nine urbanized area studies.
b. % in a.m. peak direction.

that dictates the required size of the transit fleet. It is for these reasons—which reflect the analytical trend of the transit industry—that the following approach for transit time-of-day analysis has been taken.

Figure 84 shows graphically the primary time periods and their relationship to annual average weekday (AAWD) patronage. The four periods are:

- *Annual average weekday.* Total transit patronage expected to occur on an average weekday.
- *Peak-period trips.* The sum of transit patronage expected for the two morning peak hours and the two evening peak hours.
- *Peak hour.* The peak 60 min of transit patronage for the day; this peak usually occurs from 8 AM to 9 AM in the morning.
- *Peak hour-peak direction.* The transit patronage anticipated in the direction of peak flow during the peak hour.

Table 37 gives factors for deriving ridership estimates for each or any of the foregoing time periods if patronage for any one of the time periods is known. The table quantifies the graphic relationships shown in Figure 84. The user should keep in mind the factors are to be applied to all-purpose transit trips and not to trips by purpose. It was previously discussed, however, in Chapter Four, "Mode-Choice Analysis," that it is possible to approximate total transit patronage as a percentage of HBW trips. The assumption is: transit HBW trips equal the level of patronage anticipated for the combined peak periods or, 50 percent of the AAWD patronage.

The following examples demonstrate the use of Table 37. The first example is as follows:

Given: A corridor has an estimated transit patronage of 20,000 total person-trips per AAWD.

Determine: 1. Volume of trips occurring during the peak hour.
2. Volume of trips occurring in the peak direction of the peak hour.

Solution: From Table 37:

Conversion factor from AAWD to peak hour = 0.17
Conversion factor from peak hour to peak hr, peak dir. = 0.82
Peak hr = (AAWD) × 0.17
Therefore peak hr = 20,000 × 0.17 = 3,400 trips
Peak hr, peak dir. = (Peak hr) × 0.82
Peak hr, peak dir. = 3,400 × 0.82
Therefore peak hr, peak dir. = 2,788 trips

Note: If the user had chosen AAWD to determine the "peak hour, peak direction," the conversion factor would have been 0.14 and the answer would equal 2,800 trips. (Error due to rounding of factors.)

The second example is as follows:

Given: A planner has determined the universe of HBW trips made by transit for a corridor to be 5,600 per AAWD. The corridor has transit service throughout the day.

Determine: 1. The total volume of transit trips in the corridor for an AAWD.
2. The volume of trips occurring during the peak hour.

Solution: Assume transit HBW trips = combined peak-period volumes.
From Table 37:

Conversion factor from combined peak-period volume to AAWD = 2.00

Conversion factor from combined peak-period volume to peak hr = 0.34
AAWD = (Combined peak-period volume) × 2.00

Therefore AAWD = 11,200 trips
Peak hr = (Combined peak-period volume) × 0.34
Peak hr = 5,600 × 0.34
Therefore peak hr = 1,904 trips

Trip Matrix Conversion Factors

It is conceivable the user may be required to perform an analysis within a period of time so brief that a full analysis of all trip purposes—HBW, HBNW, NHB—is not practical. For example, the user may wish to know the consequences of total trip movement within a major travel corridor and only have time to generate a trip matrix describing the HBW trip purpose. For this reason, Tables

TABLE 27

HOURLY DISTRIBUTION OF INTERNAL AUTO DRIVER TRAVEL BY TRIP PURPOSE: URBANIZED AREA POPULATION, 250,000-750,000

	PERCENT TRAVEL			
Hour	HBW	HBNW	NHB	All Purposes
24-1	1.5	0.8	0.5	0.9
1-2	0.5	0.4	0.3	0.4
2-3	0.4	0.2	0.1	0.3
3-4	0.3	0.1	0.1	0.1
4-5	0.5	0.1	0.1	0.2
5-6	1.8	0.2	0.2	0.8
6-7	10.1	0.9	0.9	4.4
7-8	20.6	3.8	3.5	10.0
8-9	9.1	4.5	4.4	6.2
9-10	2.3	4.6	4.8	3.8
10-11	1.1	5.7	6.5	4.1
11-12	1.0	5.2	8.5	4.4
12-13	1.4	5.0	9.5	4.7
13-14	1.1	5.7	8.5	4.7
14-15	2.7	5.7	8.5	5.2
15-16	6.9	6.5	9.3	7.3
16-17	12.3	7.1	9.1	9.5
17-18	14.2	8.2	8.2	10.4
18-19	4.8	8.7	4.4	6.3
19-20	1.6	9.1	4.3	5.2
20-21	1.2	6.2	3.8	3.8
21-22	1.6	5.8	2.3	3.4
22-23	1.3	3.6	1.4	2.3
23-24	1.7	1.9	0.8	1.6
	100.0	100.0	100.0	100.0

Source: Reference (36) and nine urbanized area studies.

TABLE 28

HOURLY DISTRIBUTION OF INTERNAL AUTO DRIVER AND TOTAL VEHICLE TRAVEL: URBANIZED AREA POPULATION, 250,000-750,000

Hour	Percent Internal Auto Drivers	Percent Total Vehicles (INT + EXT)	Ratio Of Total Vehicles To INT Auto Drivers
24-1	0.9	0.9	1.45
1-2	0.4	0.5	1.80
2-3	0.3	0.4	2.07
3-4	0.1	0.3	2.88
4-5	0.2	0.4	2.57
5-6	0.8	1.0	1.87
6-7	4.4	4.3	1.49
7-8	10.0	8.6	1.30
8-7	6.2	6.4	1.53
9-10	3.8	4.8	1.88
10-11	4.1	5.0	1.82
11-12	4.4	5.0	1.73
12-13	4.7	5.1	1.63
13-14	4.7	5.3	1.69
14-15	5.2	5.7	1.64
15-16	7.3	7.3	1.50
16-17	9.5	9.1	1.44
17-18	10.4	9.4	1.35
18-19	6.3	5.9	1.40
19-20	5.2	4.7	1.33
20-21	3.8	3.4	1.35
21-22	3.4	3.1	1.33
22-23	2.3	2.0	1.29
23-24	1.6	1.4	1.35
	100.0	100.0	1.50[b]

a. Source: Reference (36) and nine urbanized area studies.
b. Represents weighted average for determining ADT total VMT from total internal auto driver travel.

38 through 45 have been provided herein to permit a quick application of generalized factors, by urbanized area population, to the work trips to produce total trips or total trips for a designated time period.

The tables are organized into two sets of four tables, with each of the tables corresponding to one of the four urbanized area population groups. The sets are as follows:

- Tables 38 through 41—"Conversion Factors for Critical Periods of Internal Person-Travel."
- Tables 42 through 45—"Conversion Factors for Critical Periods of Internal Auto Driver Travel."

The tables cross-relate total travel and HBW travel by time periods most used for travel analysis. The analyst should be cognizant of the definition of each time period and of inherent subtleties contained in the tables. For example, Table 41 (for urbanized area population 750,000 to 2,000,000) describes the "peak-hour work travel" to be 46.6 percent of "peak-hour total travel" [i.e., (100 ÷ 2.148) percent of "peak-hour total travel"]. The user should keep in mind that the HBW travel peak hour generally occurs during the morning peak period whereas the total travel peak hour generally occurs during the evening peak period. Thus, the result is intended to yield the true peak volume occurring during a 24-hr period. The definitions of the time periods contained in Tables 38 through 45 are as follows:

1. *Total travel.* The sum of internal travel for all purposes (i.e., HBW, HBNW, NHB) occurring during an analysis day.
2. *Total work travel.* The total travel for the HBW purpose estimated to occur during an analysis day.
3. *Combined peak-period total travel.* Travel, for all purposes, which occurs during the two AM peak hours and the two PM peak hours.
4. *Peak-hour total travel.* Travel, for all purposes,

TABLE 29

HOURLY DISTRIBUTION OF TOTAL TRAVEL ON EXPRESSWAYS/FREEWAYS: URBANIZED AREA POPULATION, 250,000-750,000

HOUR	DISTRIBUTION & ORIENTATION BY SUBREGION										HOUR
	CBD		Central City				Suburb				
	All Orientations		Radial		X-Town		Radial		X-Town		
	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	
24-1	1.5	46	2.0	46	1.5	44	2.0	44	2.0	50	24
1-2	1.0	50	1.0	50	1.0	46	1.5	48	1.5	48	1
2-3	1.0	50	1.0	50	0.5	42	1.5	54	0.5	44	2
3-4	1.0	54	1.0	54	0.5	50	1.5	52	0.5	48	3
4-5	1.0	56	1.0	56	1.0	60	2.0	58	0.5	52	4
5-6	3.0	66	2.0	66	2.0	60	2.5	56	1.0	64	5
6-7	5.5	62	4.5	62	5.0	64	4.5	60	5.5	64	6
7-8	7.5	64	6.0	64	8.0	62	5.5	68	10.0	56	7
8-9	6.0	64	5.0	64	6.5	60	5.0	60	6.0	64	8
9-10	5.0	60	5.0	60	5.0	56	5.5	60	4.5	54	9
10-11	5.0	56	5.0	56	4.5	54	5.5	50	4.0	52	10
11-12	4.5	54	5.0	54	4.5	52	5.5	52	4.0	50	11
12-13	4.5	54	5.0	54	5.0	52	5.5	52	4.0	50	12
13-14	4.5	56	5.5	56	5.0	52	5.5	50	4.0	50	13
14-15	5.5	52	6.5	52	6.0	52	6.0	50	4.5	54	14
15-16	7.0	50	7.5	50	7.0	48	6.5	50	7.5	50	15
16-17	8.5	46	8.5	46	8.5	44	7.0	46	10.0	46	16
17-18	7.5	44	7.5	44	7.5	42	6.5	44	9.0	42	17
18-19	5.0	52	5.0	52	5.5	48	4.5	42	5.5	48	18
19-20	4.5	54	4.0	54	4.0	50	4.0	52	4.5	48	19
20-21	3.5	52	3.5	52	3.5	46	3.5	52	3.5	50	20
21-22	3.0	48	3.5	48	3.5	44	3.0	50	3.0	50	21
22-23	2.5	50	3.0	50	7.5	46	3.0	48	2.5	50	22
23-24	2.0	48	2.0	48	2.0	42	2.5	48	2.0	50	23
	100.0		100.0		100.0		100.0		100.0		

a. Source: Reference (36) and nine urbanized area studies.
b. % in a.m. peak direction.

TABLE 30

HOURLY DISTRIBUTION OF TOTAL TRAVEL ON ARTERIALS: URBANIZED AREA POPULATION, 250,000-750,000

HOUR	DISTRIBUTION & ORIENTATION BY SUBREGION										HOUR
	CBD		Central City				Suburb				
	All Orientations		Radial		X-Town		Radial		X-Town		
	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	
24-1	1.0	50	1.5	40	1.5	40	1.5	32	1.5	50	24
1-2	1.0	50	0.5	44	0.5	44	1.0	34	0.5	56	1
2-3	0.5	50	0.5	42	0.5	48	1.0	34	0.0	50	2
3-4	0.5	52	0.5	48	0.5	42	0.5	44	0.5	52	3
4-5	0.5	54	0.5	56	0.5	54	1.0	52	1.0	64	4
5-6	2.0	58	2.0	54	1.0	64	2.5	70	2.0	72	5
6-7	5.0	60	5.0	68	4.5	68	6.0	72	6.0	82	6
7-8	7.0	64	7.0	70	6.5	74	5.5	68	6.5	68	7
8-9	6.5	64	5.5	64	5.5	54	4.5	60	4.5	60	8
9-10	5.0	58	4.5	58	4.5	54	5.0	56	4.0	58	9
10-11	5.5	54	5.0	52	4.5	54	5.0	54	4.0	54	10
11-12	5.5	52	5.0	52	5.0	48	5.0	50	4.5	54	11
12-13	5.5	52	5.0	50	5.5	50	5.0	50	5.0	48	12
13-14	5.5	52	5.0	50	5.5	52	5.5	52	5.0	50	13
14-15	6.0	52	6.0	52	6.0	56	6.0	54	6.0	52	14
15-16	8.0	50	7.5	42	7.0	52	6.5	46	7.0	44	15
16-17	9.0	44	8.0	38	8.5	36	8.5	42	8.0	36	16
17-18	6.5	42	8.0	38	7.5	42	7.5	38	8.5	36	17
18-19	4.5	50	6.0	48	6.0	50	6.0	48	6.5	48	18
19-20	4.0	52	5.0	50	5.5	54	4.5	50	5.5	54	19
20-21	3.5	48	4.0	44	4.5	52	4.0	46	4.5	50	20
21-22	3.0	46	3.5	42	4.0	48	3.5	46	4.0	38	21
22-23	2.5	50	2.5	46	3.0	52	2.5	46	3.0	30	22
23-24	2.0	52	2.0	42	2.0	46	2.0	46	2.0	32	23
	100.0		100.0		100.0		100.0		100.0		

a. Source: Reference (36) and nine urbanized area studies.
b. % in a.m. peak direction.

TABLE 32

HOURLY DISTRIBUTION OF INTERNAL AUTO DRIVER TRAVEL BY TRIP PURPOSE: URBANIZED AREA POPULATION, 750,000-2,000,000

	PERCENT TRAVEL			
Hour	HBW	HBNW	NHB	All Purposes
24-1	1.4	1.5	0.6	1.3
1-2	0.6	0.6	0.3	0.6
2-3	0.4	0.3	0.1	0.3
3-4	0.3	0.1	0.1	0.2
4-5	0.4	0.1	0.1	0.2
5-6	1.5	0.1	0.1	0.7
6-7	9.1	0.9	0.4	4.5
7-8	20.4	2.7	1.4	10.4
8-9	10.8	3.5	2.6	6.6
9-10	2.6	4.3	5.0	3.7
10-11	1.1	5.1	7.7	3.8
11-12	0.9	5.0	8.7	3.9
12-13	1.3	4.5	10.0	4.0
13-14	1.1	5.2	9.2	4.1
14-15	2.4	5.7	9.1	4.8
15-16	5.4	6.4	9.5	6.5
16-17	13.0	7.0	9.8	10.2
17-18	14.6	7.2	7.3	10.5
18-19	5.1	8.2	4.0	6.1
19-20	1.8	9.9	4.4	5.3
20-21	1.2	7.3	4.3	4.0
21-22	1.4	6.1	2.7	3.4
22-23	1.5	4.8	1.5	2.7
23-24	1.7	3.5	1.1	2.2
	100.0	100.0	100.0	100.0

Source: Reference (36) and nine urbanized area studies.

TABLE 31

HOURLY DISTRIBUTION OF TOTAL TRAVEL ON COLLECTORS: URBANIZED AREA POPULATION, 250,000-750,000

HOUR	DISTRIBUTION & ORIENTATION BY SUBREGION						HOUR
	CBD		Central City		Suburb		
	All Orientations		All Orientations		All Orientations		
	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	
24-1	1.0	44	1.5	44	1.0	46	24
1-2	0.5	38	0.5	50	0.5	50	1
2-3	0.5	33	0.5	46	0.5	76	2
3-4	0.5	50	0.5	58	0.5	70	3
4-5	0.5	62	0.5	74	0.5	86	4
5-6	1.5	72	1.5	80	2.0	88	5
6-7	5.5	68	4.5	76	5.5	84	6
7-8	8.5	66	6.5	66	6.5	74	7
8-9	6.0	58	5.0	64	4.5	56	8
9-10	5.5	54	4.5	66	4.0	60	9
10-11	5.5	50	4.5	62	4.5	52	10
11-12	6.5	48	5.0	58	5.0	52	11
12-13	6.0	48	5.5	56	5.5	46	12
13-14	6.5	56	5.5	58	5.5	52	13
14-15	7.5	56	6.0	58	6.0	54	14
15-16	8.0	50	7.5	56	7.5	40	15
16-17	7.5	38	8.5	52	8.0	34	16
17-18	5.5	40	7.5	50	8.0	32	17
18-19	3.5	48	6.0	54	6.5	46	18
19-20	4.0	48	5.5	56	5.5	50	19
20-21	3.5	56	4.5	56	4.5	50	20
21-22	2.0	62	4.0	58	3.5	44	21
22-23	2.0	56	2.5	58	2.5	46	22
23-24	2.0	50	2.0	52	2.0	48	23
	100.0		100.0		100.0		

a. Source: Reference (36) and nine urbanized area studies.
b. % in a.m. peak direction.

TABLE 34

HOURLY DISTRIBUTION OF TOTAL TRAVEL ON EXPRESSWAYS/FREEWAYS: URBANIZED AREA POPULATION, 750,000-2,000,000

HOUR	DISTRIBUTION & ORIENTATION BY SUBREGION										HOUR
	CBD		Central City				Suburb				
	All Orientations		Radial		X-Town		Radial		X-Town		
	% ADT	DIR SPLT b	% ADT	DIR SPLT b	% ADT	DIR SPLT b	% ADT	DIR SPLT b	% ADT	DIR SPLT b	
24-1	1.5	46	1.5	46	1.5	44	1.5	44	2.0	50	24
1-2	1.0	50	1.0	50	1.0	46	1.0	44	1.5	48	1
2-3	0.5	52	0.5	52	0.5	42	0.5	46	0.5	44	2
3-4	0.5	54	0.5	54	0.5	50	0.5	46	0.5	48	3
4-5	1.5	56	0.5	56	1.0	60	1.0	50	0.5	52	4
5-6	3.5	58	1.5	58	2.0	60	2.0	60	1.0	64	5
6-7	6.0	54	5.5	54	5.0	64	5.5	72	5.5	64	6
7-8	8.5	58	9.0	58	8.0	62	8.5	76	10.0	56	7
8-9	5.5	54	7.0	54	6.5	60	6.0	68	6.0	54	8
9-10	3.5	50	5.0	50	5.0	56	4.5	54	4.5	54	9
10-11	3.5	46	4.5	46	4.5	54	4.5	52	4.0	52	10
11-12	4.0	46	4.5	46	4.5	52	4.5	50	4.0	50	11
12-13	4.5	40	4.5	40	5.0	52	4.5	48	4.0	50	12
13-14	4.0	44	5.5	44	5.0	52	4.5	52	4.0	50	13
14-15	5.5	46	5.5	46	6.0	52	5.0	50	4.5	54	14
15-16	7.5	40	7.0	40	7.0	48	7.0	54	7.5	50	15
16-17	9.5	34	8.5	34	8.5	44	9.0	46	10.0	46	16
17-18	7.0	36	7.5	36	7.5	42	8.0	36	9.0	42	17
18-19	5.0	44	5.5	44	5.5	48	5.5	38	5.5	48	18
19-20	4.5	48	4.0	48	4.0	50	4.5	46	4.5	48	19
20-21	4.0	50	3.0	50	3.5	46	3.5	50	3.5	50	20
21-22	3.5	48	3.0	48	3.5	44	3.0	46	3.0	50	21
22-23	3.0	48	3.0	48	2.5	46	3.0	44	2.5	50	22
23-24	2.5	48	2.0	48	2.0	42	2.5	48	2.0	50	23
	100.0		100.0		100.0		100.0		100.0		

a. Source: Reference (36) and nine urbanized area studies.
b. % in a.m. peak direction.

TABLE 33

HOURLY DISTRIBUTION OF INTERNAL AUTO DRIVER AND TOTAL VEHICLE TRAVEL: URBANIZED AREA POPULATION, 750,000-2,000,000

Hour	Percent Internal Auto Drivers	Percent Total Vehicles (INT + EXT)	Ratio Of Total Vehicles To INT Auto Drivers
24-1	1.3	1.2	1.35
1-2	0.6	0.6	1.55
2-3	0.3	0.4	1.80
3-4	0.2	0.2	2.08
4-5	0.2	0.3	2.09
5-6	0.7	0.9	1.76
6-7	4.5	4.2	1.36
7-8	10.4	9.0	1.25
8-9	6.6	6.5	1.42
9-10	3.7	4.5	1.77
10-11	3.8	4.8	1.81
11-12	3.9	4.8	1.81
12-13	4.0	4.6	1.65
13-14	4.1	4.9	1.71
14-15	4.8	5.4	1.62
15-16	6.5	6.8	1.50
16-17	10.2	9.7	1.37
17-18	10.5	9.5	1.31
18-19	6.1	5.7	1.37
19-20	5.3	4.8	1.31
20-21	4.0	3.7	1.31
21-22	3.4	3.1	1.30
22-23	2.7	2.4	1.27
23-24	2.2	2.0	1.28
	100.0	100.0	1.44[b]

a. Source: Reference (36) and nine urbanized area studies.
b. Represents weighted average for determining ADT total VMT from total internal auto driver travel.

TABLE 35

HOURLY DISTRIBUTION OF TOTAL TRAVEL ON ARTERIALS: URBANIZED AREA POPULATION, 750,000-2,000,000

HOUR	DISTRIBUTION & ORIENTATION BY SUBREGION										HOUR
	CBD		Central City				Suburb				
	All Orientations		Radial		X-Town		Radial		X-Town		
	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	
24-1	1.5	46	1.5	46	1.5	40	1.5	44	1.5	44	24
1-2	1.0	46	1.0	48	1.0	44	1.0	40	1.0	42	1
2-3	0.5	44	0.5	48	0.5	48	0.5	44	0.5	44	2
3-4	0.5	42	0.5	50	0.5	42	0.5	50	0.5	50	3
4-5	1.0	54	0.5	56	0.5	54	0.5	58	0.5	54	4
5-6	2.0	58	1.5	62	1.5	64	2.0	66	1.0	60	5
6-7	4.0	60	5.0	63	5.0	68	5.5	72	3.5	64	6
7-8	9.0	64	8.5	68	8.5	74	8.0	70	7.5	60	7
8-9	7.0	66	6.5	66	6.5	54	5.5	62	6.0	56	8
9-10	5.0	60	4.5	58	4.5	54	4.5	56	4.5	52	9
10-11	5.5	54	5.0	54	4.0	54	4.5	52	5.0	52	10
11-12	6.0	54	5.0	52	4.5	48	4.5	52	5.0	50	11
12-13	5.5	50	5.0	52	5.0	50	4.5	50	5.0	50	12
13-14	5.5	50	5.0	52	5.0	52	5.0	52	5.0	50	13
14-15	6.0	48	5.5	50	5.5	56	5.5	52	5.5	50	14
15-16	6.5	46	6.5	48	7.0	52	6.5	48	7.0	48	15
16-17	9.5	42	9.0	40	9.0	36	9.5	42	8.5	44	16
17-18	7.0	38	8.0	36	8.0	42	8.5	36	7.5	42	17
18-19	4.5	44	5.0	46	5.5	50	6.0	44	6.0	46	18
19-20	3.5	46	4.0	52	4.5	54	4.5	50	5.5	48	19
20-21	2.5	46	3.5	48	3.5	52	3.5	48	4.5	48	20
21-22	2.5	46	3.0	48	3.5	48	3.5	48	4.0	46	21
22-23	2.0	44	3.0	48	3.0	52	2.5	48	3.0	50	22
23-24	2.0	46	2.5	48	2.0	46	2.0	46	2.0	50	23
	100.0		100.0		100.0		100.0		100.0		

a. Source: Reference (36) and nine urbanized area studies.
b. % in a.m. peak direction.

TABLE 36

HOURLY DISTRIBUTION OF TOTAL TRAVEL ON COLLECTORS: URBANIZED AREA POPULATION, 750,000-2,000,000

HOUR	DISTRIBUTION & ORIENTATION BY SUBREGION						HOUR
	CBD		Central City		Suburb		
	All Orientations		All Orientations		All Orientations		
	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	% ADT	DIR SPLT[b]	
24-1	1.5	46	2.0	46	1.5	52	24
1-2	1.0	46	1.0	48	0.5	50	1
2-3	0.5	52	0.5	50	0.5	46	2
3-4	0.5	54	0.5	50	0.0	50	3
4-5	1.0	60	1.0	54	0.5	68	4
5-6	2.5	64	1.5	58	1.0	70	5
6-7	4.5	68	4.0	62	3.5	72	6
7-8	10.5	62	8.5	64	8.0	68	7
8-9	7.5	60	6.0	62	7.0	56	8
9-10	5.5	58	4.5	56	4.5	52	9
10-11	5.5	58	4.5	52	4.5	52	10
11-12	6.0	54	4.5	50	5.0	54	11
12-13	5.0	54	5.0	50	5.0	50	12
13-14	5.0	52	4.5	50	5.0	54	13
14-15	5.5	54	5.0	46	5.5	54	14
15-16	6.5	50	6.5	44	6.5	43	15
16-17	9.0	40	10.5	36	9.5	38	16
17-18	7.5	34	9.5	34	9.0	40	17
18-19	4.5	48	5.0	42	6.0	50	18
19-20	3.0	48	4.5	50	5.0	43	19
20-21	2.5	46	3.0	44	4.0	50	20
21-22	2.0	46	3.0	44	3.0	50	21
22-23	1.5	46	2.5	46	3.0	52	22
23-24	1.5	44	2.5	46	2.0	50	23
	100.0		100.0		100.0		

a. Source: Reference (36) and nine urbanized area studies.
b. Percent in a.m. peak direction.

TABLE 38

CONVERSION FACTORS FOR CRITICAL PERIODS OF INTERNAL PERSON-TRAVEL: [a] URBANIZED AREA POPULATION, 50,000-100,000 [b]

HAVE ↓ / NEED →	Total Travel	Total Work Travel	Comb. Pk.Pd. Total Travel	Pk.Hr. Total Travel	Comb. Pk.Pd. Work Travel	A.M. Pk.Pd. Work Travel	P.M. Pk.Pd. Work Travel	Pk.Hr. Work Travel
Total Travel		0.145	0.275	0.090	0.079	0.042	0.039	0.029
Total Work Travel	6.893		1.897	0.619	0.545	0.292	0.267	0.196
Comb. Pk.Pd. Total Travel	3.635	0.527		0.327	0.287	0.155	0.141	0.104
Pk.Hr. Total Travel	11.124	1.613	3.061		0.880	0.472	0.430	0.316
Comb. Pk.Pd. Work Travel	12.677	1.835	3.480	1.138		0.536	0.490	0.360
A.M. Pk.Pd. Work Travel	23.579	3.420	6.488	2.120	1.864		0.912	0.671
P.M. Pk.Pd. Work Travel	25.841	3.748	7.111	2.323	2.043	1.096		0.736
Pk.Hr. Work Travel	35.128	5.096	9.665	3.158	2.778	1.490	1.359	

a. "Work Travel" refers to HBW trips. "Total Travel" is (HBW + HBNW + NHB) trips. See text for definitions of travel for the various time periods.

b. Source: Computed from travel data contained in Reference (36), Chapter 2 and Chapter 5.

TABLE 37

CONVERSION FACTORS FOR CRITICAL PERIODS OF TRANSIT PATRONAGE

HAVE ↓ / NEED →	ANNUAL AVERAGE WEEKDAY VOLUMES	COMBINED PEAK PER. (4 HOUR) VOLUMES	PEAK HOUR VOLUMES	PEAK HOUR PEAK DIRECTION
ANNUAL AVERAGE WEEKDAY VOLUMES		0.50	0.17	0.14
COMBINED PK. PER. (4 HOUR) VOLUMES	2.00		0.34	0.28
PEAK HOUR VOLUMES	5.88	2.94		0.82
PEAK HOUR PEAK DIRECTION	7.14	3.57	1.21	

← MULTIPLY BY

Source: References (18 and 38).

Figure 84. Daily distribution of transit trips as a percentage of annual average weekday patronage (18, 38).

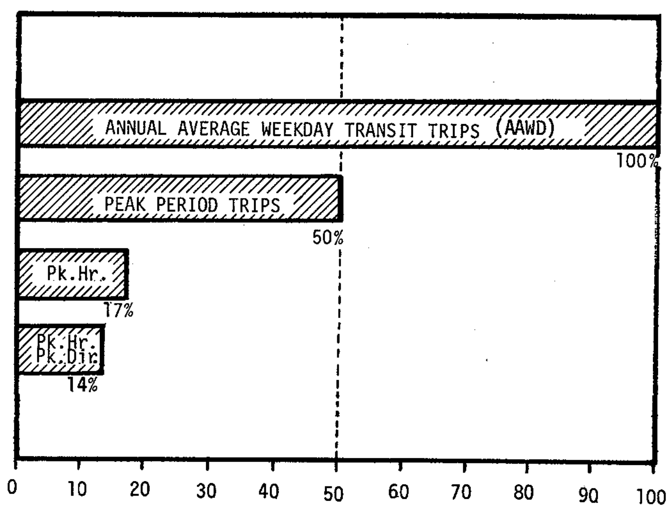


TABLE 40

CONVERSION FACTORS FOR CRITICAL PERIODS OF INTERNAL PERSON-TRAVEL:[a] URBANIZED AREA POPULATION, 250,000-750,000[b]

HAVE ↓ / NEED →	Total Travel	Total Work Travel	Comb. Pk.Pd. Total Travel	Pk.Hr. Total Travel	Comb. Pk.Pd. Work Travel	A.M. Pk.Pd. Work Travel	P.M. Pk.Pd. Work Travel	Pk.Hr. Work Travel
Total Travel		0.181	0.322	0.101	0.103	0.057	0.049	0.038
Total Work Travel	5.515		1.778	0.554	0.572	0.316	0.271	0.211
Comb. Pk.Pd. Total Travel	3.101	0.562		0.312	0.322	0.178	0.152	0.118
Pk.Hr. Total Travel	9.947	1.804	3.208		1.032	0.570	0.489	0.380
Comb. Pk.Pd. Work Travel	9.675	1.748	3.110	0.969		0.553	0.473	0.368
A.M. Pk.Pd. Work Travel	17.450	3.164	5.627	1.755	1.810		0.857	0.666
P.M. Pk.Pd. Work Travel	20.361	3.693	6.566	2.047	2.111	1.166		0.777
Pk.Hr. Work Travel	26.193	4.749	8.447	2.633	2.717	1.501	1.286	

a. "Work Travel" refers to HBW trips. "Total Travel" is (HBW + HBNW + NHB) trips. See text for definitions of travel for the various time periods.

b. Source: Computed from travel data contained in Reference (36), Chapter 2 and Chapter 5.

TABLE 39

CONVERSION FACTORS FOR CRITICAL PERIODS OF INTERNAL PERSON-TRAVEL:[a] URBANIZED AREA POPULATION, 100,000-250,000[b]

HAVE ↓ / NEED →	Total Travel	Total Work Travel	Comb. Pk.Pd. Total Travel	Pk.Hr. Total Travel	Comb. Pk.Pd. Work Travel	A.M. Pk.Pd. Work Travel	P.M. Pk.Pd. Work Travel	Pk.Hr. Work Travel
Total Travel		0.181	0.288	0.095	0.105	0.058	0.049	0.036
Total Work Travel	5.515		1.586	0.528	0.579	0.321	0.273	0.199
Comb. Pk.Pd. Total Travel	3.477	0.630		0.332	0.365	0.203	0.172	0.126
Pk.Hr. Total Travel	10.449	1.894	3.006		1.097	0.608	0.517	0.378
Comb. Pk.Pd. Work Travel	9.508	1.727	2.740	0.912		0.555	0.471	0.344
A.M. Pk.Pd. Work Travel	17.171	3.113	4.939	1.644	1.803		0.850	0.621
P.M. Pk.Pd. Work Travel	20.209	3.644	5.812	1.934	2.122	1.177		0.730
Pk.Hr. Work Travel	27.670	5.017	7.959	2.648	2.905	1.612	1.369	

a. "Work Travel" refers to HBW trips. "Total Travel" is (HBW + HBNW + NHB) trips. See text for definitions of travel for the various time periods.

b. Source: Computed from travel data contained in Reference (36), Chapter 2 and Chapter 5.

TABLE 42

CONVERSION FACTORS FOR CRITICAL PERIODS OF INTERNAL AUTO DRIVER TRAVEL:[a] URBANIZED AREA POPULATION, 50,000-100,000[b]

HAVE ↓ / NEED →	Total Travel	Total Work Travel	Comb. Pk.Pd. Total Travel	Pk.Hr. Total Travel	Comb. Pk.Pd. Work Travel	A.M. Pk.Pd. Work Travel	P.M. Pk.Pd. Work Travel	Pk.Hr. Work Travel
Total Travel		0.160	0.308	0.093	0.087	0.045	0.042	0.031
Total Work Travel	6.250		1.925	0.581	0.545	0.284	0.261	0.192
Comb. Pk.Pd. Total Travel	3.247	0.519		0.302	0.283	0.148	0.136	0.100
Pk.Hr. Total Travel	10.753	1.720	3.312		0.938	0.489	0.449	0.330
Comb. Pk.Pd. Work Travel	11.494	1.835	3.532	1.067		0.521	0.479	0.352
A.M. Pk.Pd. Work Travel	22.007	3.521	6.778	2.047	1.919		0.919	0.676
P.M. Pk.Pd. Work Travel	23.946	3.831	7.376	2.227	2.088	1.088		0.736
Pk.Hr. Work Travel	32.552	5.208	10.026	3.027	2.839	1.479	1.359	

a. "Work Travel" refers to HBW trips. "Total Travel" is (HBW + HBNW + NHB) trips. See text for definitions of travel for the various time periods.

b. Source: Computed from travel data contained in Reference (36), Chapter 2 and Chapter 5.

TABLE 41

CONVERSION FACTORS FOR CRITICAL PERIODS OF INTERNAL PERSON-TRAVEL:[a] URBANIZED AREA POPULATION, 750,000-2,000,000[b]

HAVE ↓ / NEED →	Total Travel	Total Work Travel	Comb. Pk.Pd. Total Travel	Pk.Hr. Total Travel	Comb. Pk.Pd. Work Travel	A.M. Pk.Pd. Work Travel	P.M. Pk.Pd. Work Travel	Pk.Hr. Work Travel
Total Travel		0.227	0.337	0.102	0.133	0.073	0.064	0.047
Total Work Travel	4.412		1.486	0.448	0.588	0.321	0.282	0.208
Comb. Pk.Pd. Total Travel	2.970	0.673		0.302	0.396	0.216	0.190	0.140
Pk.Hr. Total Travel	9.852	2.233	3.466		1.313	0.717	0.630	0.466
Comb. Pk.Pd. Work Travel	7.503	1.701	2.527	0.761		0.547	0.479	0.355
A.M. Pk.Pd. Work Travel	13.737	3.113	4.626	1.394	1.831		0.879	0.649
P.M. Pk.Pd. Work Travel	15.640	3.545	5.267	1.588	2.084	1.138		0.739
Pk.Hr. Work Travel	21.160	4.796	7.126	2.148	2.820	1.540	1.353	

a. "Work Travel" refers to HBW trips. "Total Travel" is (HBW + HBNW + NHB) trips. See text for definitions of travel for the various time periods.

b. Source: Computed from travel data contained in Reference (36), Chapter 2 and Chapter 5.

TABLE 44

CONVERSION FACTORS FOR CRITICAL PERIODS OF INTERNAL AUTO DRIVER TRAVEL: [a] URBANIZED AREA POPULATION, 250,000-750,000 [b]

HAVE ↓ / NEED →	Total Travel	Total Work Travel	Comb. Pk.Pd. Total Travel	Pk.Hr. Total Travel	Comb. Pk.Pd. Work Travel	A.M. Pk.Pd. Work Travel	P.M. Pk.Pd. Work Travel	Pk.Hr. Work Travel
Total Travel		0.200	0.361	0.104	0.114	0.061	0.053	0.041
Total Work Travel	5.000		1.805	0.520	0.572	0.307	0.265	0.206
Comb. Pk.Pd. Total Travel	2.770	0.554		0.288	0.317	0.170	0.147	0.114
Pk.Hr. Total Travel	9.615	1.923	3.471		1.100	0.590	0.510	0.396
Comb. Pk.Pd. Work Travel	8.772	1.748	3.156	0.909		0.537	0.463	0.360
A.M. Pk.Pd. Work Travel	16.287	3.257	5.879	1.694	1.863		0.863	0.671
P.M. Pk.Pd. Work Travel	18.868	3.774	6.811	1.962	2.158	1.158		0.777
Pk.Hr. Work Travel	24.272	4.854	8.762	2.524	2.777	1.490	1.286	

a. "Work Travel" refers to HBW trips. "Total Travel" is (HBW + HBNW + NHB) trips. See text for definitions of travel for the various time periods.

b. Source: Computed from travel data contained in Reference (36), Chapter 2 and Chapter 5.

TABLE 43

CONVERSION FACTORS FOR CRITICAL PERIODS OF INTERNAL AUTO DRIVER TRAVEL: [a] URBANIZED AREA POPULATION, 100,000-250,000 [b]

HAVE ↓ / NEED →	Total Travel	Total Work Travel	Comb. Pk.Pd. Total Travel	Pk.Hr. Total Travel	Comb. Pk.Pd. Work Travel	A.M. Pk.Pd. Work Travel	P.M. Pk.Pd. Work Travel	Pk.Hr. Work Travel
Total Travel		0.200	0.322	0.099	0.116	0.062	0.053	0.039
Total Work Travel	5.000		1.610	0.495	0.579	0.312	0.267	0.195
Comb. Pk.Pd. Total Travel	3.106	0.621		0.307	0.360	0.194	0.166	0.121
Pk.Hr. Total Travel	10.101	2.020	3.253		1.170	0.630	0.539	0.394
Comb. Pk.Pd. Work Travel	8.621	1.727	2.781	0.855		0.539	0.461	0.337
A.M. Pk.Pd. Work Travel	16.026	3.205	5.160	1.587	1.856		0.856	0.625
P.M. Pk.Pd. Work Travel	18.727	3.745	6.029	1.854	2.169	1.169		0.730
Pk.Hr. Work Travel	25.641	5.128	8.256	2.538	2.969	1.600	1.369	

a. "Work Travel" refers to HBW trips. "Total Travel" is (HBW + HBNW + NHB) trips. See text for definitions of travel for the various time periods.

b. Source: Computed from travel data contained in Reference (36), Chapter 2 and Chapter 5.

TABLE 45

CONVERSION FACTORS FOR CRITICAL PERIODS OF INTERNAL AUTO DRIVER TRAVEL:[a] URBANIZED AREA POPULATION, 750,000-2,000,000

HAVE ↓ / NEED →	Total Travel	Total Work Travel	Comb. Pk.Pd. Total Travel	Pk.Hr. Total Travel	Comb. Pk.Pd. Work Travel	A.M. Pk.Pd. Work Travel	P.M. Pk.Pd. Work Travel	Pk.Hr. Work Travel
Total Travel		0.250	0.377	0.105	0.147	0.078	0.069	0.051
Total Work Travel	4.000		1.508	0.420	0.588	0.312	0.276	0.204
Comb. Pk.Pd. Total Travel	2.653	0.663		0.279	0.390	0.207	0.183	0.135
Pk.Hr. Total Travel	9.524	2.381	3.590		1.400	0.743	0.657	0.486
Comb. Pk.Pd. Work Travel	6.803	1.701	2.565	0.714		0.531	0.469	0.347
A.M. Pk.Pd. Work Travel	12.821	3.205	4.833	1.346	1.885		0.885	0.654
P.M. Pk.Pd. Work Travel	14.493	3.623	5.464	1.522	2.130	1.130		0.739
Pk.Hr. Work Travel	19.608	4.902	7.392	2.059	2.882	1.529	1.353	

a. "Work Travel" refers to HBW trips. "Total Travel" is (HBW + HBNW + NHB) trips. See text for definitions of travel for the various time periods.

b. Source: Computed from travel data contained in Reference (36), Chapter 2 and Chapter 5.

which occurs during the 60-min period that has the largest volume of travel for the 24-hr period. The peak hour may be during the AM or PM peak period (generally assumed to occur during the PM peak period).

5. *Combined peak period work travel.* Same as item 3 except applies only to HBW travel.

6. AM *peak-period work travel.* Travel for the purpose of HBW occurring during the two consecutive morning hours representing the highest cumulative volume of daily travel.

7. PM *peak-period work travel.* Travel for the HBW purpose occurring during the two consecutive evening hours representing the highest cumulative volume of daily travel.

8. *Peak-hour work travel.* Travel, for the purpose of HBW, which occurs during the 60-min period that has the largest volume of travel during a 24-hr period (generally assumed to occur during the AM peak period).

Tables 38 through 45 have been developed from other tables in this chapter describing travel by time-of-day by purpose; from information contained in Chapter Two, "Trip-Generation Estimation," which relates work trips to total trips; and from data contained in Chapter Five, "Automobile-Occupancy Characteristics."

As the user becomes familiar with the conversion tables, it will be discovered that the conversion factors are useful from the standpoint of gaining a perspective about the distribution of travel as well as helpful for detailed analysis purposes. For example, the user should notice that total travel occurring during the peak hour is approximately 10 percent of the total daily travel. Also, peak-hour HBW travel is approximately 40 percent of the total peak-hour travel.

The following example is provided to illustrate the tables in application.

Given: In an urbanized area of 300,000 population, a major new development is proposed for immediate construction in a corridor where there exists a heavy movement of people. The developer has estimated the project will generate 7,000 daily HBW trips that will use the major arterial. The arterial currently carries 27,000 internal person-trips daily.

Determine: 1. The total daily internal person-travel generated by the development that will use the arterial.

2. The peak-hour total person-travel using the arterial.

Solution: To solve this problem, Table 40 is selected as representing an urbanized area of 300,000 population. From Table 40, the following conversion factors are noted:

HAVE	NEED	FACTOR
Total work travel	Total travel	5.515
Total travel	Peak-hr total travel	0.101

1. Total trips from the development = 7,000 × 5.515 = 38,605 person-trips
2. Total daily person-trips on arterial = 38,605 + 27,000 = 65,605

Therefore peak-hour trips = 65,605 × 0.101 = 6,626 person-trips

Similar applications can be performed for internal auto-driver travel using Tables 42 through 45. The auto-driver travel conversion factors have been adjusted to account for variations in auto occupancy.

LIMITATIONS AND USE OF REGIONAL DATA

The information contained in this chapter allows for a rapid analysis of travel by time-of-day for a multitude of conditions. The data used to develop the factors are extensive, and similar daily distributions have been observed between those urbanized areas which contributed data. But, the user should never overlook the uniqueness of local conditions nor the reasonableness of the results in light of known characteristics of local conditions. If local data exist to segregate travel by time period, the user is urged to investigate such data to the extent time allows.

CHAPTER SEVEN

TRAFFIC-ASSIGNMENT PROCEDURES

INTRODUCTION

Traffic assignment is a process used for simulating current traffic volumes and forecasting probable future volumes on a transportation system, or portion of a system, using travel-demand information developed from a survey or a modeling technique.

Traffic-assignment techniques and their products have many uses, including:

- Developing and testing alternative transportation systems.
- Establishing short-range priority programs for transportation facility development.
- Detailed study of traffic generators and the effects of such generators on the transportation system.
- Analyzing locations for facilities and service within a transportation corridor.
- Developing design volumes.
- Providing necessary input and feedback to other planning tools.

Input to the traditional traffic-assignment process includes:

- A transportation network description varying in detail from all segments and interconnections of the actual system to an approximation of the available carrying capacity of the system.
- Operating characteristics of the system varying in detail from the actual operating speed of each segment to a general categorization of level of service (high, medium, low).
- A measure of the transportation demand or movement (i.e., persons, vehicles, tons of cargo). This quantity can be represented in detail as a matrix of movements between each analysis area of the study area or in gross terms such as total travel associated with a generator. Varying degrees of detail are available between these extremes.

Traditionally, traffic-assignment techniques have relied on the determination of routes through a network of facilities based on segment impedances. Interchange values are then accumulated along these paths resulting in loads on each network segment. Other techniques, which require less detailed input and produce meaningful results for certain types of problems, are also available.

The techniques contained in this user's guide are included to allow quick response without the need for computer expertise. Three techniques are described:

1. Traditional traffic assignment.
2. Traffic generation and decay.
3. Traffic diversion/traffic shift.

Each technique provides varying levels of detail and each has application in the solution of different types of problems. Only the traditional traffic-assignment approach makes use of a network and interchange values. The other techniques require significantly less input, and, likewise, provide a lesser degree of accuracy but have definite uses as described later herein.

The traffic-assignment process is but one procedure in the transportation planning process. The results are most easily understood by the administrator, the public, and planners.

BASIS FOR DEVELOPMENT

The techniques described in this chapter are generally a combination of various procedures uncovered in the literature cited in the references. The three major classifications of techniques had one or two principal sources which provided the major direction for the description of each procedure. The three major methods are:

1. Traditional traffic-assignment methodology: This methodology is basically the common all-or-nothing assignment process. However, this method was made more versatile by incorporating techniques contained in a De-Leuw, Cather publication (*40*), a technique developed by Wickstrom and Kudlick (*49*), and a technique described by Citron (*71*).
2. Traffic-generation and decay methodology: This method was generally based on material developed by Gruen Associates under contract to the FHWA (*1*). The technique has been expanded to allow use of more specific estimates of generated trips, provide a more responsive decay function, and improve the geographic orientation sensitivity of the results.
3. Traffic diversion/traffic shift methodology: This procedure was developed from material on the multiroute probabilistic process developed by Dial (*55*). The formulation presented provides a means of determining the diversion of traffic between routes based on an improvement or the addition of a competing facility.

Each technique is illustrated in turn with actual applicational examples. An attempt has been made to describe the techniques as modular elements where the user can proceed from a condition with little available information to a condition where extensive information is known about the study area.

All techniques described allow manual application. In some cases, the user might have access to regional model outputs and may be able to obtain specific computer output. For these users, discussion has been included to relate the usefulness and application of regional models.

FEATURES AND LIMITATIONS

Some salient features and some major limitations of the three sets of traffic assignment techniques are discussed in the following sections.

Traditional Traffic-Assignment Methodology

This method provides traffic estimates on a network of highway facilities. This includes traffic flow on each street segment plus (optionally) turning movements at each intersection. The requirements of traditional traffic assignment are a matrix of trips between all origins and destinations and a street system (network) on which these trips will be accumulated (assigned).

The matrix of trips can be manually obtained (see Chapter Three, "Trip Distribution") or can be obtained from areawide computer models. If the matrix is obtained from areawide models, the number of interchanges should be reduced by aggregating trips to districts in areas removed from the portion of the street system under consideration. An additional simplification that can be applied for manual application is to eliminate interchanges that have a minimal number of trips (i.e., less than 10). This simplification greatly reduces the number of manual computations and has been shown to produce reasonably accurate results (*40*).

The basic methodology for assigning traffic manually (or with a computer) is to determine a logical path for each trip interchange and then to accumulate the number of trips on each street segment along the path. The determination of a logical path must be based on some criteria that will produce meaningful results *and* provide consistency between users of the technique. Normally, travel time is the criterion that is used to select the logical path between an origin and a destination. In most cases the logical minimum path can be determined by inspection. For a small number of cases, it may be necessary to compare travel times on alternative paths to determine the best route. Accumulation of trips along each path is basically an accounting or bookkeeping process as illustrated in the application examples that follow.

If the street network under analysis is limited in size and the number of interchanges is small, a graphical accumulation technique may be adequate. This technique simply involves recording on a map the number of trips on each segment that is included on the minimum path. After all interchanges are accounted for, the map will contain a number of interchange values on each segment which are summed to produce the traffic volume on each street segment. Obvious disadvantages of this procedure are: many movements using the same segment will be difficult to record on a single map; no provisions are made to check segment values or to adjust segment volumes quickly if an error is discovered; turn volumes are not identified.

Trips can also be assigned to the network using tabular accumulation which yields exactly the same result as the graphical process except that bookkeeping is easy and systematic.

For determining turning movements at intersections, a method described by Citron (*71*) is used. This technique involves attaching a unique number to each turning movement at highway segment intersections of interest. Trip interchanges are then assigned to turning movements (rather than segments) while maintaining the most logical paths. Accumulation of trips to turning movements is performed in a tabular form. It is also possible to use this method to compute segment volumes by accumulating appropriate turning movements at the intersections.

Traffic Generation and Decay Methodology

This technique, based on the Gruen guidelines (*1*), is useful for evaluating the effect of a proposed traffic generator (shopping center, industrial park, airport, etc.) on the highway system surrounding the development. Two elements are involved in the estimation process: determination of expected trips generated by the development, and determination of the effect of these trips at increasing distances from the generator by "geographic orientation" (i.e., north, south, etc.).

Prior to evaluating the effect of a proposed traffic generator, it is necessary to obtain information on the traffic volumes that exist or will exist on the street system in the area of interest. This information can be obtained from traffic count data or traffic assignment results (if available) from a regional model. If this base or existing traffic is not readily available, a method for approximating such traffic (*1*) is available.

Special charts are provided to enable estimation of average street volumes for suburban developments of relatively uniform density. The primary chart, for example, provides an initial approximation of traffic volumes. Adjustments to these volumes are then made by applying the adjustment factors owing to the following characteristics:

- Density and project size.
- Level of service.
- Auto ownership.
- Transit utilization.
- Project and nonresidential/residential mix.
- Freeway diversion.

These factors are derived from charts and are applied multiplicatively to arrive at a final estimate that can be used as a base-traffic estimate. It should be noted that the use of such charts involves relationships that are general in nature. These relationships are simple to apply but should be used with caution.

The evaluation of a major traffic generator involves estimating the traffic that the generator will produce and then superimposing this traffic on the traffic already existing on the street system. Determination of generated trips can be made by using local trip-generation characteristics if they are available. Obviously, this will produce the most meaningful results. If this information is not available, an alternative approach would be to use the trip-generation estimation guidelines described in Chapter Two, "Trip-Generation Estimation."

If the user has access to regional models, specifics on distribution of trips by length and purpose will be available. This information should be used in lieu of the more general tables by selecting the appropriate trip purpose that most closely represents typical travel to the generator under consideration. Trip-purpose classifications vary from study to study, but certain major classifications, such as work, shopping, school, social-recreational, usually are common and can be related to the appropriate type of generator (e.g., for a university—school trips, for a shopping center—shopping trips, for an industrial establishment—work trips).

The final requirement for estimating the effect of a proposed generator is to determine the geographic orientation of trips (in terms of movement to and from the north, south, east or west directions) that will use the generator. If no other information is available, a uniform orientation (or "spread") might have to be assumed. Usually, however, orientation of trips can be determined by examining the available street system to determine where the service is provided. An examination of the nongenerator end of the trip may also provide insight into the expected orientation of travel (i.e., a given shopping center will attract trips from areas of residential development in reasonably close proximity to the center).

The techniques described in Chapter Three, "Trip Distribution," provide the mechanism to account for both orientation and attenuation. Use of the gravity model technique requires distribution factors, F_{ij}, which can be derived as described in Chapter Three. Application of the gravity model in the context of evaluating a major generator involves the assumption that the generator "produces" the traffic and surrounding residential areas "attract" the traffic. This assumption is reverse to the normal situation where the generator attracts trips. As such, it is not entirely correct inasmuch as it does not allow for the effect of competing generators on traffic flow. In the context of quick-response procedures, this error is not serious and at worst will provide a slight overestimation of the quantity of traffic on the street system. Application of the manual trip-distribution procedure in the traffic evaluation of a major generator is given later in this chapter.

Traffic Diversion/Traffic Shift Methodology

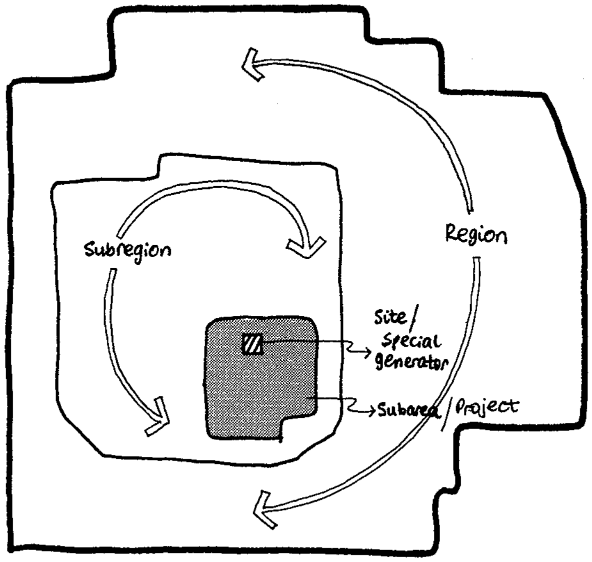
This procedure enables the user to determine the effects changes in the level-of-service variables have on highway segment volumes. For instance, if there are two routes within a corridor, and one route is improved so that higher speeds are possible, traffic will divert to this route from the other facility—this diversion can be determined graphically using a chart provided for this purpose. The traffic-diversion method is simple and easy to use.

Summary

In summary then, manual trip assignment can be handled most conveniently at the detailed level for a small-sized network. Ideally, manual trip-assignment problems should be confined to the subarea level, and, on occasions, at the subregion level. The geographical relationship of these two levels with that of the region level is shown in Figure 85. It is possible, of course, to apply the assignment methodologies to larger networks, but the sheer size of the problem can be overwhelming in terms of time requirements. For this reason, it is recommended that networks be kept simple and compact.

The choice of a suitable assignment method depends on the type of problem to be addressed. Consider the following examples of possible applications:

1. For determining traffic volumes on a highway network resulting from trip-distribution interchanges, the



HIERARCHY OF ANALYSIS AREA LEVELS:
(in ascending order of size)

1. SITE/SPECIAL GENERATOR (e.g., a regional shopping center)
2. SUBAREA/PROJECT (a conglomeration of contiguous districts or zones; e.g., a residential project)
3. SUBREGION (a conglomeration of contiguous subareas; e.g., central city or suburb portion of a region)
4. REGION (a conglomeration of contiguous subregions e.g., a metropolitan region)

Figure 85. Geographical relationships between various analysis area levels.

traditional "all-or-nothing" assignment method should be used. This trip-"stringing" procedure can be performed either graphically on a map or in a tabular format. If turning movements at intersections are desired, the turning-movement method can be employed.

2. For estimating traffic volumes through corridors or geographical sectors (and for estimating the associated street system requirements) caused by traffic from special land-use generators, the Gruen guidelines (*1*) in conjunction with the trip-geographic-orientation analysis should be considered.

3. For estimating the traffic "shift" between routes within corridors owing to level-of-service changes on certain facilities, the diversion method should be considered. Obviously, for detailed analysis a traditional assignment approach should be used.

One important clarification must be made concerning the term "traffic." Two distinct categories of traffic can be discerned: the *base or existing* traffic in the network and the *additional or newly generated* traffic owing to a newly developed or proposed land use. If the newly generated traffic is superimposed on the existing traffic, the *total* traffic estimate is obtained. Ultimately, it is the total traffic estimate that is of concern to the planner, say, for capacity analysis for a corridor or for intersection analysis.

Usually, existing traffic on the highway segments is available to the planner from previous assignment studies and/or from traffic counts. It is only necessary, therefore, to estimate and assign new trips generated by special land uses. This situation simplifies matters and works to the advantage of the user because the network that will be of interest will most probably be small in size and will be located in the immediate vicinity of the special generator.

MANUAL TRAFFIC-ASSIGNMENT METHODOLOGY FOR SMALL NETWORKS

Consider a hypothetical scenario where the peak-hour traffic impacts for an average weekday produced by a special generator (e.g., a proposed government center) are to be determined for a freeway-arterial network in the immediate vicinity of the generator; the impact subarea in this case is bounded by a traffic-analysis area boundary, and only those highway segments wholly inside this boundary are to be considered. The traffic impacts are to be quantified in terms of the segment volumes and turning movements at selected intersections. The methodology is applied as follows:

Step 1: Map of study area. Lay out a map showing the region, subregion, subarea, and the special generator. Delineate analysis areas within the subregion that produce and attract trips to and from the special generator (the same should be done for the region, but, in this example, only the subregion and analysis area will be dealt with for simplicity). There are a total of 18 analysis areas within the subregion with area 18 being the impact subarea (see Fig. 86). Lay out also the significant freeway-arterial network in the subarea. The subarea boundary acts as a cordon line to area 18: the freeway-arterial segments are extended across this cordon so that these segments, conceptually, represent entry (and exit) points into (and out of) area 18. As pointed out earlier, the network is kept compact by dealing only with facilities at the freeway-arterial level. The network could conceivably include collectors and locals but this is dictated by the time resources available and the analysis desired. The preliminary setup is shown in Figure 86.

Step 2: Trip interchanges to special generator. By using the trip-distribution methods and the time-of-day analysis methods described in the preceding chapters, the hourly/directional splits of trips to and from the special generator may be estimated. Trips *from* the 17 analysis areas *to* the special generator in area 18 can thus be determined for a particular hour. Then, using a "desire-line" concept, these interchanges are connected to the appropriate highway segment entry point. The connection proceeds in a clockwise fashion around the subarea as shown in Figure 87. In effect, the trips are funnelled into (or out of) the impact subarea through these segments. For instance, beginning with (hypothetical) trip interchanges from area 1, 240 trips destined for the special generator (i.e., the proposed government center) are connected to the nearest highway segment crossing the subarea cordon. Similarly, 130 trips from area 2 are connected to the same entry point. Then, 50 trips from area 3 and 150 trips from area 4 are linked to the next entry point; and so on until all 17 areas are accounted for. Note that intra-area trips for zone 18 are not considered for assignment and were therefore excluded.

Note also that unless the subarea under study is large enough to generate an appreciable proportion of the trips destined to and from the special generator, such exclusion of intra-area trips is an acceptable approximation.

To enable ready distinction between opposing flows of traffic, trip interchanges are always noted on the right-hand side of the desire line with respect to the direction of flow. This convention is maintained throughout this chapter as a simple means to avoid any possible confusion in trip directions.

Area 18 is then expanded onto a larger scale as shown in Figure 88. The entry points are identified alphabetically: thus, 370 trips are entering subarea 18 at entry point A; 200 trips at entry point B; 250 trips at entry point C; and so on. In total, 5,000 trips are destined for the special generator (for a particular hour) and they all cross the subarea cordon line through 11 entry points (A through K).

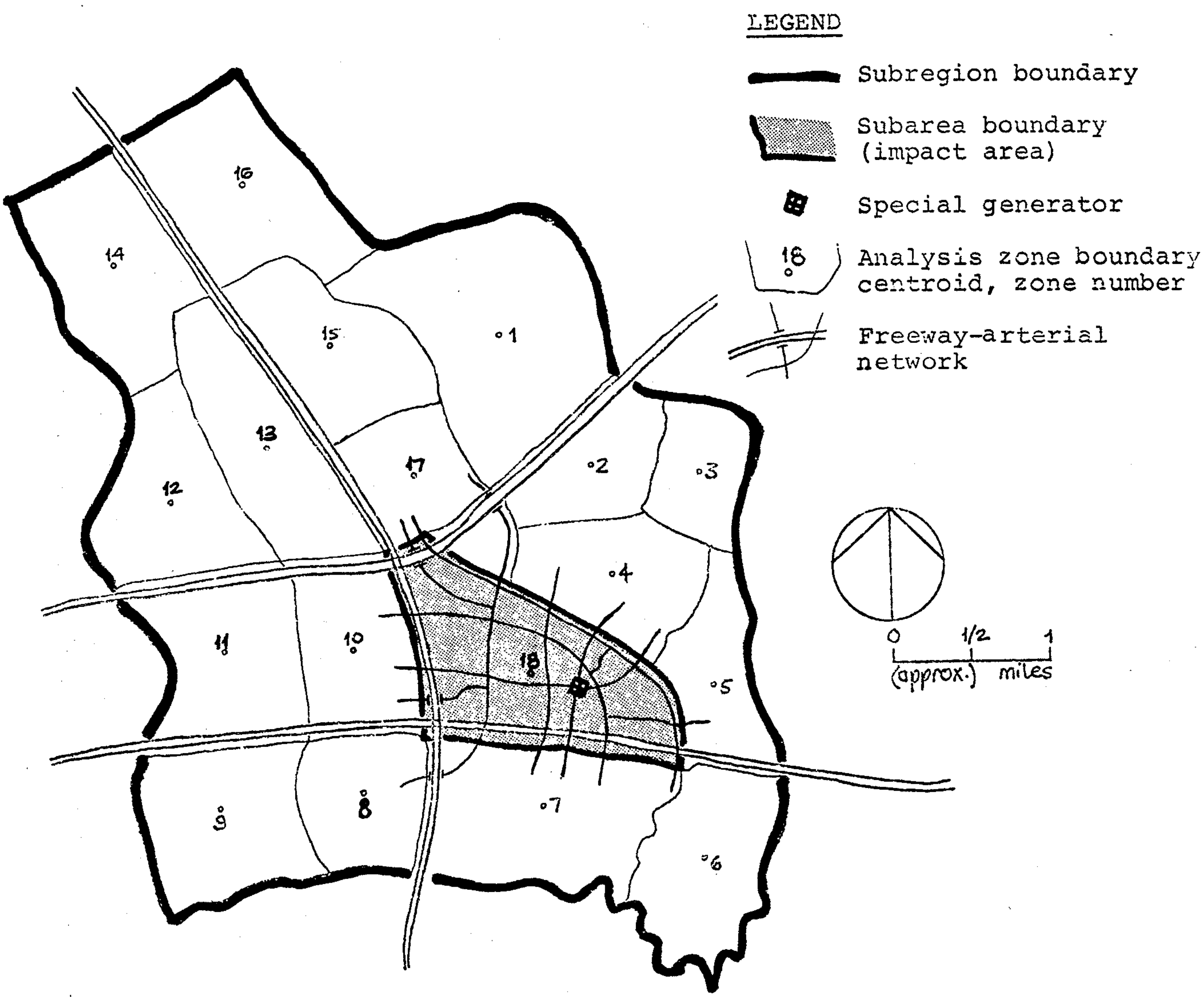


Figure 86. Map of study area.

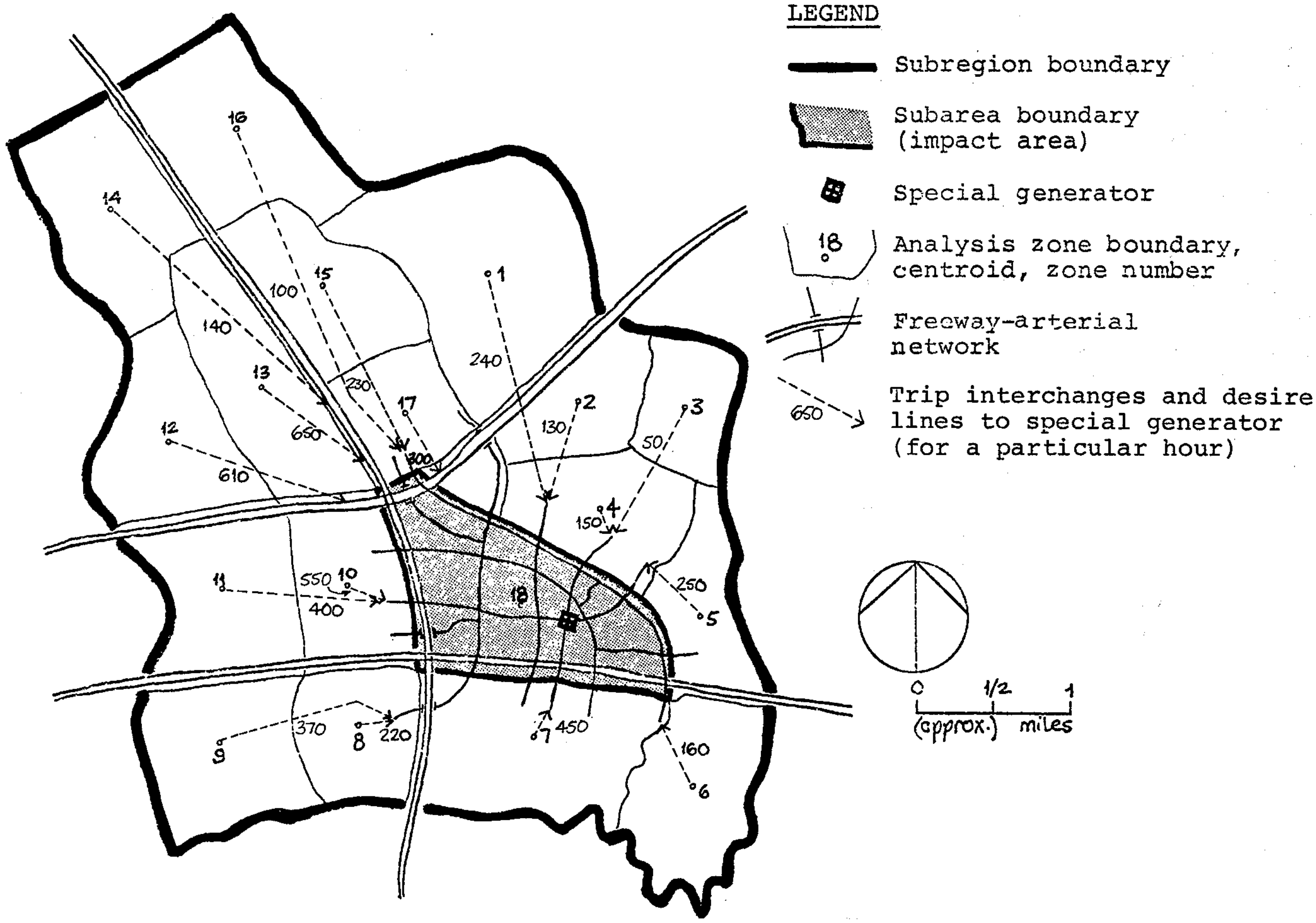


Figure 87. Study area, showing trip interchanges and desire lines to special generator.

Step 3: Number highway segments. Starting with entry point A and proceeding clockwise around area 18, the "most reasonable" highway paths to the special generator are identified and their respective highway segments uniquely numbered. Generally, the most reasonable path is the minimum-travel time path and/or the minimum-travel distance path. Experienced judgment must be exercised in identifying such paths—the manual assignment procedure makes no provision for selection of minimum paths based on quantitative factors, but rather makes a quick visual determination.

Thus, in Figure 88, the most reasonable path from entry point A to the special generator is via highway segments 1, 2, and 3; from B, highway segments 4 and 3; and from K, highway segments 19, 20, 1, 2, and 3; and so on for each entry point. The identification of all minimum paths from all entry points yields a total of 20 unique highway segments within the subarea.

Step 4. Load highway segments with entry trips. The loading—stringing—of trips (essentially the all-or-nothing method) onto the highway segments can proceed in one of two ways, depending on user preference and the size of the network. The process can be either graphical or tabular; both methods are described here.

The *graphical method* merely "strings" or assigns trips from the entry points to the special generator via the most reasonable highway paths, directly onto the map of the subarea network. Accumulation of trips for each highway segment is also done directly on the map. Again, entry points are handled alphabetically and clockwise around the subarea.

Thus, in Figure 89, highway segments 1, 2, and 3 from entry point A to the special generator are each loaded with 370 trips. This number is noted alongside the appropriate links on the right-hand side of each link with respect to the direction of flow, because trips are heading *into* the special generator. This convention is exactly that described in Step 2. Arrows also help in identifying the direction of traffic flows and are therefore inserted adjacent to the trip volumes. As another example of stringing, the 300 trips from entry point K are loaded on the right-hand side of links 19, 20, 1, 2, and 3, and so on for each entry point.

The *tabular method* of assigning trips is just as simple as the graphical method. This time, however, the trip interchanges from the entry points to the special generator, and the highway segment numbers, are arranged to form the rows and columns as shown in the table in Figure 90. The trips are then inserted in the appropriate cells. For example, from entry point A, 370 trips are inserted in columns 1, 2, and 3 corresponding to a minimum path made up of highway segments 1, 2, and 3. Similarly, from entry point K, 300 trips are inserted in columns 1, 2, 3, 19, and 20 corresponding to a minimum path made up of

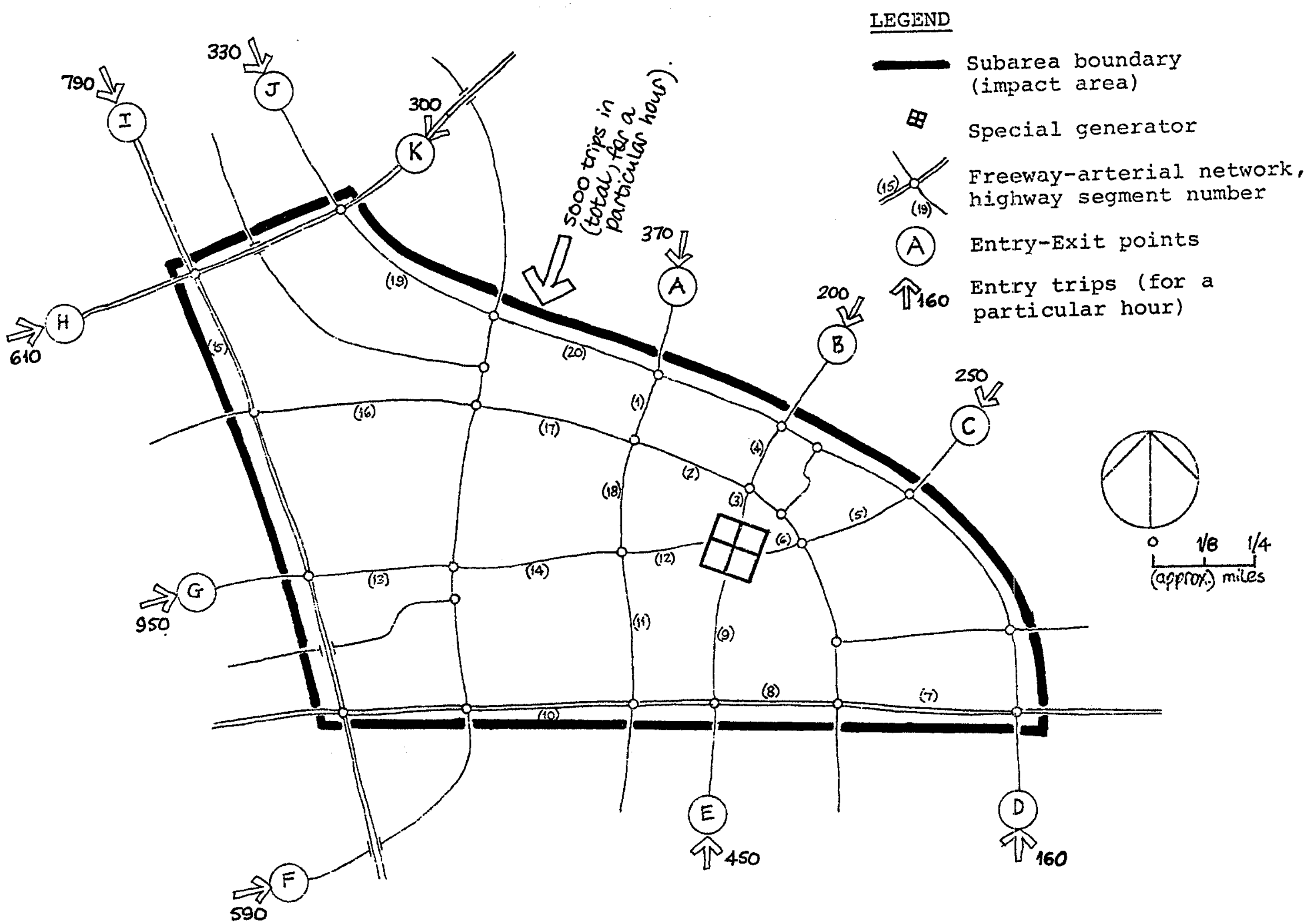


Figure 88. Subarea, showing highway network and entry trips to special generator.

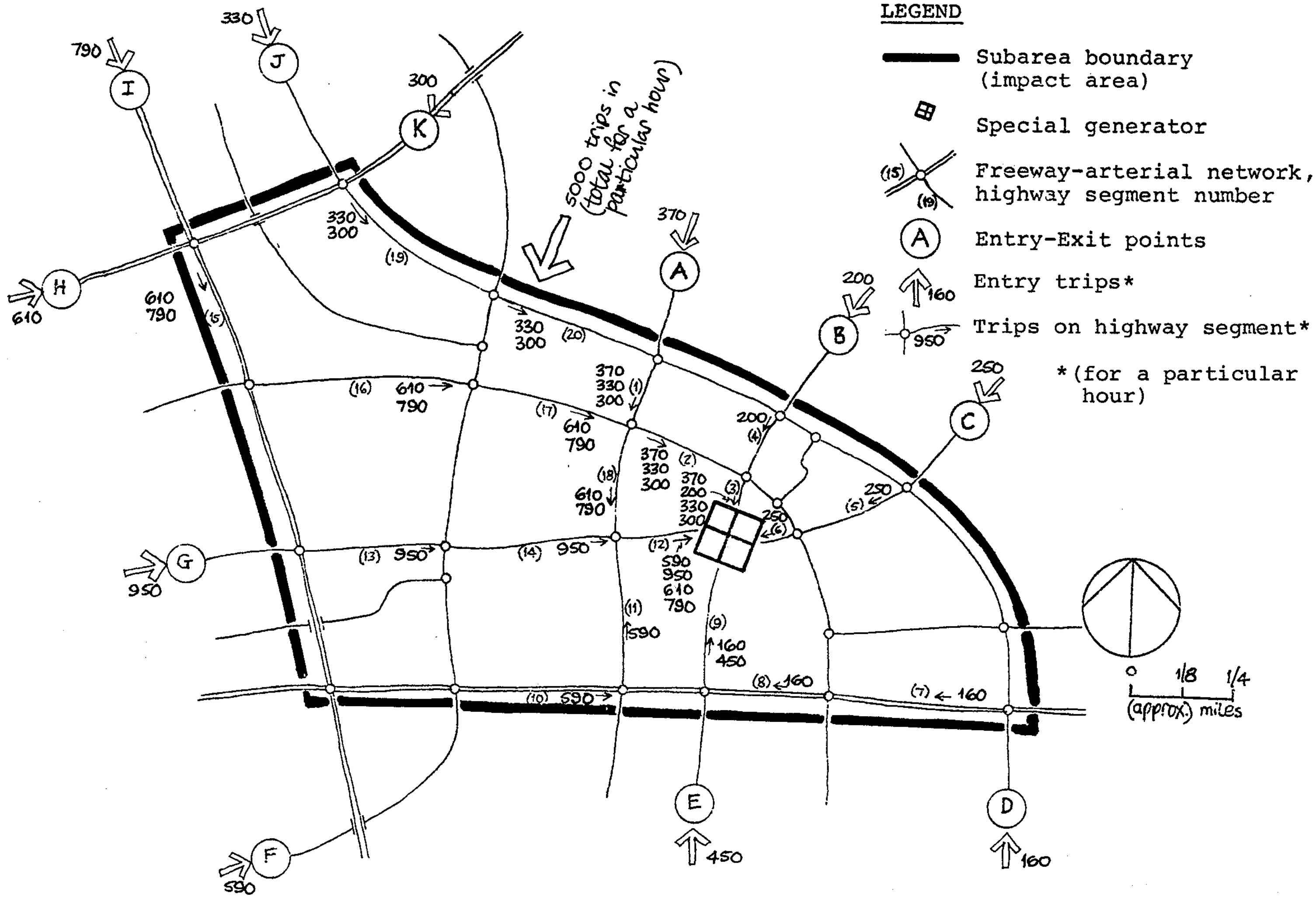


Figure 89. Subarea, showing "stringing" of entry trips to highway network.

TRIPS ENTERING GENERATOR

SEGMENT # / ENTRY POINT # AND TRIPS		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	370	370	370	370																	
B	200			200	200																
C	250					250	250														
D	160							160	160	160											
E	450									450											
F	590										590	590	590								
G	950												950	950	950						
H	610												610			610	610	610	610		
I	790												790			790	790	790	790		
J	330	330	330	330																330	330
K	300	300	300	300																300	300
ΣTrips in=5000		1000	1000	1200	200	250	250	160	160	610	590	590	2940	950	950	1400	1400	1400	1400	630	630

Figure 90. Tabular assignment of entry trips to highway network.

highway segments 19, 20, 1, 2, and 3. After all entry points have been handled, trips are summed up for each column, yielding the trip volume for that particular highway segment. For instance, the total number of trips on segment 12 headed for the special generator is $590 + 950 + 610 + 790 = 2{,}940$ trips, and so forth.

The end result from both the graphical and tabular methods is, of course, the same. Figure 91 shows the total number of trips assigned to the subarea network, flowing from the entry points to the special generator.

Step 5. Trip interchanges from special generator. This step is similar to Step 2. Trips *to* the 17 analysis areas *from* the special generator in subarea 18, for the same time period as trips *to* the generator, have been determined as before. However, the desire lines and traffic flows are now reverse to the previous ones, and the entry points now act as the exit points. Figure 92 summarizes the trip interchanges from area 18; the figure indicates that there are 50 trips destined for area 1 and 150 trips destined for area 2; that is, 200 trips are exiting through the cordon from the same highway segment. In total, there are 2,000 trips that leave the special generator (i.e., the proposed government center), and they all cross the subarea cordon line through 11 exit points (A through K; see Fig. 93).

Step 6: Load highway segments with exit trips. This step is identical to Step 4 but with reversed traffic flows. The major assumption underlying this step is that for reverse traffic flow, the most reasonable path is exactly the same as for the original direction. That is to say, the minimum path from the special generator to, for example, entry point A, is the same as that from entry point A to the generator. (The planner must, of course, deviate from this "reversal" if one-way streets are involved.) Hence, for trips entering the generator through entry point A, highway segments 1, 2, and 3 are selected, and for trips exiting the generator, highway segments 3, 2, and 1 are selected to exit point A.

Trips can be assigned graphically or tabularly in the manner described in Step 4. (Note that for graphical assignment, trip volumes are inserted on the right-hand side of the highway segments, as defined by the traffic flow convention.) The results of the graphical assignment are shown in Figure 93 and that of the tabular assignment in Figure 94.

The total two-way assignment results for trips from entry points to the special generator, and for trips from the special generator to the exit points, are shown in Figures 95 and 96. As shown in both figures, a total of 5,000 trips enter the subarea and 2,000 trips exit the same. Highway segment 14, for example, shows 950 trips headed to the special generator and 490 trips headed from the same, resulting in a total flow of 1,440 trips on this segment.

The highway segments for the subarea network are now considered assigned with trip volumes to and from the special generator. It must be pointed out that these trip volumes are those exceeding the existing traffic on the subarea network. For the total traffic impacts, the new traffic must be added onto the existing traffic. This information is frequently available from local traffic-volume count programs.

The original scenario also calls for determining turning movements at selected intersections due to the traffic generated by the special generator. In reality, turning movements must be determined for both the existing traffic on the subarea network and the additional traffic produced by the generator, for only then will such movements have any meaning in the identification of critical intersections. For this scenario, however, only the additional traffic will be used simply for illustrative purposes. Turning movements can be compiled by using a commonly used method modified by Citron (*71*).

Suppose turning movements are to be investigated for intersections inside the area designated in Figure 95. (This area is shown expanded in Fig. 97.) The turning movement method proceeds as follows:

Step 7: Trip interchanges entering and exiting designated area. These trips have been previously determined; thus, in Figure 97, highway segment 4 has 200 trips entering the designated area and 50 trips exiting the same, and so on

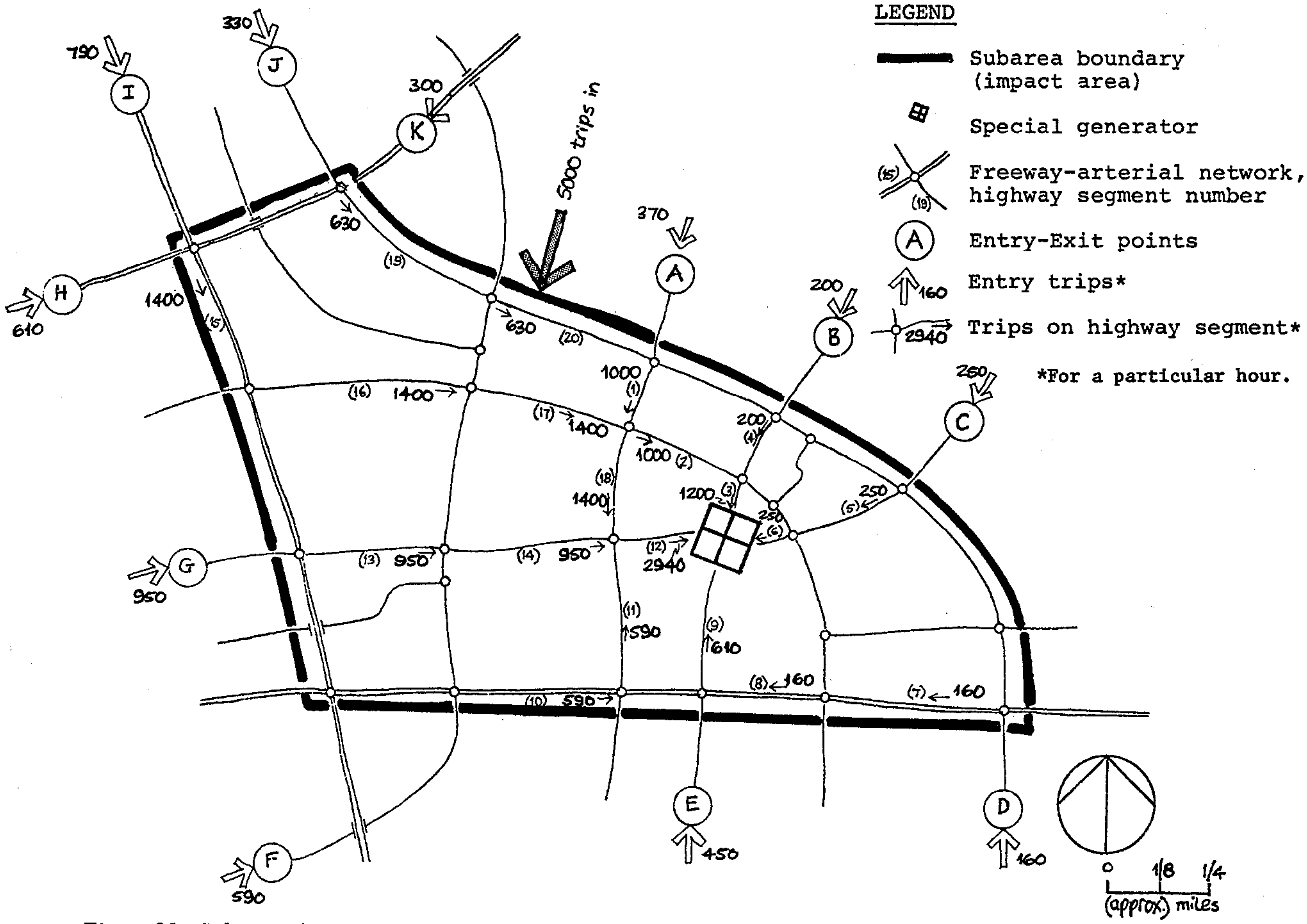


Figure 91. Subarea, showing loaded entry trips.

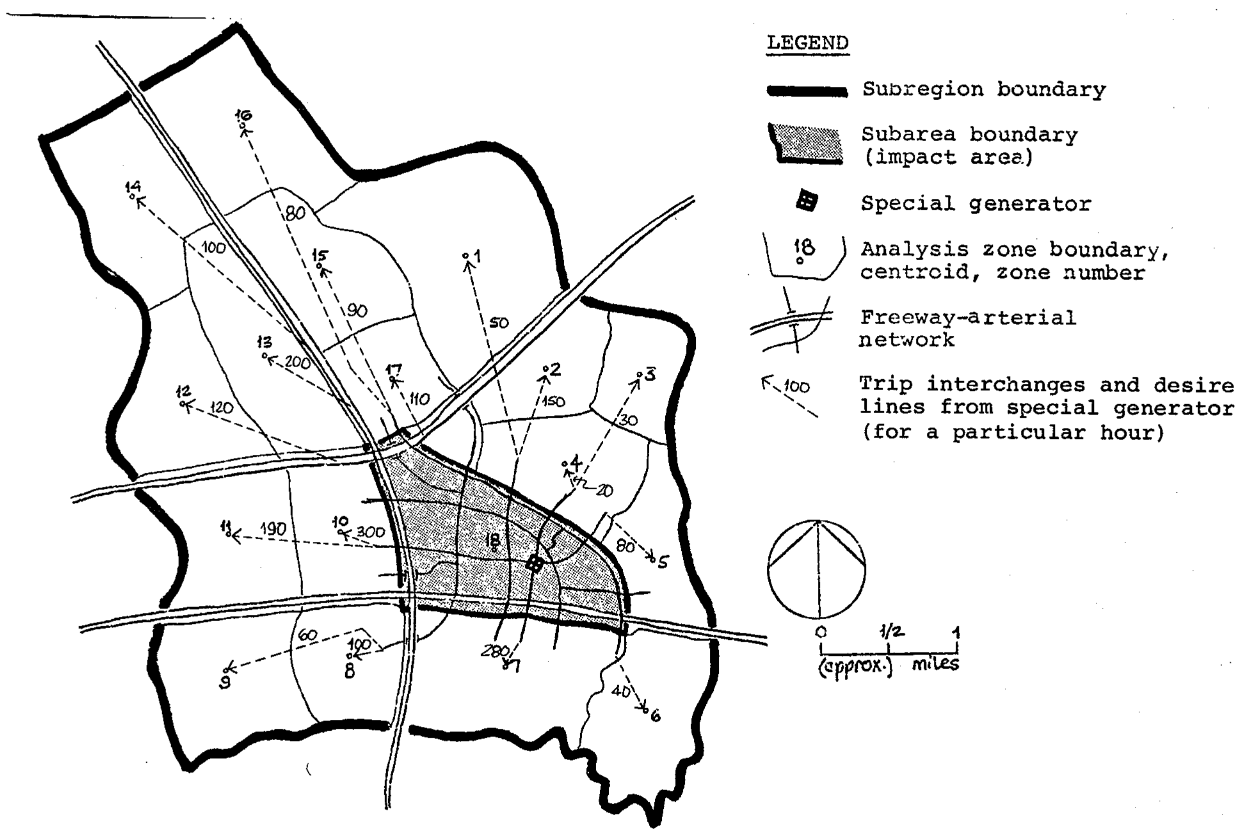


Figure 92. Study area, showing trip interchanges and desire lines from special generator.

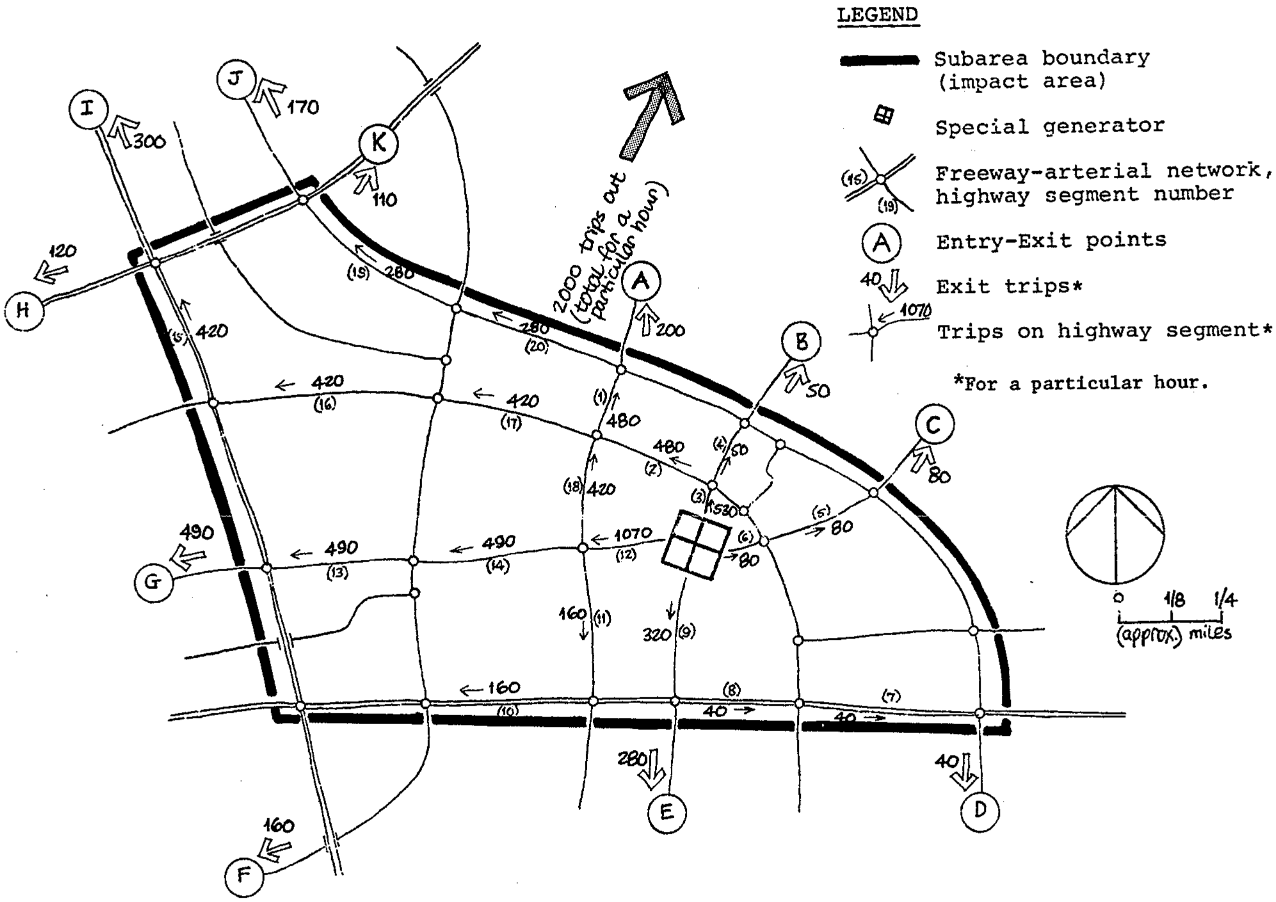


Figure 93. Subarea, showing loaded exit trips.

SEGMENT # / ENTRY POINT # AND TRIPS		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
A	200	200	200	200																	
B	50			50	50																
C	80					80	80														
D	40							40	40	40											
E	280									280											
F	160										160	160	160								
G	490												490	490	490						
H	120												120			120	120	120	120		
I	300												300			300	300	300	300		
J	170	170	170	170																170	170
K	110	110	110	110																110	110
ΣTrips out=2000		480	480	530	50	80	80	40	40	320	160	160	1070	490	490	420	420	420	420	280	280

TRIPS EXITING GENERATOR

Figure 94. Tabular assignment of exit trips to highway network.

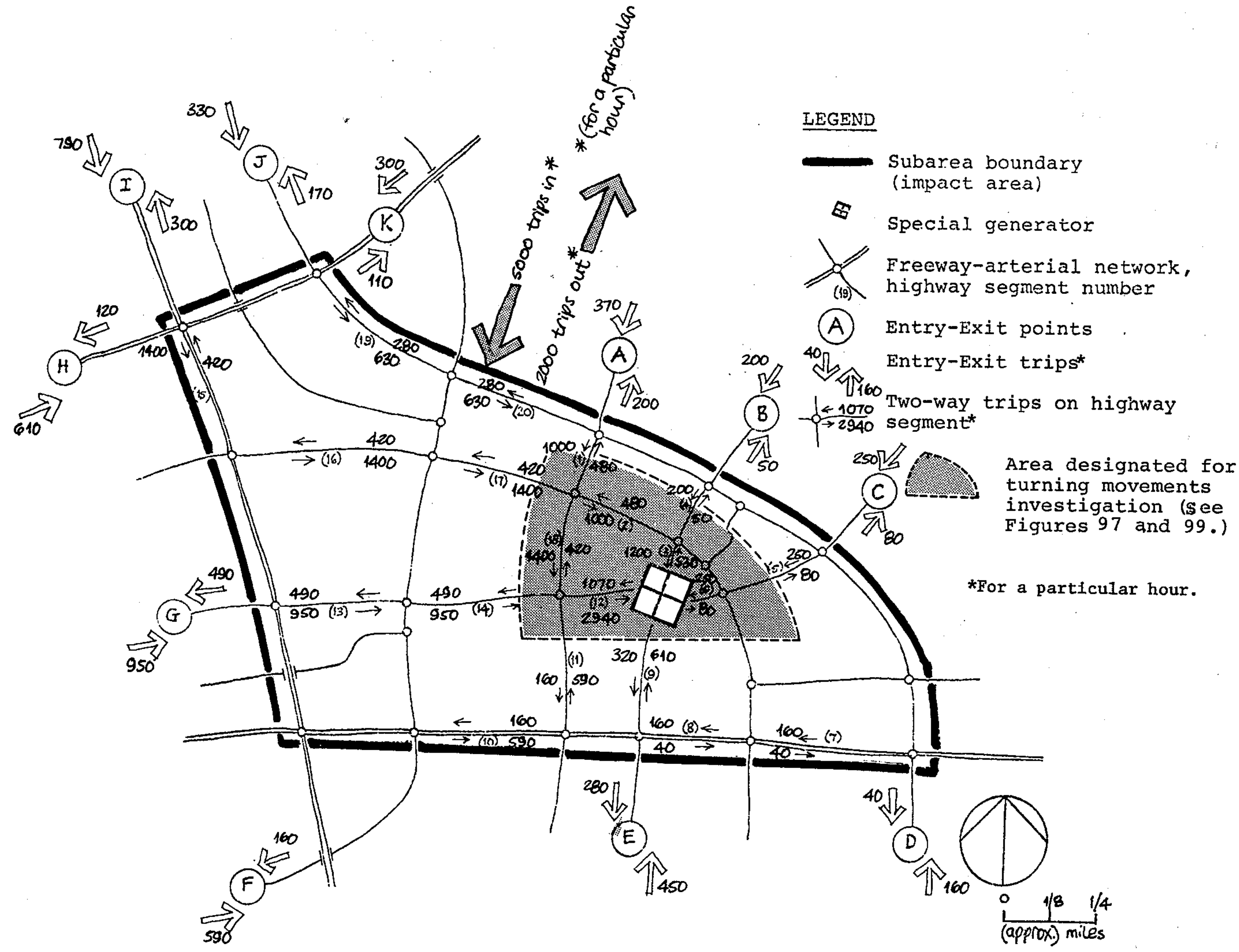


Figure 95. Subarea, showing total two-way (entry and exit) assigned trips.

for all segments crossing over into this area (for a particular hour).

Step 8: Number intersections and turning movements. All intersections within the designated area that are to be investigated are numbered using a scheme that differentiates these numbers from others. Hence, the four intersections have been numbered 101 through 104 (Fig. 97). Also numbered are all the possible turning movements for each intersection. Usually, for a four-legged intersection, these movements total up to 12. So, for intersection 101, the turning movements are numbered 1 through 12; for 102, 13 through 24, and so on. The turning movement numbers are also shown in Figure 97.

Step 9: Load-turning movements. Basically, loading is similar to the stringing process described previously, except this time, instead of assigning trips to highway segments, trips are now assigned to turning movements. Loading can be conveniently handled by using a tabular format as shown in Figure 98; the trips entering and exiting the designated area form the rows, whereas the turning movements form the columns. It is now a matter of filling in the appropriate cell.

For example, beginning with highway segment 1 (Fig. 97) and following the most reasonable path to the special generator (which was via highway segments 1, 2, and 3), it is obvious that traffic will proceed through turning movement numbers 12 and 19; thus, 1,000 trips are inserted in the respective cells in columns 12 and 19 of Figure 98. For trips exiting the designated area via highway segment 1, 480 trips will go through turning movement numbers 18 and 1, therefore, cells numbered 18 and 1 are marked with 480 trips, and so on until all entry and exit trips have been accounted for. Finally, all movements are summed up column by column to obtain the total turning movements for each intersection. (The example used here is small in size and only some of the turning movements have been "activated," and at that, only once. For a larger problem, each turning movement may be used several times by different trips.) Figure 99 shows the turning movement activities for the four intersections inside the designated area.

Because of the small size of the example problem just described, it would have been a simple matter to determine the turning movements without going through an elaborate table. For larger networks, however, the table provides a convenient bookkeeping method for the turning movements. The accumulation method thus provides a systematic means of quantifying turning movements; in addition, the method can also be used to determine highway segment volumes without going through the actual assignment process. Suppose the traffic volume on segment 18 attributed solely to the special generator had to be determined. Figure 97 shows that the northbound volume can be obtained by summing up turning movements 4, 5, and 6. From Figure 98, these movements correspond to 0, 0, and 420 trips respectively. Therefore, 420 trips flow northbound on highway segment 18. The southbound traffic is given by turning movements 46, 47, and 48; that is, 0, 0, and 1,400 trips respectively. Hence, the southbound flow on segment 18 is 1,400 trips.

The turning movement method is limited in application because of the large number of turns for every intersection (usually 12 per intersection). Hence, a large network with several intersections will render this method incapable of convenient handling.

Thus, by using the manual assignment methodologies described previously, the user can determine highway segment volumes (by using a graphical or tabular method) and turning movements at intersections (by employing the turning movement method). So long as the highway network in question is of reasonable size, manual trip assignment can be easily accomplished.

Distribution of Assigned Volumes Among Available Facilities

In any assignment of travel to a highway network, whether by manual methods or through the use of a computerized technique, the link-assigned volumes will require some redistribution between available facilities to more closely reflect actual operating conditions. Historically, transportation planning procedures have used screenlines and auxiliary cutlines to validate and analyze assignment results, and the redistribution technique described follows the same approach.

The technique described to reallocate travel between competing facilities after traffic assignment is based on screenline theory and was developed by R. H. Pratt Associates (*72*). This technique requires analysis of multiple overlapping cutlines of major screenlines within an analysis area. It may appear to the user that the procedure is difficult and time-consuming, but it will be found that an analysis area containing ten vertical and ten horizontal major screenlines can be processed and summarized in two person-days. Most analysis will not be as extensive.

	SEGMENT # / ENTRY POINT # AND TRIPS		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
TRIPS ENTERING GENERATOR	A	370	370	370	370																	
	B	200			200	200																
	C	250					250	250														
	D	160							160	160	160											
	E	450									450											
	F	590										590	590	590								
	G	950												950	950	950						
	H	610												610			610	610	610	610		
	I	790												790			790	790	790	790		
	J	330	330	330	330																330	330
	K	300	300	300	300																300	300
	ΣTrips in= 5000		1000	1000	1200	200	250	250	160	160	610	590	590	2940	950	950	1400	1400	1400	1400	630	630
TRIPS EXITING GENERATOR	A	200	200	200	200																	
	B	50			50	50																
	C	80					80	80														
	D	40							40	40	40											
	E	280									280											
	F	160										160	160	160								
	G	490												490	490	490						
	H	120												120			120	120	120	120		
	I	300												300			300	300	300	300		
	J	170	170	170	170																170	170
	K	110	110	110	110																110	110
	ΣTrips out= 2000		480	480	530	50	80	80	40	40	320	160	160	1070	490	490	420	420	420	420	280	280
	2-WAY SEGMENT VOLUMES		1480	1480	1730	250	330	330	200	200	930	750	750	4010	1440	1440	1820	1820	1820	1820	910	910

Figure 96. Results of tabular assignment of entry and exit trips to highway network.

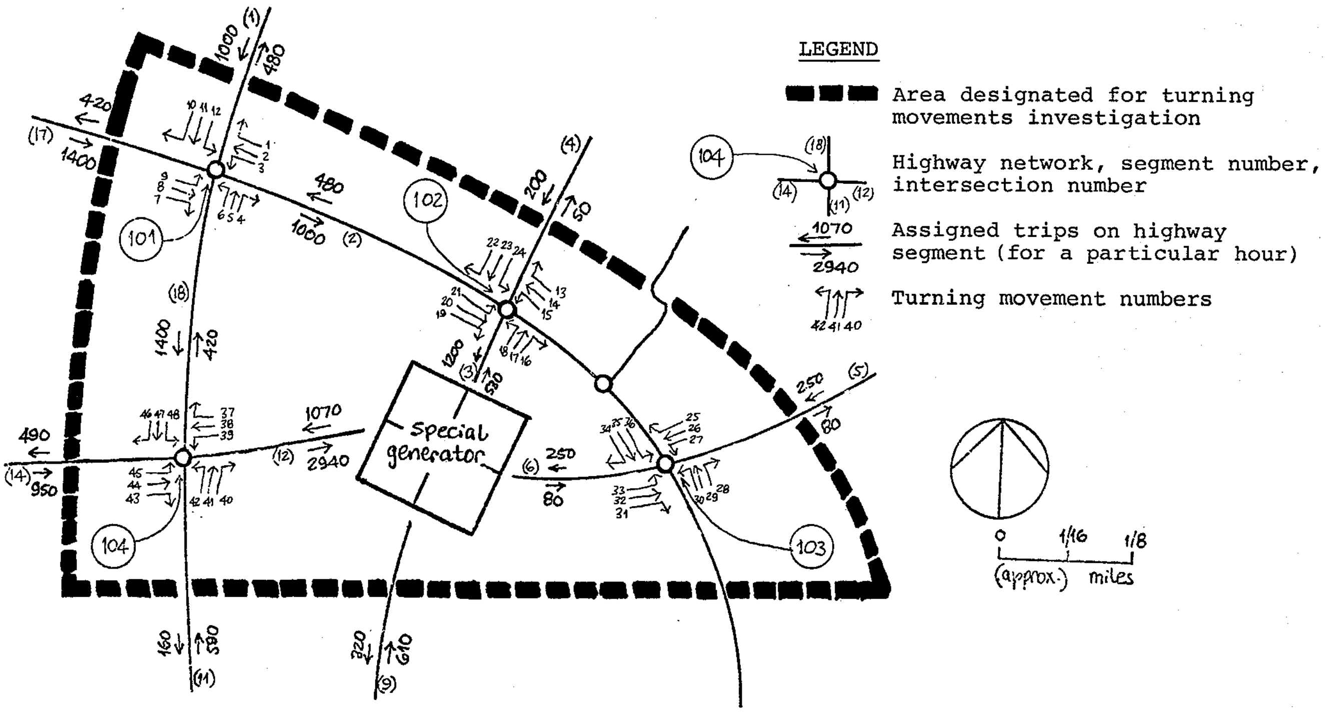


Figure 97. Turning movement investigation area, showing all possible turns.

TURNING MOVEMENTS

	ACCESS ROAD	TRIPS	NODE 101												NODE 102												NODE 103												NODE 104											
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
ENTERING	1	1000												1000							1000																													
ENTERING	4	200																							200																									
ENTERING	6	250																										250																						
ENTERING	9	610																																																
ENTERING	11	590																																								530								
ENTERING	14	950																																												950				
ENTERING	17	1400							1400																																									1400
EXITING	1	480	480																	480																														
EXITING	4	50																	50																															
EXITING	5	80																																80																
EXITING	9	320																																																
EXITING	11	160																																							160									
EXITING	14	490																																						490										
EXITING	17	420						420																															420											
								420	1400					1000					50	480	1000				200			250						80					420	490	160	530				950				1400

Figure 98. Tabular accumulation of turning movements.

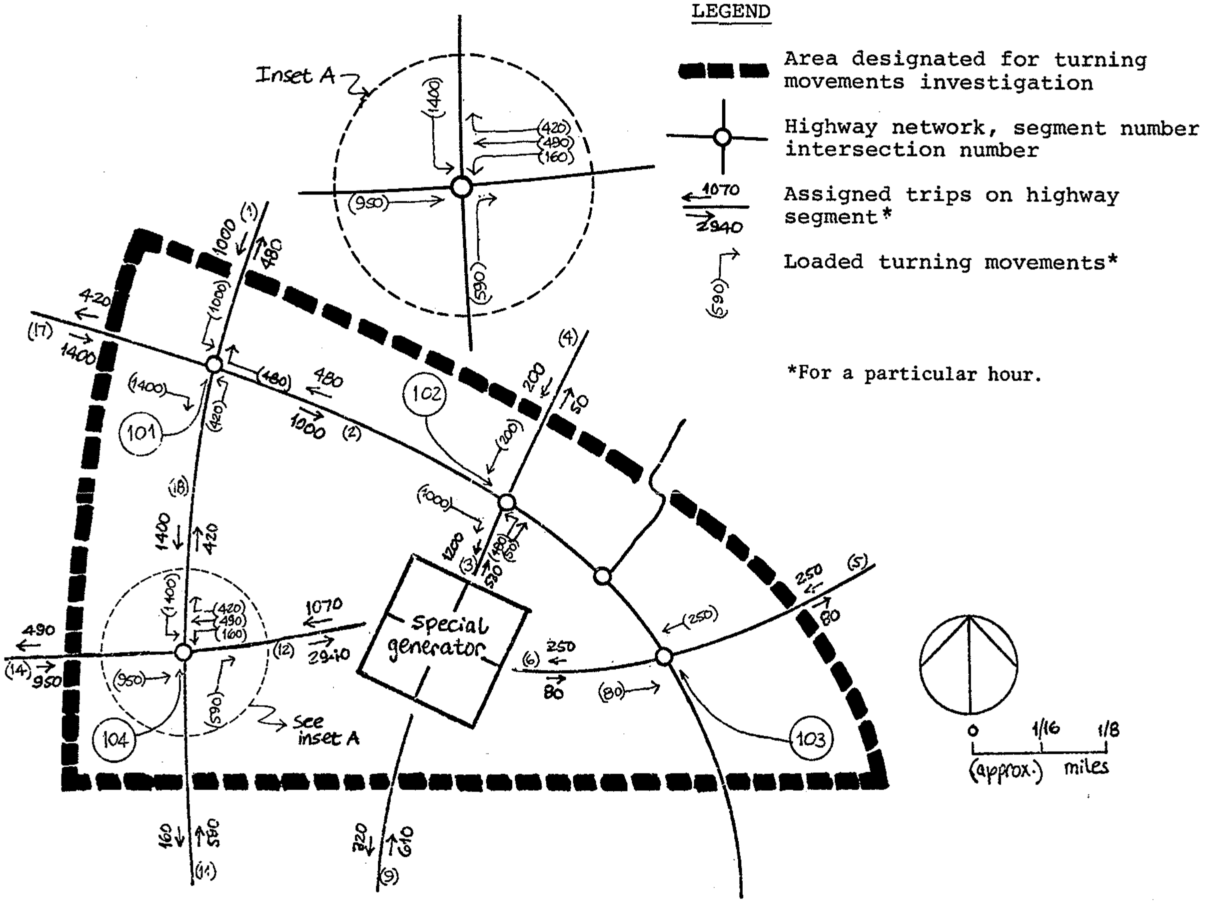


Figure 99. Turning movement investigation area, showing loaded turns.

The underlying assumption of the redistribution procedure is that forecast-year volumes on parallel facilities should tend to be distributed proportionally to the volumes as observed on the facilities in the base year. Further stated, if no capacity changes (widenings, new facilities, etc.) occur between the year observations are made and the forecast year, the forecast-year volumes on the links intercepted by the screenline are inclined to be proportional to the base-year volume. All capacity changes to the forecast-year system are interpreted as new facilities—including widenings to existing facilities.

Figure 100 shows graphically the beginning point for applying the volume-redistribution technique. It is assumed the user will employ these techniques after the appropriate vehicle trips have been assigned to the highway network via the all-or-nothing assignment procedure. The major screenlines to be used in balancing the trips between competing and available facilities are shown along with the facilities under study. The following points should be kept under consideration while constructing the analysis lines. Screenlines need only be defined across facilities within the *directional* analysis area. That is, if only north/south highways are under investigation, only screenlines A-A, B-B, C-C, and D-D would be required. Major screenlines should be constructed midway between major intersections or every 2 mi—whichever is less. Except in special cases, screenlines should cut a minimum of three facilities.

The manner in which each screenline is subdivided into cutlines is as follows. Starting at one end of the screenline, the first cutline should normally extend across at least three facilities (Fig. 101). The second cutline should do the same, and overlap the first cutline such that the overlap extends across approximately one-half of each individual cutline. Preferably, more than one facility should be intercepted within the overlap. The third cutline should be similarly laid out, and should start where the first cutline terminates. Additional cutlines as needed should be similarly established. Unless irregularities in the street system dictate otherwise, the cutlines in parallel screenlines should be opposite each other so as to intercept the same sets of highway facilities.

As an example, Figure 101 shows the subdivision of screenline A-A into three overlapping cutlines (i.e., p-p, q-q, and r-r) to be used in the redistribution of forecast-year assignment volumes. Screenline A-A will be analyzed using the hypothetical traffic data given in Table 46. Note that the forecast-year assignment volumes are supposed to have been obtained from all all-or-nothing assignment procedures (discussed earlier in this chapter). Note also, that link 50-51 is a proposed facility for the forecast year and is expected to add capacity across screenline A-A.

The work sheet used for redistribution of assigned volumes is given in Table 47. Link description, plus traffic data for columns a, c, and e are filled in Table 47 using the data given in Table 46. Such information is recorded for each of the three cutlines of screenline A-A shown in Figure 101. The cutlines are processed one at a time and the total assignment-adjustment volumes (col. h, Table 47) are input, when appropriate, into column e of the subsequent cutline analysis. The order in which the cutlines are processed is arbitrary, but such computations should proceed in an orderly fashion from one end of the screenline to the other (e.g., from left to right).

The calculations necessary for completing Table 47 are as follows:

1. Sum the base-year volumes; that is, traffic counts (col. a), and determine the percent volume contribution (col. b) for each link of cutline p-p. Note that because link 50-51 is a new facility, base-year traffic counts do not exist and therefore columns a and b are left blank.
2. Because link 50-51 contributes additional capacity in the forecast year, columns c and d are filled in a manner similar to step 1.
3. Column e is now completed using the forecast-year assignment volumes in Table 46 (from the all-or-nothing assignment).
4. As a capacity change is expected to occur across cutline p-p, column f is completed for link 50-51. Thus, the *capacity-assignment adjustment* for link 50-51 is 23.1% × 12,200 = 2,818 (i.e., this volume of traffic can be expected for the new facility). The remaining forecast-year assignment volume in column f (i.e., 12,200 − 2,818 = 9,382) is distributed to the other links of cutline p-p.
5. Hence the *volume-assignment adjustments* (col. g) for links 1-15 and 2-13 can be computed in the proportion given in column b. Hence, for the former link, this adjustment is 27.0% × 9,382 = 2,533 (i.e., this volume of traffic can be expected for link 1-15).
6. Finally, the *total-assignment adjustment* for each link crossing cutline p-p is computed by adding the volumes in columns f and g. Note that the totals for column e and h are the same for cutline p-p; only the traffic within the cutline has been redistributed among the three links.

The six steps are repeated for cutlines q-q and r-r. For q-q, the volumes for links 50-51 and 2-13 in column e are the assignment adjustments from column h of the previous calculations for cutline p-p. A similar transformation is made for r-r, (the volumes for links 2-13 and 4-8 in column e are adjustments from column h for cutline q-q). For r-r, however, no new facilities cross the cutline. Therefore, the computations in columns c, d, and f are not necessary. The adjustments in column g are now derived by proportioning the sum of traffic in column e using the percentages in column b. Thus, for link 4-8, the proportioned traffic equals 24.6% × 14,278 = 3,512. The asterisks in column h of Table 47 indicate the final balanced volumes resulting from the redistribution technique. To refine these volumes, screenline A-A could be reprocessed

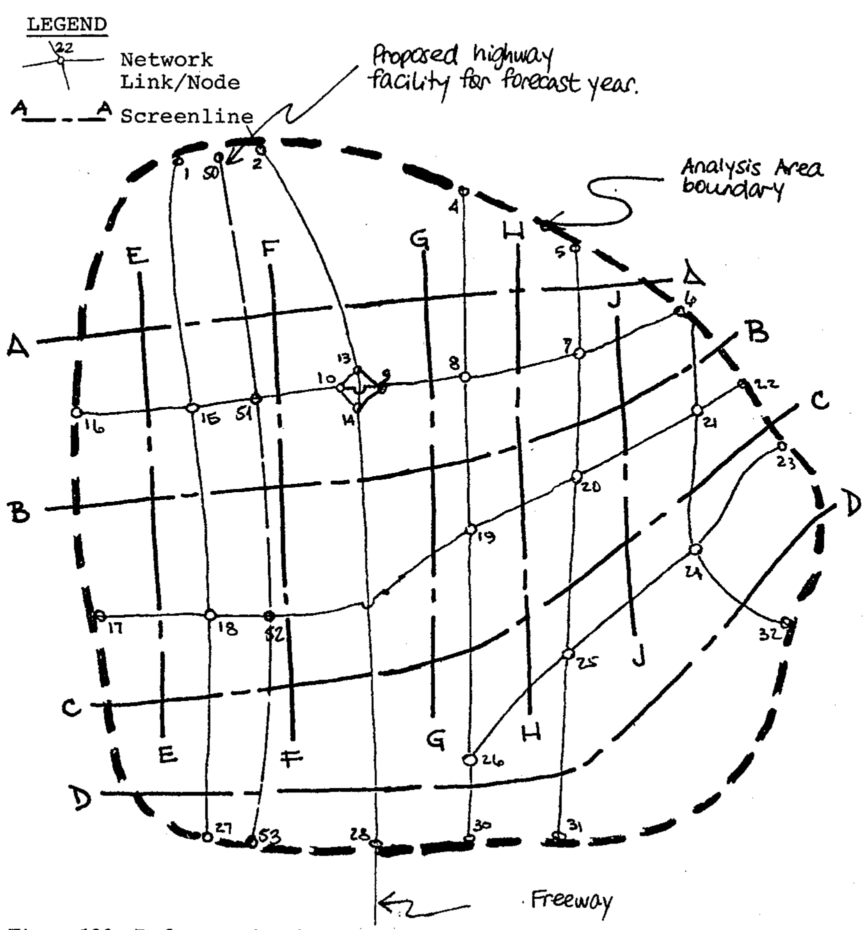


Figure 100. Definition of major screenlines.

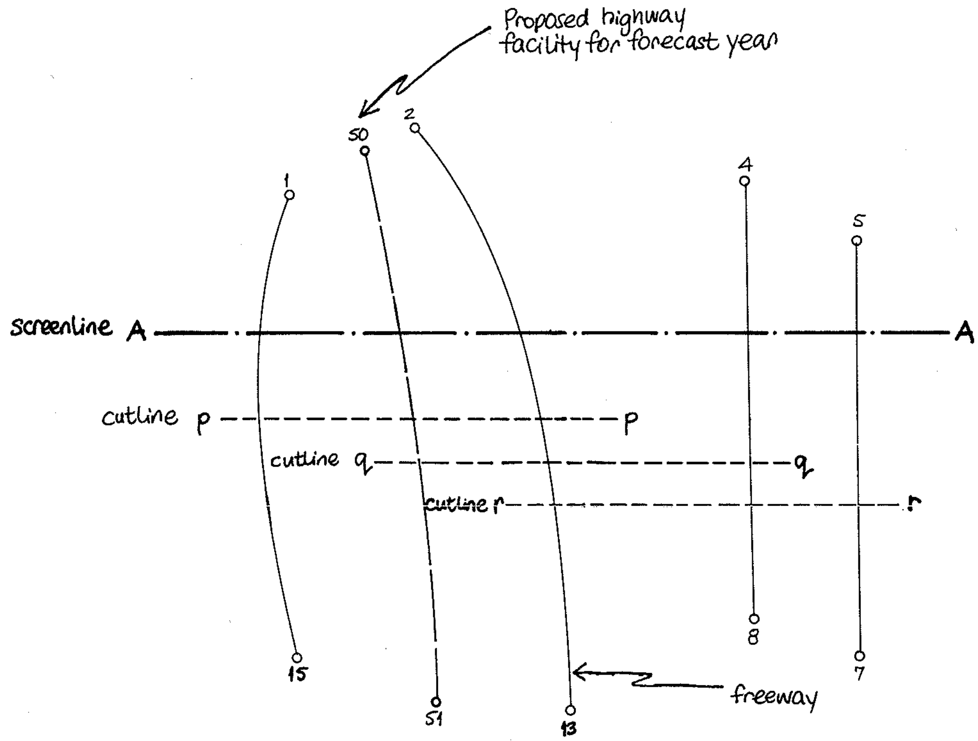


Figure 101. Cutlines of screenline A – A *for redistribution analysis.*

through the six steps outlined previously. This second iteration might result in a small gain in accuracy of the balanced volumes; iterations beyond the second one are not recommended.

Figure 102 shows the capacity, the base-year volumes, the forecast-year assignment volumes, and the balanced volumes for links crossing screenline A-A. The user can observe the effect of the redistribution of volumes among the facilities.

The user is cautioned that this technique *does not* keep track of turning movement volumes and does, in fact, negate the turning movement volumes from the all-or-nothing assignment procedure. Reestablishing a table of turning movements is possible, but the redistribution procedure requires many iterations to reach "convergence" and is not practical as a manual tool. If the user is interested in analyzing turning movements, the trips from the original assignment application should be used.

TRAFFIC GENERATION/TRAFFIC DECAY AND STREET REQUIREMENTS

Two applications are described for determining traffic volumes and estimating arterial street requirements associated with local development patterns and densities. Basically, the approaches have been derived from material contained in the Gruen guidelines (*1*). These guidelines are tailored especially for developing suburban portions of metropolitan regions where growth potentials offer a broad range of planning opportunities. The choice of the appropriate application depends on whether the traffic impacts and street requirements are to be determined within the boundaries of the development (subarea/project) or whether the impacts of a special generator are to be investigated on the street system surrounding the generator. The two applications are described subsequently in turn.

Traffic Effects Within a Subarea/Project

Two steps are involved in this application. The first step, labeled Step A, involves estimation of the base traffic generated by residential and nonresidential land-use inside the development and by land use in the subregion surrounding that development. Figure 103 provides a means for obtaining the average daily volumes (and the required lanes and spacings) as a function of the residential density of the subregion. This base volume is then adjusted by multiplicatively applying appropriate adjustment factors which account for certain land-use and transportation-related characteristics unique to the subregion and project under study. The adjustments are based on the following suburban characteristics: residential density; level of traffic service; level of transit utilization; car ownership and household income; nonresidential/residential activity mix; and proximity of freeways.

Figures 104 through 109 provide the necessary adjustment factors (F_2 through F_6). The final, adjusted base volume enables estimation of the base street requirements. (Note that if base traffic conditions are available from recent traffic-assignment results or from traffic counts, then it is advisable to use such results and bypass altogether estimation of volumes from Figs. 103 through 109.)

The second basic step, labeled Step B, involves determination of additional traffic generated by any special generators superimposed inside the development subarea. Trips related to these generators are estimated using the appropriate trip rates given in Table 1 of Chapter Two, "Trip-Generation Estimation." Then, by accounting for the geographic orientation of the trips and trip attenuation using the methodology described in Chapter Three, "Trip Distribution," or by using Figure 110, the additional street requirements can be determined.

Selection of either the trip-orientation method or Figure 110 depends, as before, on whether street requirements are to be estimated for areas *outside* the boundaries of the project/subarea (in which case the procedures in Chapter Three are pertinent) or whether estimation is for the area *inside* the project/subarea (in which case, Fig. 110 is applicable). Details on the basis of selection are addressed later.

The final step, labeled Step C, is to add the base street volumes resulting from the subregion residential development to the additional street volumes resulting from the special generators to obtain the total street volumes and the associated total street requirements for the study area.

It must be noted that Figure 103 is used for analysis of land-use patterns distributed over a subregional area, considered jointly with the over-all development pattern of uniform density in the surrounding region. The minimum development size that can be considered as subregional

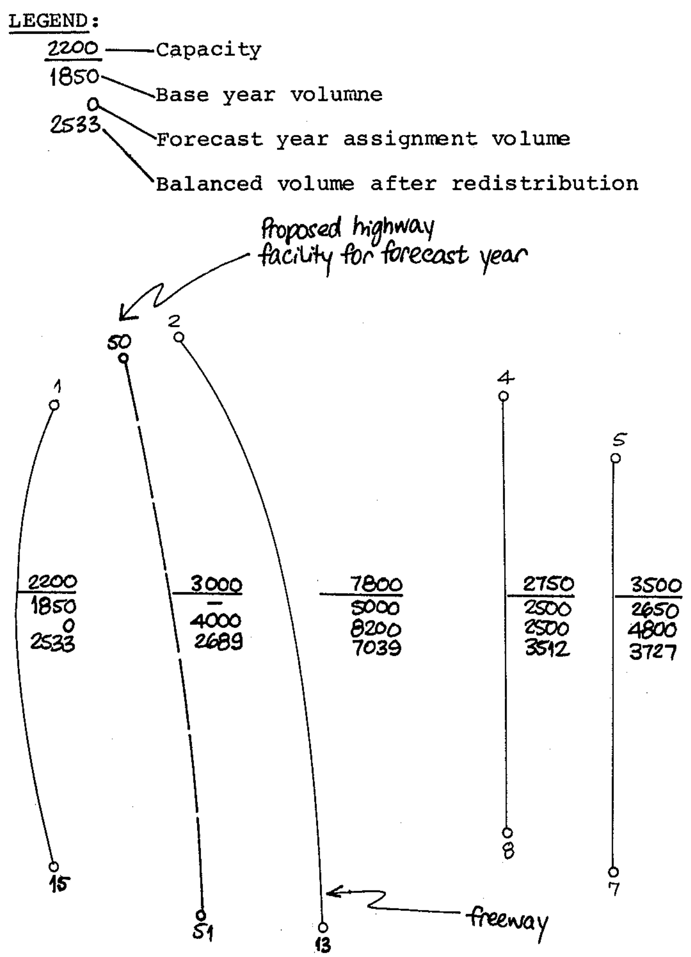


Figure 102. Comparison of capacity and base year, forecast year, and balanced volumes for highway links crossing screenline A – A.

TABLE 46

TRAFFIC DATA FOR HIGHWAY LINKS CROSSING SCREENLINE A–A [a]

LINK DESCRIPTOR A-NODE	LINK DESCRIPTOR B-NODE	BASE YEAR TRAFFIC COUNT	CAPACITY	FORECAST YEAR ASSIGNMENT VOLUME
1	15	1,850	2,200	0
50[b]	51[b]	-	3,000[b]	4,000[b]
2	13	5,000	7,800	8,200
4	8	2,500	2,750	2,500
5	7	2,650	3,500	4,800
TOTAL		12,000	19,250	19,500

a. All traffic data is 2-directional and measured in vehicles per hour (vph).

b. Link 50-51 is a new link contributing additional capacity to the screenline capacity for the forecast year.

development is determined primarily by major street system spacing; if an area is so small that it "falls through" the spaces within the major street system and cannot be integrated with the surrounding development pattern, then it is better analyzed as a major generator. However, even a small project should be analyzed by the subregional development method if the project, together with its surrounding development, can be considered as a uniform land-use pattern extending over a substantial area.

Because the primary direction of flow normally establishes the size of the major street system in both directions, Figure 103 reflects volume per mile and street requirements in the direction of maximum flow, or primary direction. Therefore, Figure 103 should be used for estimating primary direction requirements. If predictions of traffic in the secondary direction are to be developed, the degree of directional imbalance and reduction factor should be estimated from local traffic patterns in the immediate area.

To illustrate the general approach described previously, consider the following scenario. A small, new town is being planned within a developed subregion of a major metropolitan region. As part of the planning effort for this new community, an estimate of the street requirements *inside* its boundaries is needed. The general characteristics of this new land use are shown in Figure 111. The following land-use and transportation-related information is available for the community.

1. Size of project or subarea, 3 × 3 = 9 sq mi.
2. Anticipated population, 54,900 resulting in a subarea density of 6,100 residents per sq mi. Anticipated population density of surrounding subregion, 4,000 residents per sq mi.

TABLE 47

WORK SHEET FOR BALANCING FORECAST YEAR ASSIGNMENT VOLUMES [a]

SCREENLINE: A-A

CUT-LINE #	LINK DISCRIPTOR A NODE	LINK DISCRIPTOR B NODE	BASE YEAR VOLUME (a)	% BASE YEAR VOL. ON CUTLINE (b)	CAPACITY (c)	% OF TOTAL CAP. ON CUTLINE (d)	FORECAST YEAR ASSIGNMENT VOLUME (e)	CAPACITY ASSIGNMENT ADJUSTMENT (f)	VOLUME ASSIGNMENT ADJUSTMENT (g) = (b) x ∑(e)	TOTAL ASSIGNMENT ADJUSTMENT (h) = (f) + (g)
P-P	1	15	1850	27.0	2200	16.9	0	–	2533	2533 [b]
	50	51	–	–	3000	23.1	4000	2818	–	2818
	2	13	5000	73.0	7800	60.0	8200	–	6849	6849
∑			6850	100.0	13000	100.0	12200 –	2818 =	9382	12200
Q-Q	50	51	–	–	3000	22.1	2818	2689	–	2689 [b]
	2	13	5000	66.7	7800	57.6	6849	–	6322	6322
	4	8	2500	33.3	2750	20.3	2500	–	3156	3156
∑			7500	100.0	13550	100.0	12167 –	2689 =	9478	12167
N-N	2	13	5000	49.3	no new facilities proposed across this cutline, ∴ calculations not necessary for these columns.		6322	see note in columns c+d.	7039	7039 [b]
	4	8	2500	24.6			3156		3512	3512 [b]
	5	7	2650	26.1			4800		3727	3727 [b]
∑			10150	100.0			14278		14278	14278

a. All traffic data is 2-directional and measured in vehicles per hour (vph).
b. Final, balanced volumes as a result of traffic redistribution.

3. Level of service desired on street network, "C"; i.e., high volume, stable flow through the network.

4. Anticipated percent transit utilization in subarea during peak period, 10 percent.

5. Level of auto ownership for the project subarea, 1.7 autos per dwelling unit.

6. Number of jobs available inside subarea, 15,000 jobs. Resident labor force inside subarea, 30,000 residents.

7. Freeway location as shown in Figure 111, 2 mi from nearest boundary of the subarea and 5 mi from the farthest boundary.

8. Four special generators located in the center of each mile-wide corridor as shown in Figure 111. The generators possess the following characteristics:

(a) Industrial park (warehouse, research) has 2,700 employees (exclusive of the 15,000 jobs in item 6).

(b) Office center (governmental) has 600 employees (exclusive of the 15,000 jobs in item 6).

(c) Shopping center (regional) has a ground floor area of 580,000 sq ft.

(d) Hospital (general) has 300 beds.

Given all this information, the street system requirements methodology proceeds in the following manner:

Step A: Determine base traffic of subregion. This step includes several substeps as follows:

Step A1: Unadjusted traffic volumes produced by surrounding subregion (Fig. 103).

Given: Population density of surrounding subregion = 4,000

Therefore unadjusted two-way base volume = 17,000 vehicles per mile of corridor in the cardinal direction of maximum flow.

This volume is now to be adjusted for unique land-use and transportation conditions of the new community and the surrounding subregion.

Step A2: Adjustment factor, F_2, for density and project size (Fig. 104).

Given: Project size = 3 × 3 = 9 sq mi

Subregion density to project density ratio = 4,000 : 6,100; i.e., 1 : 1.5

Therefore adjustment factor $F_2 = 1.27$

Step A3: Adjustment factor, F_3, for level of traffic service (Fig. 105).

Given: Level of Service = C

Therefore adjustment factor $F_3 = 1.00$

Step A4: Adjustment factor, F_4, for transit utilization (Fig. 106).

Given: Peak-period transit use = 10 percent

Therefore adjustment factor $F_4 = 0.97$

Step A5: Adjustment factor, F_5, for auto ownership and income (Fig. 107).

Given: Auto ownership = 1.7 autos per dwelling unit

Therefore adjustment factor $F_5 = 1.32$

Step A6: Adjustment factor, F_6, for project non-residential activity mix (Fig. 108).

Given: Number of jobs available and resident labor force inside subarea is 15,000 jobs and 30,000 residents (not counting special generators).

Therefore nonresidential-to-residential activity ratio = 15,000 : 30,000; i.e., 1 : 2 = 0.5

Therefore adjustment factor $F_6 = 0.93$

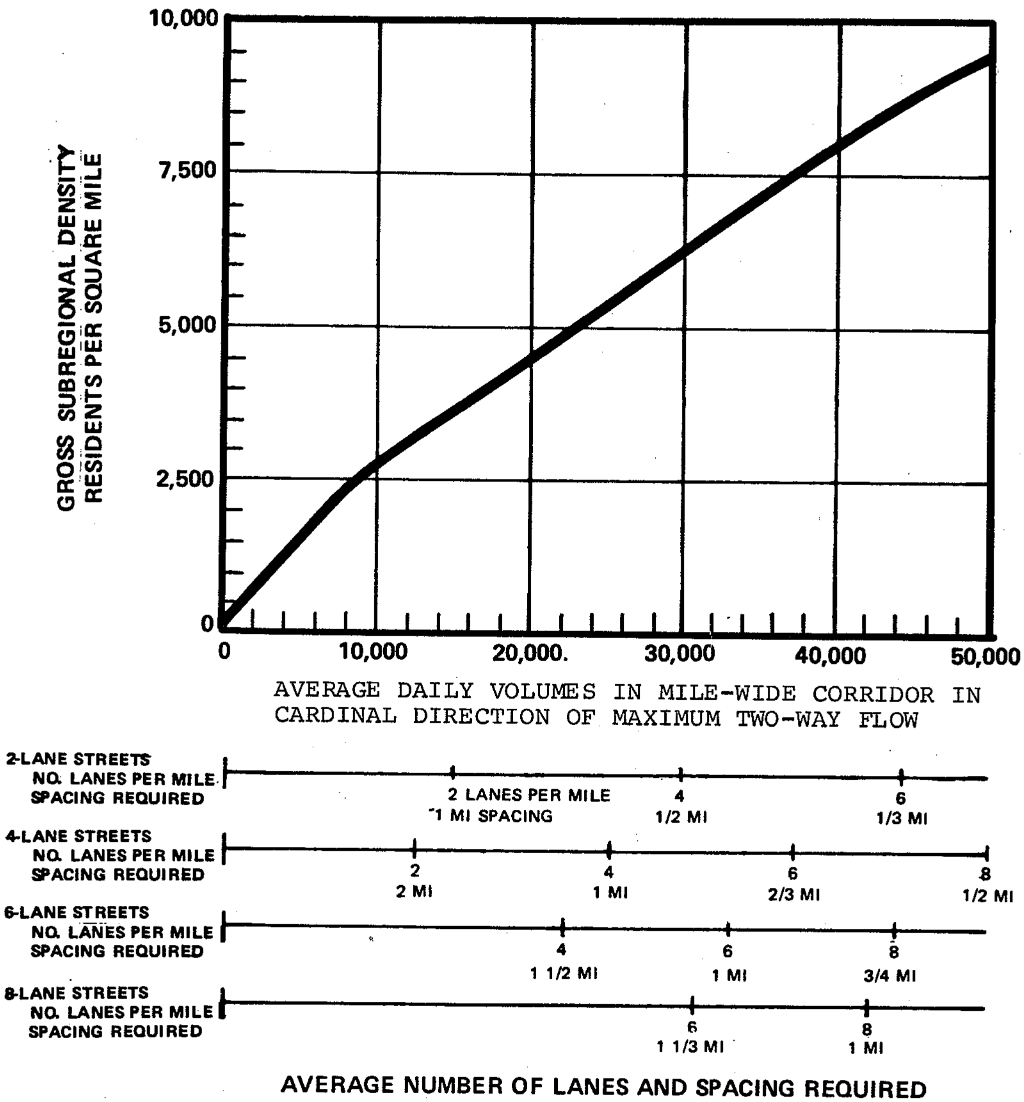
Step A7: Adjustment factor, F_7, for freeway diversion (Fig. 109).

Given: Freeway located 2 mi from nearest boundary of the project subarea and 5 mi from the farthest boundary.

For parallel streets (N-S), adjustment factor at 2 mi = 0.90 and at 5 mi = 1.00

Therefore adjustment factor F_7 (N-S) $= \frac{0.90 + 1.00}{2} = 0.95$

For perpendicular streets (E-W), adjustment factor at 2 mi = 1.05 and at 5 mi = 1.00



NOTES
ASSUMES:
UNIFORM DENSITY PATTERN OF RESIDENTIAL AND NON-RESIDENTIAL DEVELOPMENT
SOME DELAYS AT PEAK PERIOD (LEVEL OF SERVICE "C") AND KD FACTOR OF 5.2%
TRANSIT USE: 3.5% OF ALL PERSON TRIPS OR 7.0% OF PEAK HOUR TRIPS
AUTO OWNERSHIP: 1.3 AUTOS DWELLING UNIT
MEDIAN HOUSEHOLD INCOME $7,000
UNIFORM GRID PATTERN OF STREETS (NO FREEWAYS)
DIRECTIONAL BALANCE OF TRAVEL WITHIN LARGE URBAN REGION.

Figure 103. Chart for subregional density vs average volumes and lane requirements for arterials (1).

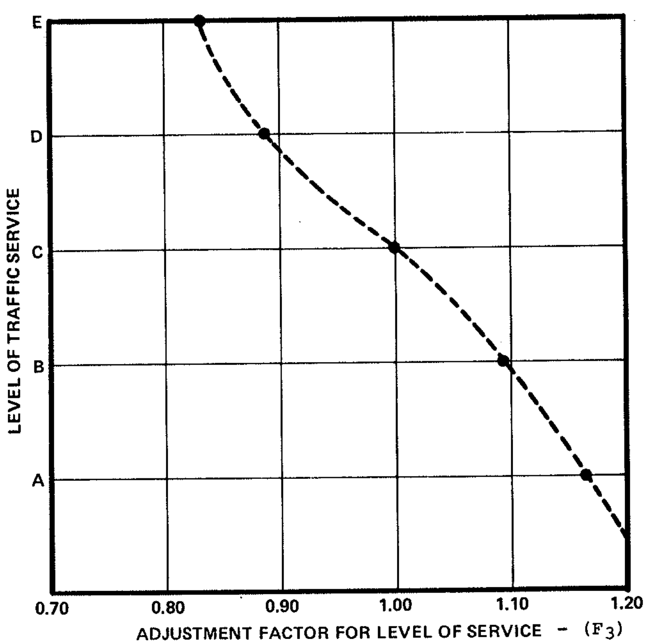
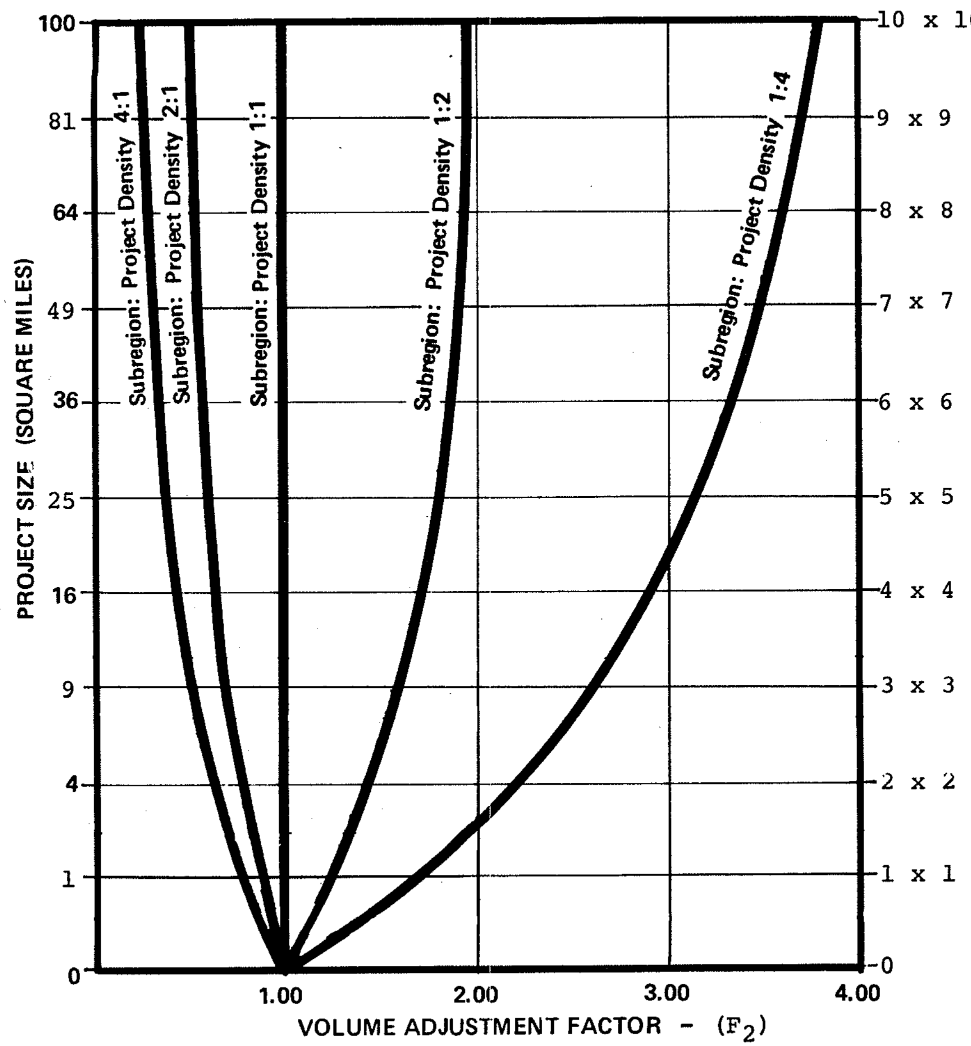


Figure 105. Chart for adjustment factor, F_3*, for level of traffic service* (1).



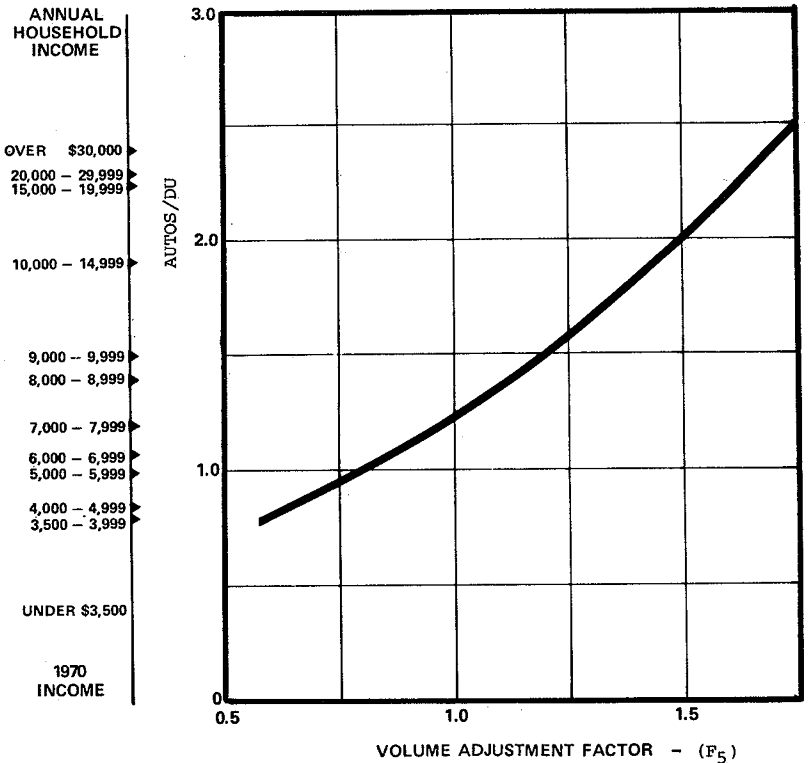
NOTES:

Assumes project of variable size and density located within subregion of variable density containing residential and non-residential development.

Assumes uniform grid pattern of streets (no freeways).

Assumes directional balance of travel in large urban area.

Figure 104. Chart for adjustment factor, F_2*, for density and project size* (1).



NOTES:

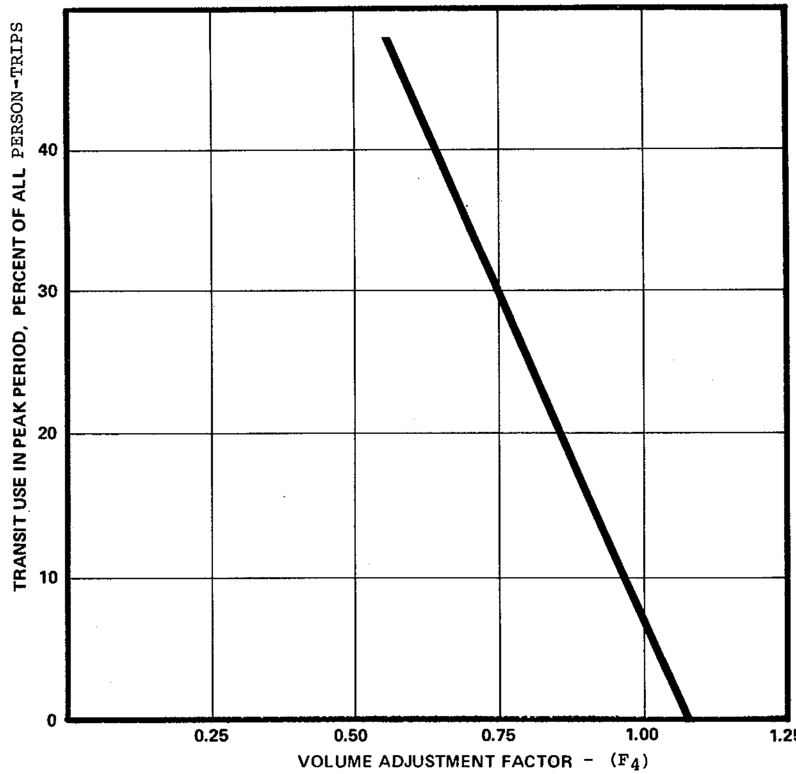
Use autos/DU as the primary parameter for volume adjustments.

Use income scale for approximation only if autos/DU data not available.

Income scale is non-linear.

See Figure 106 note concerning combined use of Figures 106 and 107.

Figure 107. Chart for adjustment factor, F_5, *for auto ownership and household income* (1).



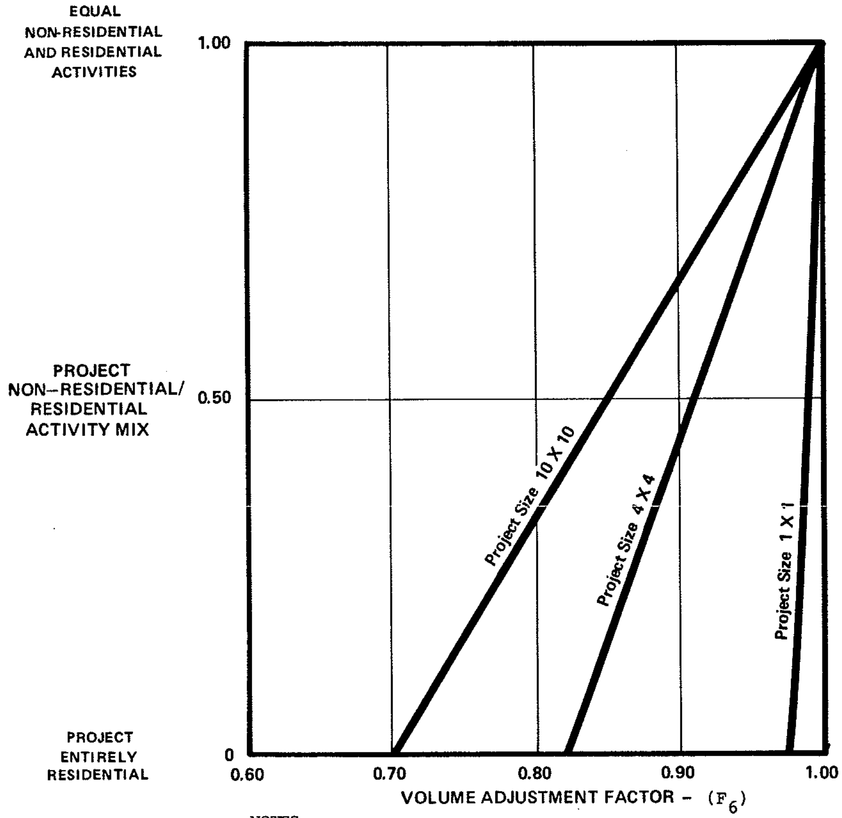
NOTES:

Assumes peak-period transit use of 7% for base condition.

Peak-period transit use of 7% is equivalent to 3.5% of all daily person-trips.

If any adjustment factor of under 0.85 is obtained from above, do not apply an adjustment factor from Figure 107 unless factors are determined to be independent.

Figure 106. Chart for adjustment factor, F_4, *for transit utilization* (1).



NOTES:

Assumes uniform density pattern of residential development and project containing residential plus nonresidential development.

Assumes uniform grid pattern of streets (no freeways).

Assumes directional balance of travel in large urban region.

Project nonresidential/residential activity mix is defined as the number of jobs provided within project, divided by labor force within project.

For predominantly nonresidential projects (i.e., activity mix greater than 1), use of trip generation tables in Chapter 2 are recommended instead of Figure 108.

Figure 108. Chart for adjustment factor, F_6, *for project nonresidential/residential activity mix* (1).

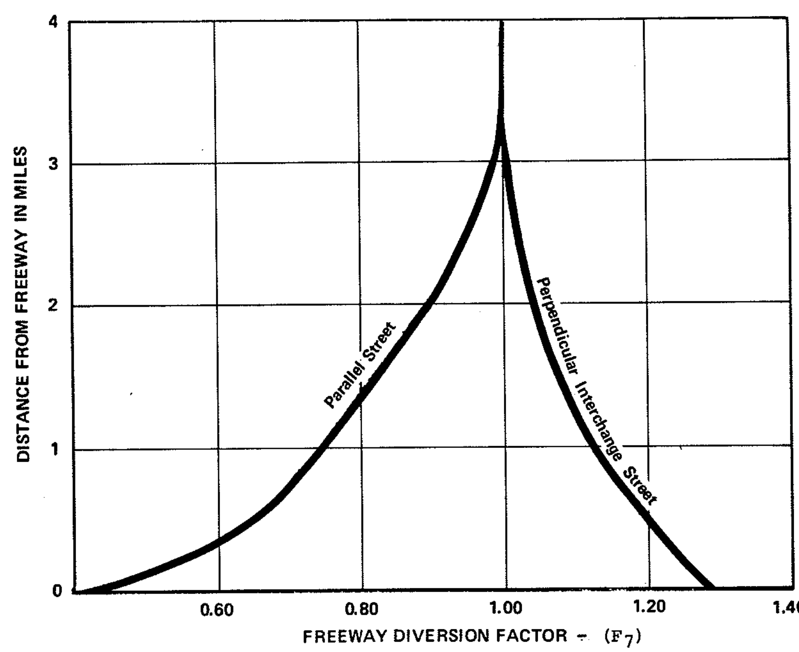


Figure 109. Chart for adjustment factor, F_7, *for freeway diversion* (1).

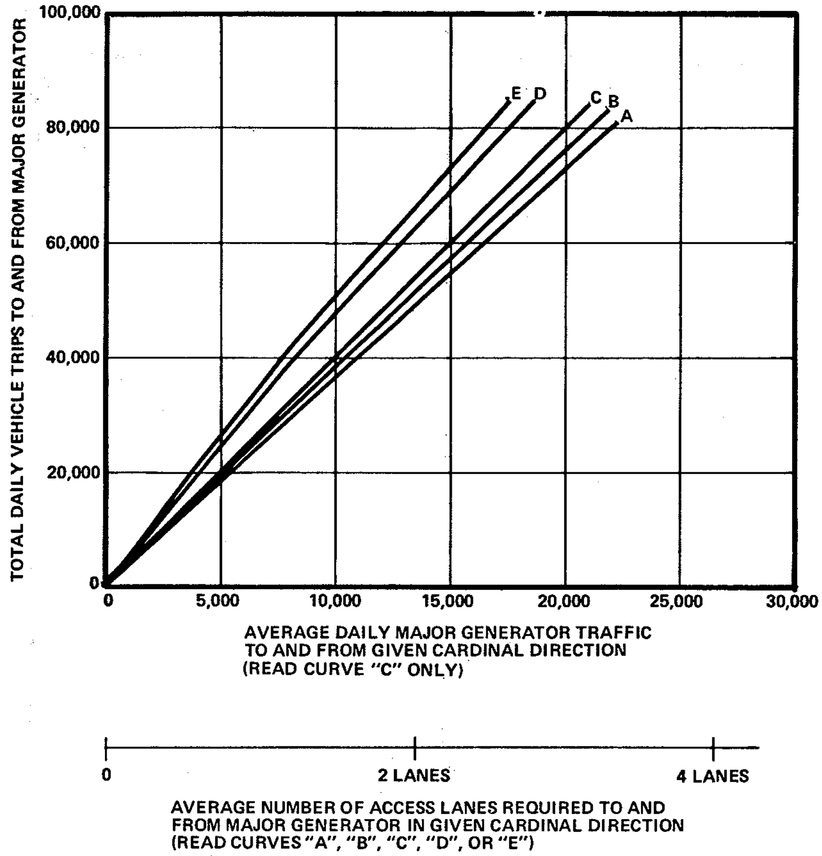


Figure 110. Major generator average daily volumes and lane requirements for arterials (1).

Therefore adjustment factor F_7 (E-W) $= \dfrac{1.05 + 1.00}{2}$

$= 1.03$

Step A8: Composite adjustment factor, F_8.

For (N-S) movement,

F_8 (N-S) $= F_2 \times F_3 \times F_4 \times F_5 \times F_6 \times F_7$ (N-S)
$= 1.27 \times 1.00 \times 0.97 \times 1.32 \times 0.93 \times 0.95$
$= 1.44$

For (E-W) movement,

F_8 (E-W) $= F_2 \times F_3 \times F_4 \times F_5 \times F_6 \times F_7$ (E-W)
$= 1.27 \times 1.00 \times 0.97 \times 1.32 \times 0.93 \times 1.03$
$= 1.56$

Step A9: Adjusted base volumes due to surrounding subregion development.

For (N-S) movement,

Adjusted base volume (N-S) in the direction of major two-way traffic flow $= 17{,}000 \times 1.44 = 24{,}500$ vehicles per mile wide corridor

For (E-W) movement,

Adjusted base volume (E-W) in the direction of major two-way traffic flow $= 17{,}000 \times 1.56 = 26{,}500$ vehicles per mile wide corridor

Step B: Determine additional traffic produced by special generators. This step includes the following substeps:

Step B1: Traffic volumes to and from special generators. Using the vehicle trip rates provided in Table 1, Chapter Two, "Trip-Generation Estimation," daily vehicle trips to and from each of the special generators shown in Figure 111 are calculated as follows:

Given: Industrial park (warehouse), 2,700 employees
Trip rate = 4.4 per employee

Therefore total daily trips $= 2{,}700 \times 4.4 = 11{,}900$

Given: Office center (governmental), 600 employees
Trip rate = 12 per employee

Therefore daily trips $= 600 \times 12 = 7{,}200$

Given: Shopping center (regional), 580,000 sq ft gross floor area (GFA)
Trip rate = 34.7 per 1,000 sq ft GFA

Therefore total daily trips $= 580{,}000 \times \dfrac{34.7}{1{,}000} = 20{,}100$

Given: Hospital (general), 300 beds
Trip rate = 14 per bed

Therefore total daily trips $= 300 \times 14 = 4{,}200$

Therefore, total daily traffic generated by the special generators inside the new community is:

$11{,}900 + 7{,}200 + 20{,}100 + 4{,}200 = 43{,}400$ trips (total to and from)

Step B2: Traffic volumes by direction. In accordance with the problem definition, street requirements are to be estimated *inside* the new community. Therefore, Figure 110 is used to determine traffic volumes by direction of flow.

Entering Figure 110 at 43,400 total trips, the average daily traffic at level-of-service "C" is 10,800 trips in the direction of major two-way flow for both the N-S and E-W directions. Because each of these cardinal directions contains three 1-mile-wide corridors (see Fig. 111), the traffic will be given by $10{,}800 \div 3 = 3{,}600$ vehicles per mile-wide corridor in each direction.

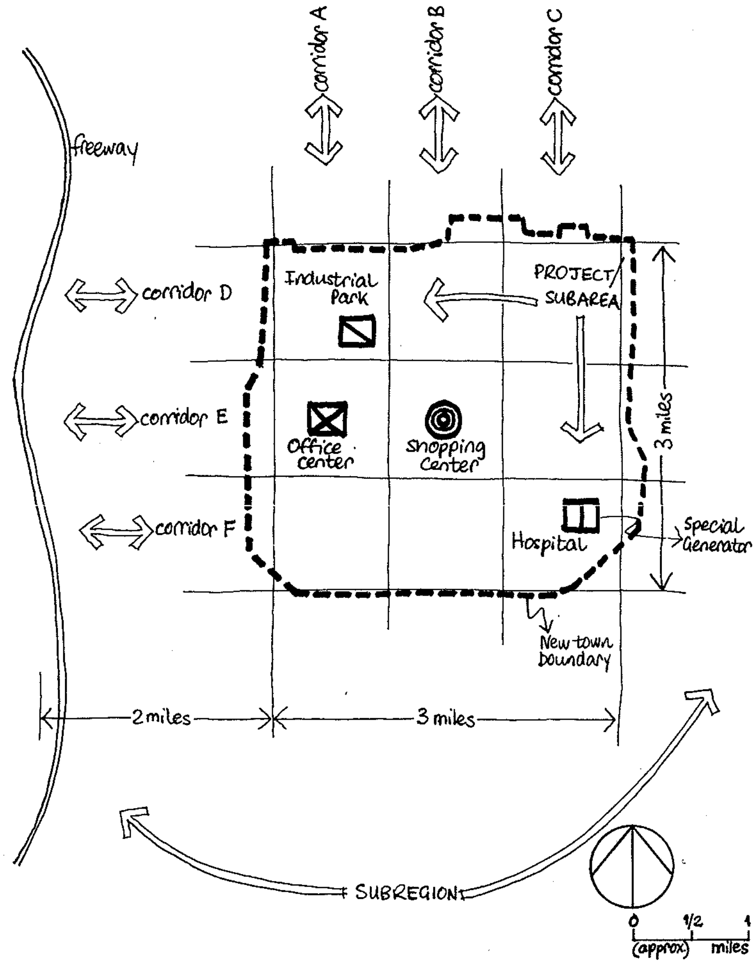


Figure 111. Land-use characteristics of new town.

Step C: Determine total traffic and total street requirements. This step involves summation of the adjusted base traffic volumes produced by surrounding subregion development and additional traffic produced by special generators. Thus:

Step C1: Total traffic.

For (N-S) movement,

Total volume in the direction of major two-way flow $= 24{,}500 + 3{,}600 = 28{,}100$ vehicles per mile-wide corridor

For (E-W) movement,

Total volume in the direction of major two-way flow $= 26{,}500 + 3{,}600 = 30{,}100$ vehicles per mile-wide corridor

Step C2: Total street requirements. Figure 103 is used here to estimate street requirements. Hence, for (N-S) movement for a total volume of 28,100 vehicles per mile-wide corridor, average number of lanes and spacing required—for 2-lane streets: 4 lanes per mile-wide corridor and a ½-mile street spacing.

For (E-W) movement for a total volume of 30,100 vehicles per mile-wide corridor; average number of lanes and spacing required—for 4-lane streets: 5 lanes per mile-wide corridor and a ⅘-mile street spacing.

The choice among 2-, 4-, 6-, and 8-lane streets is left to the planner's discretion and, therefore, alternate lane requirement and spacing estimates could very well be equally appropriate.

The problem, as presented in the new town scenario, is now considered adequately solved.

Traffic Effects of a Development on the Surrounding Areas

Until now, discussion has centered around the estimation of traffic impacts and associated street requirements *inside* the project/subarea development. Generally, a development is small in area compared to the region in which it is located. It is, therefore, reasonable to assume (as has been the case in the previous discussion) that street usage will be fairly uniform *within* the development boundaries; as such, the geographic orientation of traffic flow and its attenuation (decay) has not been given explicit treatment. However, for determination of traffic impacts *outside* a development; that is, on areas surrounding the development land use, the geographic orientation and attenuation of trips emanating from the land use must be considered. The underlying rationale here is: the orientation of trips; the quantity of trips; and trip length to and from a land use are dependent on the size and location of the attractive forces around that land use. Only after trip orientation and attenuation have been determined, can street requirements be estimated for the surrounding areas. The method suggested for obtaining orientation is identical to that documented in Chapter Three, "Trip Distribution," and is applied subsequently.

It is important to note, however, that if the project covers a land area greater than 1 sq mi, then intra-area trips must be accounted for before determining the traffic impacts on the surrounding subregion. If the development is less than 1 sq mi, then intra-area trips can be neglected for purposes of quick estimates.

Consider the shopping center inside the new town described previously. Suppose that this new town is located in the northeastern quadrant of the study subregion as shown in Figure 112. It is desired that street requirements in terms of number of lanes and spacing be estimated in the south-south-western (SSW) sector of the subregion. For illustration purposes, the street requirements are to be attributed exclusively to traffic generated by the shopping center in the new town. (Note that in the final analysis of total traffic impacts, these requirements and impacts should be superimposed on those already existent in the south-western sector of the subregion, in addition to the street requirements attributed to the residences and other special generators within the new town.)

The methodology is applied as follows. Notice that in the following application, the productions and attractions have been interchanged; that is, the shopping center is conceptually considered the producer of trips and the residences in the subregion are considered the attractors of these trips.

Step 1: "Production" trip ends due to the shopping center. Trips "produced" daily by the shopping center (at 34.7 trips per 1,000 sq ft for the 580,000 sq ft GFA shopping center) = 20,100 trips (see Step B1).

Step 2: Accumulate "attraction" trip ends by sectors by travel time bands. The 5-min travel time bands for trips originating from the shopping center of the new town to all other areas in the subregion are delineated as shown in Figure 112. Simple approximation and judgment is sufficient in locating these bands and no elaborate methods are necessary. "Attraction" vehicle trip ends are then computed for residences in the time bands within sectors (using techniques described in Chapter Two). Thus, for example, there are 1,000 attraction trip ends in the 5-min band of SSW sector, 1,300 trip ends in the 10-min band, and the like. (In this example, eight sectors and four 5-min time bands are used: the user can, of course, subdivide the study subregion into more sectors and can delineate finer time bands if more accuracy is desired.)

Step 3: Compute accessibility indices by sectors by travel time bands. The accessibility index for any sector is given by:

$$x_s = \sum_{B=1}^{B} \frac{A_B}{t^b{}_{sB}} \tag{18}$$

where

x_s = accessibility index for sector s;

s = sector of the study subregion;

B = travel time band;

A_B = attraction trip ends for travel time band B within sector s;

t_{sB} = travel time from origin to centroid of time band B in sector s*;

b = constant exponent for gravity model—function of trip purpose.

Assume that b = 3 (shopping trips) for this example (see Table 8, Chapter Three, for b values by trip purpose by urbanized area population). Equation 18 is then given by:

$$x_s = \sum_{B=1}^{4} \frac{A_B}{t^3{}_{sB}} \tag{19}$$

The accessibility indices for the eight sectors in the study subregion are calculated as follows:

$$x_1 = \frac{400}{5^3} + \frac{200}{10^3} + \frac{100}{15^3} + \frac{50}{20^3} = 3.44 \text{ for sector 1}$$

$$x_2 = \frac{500}{5^3} + \frac{400}{10^3} + \frac{100}{15^3} + \frac{100}{20^3} = 4.44 \text{ for sector 2}$$

And so on. Thus,

$x_1 = 3.44$	$x_2 = 4.44$
$x_3 = 4.96$	$x_4 = 6.06$
$x_5 = 9.70$	$x_6 = 3.19$
$x_7 = 0.90$	$x_8 = 0.73$

Step 4: Calculate trips from the shopping center to each sector (geographic orientation). Vehicle trips from the shopping center to any sector in the study subregion can be calculated by using:

$$T_{is} = \frac{P_i x_s}{\sum_{s=1}^{s} x_s} \tag{20a}$$

where

T_{is} = trips from origin i to sector s;
P_i = trips generated at origin i;
x_s = accessibility index for sector s.

(Note that Eq. 20a is merely the gravity model formulation.)

For the present example, the equation is given by:

$$T_{is} = \frac{20{,}100\, x_s}{\sum_{s=1}^{8} x_s} = \frac{20{,}100\, x_s}{3.44 + 4.44 + 4.96 + 6.06 + 9.70 + 3.19 + 0.90 + 0.73} = \frac{20{,}100\, x_s}{33.42} \tag{20b}$$

Hence, trips from the shopping center will "spray out" (distribute) to the eight sectors of the study subregion in the following proportions:

* Thus for the 5-min time band, this travel time would actually be 2.5 min. For the 10-min time band, it would be 7.5 min; for the 15-min time band, it would be 12.5 min, and so on. Note that for the example, the 2.5-min adjustment has been neglected.

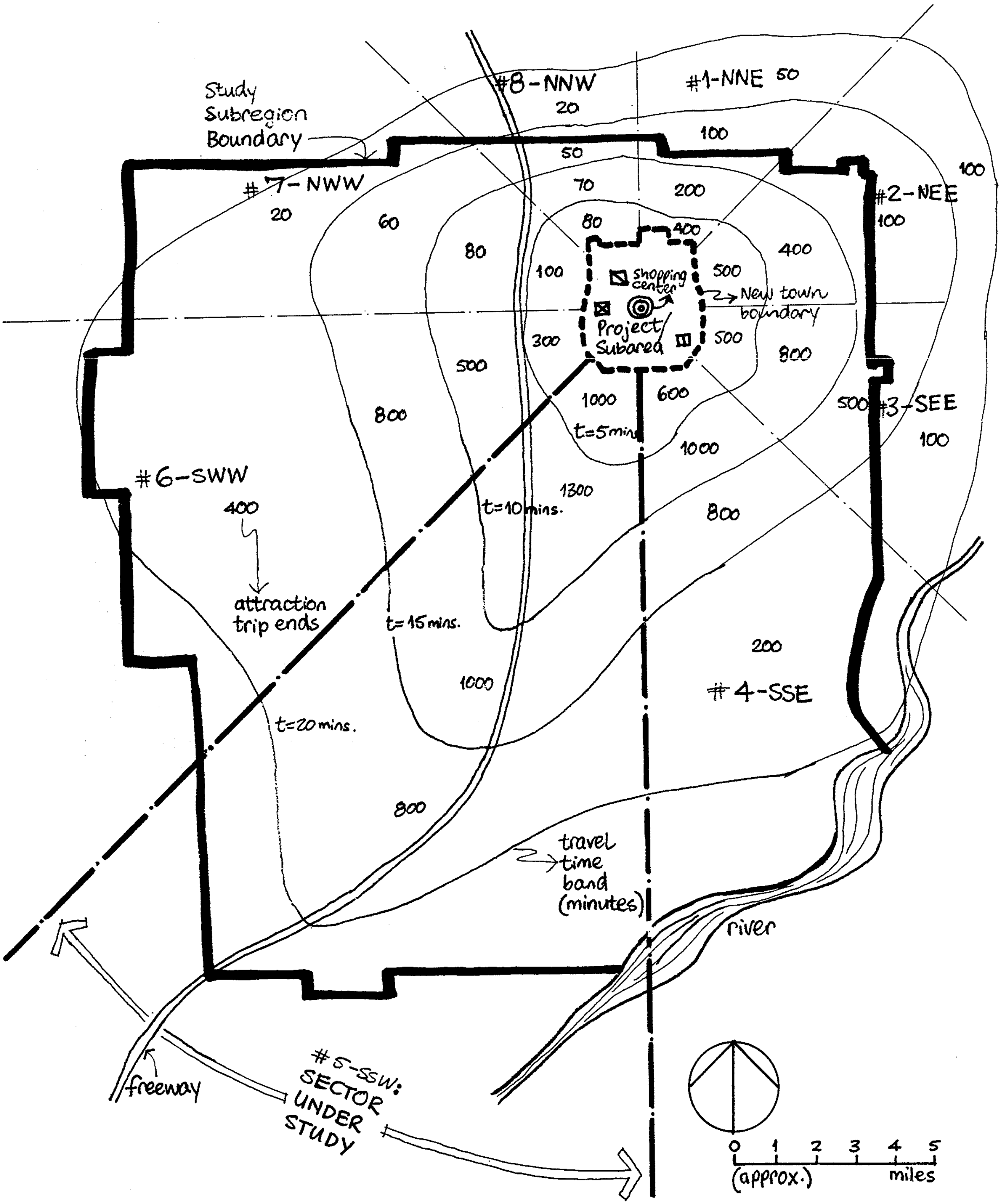


Figure 112. Study subregion, showing attraction vehicle-trip ends by sectors by travel time bands.

$$T_{i1} = \frac{20{,}100 \times 3.44}{33.42} = 2{,}069 \text{ trips}$$

$$T_{i2} = \frac{20{,}100 \times 4.44}{33.42} = 2{,}670 \text{ trips}$$

And so on. Thus,

$$T_{i1} = 2{,}069 \qquad T_{i2} = 2{,}670$$
$$T_{i3} = 2{,}983 \qquad T_{i4} = 3{,}645$$
$$T_{i5} = 5{,}834 \qquad T_{i6} = 1{,}919$$
$$T_{i7} = 541 \qquad T_{i8} = 439$$

Note that:

$$\sum_{s=1}^{8} T_{is} = 2{,}069 + 2{,}670 + 2{,}983 + 3{,}645 + 5{,}834 + 1{,}919 + 541 + 439 = 20{,}100 \text{ trips}$$

Because of the calculations carried out previously, the geographic orientation of the trips is now known. Thus, for the sector under study [i.e., sector 5 (SSW)], there are 5,834 trips.

Step 5: Calculate trips from the shopping center to each time band (attenuation) within the study sector. Trips from the shopping center to any time band within any sector can be computed by using:

$$T_{is,B} = \frac{P_i \dfrac{A_B}{t^b{}_{sB}}}{\sum_{s=1}^{s} x_s} \qquad (21a)$$

where

$T_{is,B}$ = Trips from origin i to time band B in sector s.

Because trips are to be calculated to time bands within sector 5 (SSW), the equation is given by:

$$T_{i5,B} = \frac{20{,}100 \dfrac{A^B}{t^b{}_{5B}}}{33.42} \qquad (21b)$$

Hence, trips from the development will "drop off" in the four time bands within study sector 5 as follows:

$$T_{i5,5} = \frac{20{,}100 \times \dfrac{1{,}000}{5^3}}{33.42} = 4{,}812 \text{ trips}$$

$$T_{i5,10} = \frac{20{,}100 \times \dfrac{1{,}300}{10^3}}{33.42} = 783 \text{ trips}$$

$$T_{i5,15} = \frac{20{,}100 \times \dfrac{1{,}000}{15^3}}{33.42} = 179 \text{ trips}$$

$$T_{i5,20} = \frac{20{,}100 \times \dfrac{800}{20^3}}{33.42} = 60 \text{ trips}$$

Note that:

$$\sum_{B=1}^{4} T_{i5,B} = 5{,}834 \text{ trips}$$

The attenuation of the trips from the shopping center to study sector 5 is now known. Hence, it can be expected that for the 5-min time band, 5,834 trips produced by the shopping center would use the street network, with 4,812 trips eventually "dropping off" and the remaining 1,022 trips (5,834 − 4,812) passing through to the 10-min time band.

In time band 10, 1,022 trips would use the street network, with 783 trips dropping off and the remaining 239 trips (1,022 − 783) passing through to time band 15.

The attenuation (and street use) is shown in Figure 113.

Step 6: Estimate street requirements due to traffic from the shopping center. Because street network use is now known in all the time bands within study sector 5, it is relatively simple to estimate numbers of lanes and spacing required. For this purpose, Figure 103 is employed. So, for the 5-min time band, there are 5,834 trips on the street network (Fig. 113). Average width of the band is approximately 2 mi and, therefore, volume per mile-wide corridor is 2,917 trips (5,834 ÷ 2). For this traffic volume, Figure 103 indicates that two, 2-lane streets at 2-mi spacing would be adequate to handle the traffic.

For the 10-min time band, there are 1,022 trips on the street network. Average width of band is approximately 3 mi and, therefore, volume per mile-wide corridor is 341 trips (1,022 ÷ 3). For this traffic volume, Figure 103 indicates that one, 2-lane street would be sufficient.

And so on for the remaining time bands. Because trips drop off rapidly, trip ends in the outer time bands will be small in number and therefore the street requirements owing to the shopping center would be negligible.

It should be remembered that these requirements correspond to traffic generated *only* by the shopping center in the new town. In reality, however, this traffic should be superimposed on "other" existing traffic, in addition to that generated by the remaining special generators and residences in the new town. This would provide the total traffic and the corresponding street requirements.

Street requirements can be estimated for the other seven sectors in the same manner as that described previously.

TRAFFIC-SHIFT METHODOLOGY FOR CORRIDORS

For corridor analysis, often a sketch-planning—quick-response—technique is desirable to evaluate the effects of an improvement in one of the facilities in the corridor. Such a process, if it is to be applied quickly, should not consider origin-destination movements but rather a general shift of traffic between facilities. Such a process has been suggested by the multiroute probabilistic process developed by Dial (*55*). The required equations for the usual two competing-route problem are as follows:

$$V_{mtr} = \frac{1}{1 + e^{\theta}\,(t_m - t_i)} \cdot (V_T) \qquad (22)$$

$$V_i = \frac{e^{\theta}\,(t_m - t_i)}{1 + e^{\theta}\,(t_m - t_i)} \cdot (V_T) \qquad (23)$$

$$\theta = \frac{1n \dfrac{V_i}{V_{mtr}}}{t_m - t_i} \qquad (24)$$

where

V_{mtr} = volume on minimum time route;
θ = diversion parameter;

TIME BAND (mins.)	TRIPS ON STREET NETWORK	TRIPS DROPPING OFF
0- 5	5,834	4,812
5-10	1,022	783
10-15	239	179
15-20	60	60
	$\sum_{B=1}^{4} T_{i5,B}$	5,834

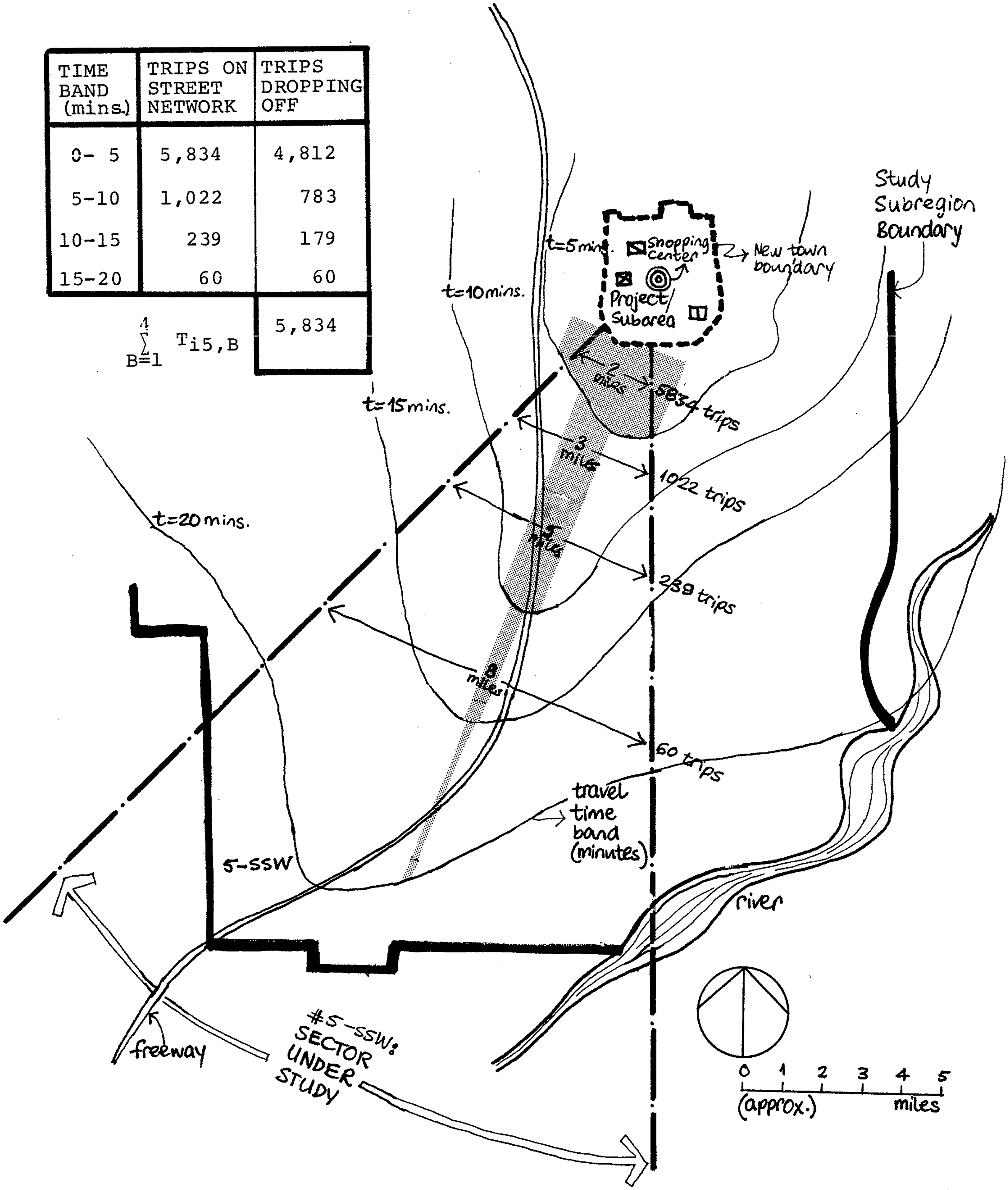


Figure 113. Study sector, showing vehicle-trips on street network by time bands.

t_m = time on minimum time route;
t_i = time on alternate route [*Note:* $(t_m - t_i)$ is always negaitve];
V_T = total volume on two facilities ($V_T = V_{mtr} + V_i$);
V_i = volume on alternate route.

The process assumes that current traffic volumes and operating characteristics for a base condition are known. These data may be obtained from traffic volume counts and speed/delay travel-time studies or from the results of the planning process. To describe application of the process, the following simplified example is offered. The two competing facilities example is shown at the top of Figure 114.

To calculate the diversion parameter (based on existing volumes), the function given in Eq. 24 would be used as follows:

$$\theta = \frac{1n \frac{1240}{7500}}{7.1 - 12.0} = \frac{-1.8}{-4.9} = 0.367 \qquad (25)$$

This parameter describes the diversion of traffic between the two routes being considered. Assume an improvement is to be made in route A by adding another lane in each direction. A speed of 50 mph for the improved facility is estimated based on a capacity calculation using the original volume of 7,500 vehicles. The volume-to-capacity ratio would be developed from:

$$\frac{7{,}500 \text{ vph}}{5 \text{ lanes} \times 2{,}000 \text{ vph capacity}} = 0.75 \qquad (26)$$

The travel time for the 5-mi route A section would then be calculated as:

$$\frac{5 \text{ mi}}{50 \text{ mi}} \times \frac{60 \text{ min}}{\text{hr}} = 6.0 \text{ min} \qquad (27)$$

Based on this improvement, a new estimate of the average volumes can be calculated using Eq. 22 and 23 as follows:

$$V_{mtr} = \frac{1}{1 + e^{0.367\ (6.0-12.0)}} \cdot (7{,}500 + 1{,}240) = 7{,}869 \text{ vph} \qquad (28)$$

$$V_i = \frac{e^{0.367\ (6.0-12.0)}}{1 + e^{0.367\ (6.0-12.0)}} \cdot (8{,}740) = 871 \text{ vph} \qquad (29)$$

The volume-to-capacity ratio for route A would now be [7,869/(5 × 2,000)], or 0.79 resulting in a speed of about 48 mph as calculated from capacity curves. Route B would carry about 871 vehicles per hour. Another iteration of the process could be carried out to try to effect a closer relationship between volume and speed, but for sketch-planning purposes and because of the inaccuracies of volume/capacity/speed relationships, especially for arterials, it is not expected to improve the results. Only if a large imbalance exists in resulting volumes and speeds should additional iterations be tried (i.e., greater than 5 mph difference between input and calculated speeds).

To demonstrate how the foregoing process handles variations in operating conditions, Table 48 is provided for the example case described previously.

Where three competing facilities exist in a corridor, the process must be applied twice, with the calculation of two θ values. Assume routes A, B, and C as shown in the lower half of Figure 114. The θ for route pair A and B would be calculated as shown previously and equals 0.367. Using Eq. 24, the θ value for route pair B and C would be calculated as follows:

$$\theta = \frac{1n \frac{800}{1{,}240}}{12 - 14} = \frac{-0.438}{-2.0} = 0.219 \qquad (30)$$

To calculate the effects of the improvement in route A to 50 mph, the volume on routes A and B would be calculated at 7,869 and 871, respectively, as shown previously. To calculate the effect relative to routes B and C the following computations would be made:

$$V_{mtr} = \frac{1}{1 + e^{0.219\ (12-14)}} \cdot (871 + 800) = 1{,}016 \text{ vph} \qquad (31)$$

$$V_i = \frac{e^{0.219\ (12-14)}}{1 + e^{0.219\ (12-14)}} \cdot (1671) = 655 \text{ vph} \qquad (32)$$

These calculations may be iterated a few times to bring the results to a more stable condition. For example, now considering the volumes of 7,869, 1,016, and 655, a new calculation between routes A and B would result in volumes of 8,000 and 885 for A and B, respectively. The three-route case for a corridor is unusual; generally, only two competing routes will be handled.

Capacity analysis should be considered as part of this traffic-shift analysis. After the process is applied, volume/capacity/speed calculations should be performed to determine if the resulting speed is in balance with the speed used in the preceding described process. If not, the new speed should be used to re-do the calculations.

TABLE 48

VARIATION IN TRAFFIC VOLUMES WITH CHANGES IN SPEED

BASE CONDITIONS: 5 Mile Section
% Route A Volume 86%
Route A Speed = 42 mph; Route B Speed = 25 mph
Calculated θ =0.367

SPEED		Difference In Travel Time =	% Volume On
Route A	Route B	Route B -Route A	Route B
30	25	-2.0	67
35	25	-3.4	78
40	25	-4.5	84
45	25	-5.3	87
50	25	-6.0	90
55	25	-6.5	92
30	35	+1.4	37
35	35	0.0	50
40	35	-1.1	60
45	35	-1.9	67
50	35	-2.6	72
55	35	-3.1	76
30	45	+3.3	23
35	45	+1.9	33
40	45	+0.8	43
45	45	0.0	50
50	45	-0.7	56
55	45	-1.2	61

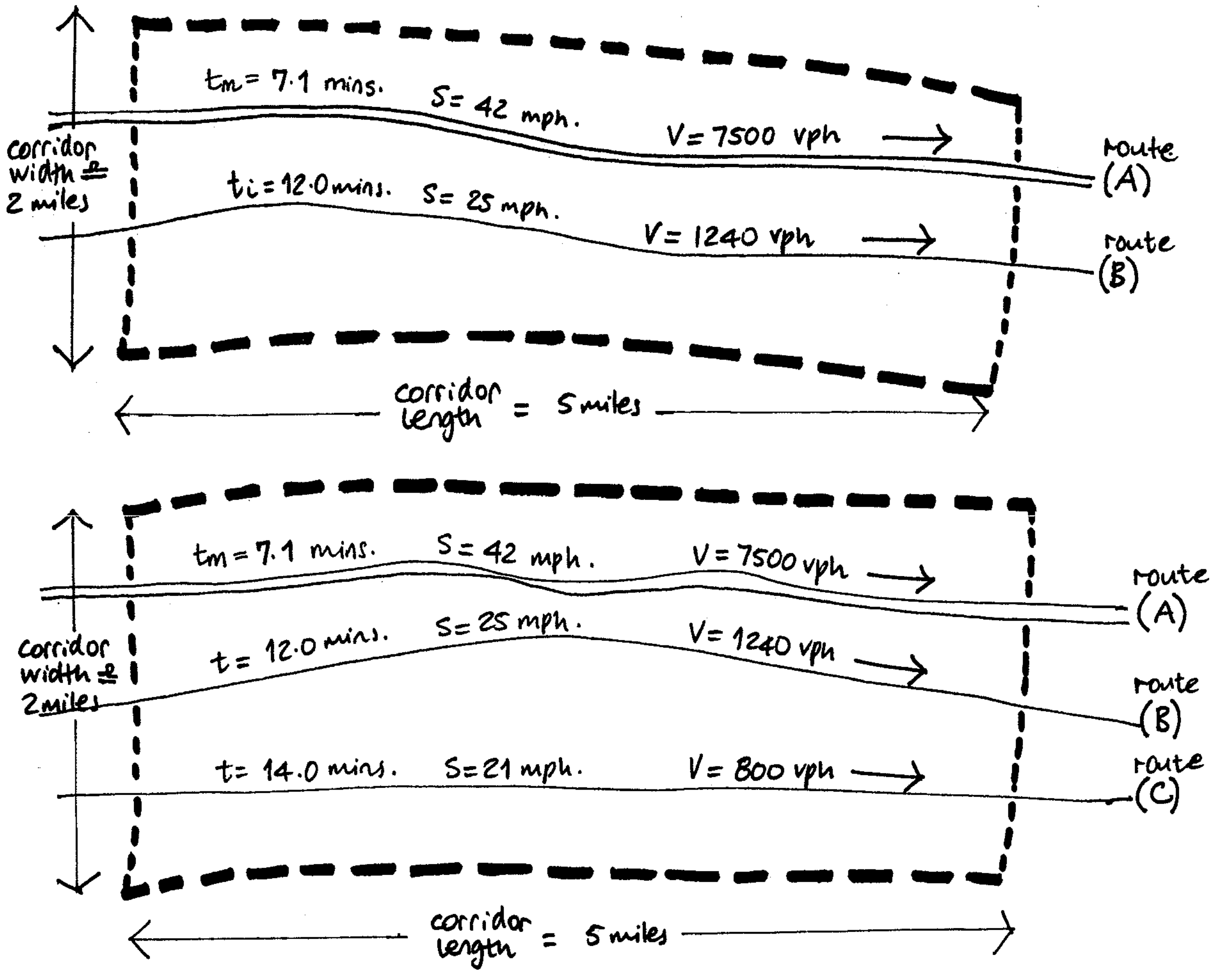


Figure 114. Example corridors for traffic shift analysis.

Usually, a number of sections will exist along each facility in a corridor where volumes and speeds may vary. The approximate speeds and section distances should be used to calculate section times added to obtain the total time through the corridor. An average volume should be used based on the calculation:

$$\text{Average Volume} = \frac{\Sigma\,(\text{Volume in Section} \times \text{Section Length})}{\Sigma\,\text{Section Lengths}} \quad (33)$$

Traffic shifts can also be determined graphically by using a simple set of curves as shown in Figure 115. In order to use the graph, the user has to know at least two variables:

1. If the diversion parameter, θ, for routes within a corridor is to be determined, then the user must input the percent volume on the minimum time route; that is, V_{mtr}, and the travel time difference, Δt, between the faster and slower routes; that is, $(t_m - t_i)$.
2. If the percent volume on any route is to be determined, then the user must input the diversion parameter θ and the travel time difference Δt. Note that in all cases, the following relationships hold:

$$\% \; V_{mtr} + V_i = 100\% \text{ and}$$
$$\Delta t = t_m - t_i < 0 \text{ (always negative)} \quad (34)$$

Usually, the diversion parameter is first determined for a corridor, given travel volumes and travel times on the two routes. Then to study the effects of a travel time change on any one route, θ is held constant and the new volumes determined.

To illustrate the use of the graph shown in Figure 115, consider the example illustrated in the upper portion of Figure 114. In the condition shown, the user knows the following variables:

$$V_{mtr} = \frac{V_{mtr}}{V_{mtr} + V_i} \times 100$$
$$= \frac{7{,}500}{7{,}500 + 1{,}240} \times 100 = 85.8\%$$

therefore

$$\% \; V_i = 100 - 85.8 = 14.2\% \quad (35)$$

$$\Delta t = t_m - t_i$$
$$= 7.1 - 12 = -4.9 \text{ min} \quad (36)$$

By entering the curves in Figure 115 at $V_{mtr} = 86$ percent and $\Delta t = -4.9$ min, θ is interpolated at 0.37, which checks with that calculated mathematically in the example described earlier.

Now suppose, as before, route A is improved so that the

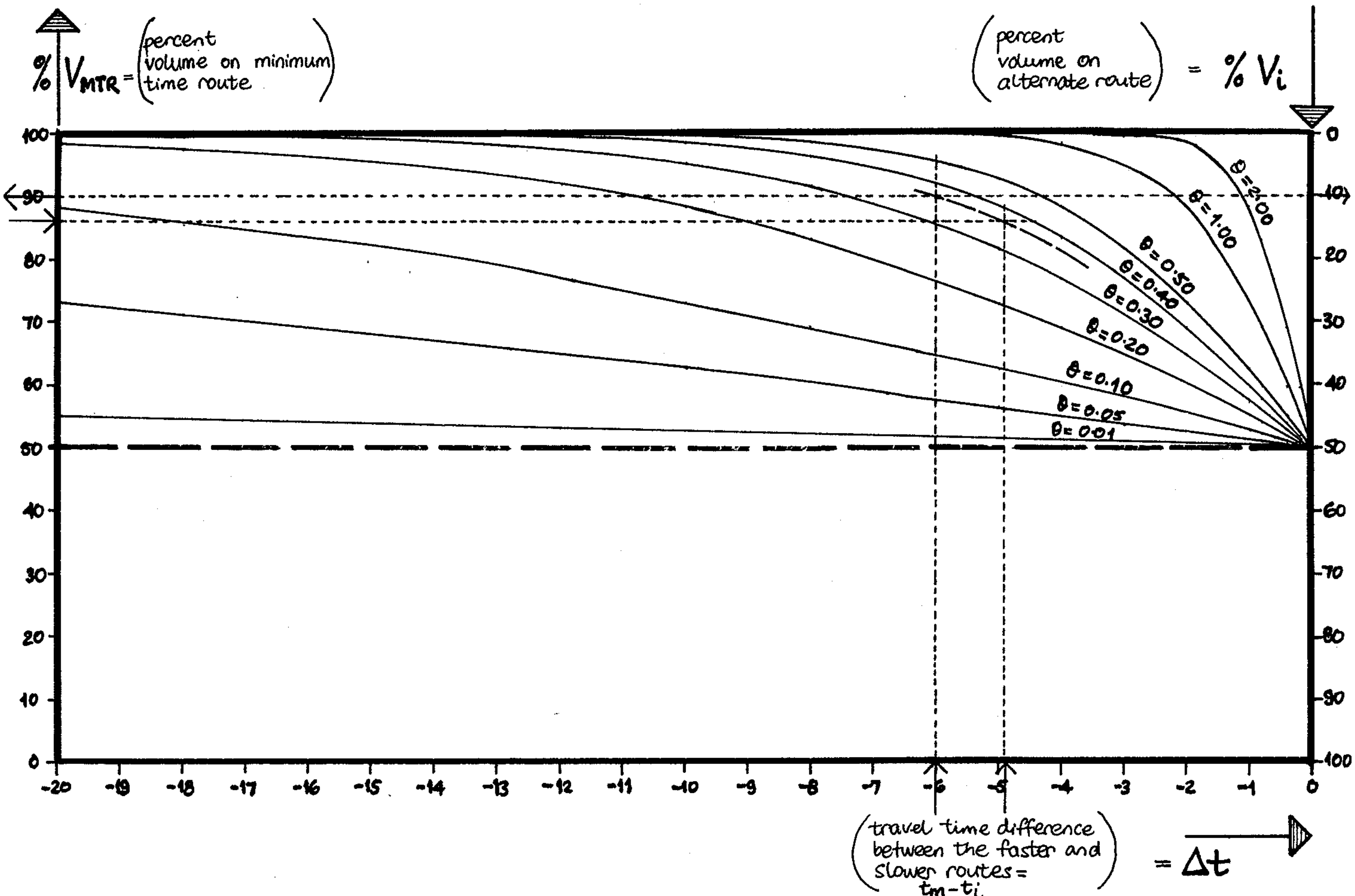


Figure 115. Graph for determining traffic shifts between facilities in a corridor.

travel time on this route is reduced to 6 min from the original 7.1 min. Thus,

$$\Delta t = 6 - 12 = -6 \text{ min}$$

Entering the graph in Figure 115 at $\Delta t = -6$ min and $\theta = 0.37$, the corresponding $\% V_{mtr}$ is read off at 90 percent and $\% V_i$ at 10 percent. Because the total volume entering the corridor is known to be 8,740 vph, then:

$$V_{mtr} = \frac{90}{100} \times 8{,}740 = 7{,}866 \text{ vph} \quad (37)$$

$$V_i = \frac{10}{100} \times 8{,}740 = 874 \text{ vph} \quad (38)$$

These results check with the values of V_{mtr} and V_i obtained in the previous example.

Thus, the graphical method is accurate and quite simple to use, and it is recommended if time savings are to be achieved in the application of the traffic-shift methodology.

CHAPTER EIGHT

CAPACITY ANALYSIS

INTRODUCTION

An important analytical question is how much system is required to satisfy the estimated travel demand or, how much traffic can the existing system accommodate before it breaks down. It is interesting to note that procedures to address these questions were developed for the Highway Research Board (HRB) and, as practiced by most professionals, are manual procedures.

It is not the intent of this chapter to duplicate the contents of the *Highway Capacity Manual* (*56*). Most procedures described therein are designed for manual application. The intent of the procedures described herein is to present capacity analysis in a simplified form so that it is compatible with other phases of the transportation planning process.

Highway volume/capacity (V/C) evaluations are conducted at two levels of detail. The more rigorous of the two is for designing facility configuration and operation; that is, traffic engineering design applications. The other is for conducting systems analysis to assess the ability of the general system configuration to move the required amount of traffic at a satisfactory service level. It is the latter application that should be addressed with the procedures presented in this chapter. If the user desires to advance the capacity evaluation to a greater level of detail, the more traditional analysis procedures should be applied.

BASIS FOR DEVELOPMENT

The techniques included in this chapter have been selected to respond to the types of problems anticipated to be subjected to evaluation using the procedures of this user's guide. In general terms, such techniques are viewed to be either intersection problems or corridor problems stemming from a site/special generator analysis. Each type of problem is addressed in this chapter; the techniques described have basic similarities but vary in actual application. The similarities stem from the fact that capacity, whether for a link or for an intersection, is generally determined by the characteristics of the intersections involved. Consequently, each approach to the two basic problems involves calculating capacity conditions at intersections.

The intersection, by definition, is site-specific and viewed as an entity, whereas the corridor problem is analyzed in terms of general aggregate volume/capacity conditions within the corridor. The latter could be investigated by facility; however, it is recommended the more detailed procedures in the *Highway Capacity Manual* be used for that level of detail.

The operating condition of a highway facility is generally measured using the level-of-service concept (*56*). Level of service has been stratified into six classes defined as follows:

LEVEL OF SERVICE	OPERATING CONDITIONS
A	Free flow, low volume, high-operating speed, high maneuverability.
B	Stable flow, moderate volume; speed somewhat restricted by traffic conditions, high maneuverability.
C	Stable flow, high volume; speed and maneuverability determined by traffic conditions.
D	Unstable flow, high volumes, tolerable but fluctuating operating speed and maneuverability.
E	Unstable flow, high volumes approaching roadway capacity, limited speed ($\simeq$ 30 mph), intermittent vehicle queuing.
F	Forced flow, volumes lower than capacity due to very low speeds. Heavy queuing of vehicles, frequent stoppages.

The user will need to decide the level of service to be used as the benchmark or operating goal. The decision may depend on several factors, including financial resources to correct deficiencies, public opinion, and established policy. Chapter Nine, "Development Density/Highway Spacing Relationships," discusses "least-cost" solutions that may assist in selecting a benchmark. (See Fig. 130 in Chapter Nine.) Historically, level-of-service "C" (*59*) has been used for evaluative purposes and is referenced as the benchmark for the remainder of these capacity discussions. The user should, however, differentiate between a desirable operating capacity and the physical or maximum capacity of a facility. The analyst may select a desirable operating capacity not to be exceeded—such as level-of-service "C" or "D"—but physical capacity is defined at level-of-service "E" (*56*). Thus, capacity relationships are, in these procedures, reported assuming capacity at level-of-service "E."

There are two basic and independent indicators of level of service—the volume-to-capacity (V/C) ratio and the operating speed. Where applicable, these procedures use only the V/C ratio to assess service levels. For further discussion of these concepts the user is directed to the *Highway Capacity Manual* (*56*).

Determination of Intersection Capacity

The intersection capacity analysis for use in site-planning applications is based on the "Critical Movement Summation" technique developed by McInerney and Petersen (*57*). The technique has been adopted by many local and regional planning agencies for use in development impact studies (*58*).

The technique does not actually calculate intersection capacity but, instead, calculates a critical intersection volume and compares that volume against a benchmark intersection capacity that is stratified by level of service. Table 49 gives the capacity ranges of an intersection for each level of service.

TABLE 49

INTERSECTION CAPACITY BY LEVEL OF SERVICE

LEVEL OF SERVICE	RANGE OF CAPACITY (VPH) LOW	HIGH
A	0	900
B	901	1,050
C	1,051	1,200
D	1,201	1,350
E	1,351	1,500
F	(Special case)	1,500

It is recommended that the intersection capacity "standard" be defined as level-of-service "C" although final determination of what might be termed a "satisfactory operating level" rests with the user.

Input Data Requirements

It is assumed that the user would undertake an intersection capacity analysis after vehicle trips have been assigned to the highway network. The user is required to furnish the following information for the intersection:

- Number of approach lanes—defined as the number of through lanes operating in the intersection.
- Exclusive-use lanes (left turn, etc.) need to be noted but are not considered as approach lanes.
- Volumes and turn volumes for all allowable intersection movements for the peak hour. (The user is directed to Chapter Six, "Time-of-Day Characteristics," for converting average daily traffic (ADT) volumes to peak-hour volumes.)
- Special operating characteristics that might affect lane volumes, such as free right turns, also need to be identified. This turn traffic should be subtracted from the appropriate approach-lane volume.

It is desirable if the user can provide volumes for each lane, although it is recognized it might be extremely difficult or impossible to do so. The following data allow conversion of a total directional through movement into a lane volume.

APPROACH LANES	LANE-USE FACTOR
1	1.00
2	0.55
3	0.40
4	0.30

The lane-use factors exceed the inverse of the number of approach lanes to account for the unequal distribution of travel between lanes. In effect, the user desires to know the maximum traffic in an approach lane.

The Critical Movement Summation Technique

This technique defines the critical movement volumes as: "The volume of travel represented by the highest lane volumes of opposing travel (through and left turn) from both the north-south and east-west directions that occurs during the peak hour."

The definition is better understood through an example application. Figure 116 shows the information available to an analyst for intersection capacity evaluation. Volume numbers shown represent vehicles occurring during the peak hour. If the analyst has only ADT volumes available, they must be converted to hourly volumes. The user would then proceed as follows to determine the operating level of service.

1. Determine the net approach volume (through volume) and multiply by the appropriate lane-use factor to obtain lane volume. (If lane volumes are available this step is not necessary.) Thus, with reference to Figure 116, this step would yield the following results:

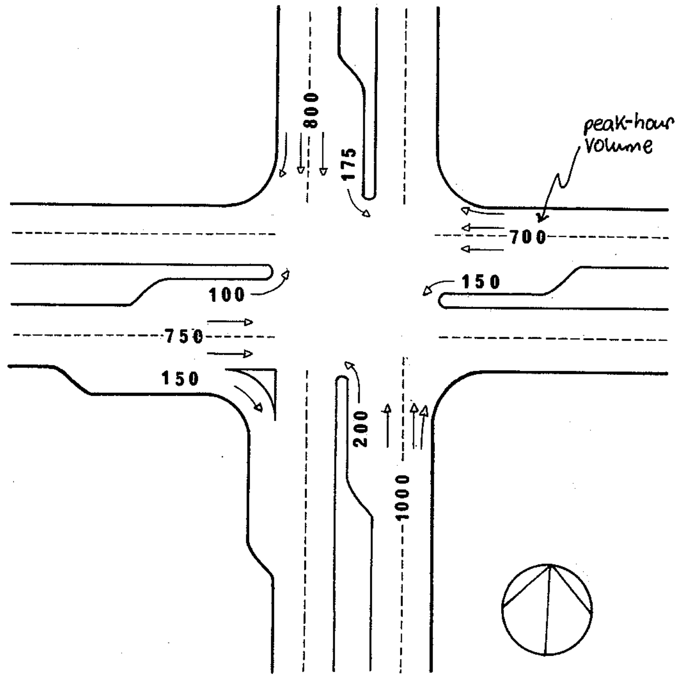


Figure 116. Traffic data for intersection capacity analysis.

DIRECTION	NET APPROACH VOL.	LANE-USE FACTOR	LANE VOLUME
Northbound	1,000	0.55	550
Southbound	800	0.55	440
Eastbound	750	0.55	413
Westbound	700	0.55	385

2. Determine the critical lane volume for each approach as follows:

	N-BOUND	S-BOUND	E-BOUND	W-BOUND
Through volume	550	440	413	385
Opposing left-turn volume	175	200	150	100
Total	725	640	563	485

3. Select maximum of N-S volumes and E-W volumes and sum to determine Critical Movement Summation (CMS).

CMS = Northbound + Eastbound
CMS = 725 + 563
CMS = 1,288 vehicles

4. Compare CMS to volume ranges given in Table 49 to determine intersection operating service level.

Thus, from Table 49, the user can conclude that the intersection described by Figure 116 is operating at level-of-service "D."

The example described previously contains conditions anticipated by most intersection configurations except one—the unprotected left turn. In that instance the user should calculate the lane volumes as previously described but should add the left-turn volume to the critical lane volume to account for turbulence caused in the through lane by the left-turning vehicles.

DETERMINATION OF CORRIDOR CAPACITY

The objective of the corridor analysis is to produce an assessment of volume/capacity relationships for the corridor. The technique to accomplish this objective is comprised of cutline evaluations within the corridor and the subsequent preparation of a "Facilities Stress Diagram." Each element is described more fully in the following paragraphs.

Cutlines are strategically placed lines orthogonal to the direction of the travel being analyzed and define points on the highway system that can be termed a "cross-section for analysis." Figure 117 shows a schematic representation of a corridor with the cutlines defined. Five cutlines are shown for the analysis of travel estimated in the north-south direction. As shown later, the procedure requires an estimation of capacity for each facility (i.e., for routes A, B, and C) at each point of intersection with each cutline.

The user can analyze the results of the preceding approach in one of the two forms:

1. The user may aggregate the volumes and capacities across a cutline to obtain a corridor volume-to-capacity relationship (in preparation of a facilities stress diagram).
2. If the user has balanced the assignment volumes (see Chapter Seven, section entitled, "Distribution of Assigned Volumes Among Available Facilities"), an analysis of the V/C relationship can be made independently for each facility (A, B or C).

The user is cautioned in using the form in item 2, because the level of detail of the capacity investigation may be inconsistent with other travel-estimation procedures in this user's guide. The analyst will need to impose technical judgment to determine if such detailed investigations are appropriate.

The facilities stress diagram is a plot of the V/C ratio for either the entire corridor (after summing volumes and capacities across each cutline) or a major facility (as in Fig. 117 for routes A, B, or C).

An example of a facilities stress diagram is shown in Figure 118. The diagram represents the corridor shown in Figure 117. The datum (horizontal line) represents the benchmark level of service, measured as a V/C ratio at which the analyst desires the system to operate. In viewing the diagram, the user can see both where the system is congested (over capacity) and where surplus capacity exists in the corridor. The user might conclude from the diagram that a large volume of traffic is leaving the corridor [probably from the freeway (route B) at the interchange between cutlines 1 and 2], resulting in a surplus of capacity between cutlines 2 and 4. Traffic begins to build up between cutlines 3 and 4, probably because of entering freeway volumes at the southern interchange.

Input Data Requirements

The corridor capacity analysis procedures require input data for two purposes: (1) to provide sufficient traffic volume data to allow for a V/C determination for the facility; and (2) to determine the capacity for each facility (physical and operating characteristics).

The first item relates to assignment volumes. Assignment volumes are needed in the form of directional peak-hour volumes for application to the capacity-analysis procedures. They may require manipulation inasmuch as most volumes are produced in ADT form. The task is not as laborious as it might seem at first. The user is directed to Chapter Six, "Time-of-Day Characteristics," where sufficient information has been provided to convert ADT assignment volumes into hourly directional volumes.

The second category of required input data describes the attributes of the facility and includes several items. Input requirements need to be stratified into two categories—freeway and nonfreeway. Freeway capacity is calculated using a different procedure from that used for arterial facilities (*56*).

Freeway/Expressway Capacity Calculation

Conditions such as access, parking, and the like, are controlled on freeways and expressways and, consequently, make the capacity determination for high-design facilities less complicated than is experienced for arterials. To facilitate the ease with which the user can determine freeway capacity, average assumptions have been made regarding operating conditions. Table 50 gives the resulting capacities, considering these assumptions, in a form that requires the user to provide only the number of lanes (per direction) in order to determine facility capacity. The capacity quantities assume a peak-hour factor of 0.85* and 10 percent trucks. Volume-to-capacity (V/C) ratios are provided to give the analyst an idea of the maximum usage rates a freeway should experience for any given service level. It must be noted that V/C ratios *and* operating speed determine level of service; therefore, the V/C relationships used to determine service level are approximations.

Table 50 contains data, by level of service, for three strata of facility sizes (2, 2, and 4 lanes per direction) and an additional column to "add-on" capacity for each lane over 4 lanes. The capacity (2, 3, and 4 lanes) represents total roadway capacity for the direction of travel.

An example is provided to stress the interrelationship between capacity, V/C ratio, and level of service. A 2-lane per direction freeway has a capacity of 3,600 vehicles per hour (capacity = level-of-service "E") with a corresponding V/C ratio of 1.00. If level-of-service "C" is the desired operating condition, the facility should operate at 65 percent, or less (V/C = 0.65), of available capacity. Stated differently, the capacity of the facility at the *desired* level of service is 2,250 vehicles per hour.

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* Peak-hour factor is the ratio of the peak-hour flow to twelve times the peak 5-min flow that occurs during the peak hour.

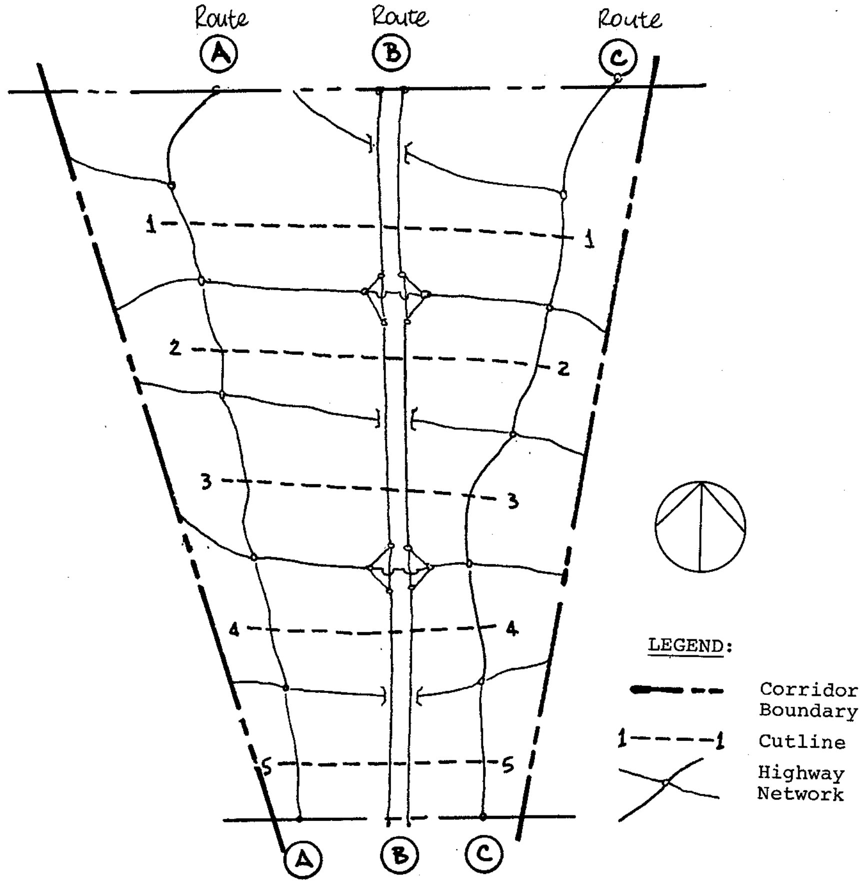


Figure 117. Transportation corridor, showing cutlines for corridor capacity analysis.

Urban Arterial Capacity Calculation

In terms of capacity determination, urban arterials cannot be generalized as easily as freeways. The capacity techniques, therefore, provide the user with the flexibility of considering local conditions for several operating variables or of using default (average) values. For most cases a simplified table should be sufficient; thus, Table 51 from which capacity can be determined has been provided (*60*).

Link capacity on urban arterials is generally controlled by intersections. Obviously, occasional situations arise where mid-block (link) conditions control link capacity. In such cases, the user will be required to exercise judgment, using local information. Except in cases where mid-block conditions control the link capacity, the user should be guided by the following rule: *link capacity is equal to the capacity of the most restricted intersection on the link.*

The following list represents the variables that should be considered to determine urban street capacity:

1. *Approach width* must be determined by the user. Approach width is equal to the curb-to-curb street width for one-way streets and the painted centerline-to-curb street width for two-way streets. Boulevards are considered as two one-way streets with the approach width of each measured from the median edge of the roadway to the curb. Approach width excludes any special-purpose (i.e., turning bays) lanes.

2. *Load factor* is assumed equal to 1.0 in the simplified table provided. This corresponds to a level-of-service "E" which represents available capacity. Load factor is defined as the number of green cycles that are fully used in the peak hour, divided by the number of available green cycles occurring during the peak hour.

3. *Peak-hour factor* (*PHF*) is equal to the observed peak-hour volume divided by four times the volume observed during the peak 15 min of the peak hour. The simplified table assumes an average PHF of 0.85 (*59*).

4. The *urbanized area population factor* is used to adjust table entries. The factors correspond to similar stratifications in other sections of this user's guide. (See Table 51.)

5. Other adjustment factors have assumed values for the simplified table that represent average conditions as follows:

FACTOR	ASSUMED AVERAGE
Percent commercial vehicles	5
Percent left turns	10
Percent right turns	10
Bus stop factor	1.0 (no bus stop)

The user may proceed to use the simplified table if the foregoing assumptions are acceptable. If not, the user may

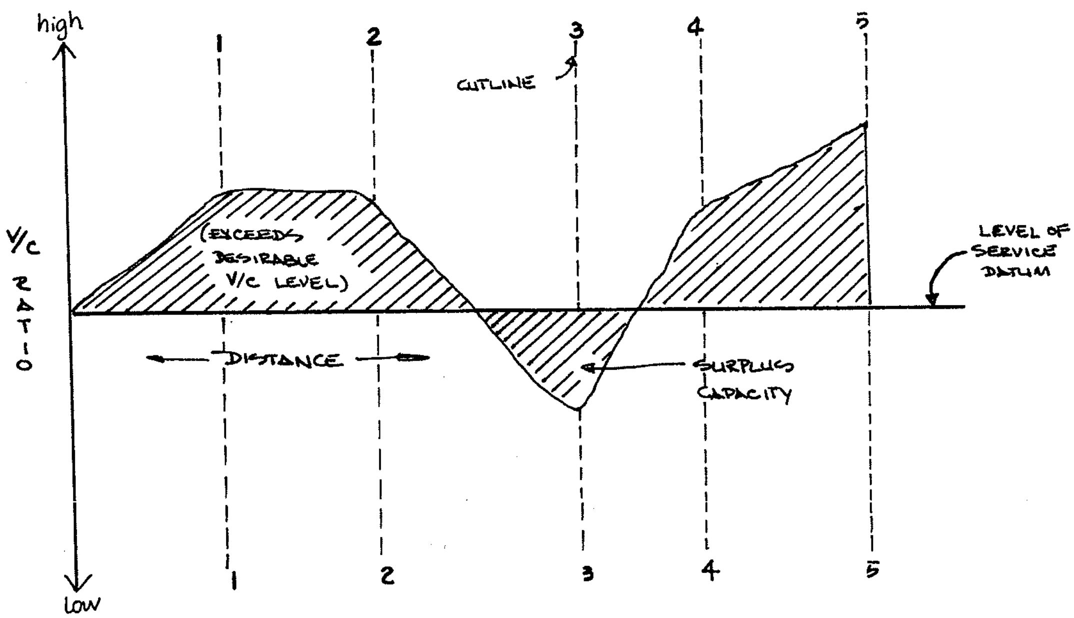


Figure 118. Facilities stress diagram.

construct a simplified table with different assumptions (*56*) or use directly the detailed nomographs described.

Seven detailed capacity nomographs (Figs. 119 through 125) are provided for the analyst to determine link capacity. Nomographs are presented for the following operations:

- One-way streets—No parking — Figure 119
- One-way streets—Parking one side — Figure 120
- One-way streets—Parking both sides — Figure 121
- Two-way streets—No parking — Figure 122
- Two-way streets—With parking — Figure 123
- Rural two-way streets—No parking — Figure 124
- Capacity conversion for green/cycle (G/C) ratio — Figure 125

The charts analyze urban arterial capacity through a known approach width using turning lines (TL) to adjust for previously mentioned factors. Figure 126 shows by example the use of the nomographs. For the example, the following information is given:

One-way street—No parking
Approach width—30 ft
Peak-hour factor—0.85
Urbanized area pop.—3 (i.e., 100,000-250,000 pop.)
Facility location—Central city
Percent commercial vehicles—5
Percent left turns—10
Percent right turns—10
Bus stops—None

TABLE 50

FREEWAY/EXPRESSWAY CAPACITY MEASURES (TOTAL VEHICLES PER HOUR)[a]

LEVEL OF SERVICE	2 LANES PER DIRECTION		3 LANES PER DIRECTION		4 LANES PER DIRECTION		EACH LANE OVER 4	
	V/C	CAPACITY[b]	V/C	CAPACITY[b]	V/C	CAPACITY[b]	V/C	CAPACITY[b]
A	≤ 0.35	1250	≤0.40	2200	≤0.45	3100	d	900
B	≤0.50	1800	≤0.60	3200	≤0.65	4500	d	1350
C	≤0.65	2250	≤0.70	3600	≤0.70	5000	d	1350
D	≤0.75	2700	≤0.75	4100	≤0.75	5400	d	1350
E (Capacity)	≤1.00	3600	≤1.00	5400	≤1.00	7200	d	1800
F	c	e	c	e	c	e	c	e

a. Source: Highway Capacity Manual (56).

b. Calculated at a load factor of 0.85; assumes 10% trucks.

c. Not meaningful.

d. Approximates 4 lanes per direction V/C values.

e. Varies from 0 to capacity (E).

The steps necessary to determine the capacity of an arterial are as follows:

1. Select peak-hour factor = 0.85 and move vertically to intersect urbanized area 3; then, move left horizontally to the pivot line, P.
2. Using the point on the pivot line, lay a straightedge from that point to the proper approach width and mark the intersection with TL 1.

   Note: Entire approach width is used if no turning bays are provided. If turning bays are provided, subtract turning bay width from approach width *and* assume percent left and/or right turns (whichever is appropriate) equals 0.
3. Using the point on TL 1, lay a straightedge between TL 2 and "central city" and note the point the straightedge intersects TL 2.
4. Using the point on TL 2, lay a straightedge between TL 2 and "5 percent commercial vehicles" and note the point the straightedge intersects TL 3.
5. Using the point on TL 3, lay a straightedge between TL 3 and 10 percent right turns and note the point the straightedge intersects TL 4.

   Note: One-way and two-way streets—No parking. For approach widths of from 16 to 24 ft, use the left-hand scale. For approach widths of 25 to 34 ft, use the right-hand scale. For widths of 35 ft or more, use the point representing 10 percent right turns.

   One-way and two-way streets—With parking. For approach widths of 21 to 29 ft, use the left-hand scale. For approach widths of 30 to 39 ft, use the right-hand scale. For widths of 40 ft or more, use the point representing 10 percent right turns.
6. Using the point on TL 4, lay a straightedge between TL 4 and 10 percent left turns and note the point the straightedge intersects TL 5.

   Note: Lay a straightedge between the point on TL 4 and the proper percentage of left turns. The following special instructions relate to the use of the left-turn scale.

   One-way streets—No parking. For approach widths from 16 to 24 ft, use the left-hand scale. For approach widths from 25 to 34 ft, use the right-hand scale. For widths of 35 ft and over, use the point representing 10 percent left turns.

   One-way streets—With parking. For approach widths from 21 to 29 ft, use the left-hand scale. For approach widths from 30 to 39 ft, use the right-hand scale. For approach widths over 40 ft, use the point representing 10 percent left turns.

   Two-way streets—No parking. For approach widths

TABLE 51

GENERALIZED CAPACITIES OF URBAN ARTERIALS

APPROACH WIDTH (FEET)	POSSIBLE CAPACITY (VPH OF GREEN)					
	ONE WAY NO PARKING	ONE WAY PARKING ONE SIDE	ONE WAY PARKING BOTH SIDES	TWO WAY NO PARKING	TWO WAY WITH PARKING	RURAL[a] TWO WAY NO PARKING
20	1800	1000	-	1700	1200	1800
25	2300	1500	1200	2200	1500	2300
30	2800	2000	1700	2700	1900	2700
35	3300	2600	2200	3200	2300	3300
40	3900	3200	2800	3700	2700	3700
45	4400	3700	3400	4200	3100	4300
50	5000	4300	4000	4700	3500	4700
55	5600	4900	4600	5200	3900	5200
60	6200	5500	5200	5700	4300	5700

CODE	URBANIZED AREA POPULATION	ADJ. FACTOR
4	50,000 - 100,000	0.92
3	100,000 - 250,000	0.97
2	250,000 - 750,000	1.06
1	750,000 - 2,000,000	1.11

ADJUSTED CAPACITY(VPH OF GREEN) =

(POSSIBLE CAPACITY) x

(URBANIZED AREA POP. ADJ. FACTOR)

x (LOCATION ADJ. FACTOR)

LOCATION	ADJ. FACTOR
CBD	1.00
CENTRAL CITY	1.20
SUBURB	1.25

ASSUMPTIONS:

PK HR FACTOR = 0.85

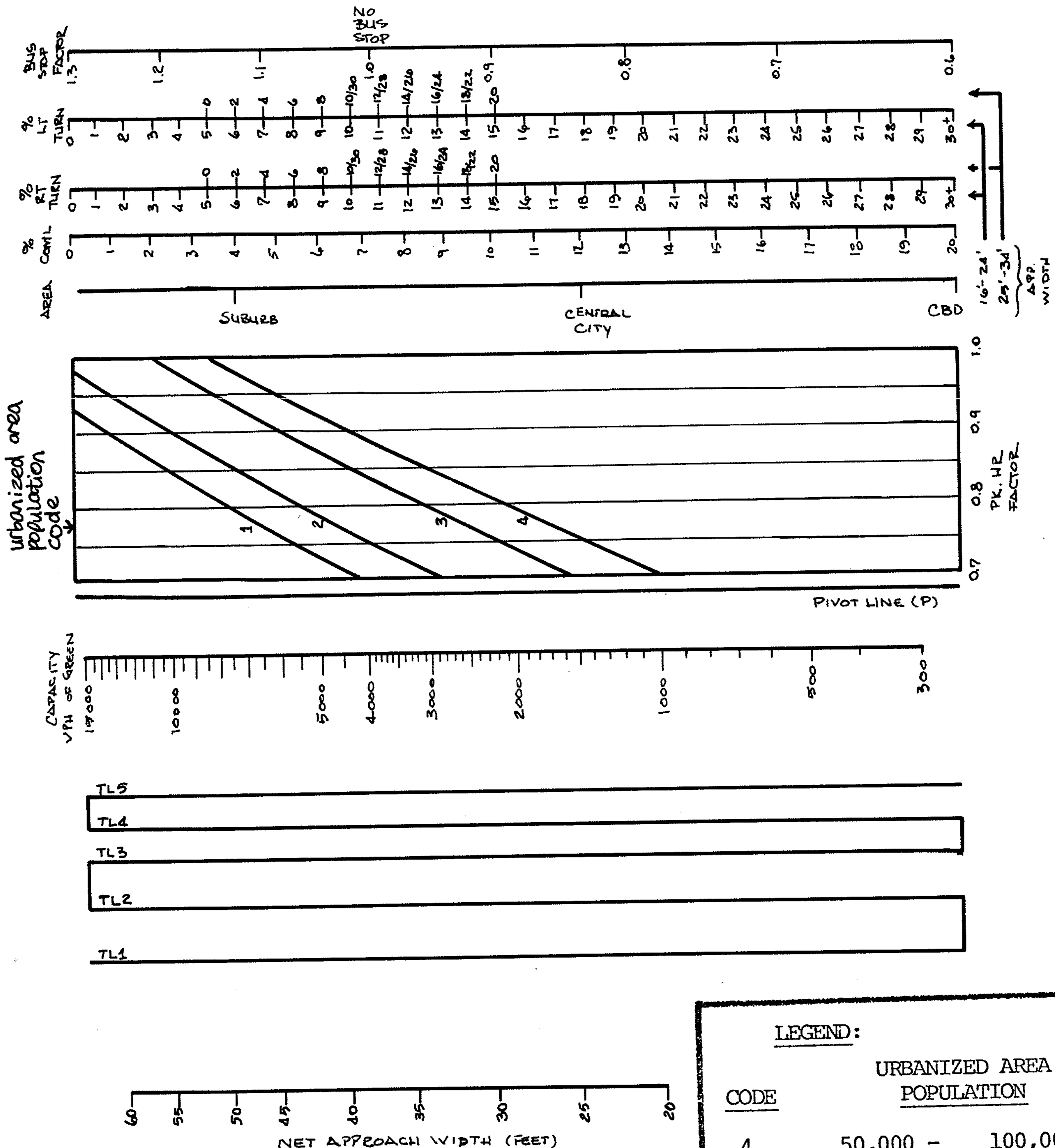
% COM'L VEH = 5%

% RT TURN = 10%

% LT TURN = 10%

BUS STOP FACTOR = 1.0

a. Do not adjust for urbanized area population <u>or</u> location. Capacity shown is adjusted capacity.



LEGEND:

CODE	URBANIZED AREA POPULATION
4	50,000 - 100,000
3	100,000 - 250,000
2	250,000 - 750,000
1	750,000 - 2,000,000

Figure 119. Detail capacity nomograph for urban arterials: one-way, no parking.

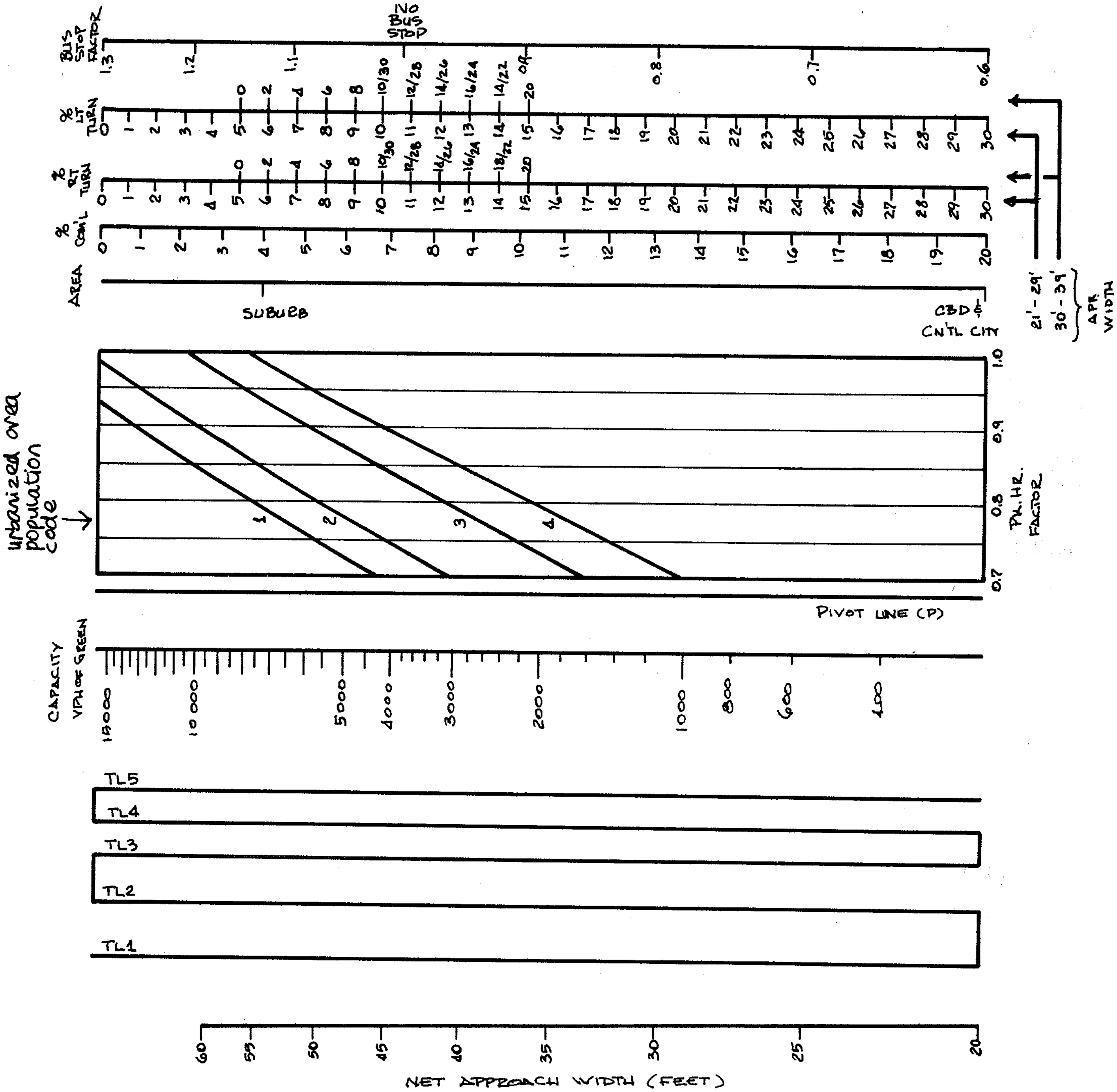


Figure 120. Detail capacity nomograph for urban arterials: one-way, parking one side.

LEGEND:

CODE	URBANIZED AREA POPULATION
4	50,000 - 100,000
3	100,000 - 250,000
2	250,000 - 750,000
1	750,000 - 2,000,000

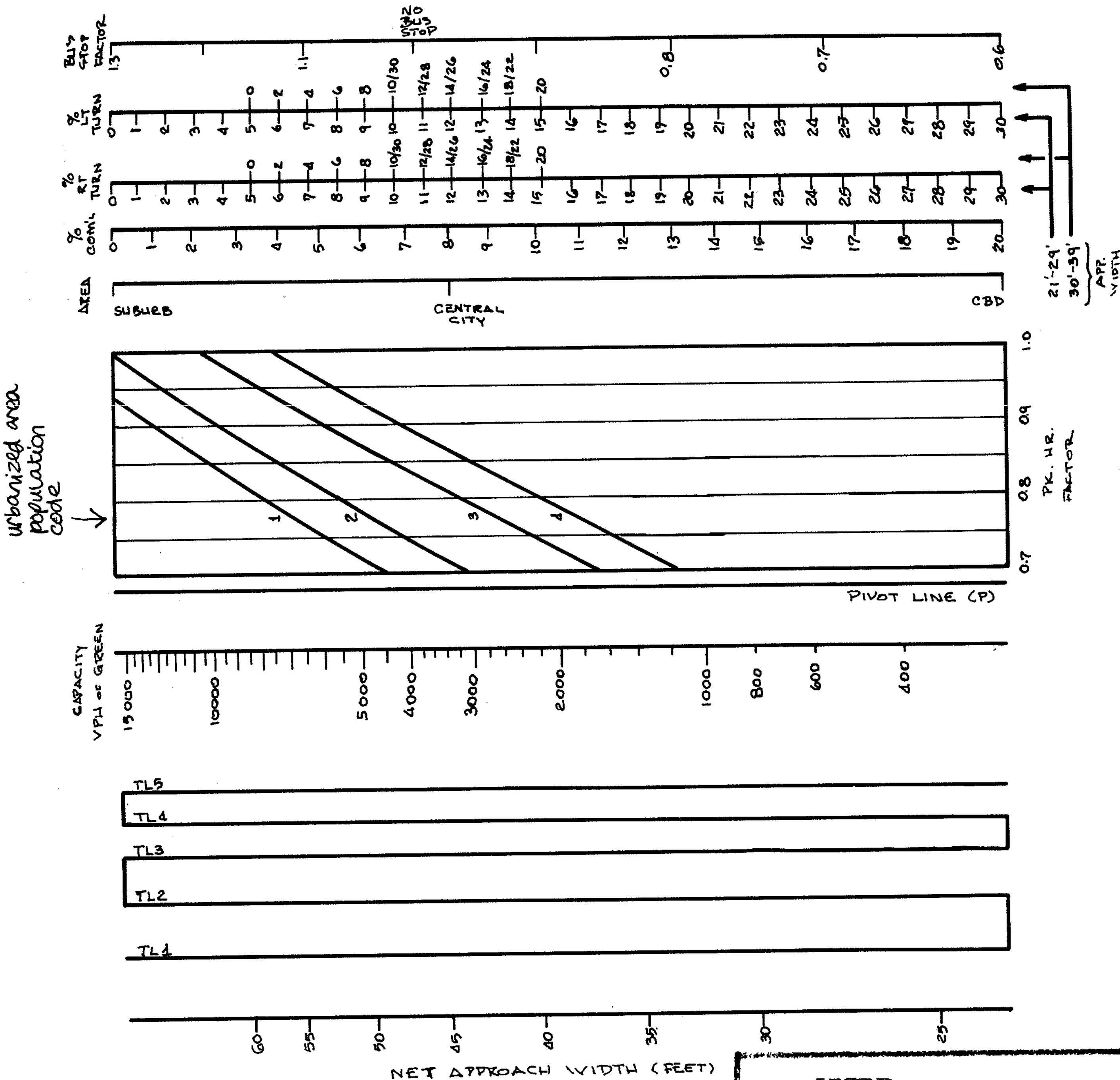


Figure 121. Detail capacity nomograph for urban arterials: one-way, parking both sides.

LEGEND:

CODE	URBANIZED AREA POPULATION
4	50,000 - 100,000
3	100,000 - 250,000
2	250,000 - 750,000
1	750,000 - 2,000,000

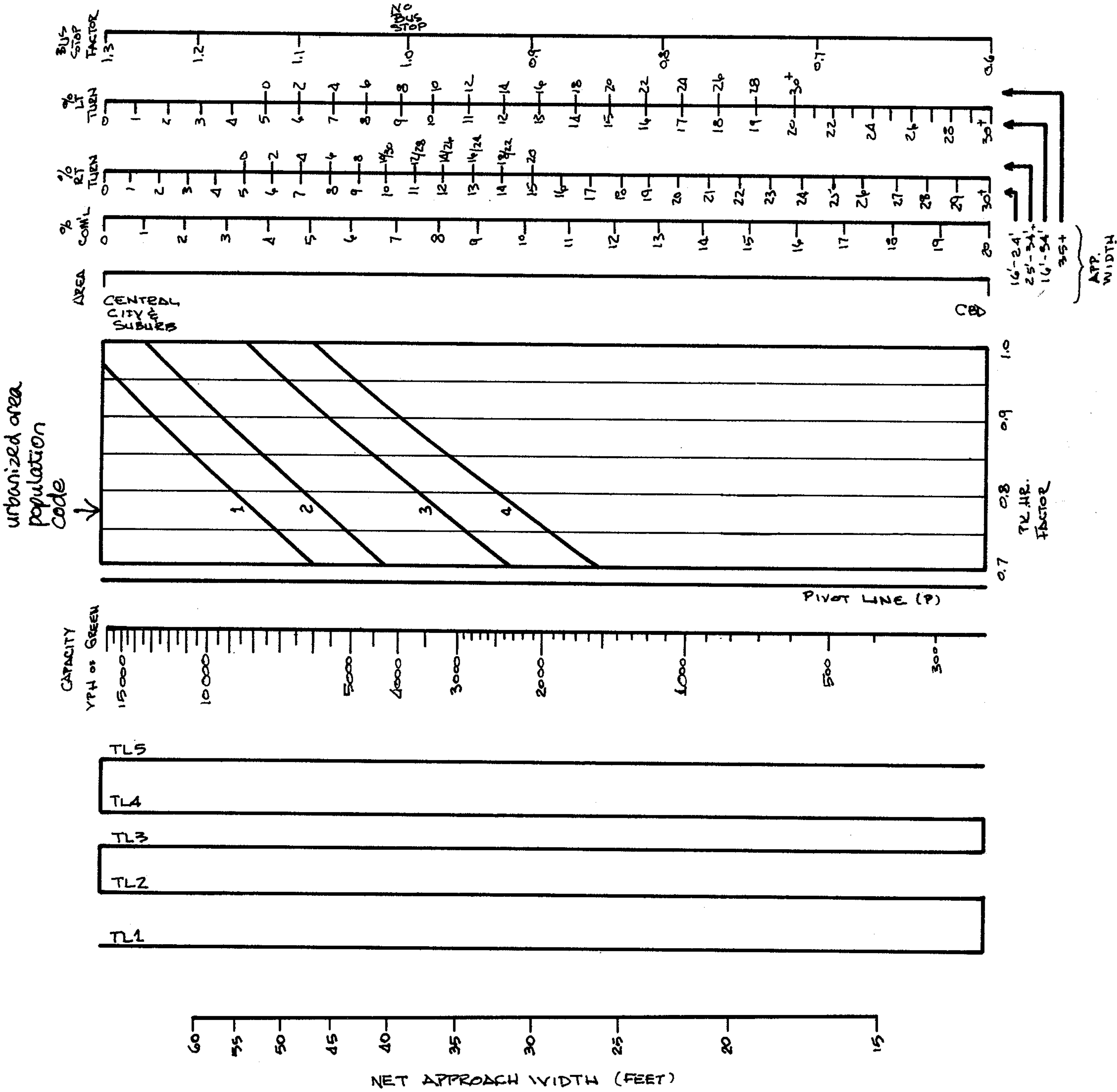


Figure 122. Detail capacity nomograph for urban arterials: two-way, no parking.

LEGEND:

CODE	URBANIZED AREA POPULATION
4	50,000 – 100,000
3	100,000 – 250,000
2	250,000 – 750,000
1	750,000 – 2,000,000

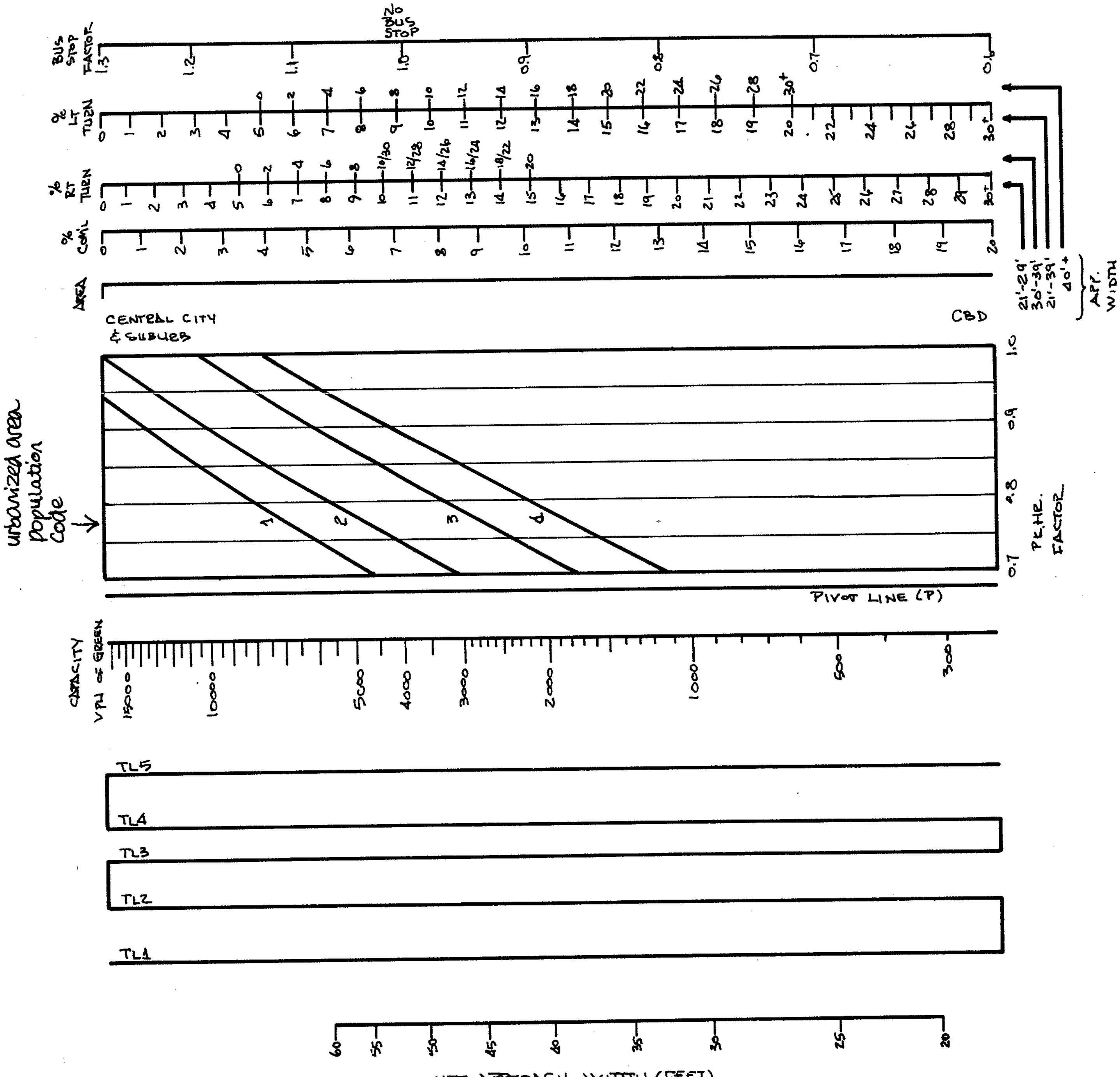


Figure 123. Detail capacity nomograph for urban arterials: two-way, with parking.

LEGEND:

CODE	URBANIZED AREA POPULATION
4	50,000 - 100,000
3	100,000 - 250,000
2	250,000 - 750,000
1	750,000 - 2,000,000

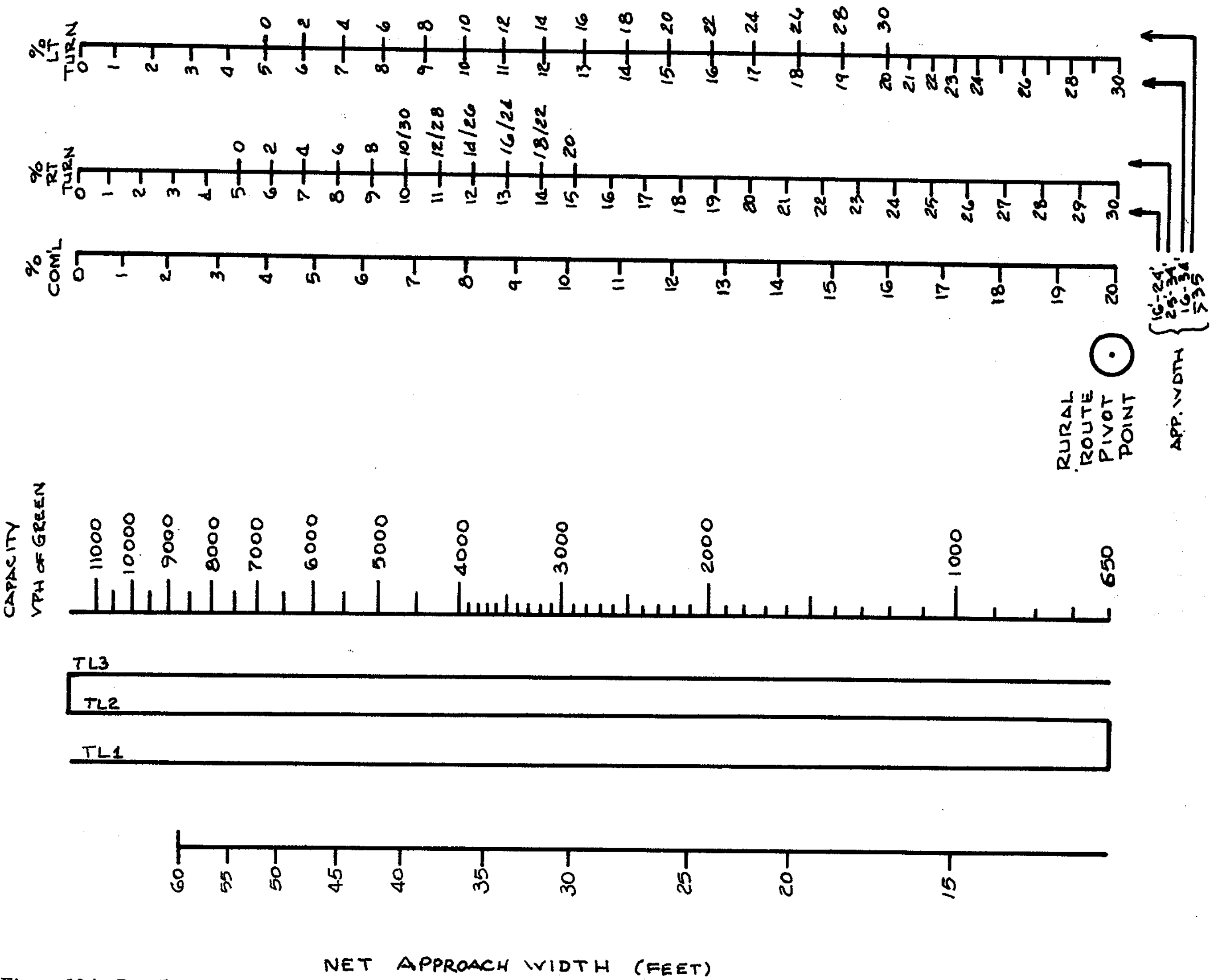


Figure 124. Detail capacity nomograph for rural route: two-way, no parking.

from 16 to 34 ft, use the left-hand scale. For approach widths over 35 ft, use the right-hand scale. If the left-turn lane is calculated separately, use the point representing 0 percent left turns.

Two-way streets—With parking. For approach widths from 21 to 39 ft, use the left-hand scale. For approach widths over 40 ft, use the right-hand scale. If the left-turn lane is calculated separately, use the point representing 0 percent left turns.

7. Using the point on TL 5, lay a straightedge between TL 5 and "no bus stop" on the bus stop line. The point of intersection with the capacity line gives the capacity in VPH of green time. (Solution: Capacity = 3,050 VPH/G.)

8. Using Figure 125, the capacity in VPH of green time can be used to derive the approach-capacity estimate if the percent green time is known. For example, if green time was 50 percent of total time the hourly capacity would be 1,600 VPH.

If Figure 124 is used, the procedure is essentially the same except less variables (consequently fewer turning lines) are considered. The procedure is as follows:

1. Lay a straightedge between the approach width and the "rural route pivot point" and note the intersection with TL 1.

2. Using TL 1, lay a straightedge between TL 1 and "percent commercial vehicles" and note the point the straightedge intersects TL 2.

3. Using TL 2, lay a straightedge between TL 2 and "percent right turns" and note the point the straightedge intersects TL 3.

4. Using TL 3, lay a straightedge between TL 3 and "percent left turns." The point of intersection with the capacity lines gives the capacity in vehicles per hour (VPH) of green time.

5. Adjust the capacity to give hourly approach capacity by multiplying by the G/C ratio or by using Figure 125.

DETERMINATION OF LEVEL OF SERVICE

The user now has the necessary information (volume and capacity) to determine the level of service at which the corridor or facility is operating. The determination can be displayed graphically using a facilities stress diagram

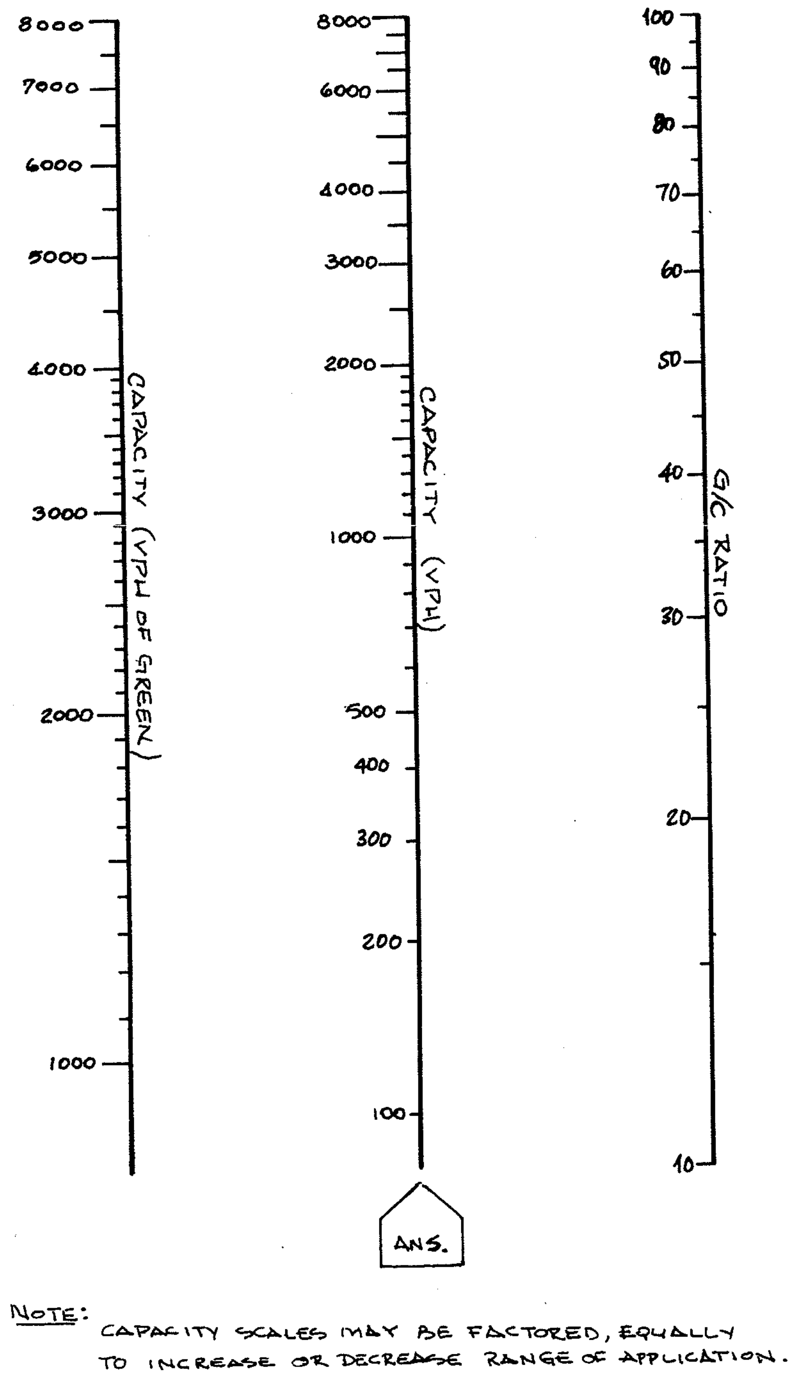
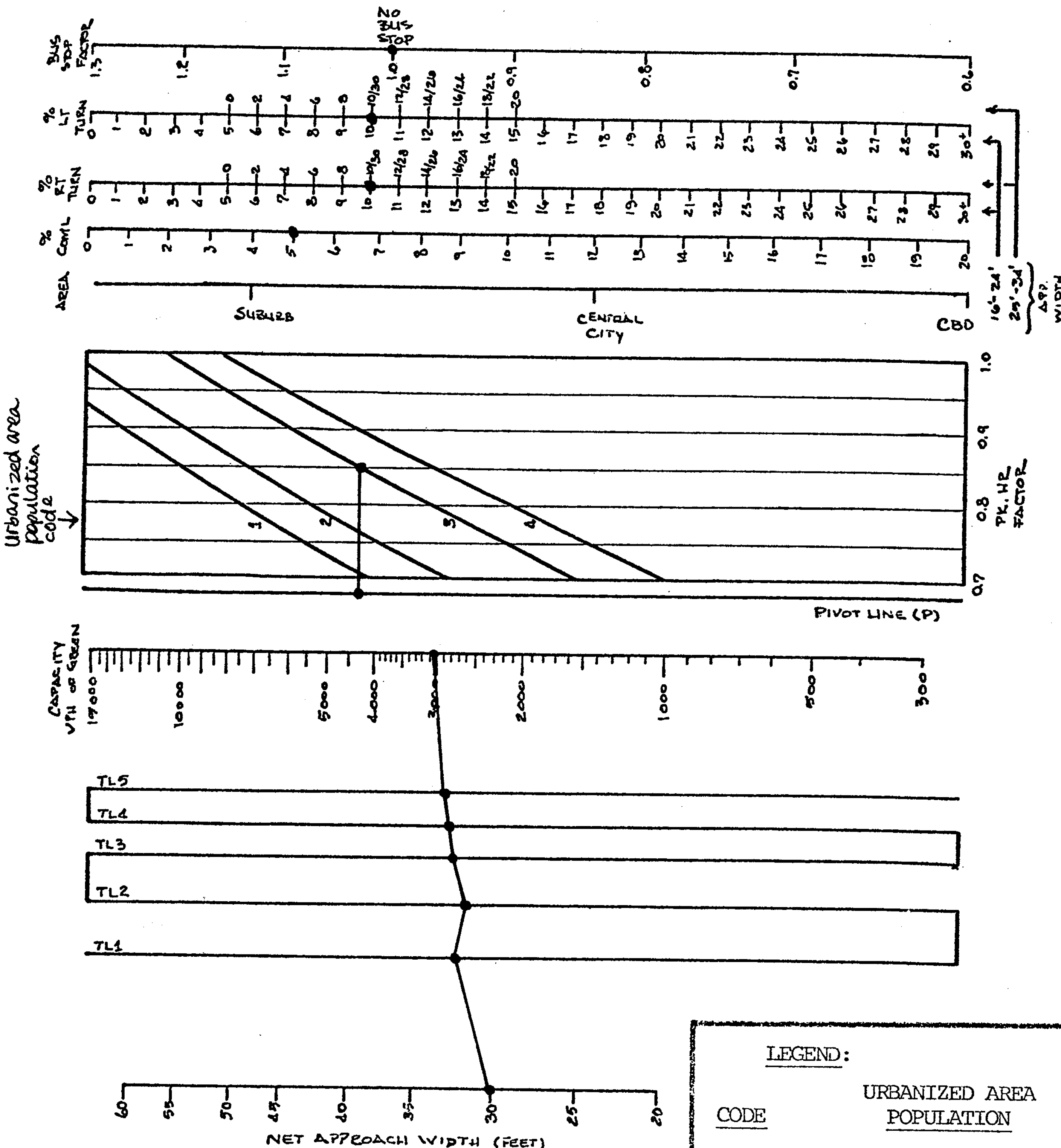


Figure 125. Capacity conversion nomograph for urban arterials for cycle length.

as previously described. Benchmark V/C ratios for each level of service are required to use as a datum for that determination.

Volume-to-capacity ratios were previously shown for freeway configurations (Table 50) and should be used as datum lines when evaluating freeways and expressways. For urban arterials and corridor analyses (consideration of combined facilities), V/C ratios should be used as the upper limit of each service level as follows:

LEVEL OF SERVICE	MAXIMUM V/C RATIO
A	0.6
B	0.7
C	0.8
D	0.9
E	1.0
F	(varies)



LEGEND:

CODE	URBANIZED AREA POPULATION
4	50,000 - 100,000
3	100,000 - 250,000
2	250,000 - 750,000
1	750,000 - 2,000,000

Figure 126. Sample application of detail capacity nomograph for urban arterials.

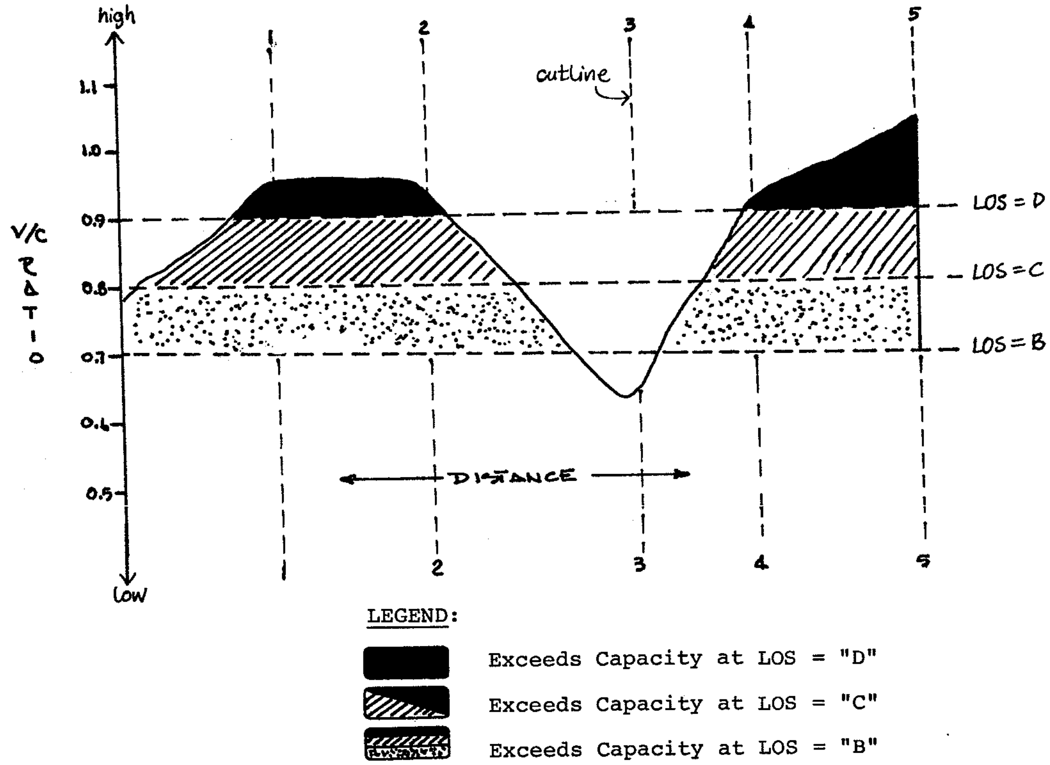


Figure 127. Facilities stress diagram with varying service levels.

Figure 127 is an extension of Figure 118 to show the impact of specifying a level of service for determining areas where available capacity is exceeded. The user can readily see the impact of establishing a level-of-service "C" as the datum versus using level-of-service "D" as the datum. Ultimately, the decision to use a higher service level will require capital and/or maintenance funds to remedy the deficiencies. Although a service level of "C" may be the least-cost solution, the analyst may need to reassess that position in light of available funds.

CHAPTER NINE

DEVELOPMENT DENSITY/HIGHWAY SPACING RELATIONSHIPS

INTRODUCTION

The trend toward lower population densities in and around major metropolitan areas has been underway for decades and apparently is continuing. The 1970 census disclosed that nearly one-half of the population of all metropolitan areas lived outside the central city. A large percentage of people seem to prefer low-density living. In addition, employment opportunities have followed the increase in households in suburban areas. This has resulted in a growing tendency for people to both live *and* work in relatively low-density suburban areas. The 1970 census reports that nearly a third of all work trips in large metropolitan areas now begin and end in the suburbs. This basic change in the structure of urban areas has been accompanied by increased demands for travel by auto. The auto is used for the vast majority of work travel in metropolitan areas, and the trends (despite improvements to transit systems) indicate that auto travel will continue to increase in suburban areas. Almost all travel for purposes other than work in suburban areas is made by auto. In turn, people are becoming increasingly more dependent on the auto. A major difficulty is that the auto, especially under low-density conditions which force lengthy travel, generates the need for substantial investments in the highway system.

New or widened freeways and arterials will be required in growing suburban areas if the level of transportation service is to remain at acceptable levels. Transportation facilities, however, are not now and never have been ends in themselves. It is becoming increasingly obvious to decision-makers that it will no longer be possible to provide an unlimited supply of new transportation facilities to meet these travel demands, and that other alternatives must be pursued. Such alternatives can include mixed public transportation systems, including taxi, dial-a-bus, or some other form of flexible-route systems interfacing with line-haul, transit modes. Other alternatives include ride-sharing modes such as van pooling. These systems are being planned and made operational in many urban areas and show promise in reducing the need for new and improved highway systems. Another method of reducing travel demands is to locate new development in such a manner to use available capacity or to place it where capacity can be provided, rather than permitting such development to overload existing facilities.

The purpose of this chapter is to relate suburban development to estimates of highway levels of service so that the planner and policymaker can rapidly assess the highway transportation needs of land-use growth and change. To make this chapter most useful and responsive, a method has been developed which interrelates land development and its subsequent transportation demands with highway system supply and the level of highway transportation service to be provided.

The following sections describe such a method, and examples are provided to illustrate the various steps involved. A complete "example application" is presented at the end of the chapter to enable the user to execute and become acquainted with the entire methodology. This example provides the specifics of computation, definitions of analysis areas, and the like.

BASIS FOR DEVELOPMENT

Several examples of pertinent methods are in the literature; those which seem most applicable are:

1. "Estimating Efficient Spacing for Arterials and Expressways," (*62*).
2. "The Highway Needs Model," (*63*).
3. "The Community Aggregate Planning Model," (*64*).

The first method develops theoretically optimum spacings so that the total regional transportation cost is minimized. The method uses uniform trip destinations per square mile, travel time, and operating and construction costs to arrive at desired freeway and arterial spacings.

The second method computes freeway spacing after having estimated vehicle-miles of travel (VMT) based on vehicle trip-end density and on the proportion of total roadway surface made up of freeways. Again, optimum solutions based on least costs are computed. Arterial spacing is not considered.

The third method generates a regional system-sensitive vehicular travel demand, distributes the demand to the arterial and freeway systems in each community, and computes a full range of useful evaluation measures.

Although other methods exist, or are being developed, it was felt that none fully met the need for a simple, straight-forward means of computing the need for improved highways based on increasing land-use activities in suburban areas. Stated differently, none of these methods could determine the effects on the level of highway transportation service if such facilities were not provided. In developing such a method, several criteria were thought to be desirable; of course, key simplifying assumptions had to be made. The criteria and assumptions are as follows:

1. Desirable criteria:
   - (a) An absolute minimum amount of information would be required.
   - (b) The terms and concepts would be understandable to citizens and politicians as well as planners.
   - (c) The method could be applied quickly and easily so that many alternatives could be evaluated.
   - (d) No computer would be required.
2. Simplifying assumptions:
   - (a) The levels of transportation service being examined would not so radically depart from today's service levels that travel demand would be altered significantly.
   - (b) The pricing of transportation service would not so radically depart from today's costs that travel demands would be altered significantly.

With these two key assumptions, an empirical rather than theoretical approach could be used.

DATA REQUIRED FOR APPLICATION

The basic data required consist of two parts: (1) land-use activity data, and (2) data about the highway transportation system.

If a major investment in transit is to be considered, some information is needed about that system as well. The land-use activity data needed are used as the means to generate the amount of highway travel by analysis areas (districts). Some experimentation may be required to determine the size and number of analysis areas to be used. The developers of the Community Aggregate Planning Model (CAPM) recommend that the size of the basic analysis units may range in area from 8 to 30 sq mi.

Land-use activity data required include as a minimum:

1. Number of households.
2. Number of jobs (at-place employment).

As an option, slightly better (more accurate) results may be obtained if the household information is subdivided further into:

1. Number of apartment units.
2. Number of townhouse units.
3. Number of single-family units.

Also, the employment information may be divided into:

1. Office employment.
2. Manufacturing employment.
3. Retail employment.
4. Other employment.

The existing highway transportation system data needed include the number of miles of highway by type by analysis area. Types of highway include:

1. Two-lane arterials and *major* collectors.
2. Four-lane arterials.

3. Six-lane arterials.
4. Freeways.

The method does not deal explicitly with non-line-haul transit improvements such as jitneys or dial-a-ride systems. Existing levels of conventional bus service resulting in typical levels of suburban transit use are assumed by the method used. Corrections may be made, if desired, to account for variations from the typical "mode split" percentage assumed. Corrections for auto-occupancy levels above or below those assumed may also be made, if desired.

FEATURES AND LIMITATIONS

The development density/highway spacing methodology is designed to produce the number of lane-miles of arterial highways required in an analysis area given land-use activity, a freeway system, and a desired level of arterial traffic service for that analysis area.

An estimate of the number of miles of freeway to be provided is made outside the procedure, but the method does indicate where such additional facilities would be desirable to improve the level of transportation service provided.

The methodology is shown diagrammatically in Figure 128. Computation steps are shown on the right-hand side, with inputs on the left and outputs in the center. Note that Step 3A is pertinent only if the analysis area (e.g., district) in question is at the periphery of the metropolitan region, in which case the external traffic makes a significant contribution to the vehicle-miles of travel (VMT) in that analysis area. This step is described in detail later in this chapter.

Limitations of the Methodology and Substitutability of Local Data

The development density/highway spacing method described is quite similar to the Community Aggregate Planning Model (CAPM) previously discussed. CAPM is a computer-based model, not a manual procedure. The density/spacing methodology does not, however, (as CAPM does) output economic, social, and environmental measures, it being limited in scope to the land-use/highway spacing area. But because the methodology does contain performance measures (the amount of VMT on freeways, and the arterial level-of-service distribution), it is possible to produce travel speed measures on an areawide basis if the user so desires.

For such a case, it may be useful to express level of service as a speed as well as a percentage of VMT over a level of service. Figure 129 has been derived to express the relationship between these variables. The curve was constructed for arterial routes by assuming the level-of-service speeds given in Table 52 and weighting those speeds by the amount of travel at different levels of service from Table 52 (and Fig. 142 shown later in the text). The daily curve reflects an assumption of no congestion in the off-peak period. Estimates of the average speed of travel, along with VMT can be used in conjunction with emission rates by speed of travel to provide first-cut estimates of changes in air quality (*65*). Speed of travel may also be used in estimating changes in operating, accident, and travel time costs in an area (*66*). This information can be used in evaluating the cost-effectiveness of alternative program proposals. Because most social, economic, and environmental measures require vehicle-miles of travel and speed as inputs to subsequent calculations of accessibility, mobility, value of travel time, and air quality computations, it would be possible to add such output capabilities to the density/spacing methodology described herein.

As volumes increase on a facility (the new volumes being output from a traffic assignment), speed declines, and operating, accident, and time costs (i.e., user costs) increase. At some point, a new or widened facility is warranted because the costs of improving the system are exceeded by the costs in allowing congestion to continue. Figure 130 shows the total user cost of travel per mile for different facilities and at different traffic volumes, including construction and maintenance costs for new facilities. Construction and maintenance costs were based on recent estimates for the Washington, D.C. metropolitan area whereas operating and accident costs were derived from published data and corrected to reflect current gasoline prices. The value of time was set at $2.50 per person-hour. Construction costs were annualized over 20 years at a 10-percent interest rate. The data shown in Figure 130 (and in Table 52) indicate that under these assumptions, least-cost solutions correspond to traffic volumes which exist between levels-of-service "C" and "D." It should be pointed out that Figure 130 is not an integral part of the method, as will be shown in the application described in the next section.

Other limitations revolve about the assumptions made and the use of average trip rates and trip lengths. These can be overridden, however, and locally supplied data substituted. There probably is no adequate substitute for a complete set of traffic counts in this regard. Many problems of limitations in accuracy owing to generalization can be overcome based on traffic counts and with the use of common sense.

APPLYING THE DEVELOPMENT DENSITY/HIGHWAY SPACING METHODOLOGY

At least three distinct, potential applications of the density/spacing method exist. The method is an attempt to fill a critical void in transportation planning; that is, the rapid estimation of the effects of alternative land-use and transportation plans on the level of transportation service.

The first application would be:

Given existing land development and existing transportation facilities, what level of service is being provided by the transportation system?

The density/spacing method would indicate the following key items:

1. Percentage of vehicle-miles of travel accommodated on freeways and arterials.
2. Average volume per lane on the freeway system.
3. Percentage of arterial vehicle-miles of travel over level-of-service "C."

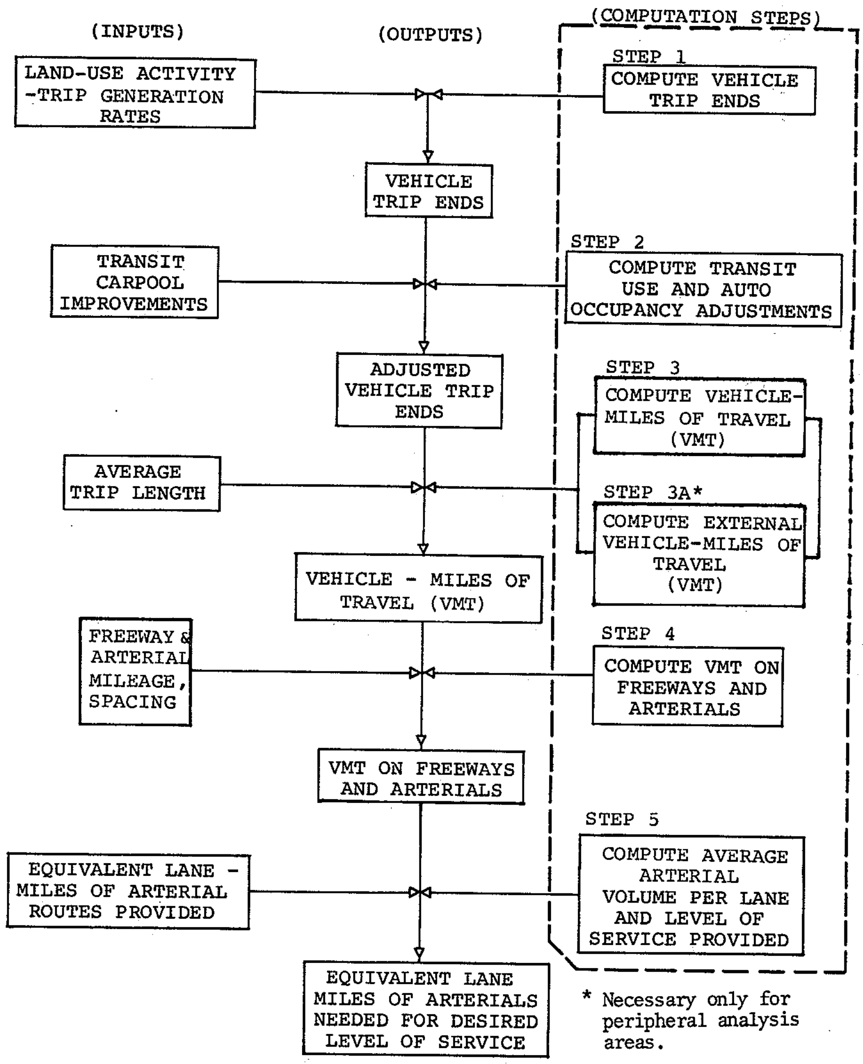


Figure 128. Diagrammatic representation of the development density/highway spacing methodology.

TABLE 52

ARTERIAL LEVEL OF SERVICE VOLUMES

Approximate Peak Hour Operating Speed (MPH)	Traffic Volumes All Lanes						Level of Service
	2-Lane		4-Lane		6-Lane		
	Peak Hour[a]	Daily[b]	Peak Hour[a]	Daily[b]	Peak Hour[a]	Daily[b]	
35	<250	<4,150	<800	<13,330	<1,300	<21,500	A
30	250	4,150	800	13,300	1,300	21,500	B
25	375	6,250	1,200	20,000	1,950	32,500	C
20	450	7,500	1,440	24,000	2,340	39,000	D
15	500	8,333	1,600	26,600	2,600	43,300	E
10	>500	>8,333	>1,600	>26,600	>2,600	>43,300	F

a. One-way
b. Two-way (assumes a peak hour factor (K) = 0.10 and a directional factor (D) = 0.60)
Source: Adapted from Highway Capacity Manual (56).

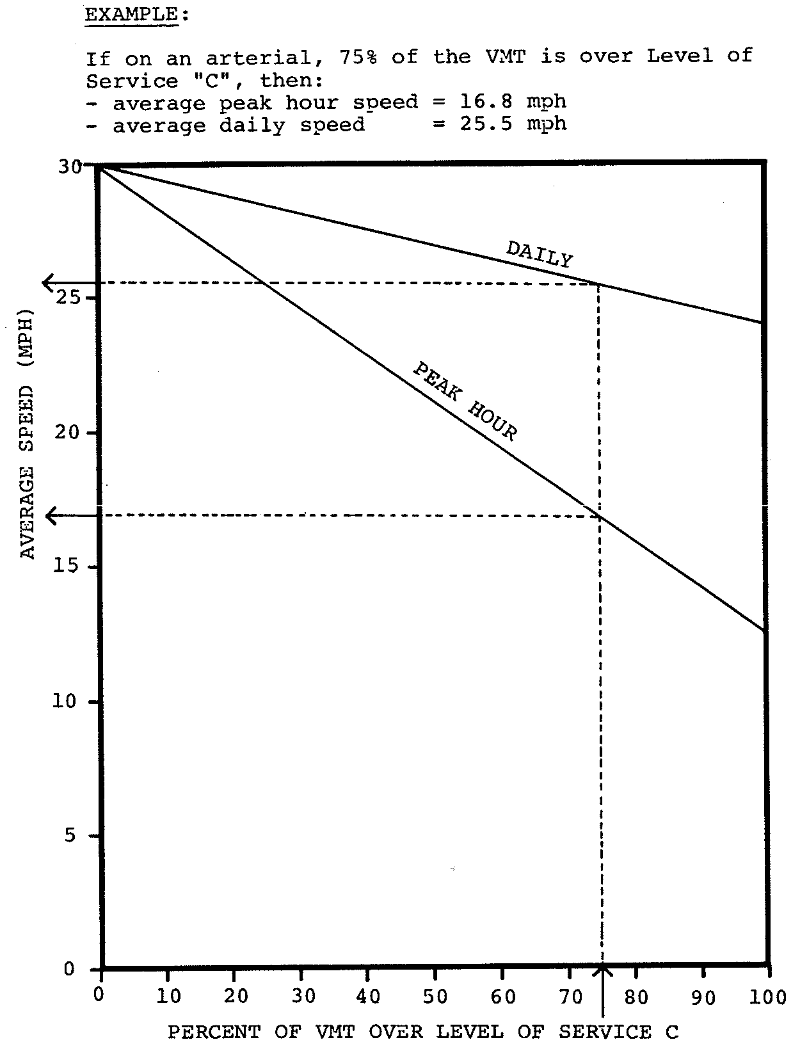


Figure 129. Arterial level-of-service speeds, by analysis areas.

A second application would be:

Given a future land-use plan, what increases in transportation facilities are required in order to keep today's (or a desired) level of transportation service?

The density/spacing method would indicate the following key items:

1. Given a fixed or revised freeway system, it would compute the vehicle-miles of travel on freeways and arterials.
2. Number of equivalent lane-miles of arterials that need to be added, either by widening existing routes or by new construction, to achieve today's (or a desired) level of service.
3. Where enlarged or new freeways or improved transit service may be desirable in order to reduce the need for arterial improvements.

A third possible application would be:

Given an existing or future transportation plan, what amount of land development can be added without allowing the level of traffic service to deteriorate below a specified level?

This third application is best accommodated through a trial and error process, successively increasing (or reducing) the amount of land development by analysis area until the level of service limitation is reached. Because the technique can be applied rapidly, many "runs" can be made in a reasonable time-frame. The effect of freeways and additional transit service can also be taken into account.

Steps in Application

To apply the density/spacing method, the following steps must be undertaken for each analysis area in the study area of interest.

Step 1: Computation of vehicle trip ends. Vehicle trip-generation rates are based on those given in Chapter Two, "Trip-Generation Estimation." Two methods (I and II) can be used, one assuming that only the number of households and the number of at-place jobs are known by analysis area, and the other assuming further breakdowns into type of dwelling unit and kinds of employment as outlined in the preceding section on "Data Required for application."

It must be noted that because trips have both an origin and destination trip end, and because the procedure

EXAMPLE:

It is expected that on an existing 4-lane arterial, the traffic volume is projected to increase from the current 25,000 to 30,000 vehicles per day. The graph shows that it would be economical to widen the 4-lane arterial to a 6-lane rather than building a new 4-lane arterial. For the former option the total user cost of travel would be 25¢/mile, and for the latter it would be 38¢/mile.

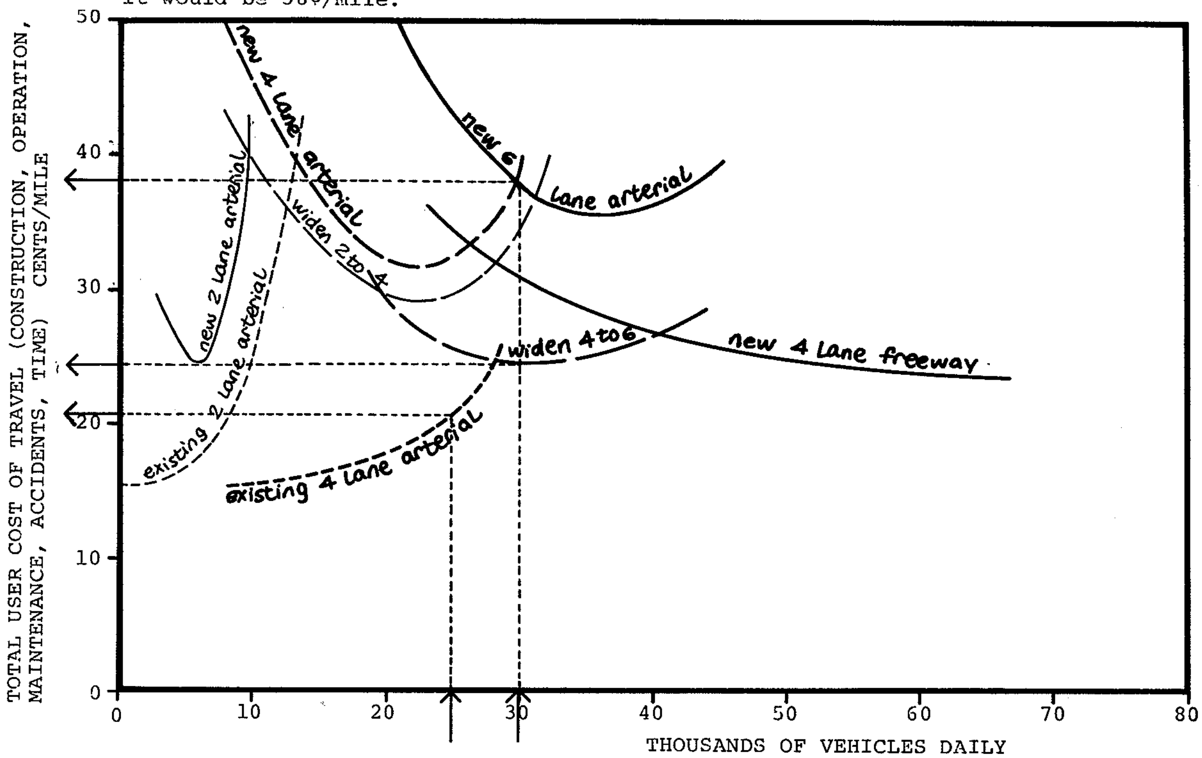


Figure 130. Least-cost solutions for various highway volumes and facilities.

involves calculation of trip-end generation for both residential and nonresidential activities, the sum derived for trips to and from all trip generators will be twice the area total number of one-way trips. Accordingly, the number of trip ends computed must be cut in half for use in computing vehicle-miles of travel.

Method I uses just total households and total employment for each analysis area. Rates for this method are derived from data given in Table 1, Chapter Two. For example, a trip rate per household of approximately 5 one-way vehicle trips daily (10 ÷ 2) would be used for single-family dwellings, 3.5 for medium-density dwellings, and 3.0 for apartments. Based on the approximate proportion of areawide single, medium- and high-density dwelling units expected, a single over-all rate per dwelling unit can be computed and utilized.

Method I uses (for nonresidential activities) an average trip rate per employee derived from a weighted average of rates for individual employment categories. For example, if the proportion of total jobs in a study area were 21.5 percent for office employment, 18.5 percent for retail, 10.0 percent for manufacturing, 23.0 percent for military, and 27.0 percent for other, and the trip rates were, respectively, 1.75, 10, 1.5, 1.25, and 5 one-way vehicle trips daily (appropriate trip ends in Table 1, divided by 2), the weighted average daily vehicle trip rate per job would be 4.0. This average trip rate is applied to all analysis areas.

Method II uses these rates directly by type of residential unit for each analysis area rather than developing the single over-all rate previously described. In this case, a breakdown by type of unit is needed for each analysis area.

For nonresidential activities, trip-generation rates can be expressed as functions of at-place employment, floor space, or acres as given in Table 1. Again, vehicle trips per day are used, but reduced by half to reflect the one-way nature of travel. The best measure, if available, is employment, as this can be summed to a control total for the area as a check.

Method II applies individual rates to each land-use or employment category for each analysis area, thereby requiring more detailed input information than Method I.

An alternate approach to using Table 1, as described previously, for Methods I and II would be the use of generalized data and equations provided in Table 3, Parts A and C. Use of this information would minimize much of the land-use mix data and also eliminate "averaging."

Step 2: Computation of transit use and auto-occupancy adjustments. In some urban areas, particularly larger ones, transit improvements may be planned which could have significant impacts on future vehicle-miles of travel within the area. Figure 131 shows the effect of changes in the percentage use of transit on the percentage of auto driver trips (of total person-trips), and hence on VMT. For example, if an analysis area had a percentage transit use of 6 percent, and this could be increased to 15 percent, the percentage of auto driver trips would drop (given an auto-occupancy rate of 1.33) from 70 to 64 percent. This represents a change of 8.6 percent, assuming that total travel would remain constant. Where changes in the relative use of transit are contemplated, this curve can estimate the effect on auto use and VMT. In addition to this curve, local relationships can be used (or derived) to estimate changes in transit use.

Changes in auto occupancy also affect vehicular travel and VMT. Figure 132 shows the percentage change in auto driver trips as vehicle occupancy increases. Again, reductions in vehicular miles of travel can be computed for various increases in auto occupancy using a method similar to that illustrated for transit increases. (Note that adjustments can also be made simultaneously for increases in both transit use and auto-occupancy rates using Figure 131.) This is particularly applicable where vigorous car and van pooling programs are planned. Local area experience can be used as required. Present daily car occupancies range from 1.7 in urbanized areas with less than 100,000 population to 1.5 in urbanized areas with more than 750,000 population.

Adjustments for transit use and auto occupancy are optional, but the use of high-occupancy vehicles can impact on freeway and arterial highway requirements and should be considered, if warranted.

Step 3: Computation of Vehicle-miles of travel. The third step is to compute vehicle-miles of travel for each analysis area by multiplying the results of Step 1 (i.e., vehicle trip ends) by the areawide, average over-the-road vehicular trip length. The airline trip distance can be obtained from Figure 133. The data shown are based on prior research into urbanized area population and average trip length (*18*) adjusted upward by 10 percent to account for increased speeds and lower densities of development in urbanized areas since the research source data was obtained. For future years, an estimate of such corrections

EXAMPLE:

Given an auto occupancy rate of 1.33 persons/auto, then:
- @ 6% transit use, auto driver trips = 70%
- @ 15% transit use, auto driver trips = 64%
- ∴ $\% \Delta = \frac{64-70}{70} \times 100 =$ 8.6% reduction in auto driver trips.

If the auto occupancy rate were to concurrently increase from 1.33 to 1.50 persons/auto, then:
- @ 6% transit use and 1.33 persons/auto, auto driver trips = 70%
- @ 15% transit use and 1.50 persons/auto, auto driver trips = 57%
- ∴ $\% \Delta = \frac{57-70}{70} \times 100 =$ 18.6 reduction in auto driver trips.

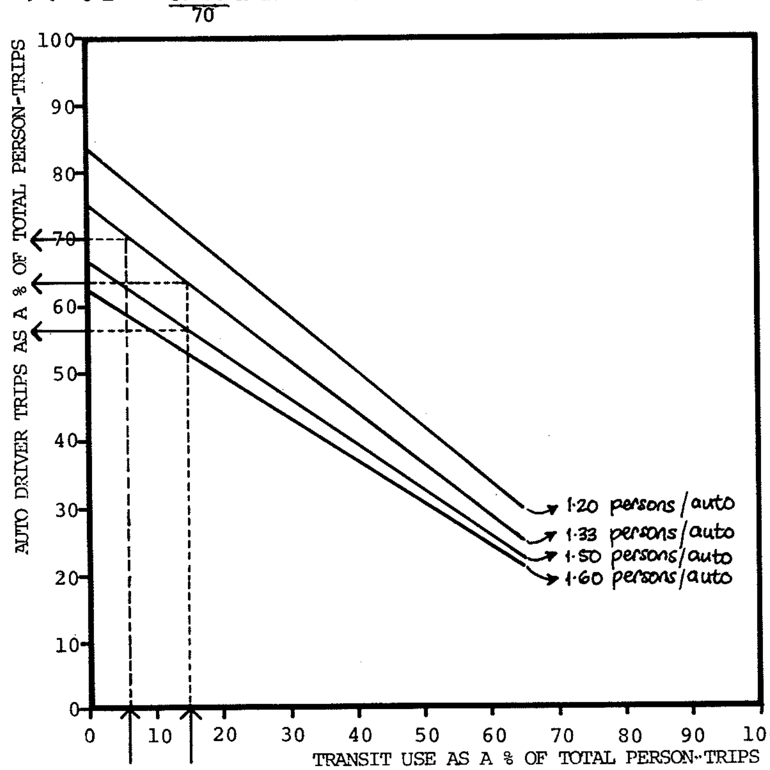


Figure 131. Effect of change in transit use on auto driver trips.

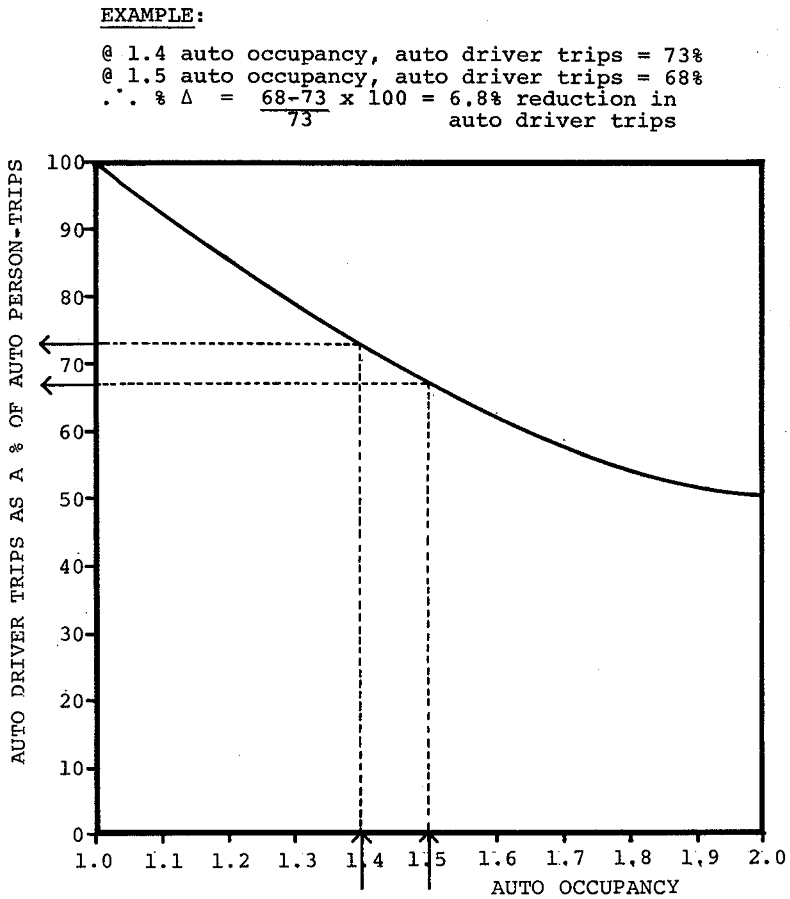


Figure 132. Effect of change in auto occupancy on auto driver trips.

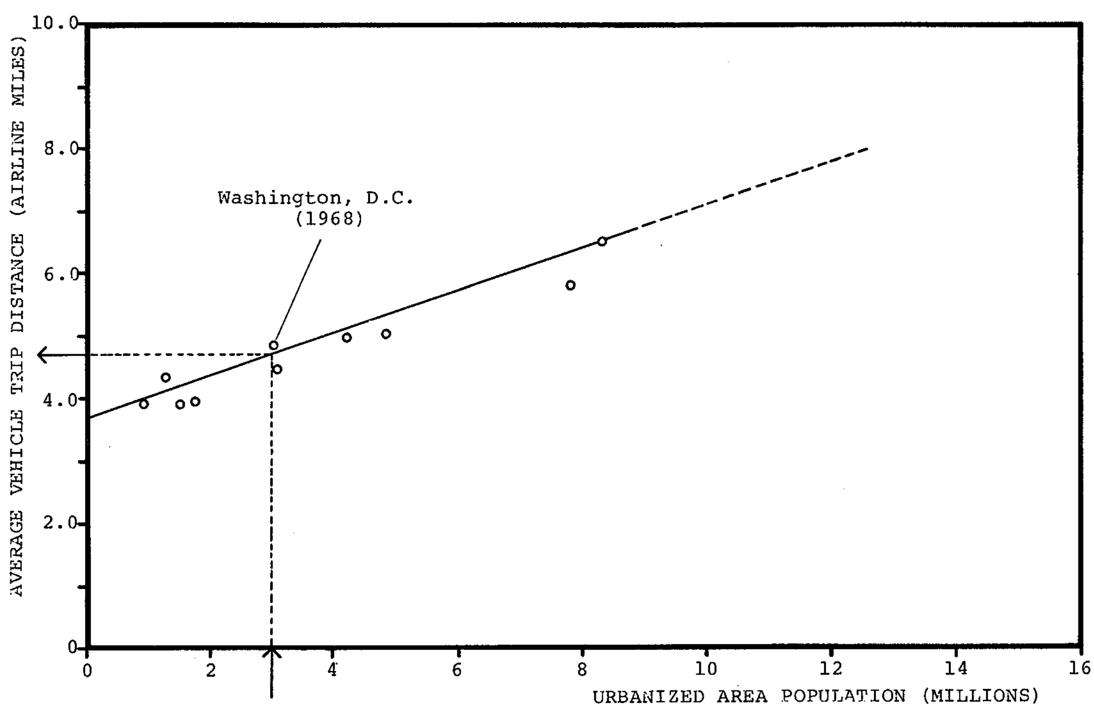


***Figure 133. Average vehicle trip distance (airline) vs urbanized area population* (18).**

to be applied can be obtained from Figure 134 for home-based work (HBW) trips. These corrections for changing speed are based on more recent research into trip lengths (*67*).

To illustrate the use of Figure 134, suppose that the average network speed change is +10 percent over the base-year conditions, that is, $S_2/S_1 = 1.10$. Entering Figure 134, the average auto HBW trip distance (airline) change would be given by $L_2/L_1 = 1.15$, that is, a change in trip distance of +15 percent.

If the average trip distance for a study area is known, it may, of course, be used. If the average home-based nonwork (HBNW) trip distance is estimated using Figure 135 (which relates the length of HBW and HBNW trips), then by weighting the trip lengths by the amount of HBW and HBNW travel, one can obtain an estimate of total trip length. For example, in Washington, D.C., the average HBW airline trip length was 8.0 mi. Using Figure 135, the average HBNW airline trip length is then 4.0 mi. Table 3, Chapter Two indicates that 25 percent of all trips are for work purposes. Therefore, the daily weighted average is [(8.0 × 0.25) + (4.0 × 0.75)], or 5.0 airline miles. Note that Figure 133 shows that the result for a city of just over 3,000,000 population is aproximately 4.8 airline miles, thus confirming the aforementioned results.

As these figures represent airline distance travel, they need to be expanded to over-the-road trip distances by multiplying by a circuity factor. This factor can range from 1.2 to 1.4 (or even higher) depending on the configuration of the highway network in the urbanized area. The presence of river or topographic barriers will cause higher values. For example, if the 5-mi airline distance in Washington, D.C., is multiplied by 1.3, it results in an average over-the-road vehicular trip length of 6.5 mi.

Thus, having obtained the areawide average over-the-road trip distance, this figure is then multiplied by the results of Step 1 (i.e., vehicle trip ends) to compute vehicle-miles of travel by analysis area.

Step 3A: Computation of external vehicle-miles of travel adjustment. In addition to the vehicle-miles of travel generated by the residential and nonresidential activities *within* each analysis area, an adjustment has to be made for traffic generated *beyond* the boundaries of the study area. This adjustment, however, need only be applied to those analysis areas that are located on the periphery of the study area; here, the "external" traffic contributes significantly to the VMT calculated from Step 2. This correction was deemed necessary through empirical testing of the density/spacing methodology.

This external traffic is obtained from counts located at the circumference (cordon) of the analysis area in question. Note that the count must first be adjusted to account for the "double-counting" of through trips. For this purpose, the user is referred to Figure 1 in Chapter Two. Should any of the count stations be located at a freeway, such counts must be excluded altogether from the adjustment process. This also is based on empirical evidence gathered through testing of the density/spacing method.

Because some of the external trips at nonfreeway cordon locations are already reflected at one end in the peripheral analysis areas, they should be reduced by one-half. The

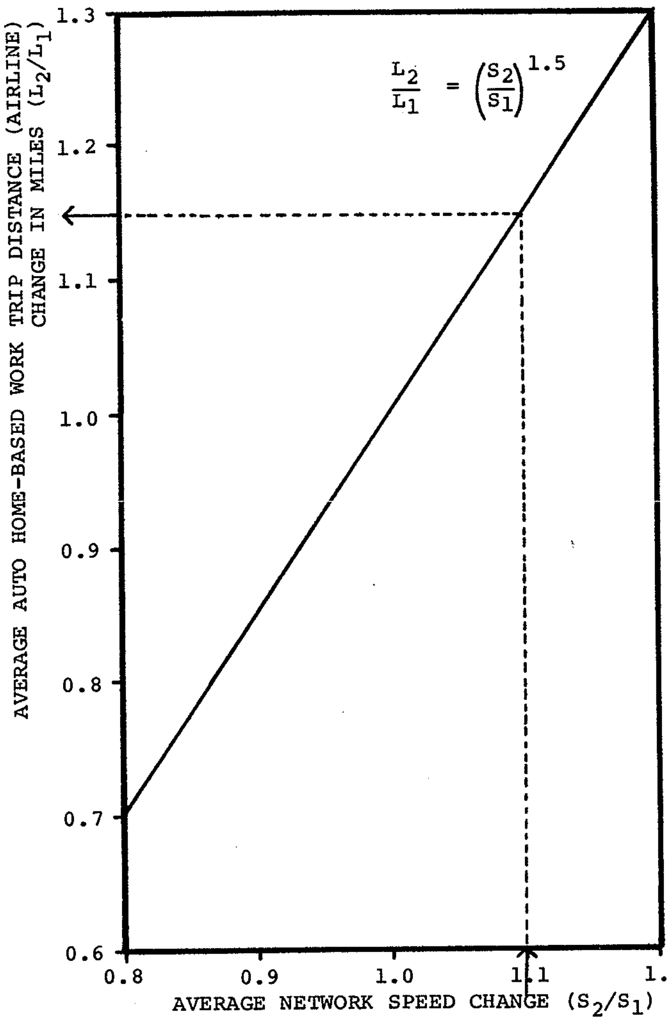


Figure 134. Adjustments to average auto home-based work/trip distance (airline) for average network speed change (67).

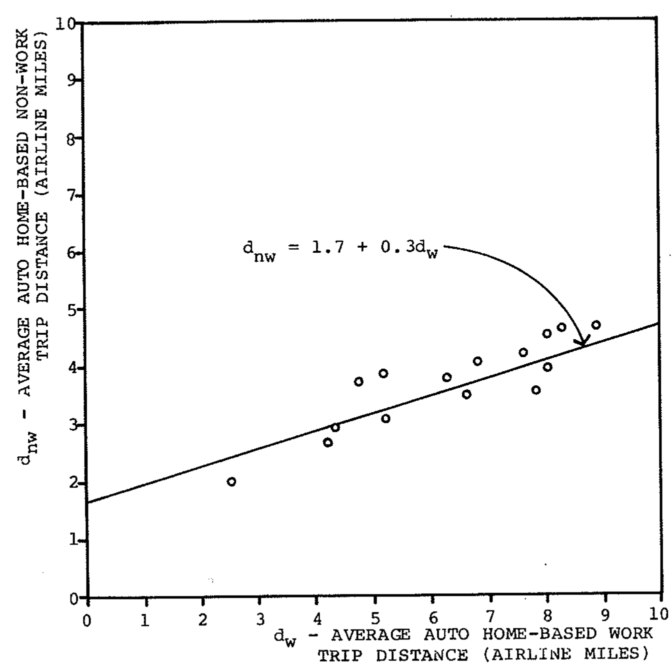


Figure 135. Relationship between auto home-based work and auto home-based nonwork trip distances (airline) (64).

result is then multiplied by the average trip length computed from Step 3 to arrive at the external VMT. Then, this VMT owing to the external trips is added to the VMT calculated from Step 3 for the peripheral analysis area to obtain the total VMT.

Step 4: Computation of vehicle-miles of travel on freeways and arterials. The vehicle-miles of travel computed through application of the previous steps must be accommodated by three levels of highway transportation systems; that is, freeways, arterials (and major collectors), and local streets (including minor collectors). The amount of travel that desires to be accommodated on the freeway system is a function of the spacing between freeways, the spacing of arterial and local routes, the average trip length, and the average vehicle trip density (*68*).

The relationship can be expressed as follows:

$$V_1 = \frac{P\bar{r}}{2\left[\frac{1}{Z_1} + \frac{1}{\bar{r}} + \frac{Z_2}{\bar{r}(Z_1 - Z_3)}\right]} \qquad (38)$$

where:

V_1 = average daily traffic on freeway;
P = average daily vehicle trip origins/sq mi;
$\bar{r}$ = average vehicle trip distance (mi);
Z_1 = freeway spacing (mi);
Z_2 = arterial spacing (mi);
Z_3 = local street spacing (mi).

This relationship can be used to solve for freeway spacing if desirable freeway traffic volumes are known. Then in solving for Z_1, and approximating Z_3 at 0 to simplify solution:

$$Z_1 = \frac{2V_1(\bar{r} + Z_2)}{P\bar{r}^2 - 2V_1} \qquad (39)$$

Figure 136 shows desirable freeway spacing based on this relationship for a 6-mi average trip length. Thus, for example, for a daily vehicle trip origin density of 14,000 trip ends/sq mi, a 6-lane freeway must be spaced at 4.8 mi, and an 8-lane freeway at 8.2 mi. A full discussion concerning the determinants of freeway spacing appears in the Institute of Traffic Engineers publication, "System Considerations for Urban Freeways" (*69*).

Given the information required * for the relationships previously described, either freeway volumes or spacing can be computed. If a specific level of service is desired,† it is possible to compute the miles of freeway required. Daily volumes corresponding to levels of service are given in Table 53. Similarly, if spacing is set (i.e., no new routes are contemplated), then the traffic volume on freeway facilities (and hence VMT) can be computed.

Subtracting this freeway VMT from the total gives the residual VMT that must be accommodated on arterial and local streets.‡ After subtracting a percentage of the total

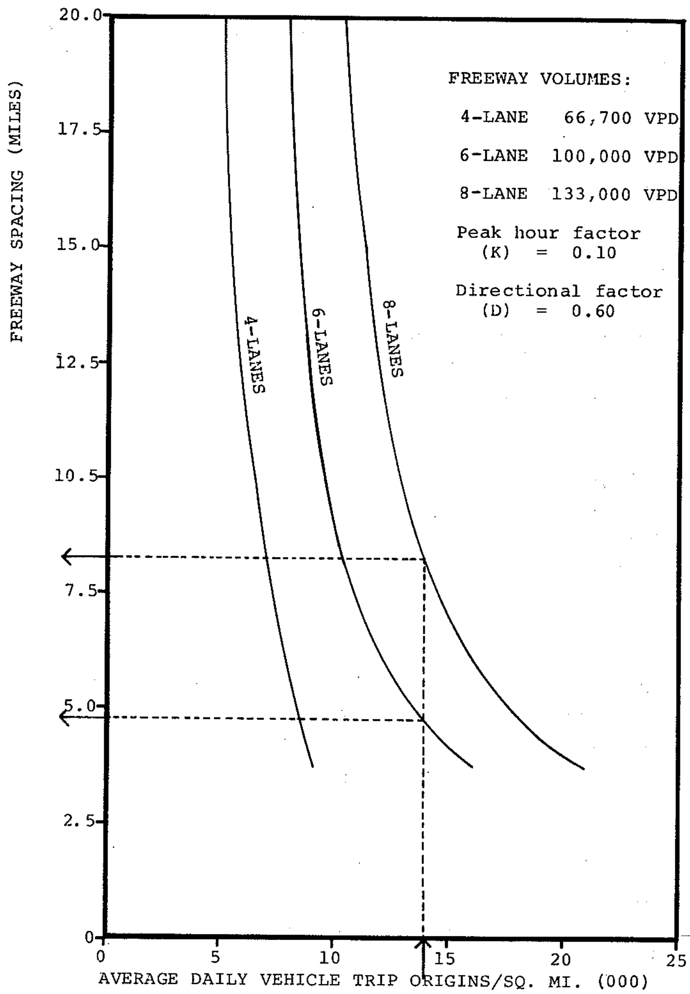


Figure 136. Freeway spacing vs average daily vehicle trip origins/square mile (for average trip length of 6 miles and arterial spacing of 1 mile (69).

VMT for local streets, the residential is the VMT on arterial routes.

Thus, for any analysis area other than a peripheral analysis area (i.e., not at the boundary of the metropolitan region), the arterial VMT is given by:

$$\text{Arterial VMT} = (\text{residential} + \text{nonresidential})\ \text{VMT} - \text{freeway VMT} - \text{local VMT} \qquad (40a)$$

For a peripheral analysis area (i.e., at the boundary of the metropolitan region), the arterial VMT is given by:

$$\text{Arterial VMT} = (\text{residential} + \text{nonresidential})\ \text{VMT} + \text{external VMT} - \text{freeway VMT} - \text{local VMT} \qquad (40b)$$

To compute freeway volumes or spacings, larger areas than the analysis areas (such as a subarea; i.e., a group of districts) used for arterials should be described. For

* Spacing, Z, can be easily computed from the formula $Z = 2A/L$, where L = the number of miles of route within an area A in sq mi.

† Desired freeway (and arterial) volumes can also be computed through least-cost techniques. See, for example, Ref. (*62*).

‡ The simplest way to compute the local street VMT is as a percentage of the total (including freeway). Local street VMT range from 8 to 20 percent, approximating 8 to 10 percent for urbanized areas over 200,000 population.

TABLE 53

FREEWAY LEVEL OF SERVICE VOLUMES

Approximate Peak Hour Operating Speed (MPH)	Traffic Volumes All Lanes				Level of Service
	4-Lane		6-Lane		
	Peak Hour[a]	Daily[b]	Peak Hour[a]	Daily[b]	
60	<1,400	<23,300	<2,400	40,000	A
55	2,000	33,300	3,600	60,000	B
50	2,500	41,600	4,050	67,500	C
40	3,000	50,000	4,500	75,000	D
30	4,000	66,700	6,000	90,000	E
<30	>4,000	>66,700	>6,000	90,000	F

a. One-way
b. Two-way (assumes a peak hour factor (K)=0.10 and a directional factor (D)=0.60)
Source: Adapted from Highway Capacity Manual (56).

example, areas on both sides of a freeway should be included. Figure 137 shows the freeway network for Fairfax County, Virginia (a subregion of the Washington metropolitan region). Figure 138 shows the subareas (i.e., portions of the subregion) used in the freeway volume computation whereas Figure 139 shows the analysis areas (i.e., districts or portions of the subarea) used for arterial spacing analysis.*

Step 5: Computation of average arterial volumes per lane and level of service. For uniform trip distributions and arterial loadings, the relationship between traffic demand, arterial grid spacing, and traffic volume is given by the equation:

$$D = \frac{2}{S} V \qquad (41)$$

where

D = the arterial vehicle-miles of travel per sq mi;
V = the average daily arterial traffic volume (VMT per mile of route);
S = the distance between adjacent arterials in miles (spacing).

This relationship is shown graphically in Figure 140. The graph could also be used to compute arterial spacing. Hence, if $D = 40{,}000$ arterial VMT/sq mi and $V = 18{,}000$ VMT/mi of arterial route, then 1-mi arterial spacing would be required to accommodate this traffic.

Volume (VMT per mile of route), although a useful indicator, is not as useful as volume per lane, because urban and suburban areas have a mix of 2-, 4-, and 6-lane arterial facilities. Table 52 gives the level-of-service volumes of different arterial facilities. It should be noted that 2-lane arterials have a significantly lower service volume per lane than a multilane arterial at level-of-service "C."

* The total area of the county is 417 sq mi. There are 25 subareas (districts) averaging approximately 16 sq mi. These were grouped into four subregions for freeway volume and spacing computation.

A better method, and one that is used in the example provided at the end of this chapter, is described as follows.

The Equivalent-Lane Concept. To relate traffic demands on different size arterial routes on an equal basis, each lane of a 4-lane arterial is set equal to 1.6 lanes of a 2-lane arterial, and each lane of a 6-lane arterial is set equal to 1.73 lanes of a 2-lane arterial. Average volumes per equivalent lane are then computed by analysis area (i.e., arterial VMT divided by equivalent lane-miles) and related to the level of service provided to the analysis area.

Arterial Level of Service. Because it is not possible to calculate the traffic volume on each segment of each arterial (only an average volume can be calculated), a relationship was developed from traffic count data between the average equivalent-lane volume and the percentage of all VMT in the analysis area operating above levels-of-service "C," "D," and "E." † This relationship was derived from complete count data for Fairfax County, Virginia, and is shown in Figure 141. Existing levels of service based on traffic count data and using Table 52 is shown in Figure 142. In addition, another relationship was derived relating the percentage of route-miles over specified levels of service to the percentage of VMT over such levels of service as shown in Figure 143. These relationships may now be used to measure the level of arterial service provided.

Although derived from only one set of complete count data, there seems to be no reason why these relationships cannot be used in any urbanized area, inasmuch as they are dependent on the standard level-of-service volumes given in Table 52, and on a distribution of traffic over an arterial network. (If data are available, it would be desirable, however, to check the absolute values on the curves for some sample subareas.) Although that distribution might change and vary the slope of the curves, the use of the standard is believed valid and can provide an index value of level of

† Above C means D, or above, etc.

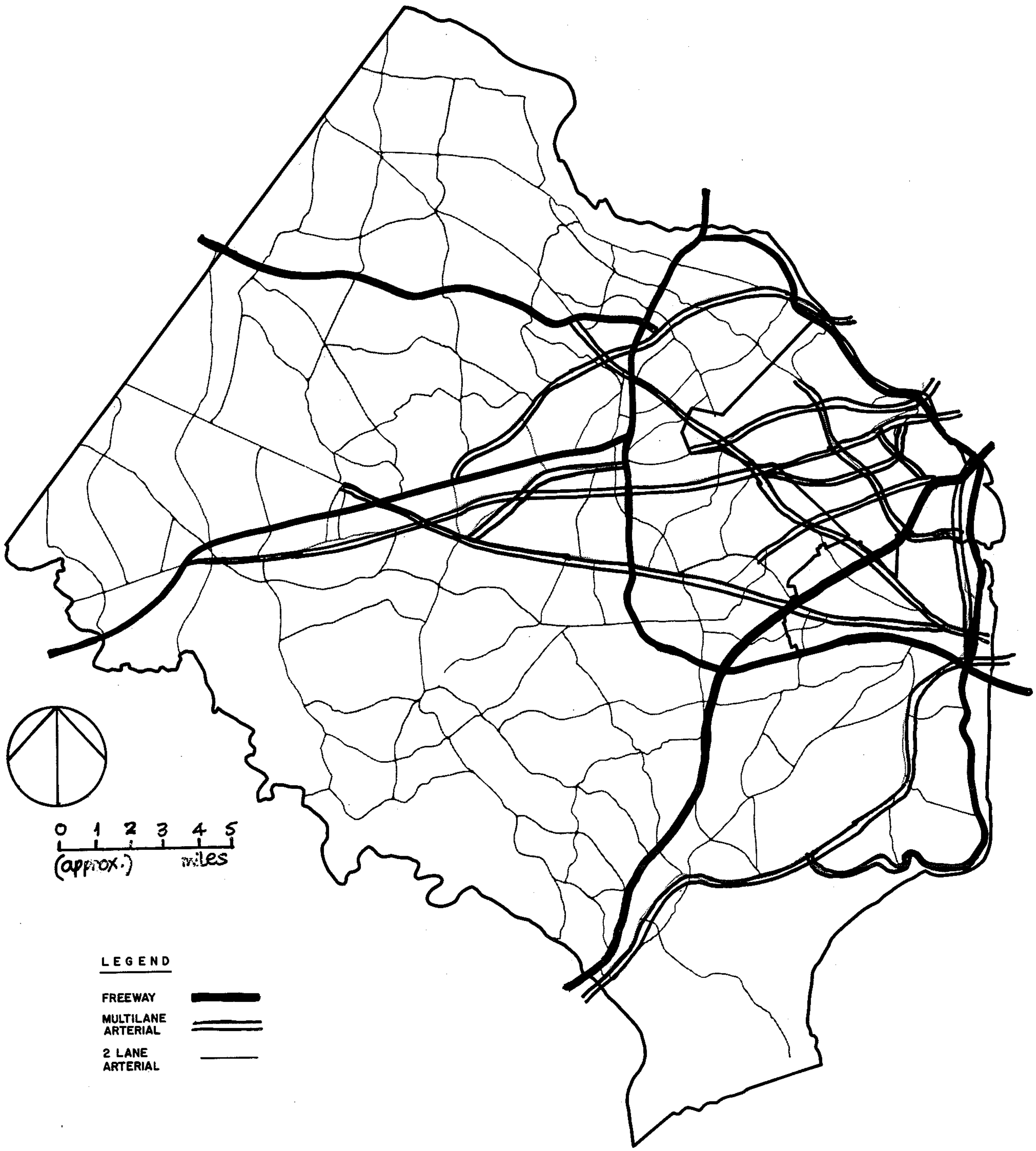


Figure 137. Fairfax County, Va. (subregion), freeway and arterial road system (1968).

service or congestion. This value can be maintained by keeping the average volume per equivalent lane the same; lowered by raising VMT; or raised by adding arterial lanes.

Determination of the number of equivalent arterial lane-miles of travel by district through the method illustrated can be used along with these guidelines to aid in the design of an arterial highway system for an urbanized area. The next step is to convert the number of equivalent lanes to miles of 2-, 4-, or 6-lane facilities and space them as desired. Widenings of existing routes should also be considered as appropriate. (See Figure 130 for least-cost solutions for various highway volumes and facilities.)

Feedback

The process described previously can also be used to modify the lane-miles of arterial routes needed by subareas. The planner can reverse the process or "feedback" to

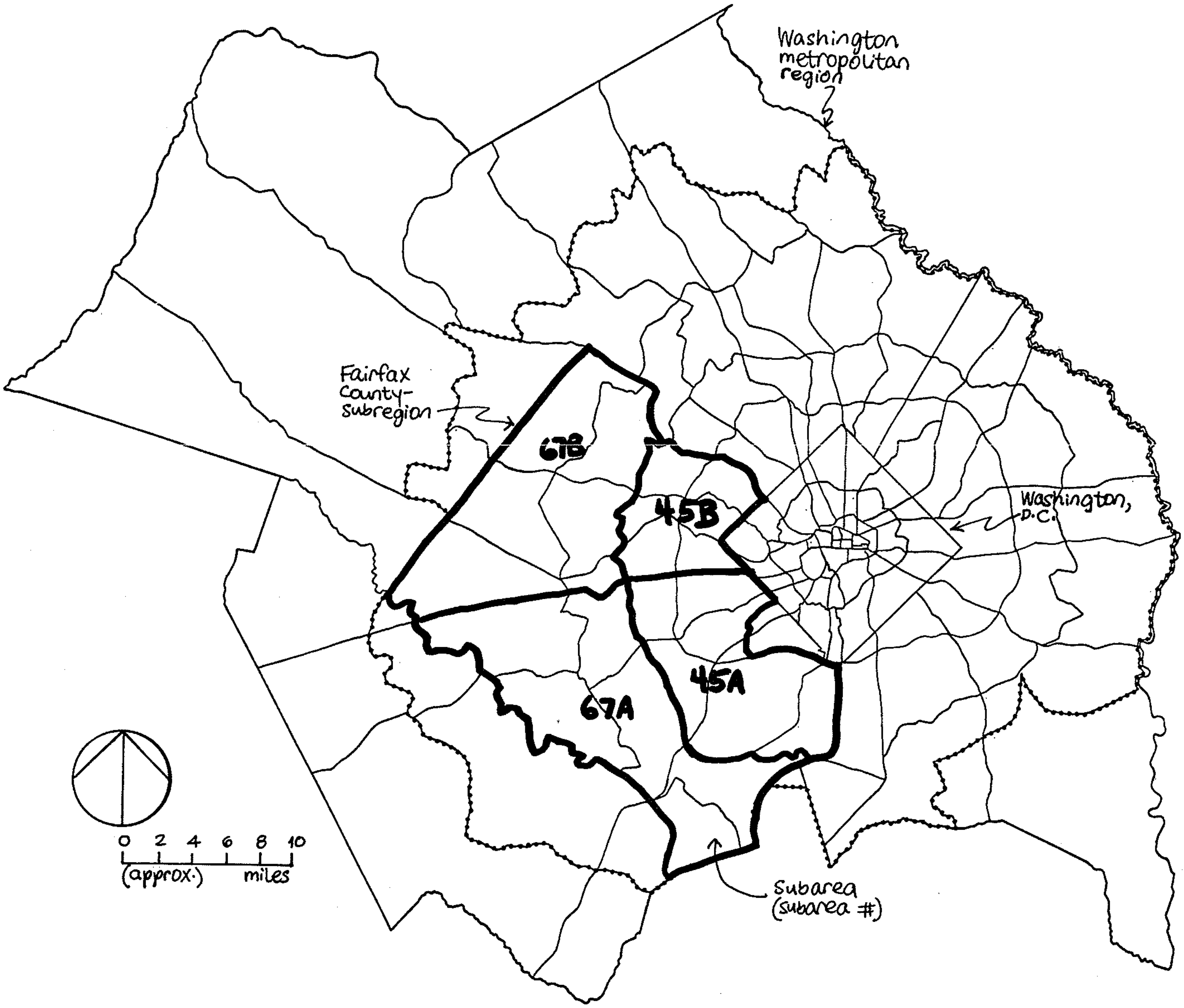


Figure 138. Subareas used for freeway spacing analysis in Fairfax County, Va. (1968).

prior steps by modifying inputs as desired. The following options are available:

1. Revise the level of service desired. By accepting a higher percentage of vehicle-miles of travel over a set level of service, the number of equivalent lanes can be reduced, because a higher average volume per equivalent lane can be accommodated.
2. Add freeways. By adding high-type limited access facilities in areas of high travel demands, the volume on arterials can be reduced.
3. Increase the use of transit or increase auto occupancy. This will have to be accommodated by the highway system.
4. Reduce or reallocate land use. Reductions or reallocations of land use will reduce travel demands in areas that have low levels of service.

Testing of various options, singularly or in combination, is most useful in designing or evaluating a land-use or transportation plan. This can be accomplished in a very short time using the relationships developed.

Effect of Pricing and Transit Service Policies on Vehicle-Miles of Travel

As noted previously, the method of determining vehicle-miles of travel is based on empirical data and cannot take into account variations from present policies. An indication of the possible magnitude of change in VMT estimates which might be caused by the introduction of selected pricing and transit service policies are given in Table 7 of the companion report, "Travel Estimation Procedures for Quick Response to Urban Policy Issues" (*NCHRP Report 186*) (*73*). These figures are intended to indicate over-all magnitudes of change, and may well be different, for different urbanized areas. They are provided here as a guide to judge the minimum magnitude of transportation

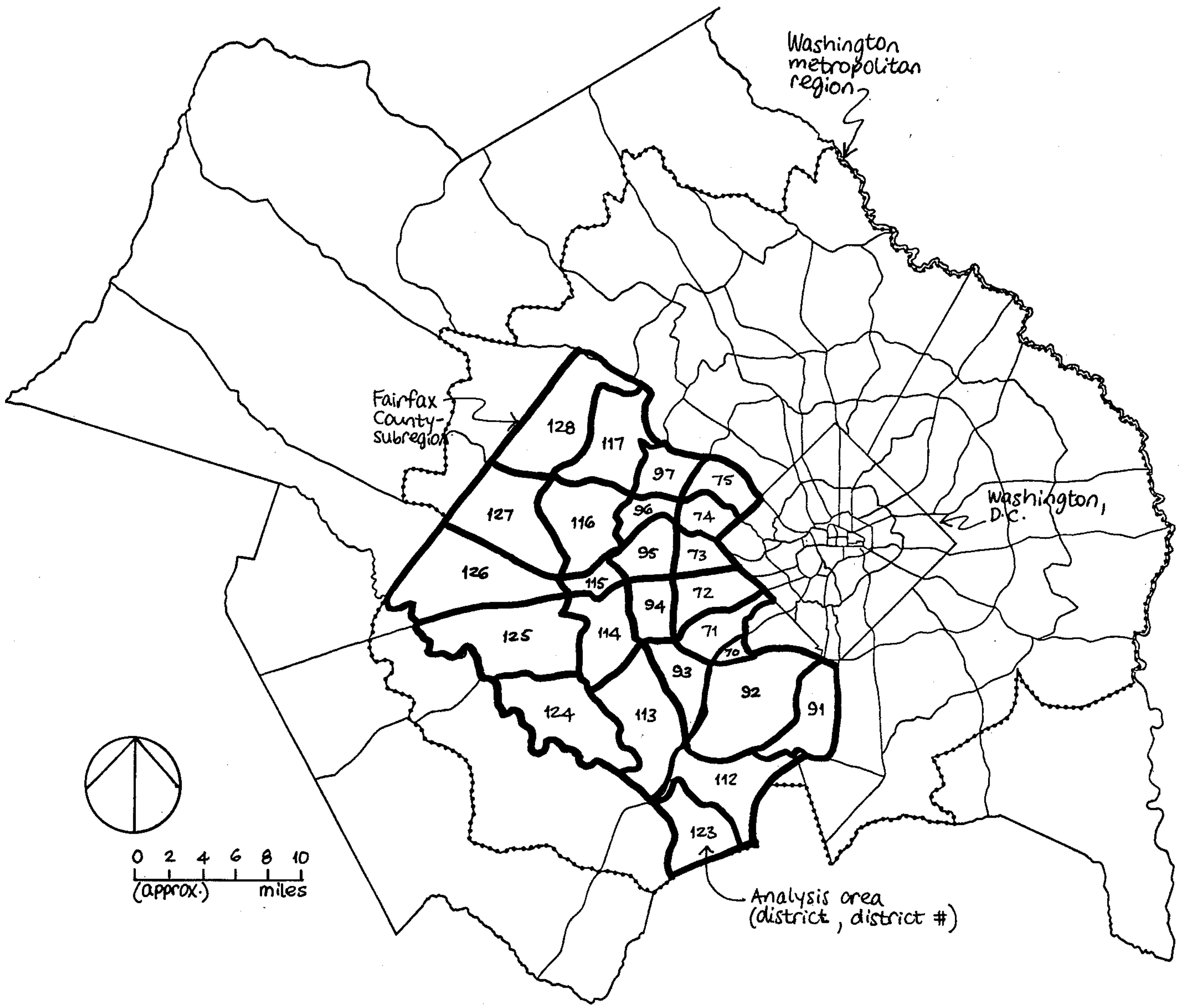


Figure 139. Analysis areas (districts) used for arterial spacing analysis in Fairfax County, Va.

improvements required in order to achieve a desired level of service.

To enable the user to apply the development density/highway spacing methodology described previously, the following section provides an illustrative example.

AN EXAMPLE APPLICATION

Suppose that the transportation service in a subarea located in the northeast quadrant of a hypothetical metropolitan region is to be analyzed for some future year. (See Fig. 144.) More specifically, given the projected land development density and the projected transportation supply in the subarea (and districts within the subarea), the objective is to determine the level of service at which the transportation system will be operating for that future year. It is anticipated that improved transit and car pool programs are to be put into effect. Concurrently, the highway network itself will undergo traffic flow improvements, resulting in increased average speeds.

This example describes the use of the development density/highway spacing methodology. In Figure 144, district 21, a peripherally located district, has been selected for analysis for illustrative purposes only. Computation steps similar to those outlined hereunder, must be executed for all districts of interest in a "real" application.

Input Information

Assume that the following input data are available for the metropolitan region, the study subarea, and the peripherally located study district 21. Except where noted (and where inappropriate), this input data represents the *future* condition.

1.	Existing population of the metropolitan region	1,200,000
2.	Area of the study subarea (sq mi)	55
3.	Area of district 21 (sq mi)	8

4. Residential development in district 21:

Single family units (at 1 DU/acre)	5,100
Townhouse units	2,000
Apartment units	500
Total number of dwelling units	7,600

5. Nonresidential development in district 21:

General office employees	220
Industrial park employee	180

6. Transit use in district 21:

Existing (transit as a percent of total person-trips)	10
Future (transit as a percent of total person-trips)	20

7. Auto-occupancy rates in district 21:

Existing (persons/auto)	1.5
Future (persons/auto)	1.6

8. Average network speeds in metropolitan region:

Existing (mph)	26
Future (mph)	29

9. Daily through and external traffic volume at the external count stations (*excluding* freeway volumes) (vehicles) 20,000

10. Facility mileages:

For district 21:

2-lane arterials (mi)	8
4-lane arterials (mi)	3
6-lane arterials (mi)	12
All arterials (mi)	23
Freeways (mi)	6

For study subarea:

All arterials (including district 21) (mi)	86
Freeways (including district 21) (mi)	18

Methodology

The density/spacing methodology is applied in a step-by-step manner as shown in Figure 128 and as discussed in the preceding sections.

Step 1: Compute vehicle trip ends. Using the average daily vehicle trip-generation rates given in Table 1, Chapter Two, and Method II described previously, the future one-way vehicle trip ends for the residential and nonresidential development in district 21 are computed as follows for:

Single family units	= ½ (9.3 × 5,100) =	23,715 trips
Townhouse units	= ½ (7.0 × 2,000) =	7,000 trips
Apartment units	= ½ (6.0 × 500) =	1,500 trips
General offices	= ½ (3.5 × 220) =	385 trips
Industrial park	= ½ (3.9 × 180) =	351 trips

Hence, the total one-way vehicle trips generated daily by the development in district 21 is given by 32,951 vehicle trips. Note that Table 1 provides vehicle trips to and from the generators (i.e., vehicle trip ends); consequently, such

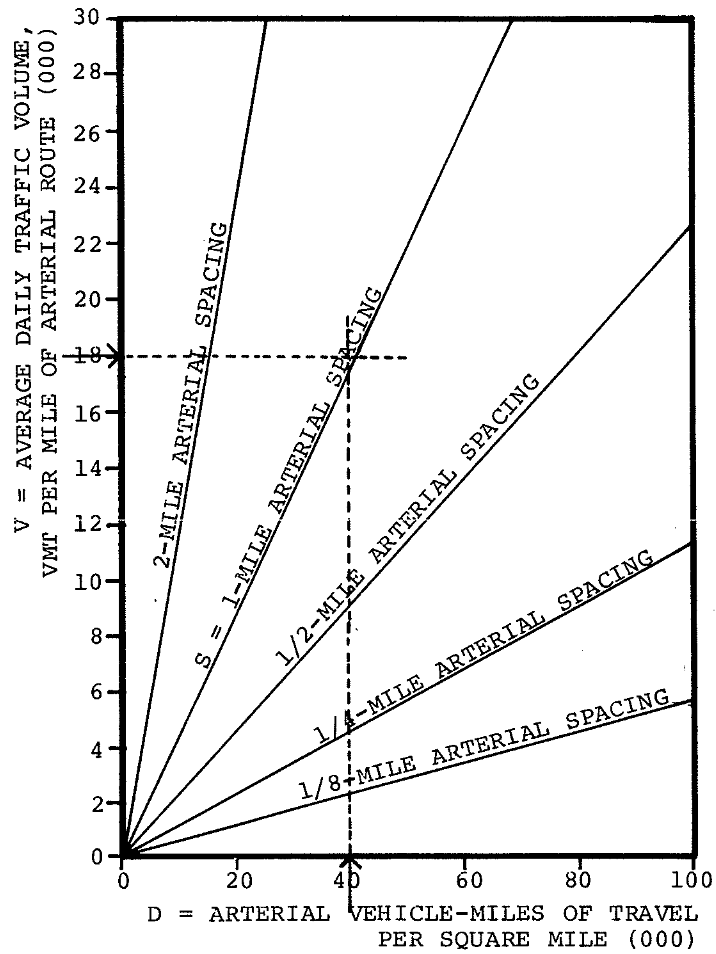


Figure 140. Relationship between arterial travel demand, arterial grid spacing, and traffic volume (70).

trips must be halved as shown previously to obtain the one-way trips.

Step 2: Compute transit use and auto-occupancy adjustments. Figure 131 can be used to adjust the daily vehicle trips output from Step 1 for the future improvements in transit and car pooling programs. Thus:

For the existing condition:

At 10 percent transit use and 1.5 persons/auto, auto driver trips as a percent of total person-trips = 60%

For the future condition:

At 20 percent transit use and 1.6 persons/auto, auto driver trips as a percent of total person-trips = 50%

Therefore, percent reduction in auto driver trips

$$= \frac{50 - 60}{60} \times 100 = 16.7\%$$

Therefore, adjusted daily vehicle trips = 32,951 (1-0.167)
= 27,448

These trips represent the future internal-internal daily vehicle trips in district 21.

EXAMPLE:

If for an analysis area, the arterial VMT has been computed at 75,000 and the equivalent arterial lane-miles = 15, then equivalent lane volume = 75,000/15 = 5,000 VPD. Hence:

% VMT over Level of Service "C" = 93
% VMT over Level of Service "D" = 80
% VMT over Level of Service "E" = 66

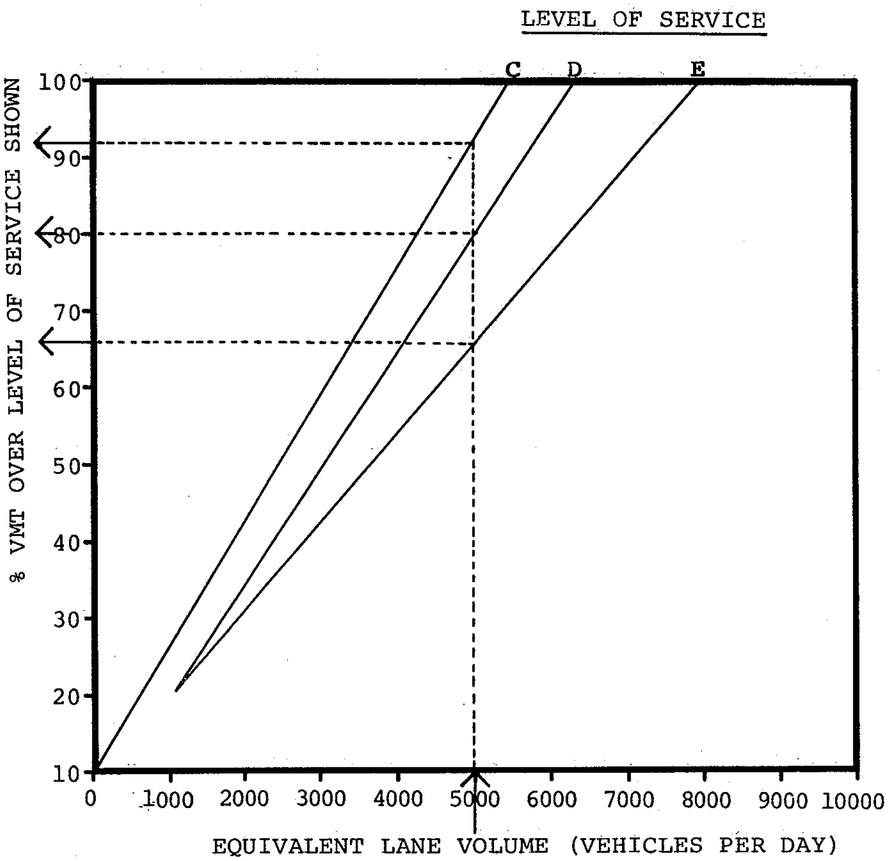


Figure 141. Arterial VMT level of service vs equivalent lane volumes. (Derived from Fairfax County, Va., data.)

Step 3: Compute vehicle-miles of travel. Before computing VMT, the average over-the-road trip distance must be calculated. Figure 133 enables the estimation of the average airline trip distance with respect to urbanized area population; that is, if such a measure is not available from local information. For an urbanized area of 1,200,000 existing population, Figure 133 shows that an average vehicle trip distance of approximately 4.0 airline miles is the current measure of trip length.

Because it is expected that average network speeds will change in the future (in the ratio 29/26; i.e., 1.12), Figures 134 and 135 provide the means for estimating the corresponding changes in HBW and HBNW average auto airline trip distances.

From Figure 134.
Adjustment factor for HBW auto trips = 1.22
Therefore, adjusted HBW average auto airline trip distance $= 4 \times 1.22$ mi $= 4.90$ mi

From Figure 135:
Adjusted HBNW average auto airline trip distance = 3.20 mi
Assuming that work trips will constitute 25 percent of all trips (see Table 3, Part A), then:
Weighted auto airline trip distance
$= [(4.9 \times 0.25) + (3.2 \times 0.75)]$ mi $= 3.60$ mi
Assuming a circuity factor of 1.22 (see Chapter Two, section entitled "Constructing Airline Distance vs. Travel Time vs. Distribution Factors Graphs"):
Average auto over-the-road trip distance for the metropolitan region $= 3.5 \times 1.22 = 4.3$ mi
Average daily internal-internal vehicle miles of travel for district 21 $= 27{,}448 \times 4.4$ VMT
$= 120{,}771$ VMT

Step 3A: Compute external vehicle-miles of travel adjustment. District 21 is located at the periphery of the metropolitan region, and, therefore, a significant amount of traffic within its boundary can be attributed to that traffic which has origins or destinations external to that district. This external traffic contribution must be added to the VMT from Step 3. Note that this addition of external traffic is made to traffic in districts that are peripheral to the metropolitan region, that is, districts 18, 19, 21, and 25 in the study subarea. It is assumed that for the internally located districts, that is, 20, 22, 23, and 24, the external traffic contribution is small, because most of these trips will have "dropped off" in the peripheral districts.

For district 21, daily volume of traffic at the non-

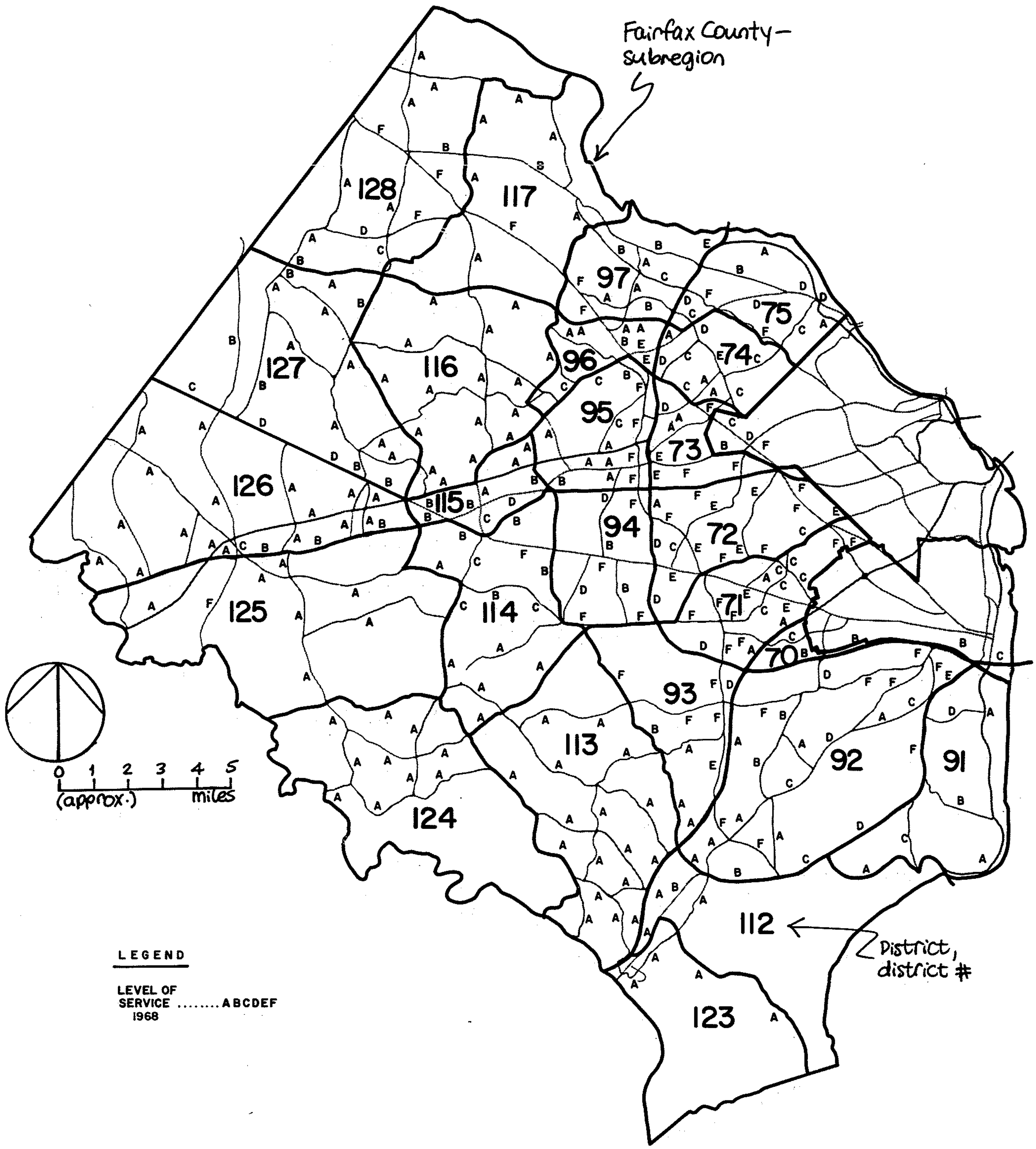


Figure 142. Level of service, by district: Fairfax County, Va. (1968).

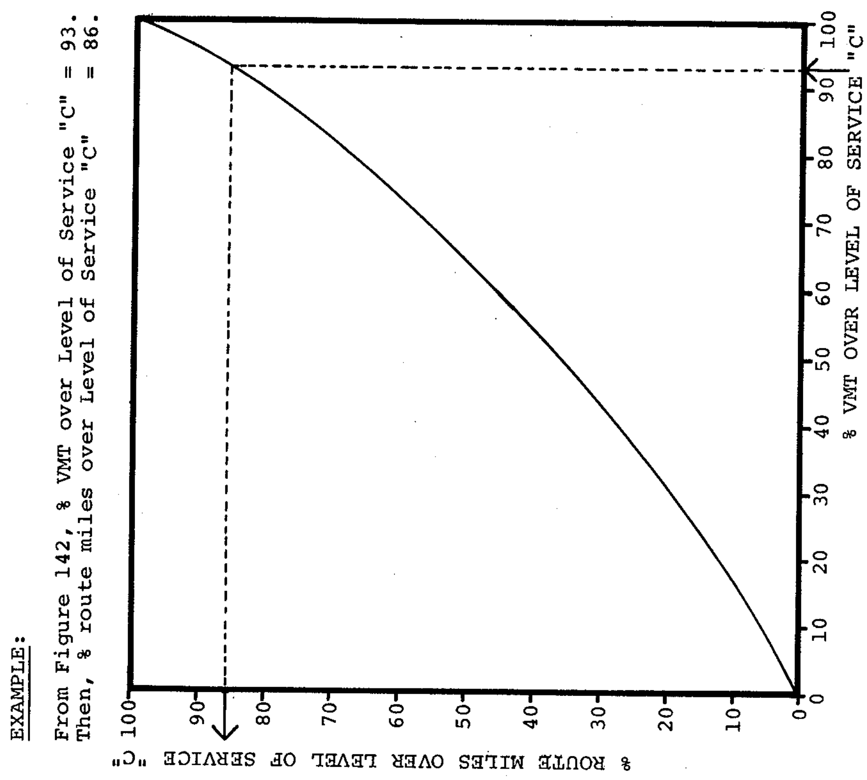


Figure 143. Relationship between level of service and route miles. (Derived from 1968 data for Fairfax County, Va.)

freeway external count stations is 20,000 vehicles. This volume includes through trips, which must first be accounted for. Table 3, Part B, Chapter Two, shows that 4 percent of external vehicle trips are through trips. Reference to the example for the conversion of cordon count to external trips (Fig. 1, Chapter Two) shows that:

$$\text{External trips} = \frac{\text{Cordon Count}}{(1 + \text{Proportion of Through Trips})}$$

Hence

$$\text{External trips} = \frac{20{,}000}{(1 + 4/100)} = 19{,}230 \text{ vehicles}$$

Because many of these trips are accounted for by the population and employment trip estimates made for the districts, the external trips are reduced by one-half. Therefore:

Average daily external vehicle-miles of travel

$$= \tfrac{1}{2}\ (19{,}230) \times 4.4 \text{ mi}$$
$$= 42{,}306 \text{ VMT}$$

Average daily total VMT in district 21

$$= 120{,}771 + 42{,}306$$
$$= 163{,}077 \text{ VMT (or } 163{,}100 \text{ VMT)}$$

At this point, the planner must be reminded that Steps 1 through 3 (and Step 3A where appropriate) must be accomplished for all the eight study districts in the study subarea shown in Figure 144. For illustrative purposes, assume the following daily total VMT's have been calculated for the eight districts.

DISTRICT NO.	CALCULATED AVERAGE DAILY TOTAL VMT	% SUBAREA TOTAL VMT
18 *	120,200	12.6
19 *	135,700	14.2
20	96,800	10.2
21 *	163,100	17.1
22	110,900	11.6
23	80,100	8.4
24	95,000	10.0
25 *	151,900	15.9
Subarea total VMT	953,700	100.0

* Peripheral districts requiring addition of external station VMT.

Step 4: Compute VMT on freeways and arterials. In order to calculate arterial VMT in district 21, the freeway VMT in the entire study subarea must first be obtained by employing Eq. 39. This equation requires measures for freeway spacing (Z_1 mi), arterial spacing (Z_2 mi), and local spacing (Z_3 mi) as input. Thus for the whole subarea:

$$\text{Freeway spacing } Z_1 = \frac{2A}{L}\text{; i.e., } \frac{2\ (\text{study subarea})}{\text{freeway mileage}}$$
$$= \frac{2 \times 55}{18} = 6.1 \text{ mi}$$

$$\text{Arterial spacing } Z_2 = \frac{2 \times 55}{86} = 1.3 \text{ mi}$$

Local spacing Z_3 $= 0$ mi (assumption for ease of calculation)

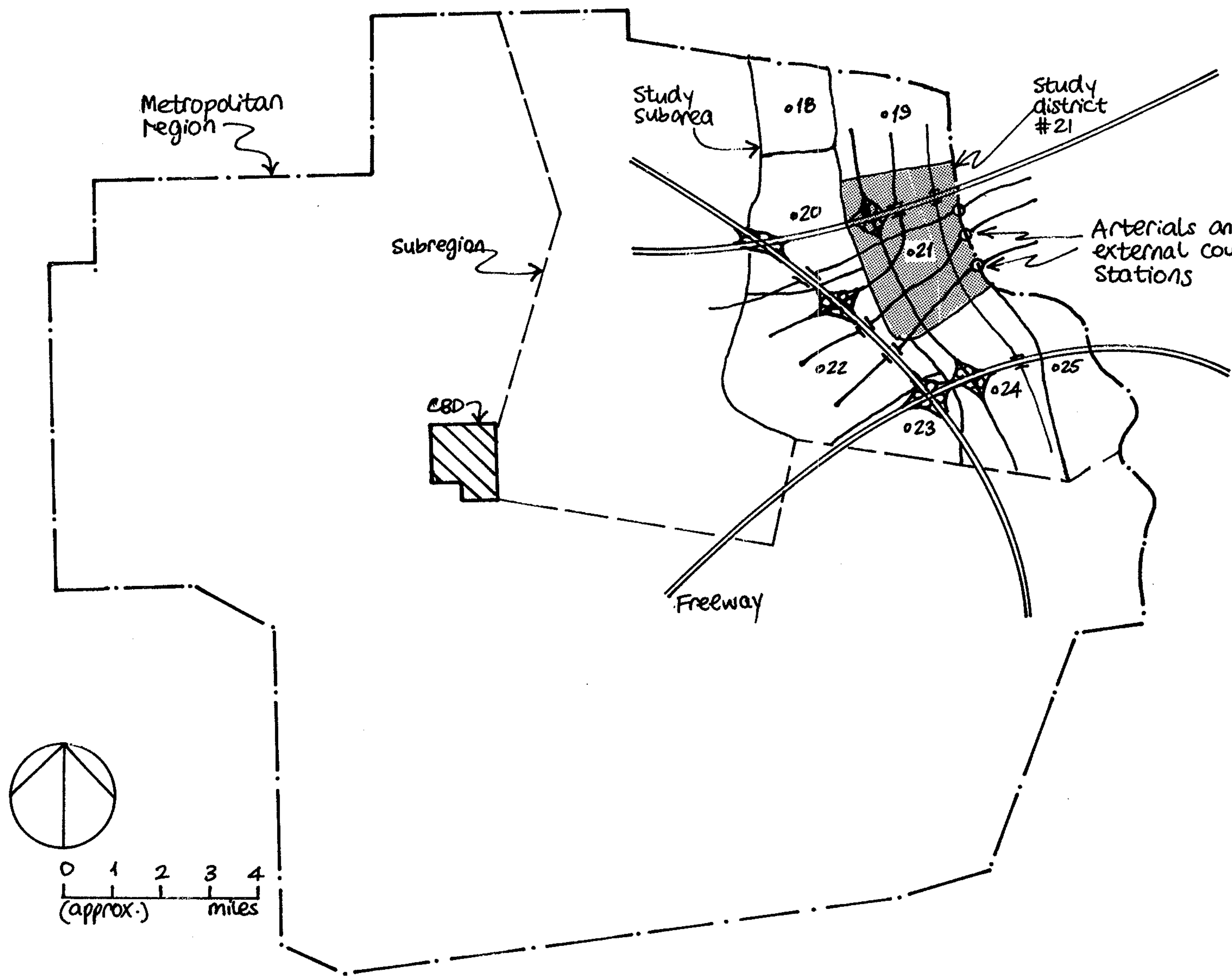


Figure 144. Hypothetical metropolitan region, showing study subarea and study district for transportation service analysis.

So, from Eq. 39, average daily traffic on the freeways, V_1, in the subarea is given by:

$$V_1 = \frac{953{,}700/55}{2\left[\frac{1}{6.1} + \frac{1}{4.4} + \frac{1.3}{4.4(6.1)}\right]}$$
$$= 19{,}721 \text{ vehicles} \qquad (42)$$

Note that 953,700/55 (i.e., average daily total VMT for subarea ÷ area of subarea) is the numerator $P\bar{r}$ in Eq. 39. Also, 4.4 is the average auto over-the-road trip distance (miles) for the metropolitan region.

For the study subarea then:

$$\text{Freeway VMT} = V_1 \times \text{freeway mileage}$$
$$= 19{,}721 \times 18 = 354{,}978 \text{ (or } 355{,}000\text{) VMT}$$

$$\text{Therefore arterial VMT} = \text{subarea total VMT} - \text{freeway VMT} - \text{local VMT} \qquad (43)$$

If it is assumed that 10 percent of all subarea VMT is on local streets, then:

$$\text{Arterial VMT} = 953{,}700 - 355{,}000 - \frac{10}{100}(953{,}700) \text{ VMT}$$
$$= 503{,}300 \text{ VMT} \qquad (44)$$

This subarea arterial VMT can then be distributed to each of the eight districts within the study subarea in proportion to the distribution of the total VMT (derived earlier). Then, the arterial VMT by district is as follows:

DISTRICT NO.	% SUBAREA TOTAL VMT	PROPORTIONED ARTERIAL VMT
18	12.6	63,400
19	14.2	71,500
20	10.2	51,300
21	17.1	86,100
22	11.6	58,400
23	8.4	42,300
24	10.0	50,300
25	15.9	80,000
Subarea Arterial VMT	100.0	503,300

Thus for study district 21, the average daily arterial VMT that can be expected is 86,100 VMT.

Step 5: Compute average arterial volumes per lane and level of service. To determine the level of service provided by the arterial network in district 21, the equivalent lane-miles must first be calculated. (See previous section in this chapter entitled "The Equivalent Lane Concept.") Now,

$$\text{Equivalent lane-miles} = 1.00 \text{ (2-lane arterial mileage)} + 1.60 \text{ (4-lane arterial mileage)} + 1.73 \text{ (6-lane arterial mileage)}$$

$$\text{Therefore, equivalent lane-miles} = 1.00(8) + 1.60(3) + 1.73(12)$$
$$= 33.56 \text{ lane-miles} \qquad (45)$$

$$\text{Therefore, equivalent arterial lane volume} = \frac{\text{Average daily arterial VMT}}{\text{Equivalent arterial lane-miles}}$$
$$= \frac{86{,}100}{33.56}$$
$$= 2{,}566 \text{ vehicles/day} \qquad (46)$$

Entering Figure 141 at 2,566 average daily vehicles per equivalent lane, the following level-of-service results can be obtained (for district 21):

VMT over level-of-service "C" = 51%
VMT over level-of-service "D" = 42%
VMT over level-of-service "E" = 36%

Next, Figure 143 can be entered to determine the percent of arterial route-miles operating over level-of-service "C." Hence, 37 percent of the arterial mileage in district 21 can be expected to operate over level-of-service "C."

Output Information

It can be seen that the development density/highway spacing methodology, as applied previously, yields the freeway VMT, the arterial VMT, and the level of service provided by the transportation network in district 21 for some future year. The remaining seven districts in the study subarea can be similarly analyzed.

CHAPTER TEN

SCENARIO FOR SITE DEVELOPMENT IMPACT ANALYSIS: BOISE, IDAHO

INTRODUCTION

The purpose of this scenario is to demonstrate the applicability of manual procedures, described in the preceding chapters of this user's guide, to a transportation problem in a small urbanized area. The problem to be solved involves investigation of traffic effects of significant site development on the surrounding street system.

The scenario described is for a proposed residential development and major shopping center in the Boise, Idaho, urbanized area. The Boise metropolitan transportation study area is approximately 93 sq mi. The population in 1970 was 85,0000 and grew to approximately 108,000 by 1974; it is expected to reach 158,000 by 1990—a relatively rapid growth. In 1970, the median family income in the Boise urbanized area was $9,900; there was an average of 1.50 automobiles per household, and approximately 91.4 percent of work trips were made by automobile.

Because of Boise's anticipated growth, numerous requests have been made to the metropolitan planning organization to analyze and evaluate local and regional effects of proposed new developments. Quite often the time to evaluate these proposals and impacts is short; and short-cut, manual methods are desirable for planning and analysis.

This scenario considers the analysis of the transportation impacts of two proposed developments in the Foothills area north of the Boise central business district and an existing north-end community. The proposed developments include:

- The Highland Square Shopping Mall which will consist of 179,000 sq ft of enclosed commercial area, 139,000 of which will be shopping and 40,000 will be office space.
- Thunder Hill Village (which is a part of the Foothills development) is proposed with 1,159 dwelling units consisting of single family homes, townhouses, and apartments units, as well as 50,000 sq ft of convenience shopping area and office space. The dwelling unit density is proposed at 3.40 dwelling units per acre.
- Claremont development (also in the Foothills development) is proposed at 1,151 dwelling units (mixed single family, townhouses, and apartments) at 1.28 dwelling units per acre with no commercial development.

A map of the Boise area showing the location of the proposed developments is shown in Figure 145. Land-use estimates by type were available from the developer for the proposed developments in terms of population, household income, square feet in commercial uses, acreage in open space, and recreational use, and the like.

The techniques provided in this user's guide for trip generation, trip distribution, mode choice, auto occupancy, time-of-day analysis, traffic assignment, and capacity analysis will be applied to determine the effects of the proposed development on the street system.

Summary of Steps Undertaken for Scenario

It was assumed that the proposed developments would be completed by the year 2000. The Boise metropolitan transportation study had recently developed forecasts of trip generation for 149 analysis areas (zones) representing the future study area. The proposed Foothills residential development is located outside these analysis areas and the Highland Square Shopping Mall is sited within one of the zones (see Fig. 145). The new development was not accounted for in the actual forecasts and is, therefore, treated as new activity not previously considered. The general steps undertaken were as follows:

Step 1: Zone the entire study area for ease of manual application and to provide sufficient detail for traffic estimates in the impact area surrounding the new development.

Step 2: Aggregate the zonal trip-generation forecasts to the new analysis areas.

Step 3: Estimate the amount of proposed development distribution of land use within each analysis area established.

Step 4: Use trip-generation characteristics from Chapter Two to develop person-trip generation estimates for the proposed developments based on land use and anticipated socioeconomic characteristics.

Step 5: Use the gravity model manual distribution procedure and parameters in Chapter Three to determine the distribution of trips to and from the new development.

Sept 6: Use transit-use and auto-occupancy estimates from Chapters Four and Five to estimate auto vehicle trips to and from the new development.

Step 7: Use traffic assignment procedures described in Chapter Seven to assign trips to appropriate routes. Only trips to and from the new development are to be considered in the assignment.

Step 8: Redistribute traffic allocated to alternate routes based on a balancing technique to account for deficiencies in all-or-nothing assignment procedures.

Step 9: Analyze capacity implications for the new developments.

SCENARIO DETAILS

The following sections describe in detail the steps undertaken to evaluate the traffic impacts of the Foothills residential development and the Highland Square Shopping Mall.

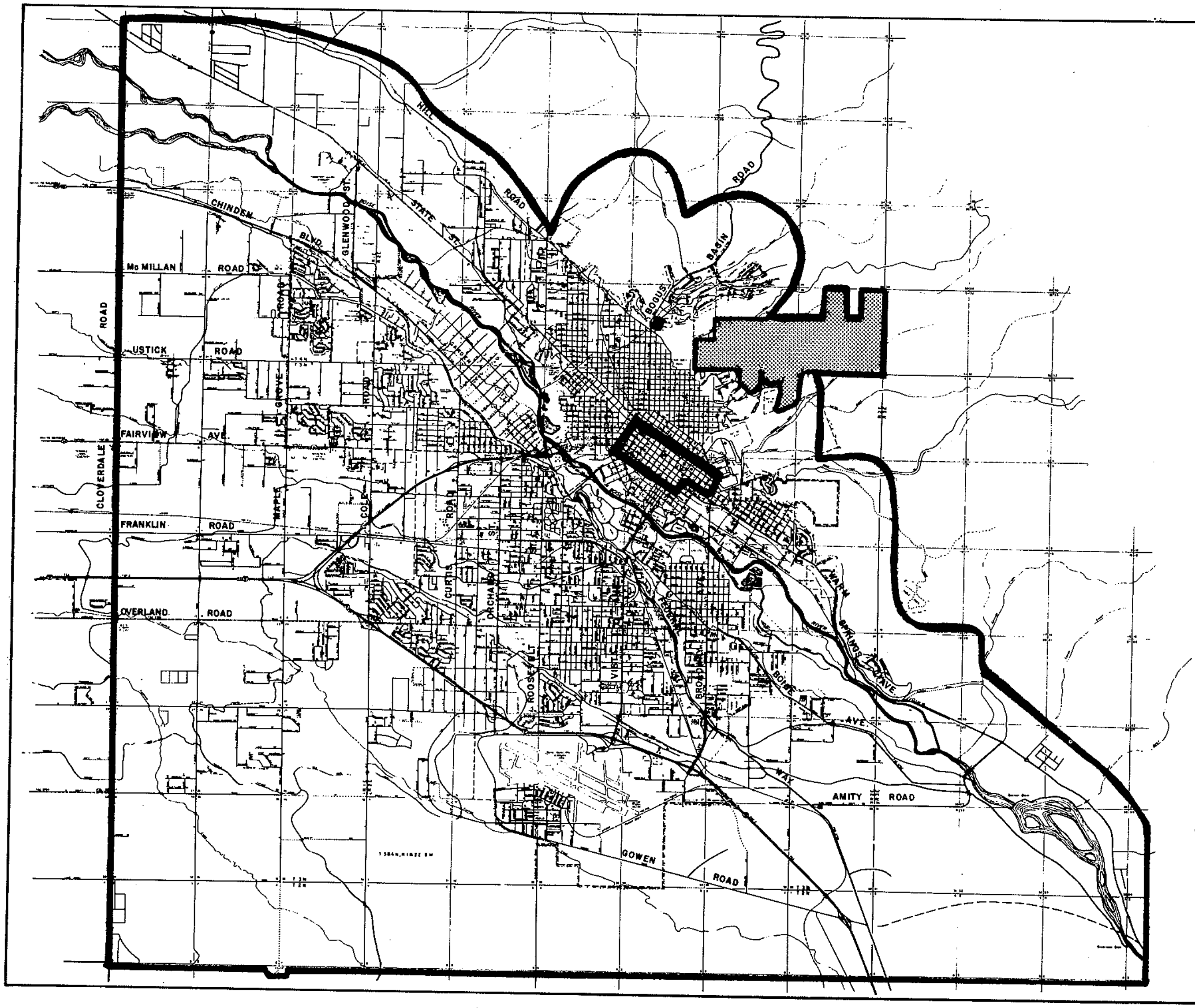
Character of Development

The developers of the new residential area presented their proposed plans which indicated the mix of land uses within the developments. These characteristics are given in Table 54. There are a total of 2,310 residential units, 178,000 sq ft of shopping area, 45,000 sq ft of office space, and 103 acres of recreation area.

The site plan for the residential area was used to estimate the number of residential units by type within four analysis areas. The four analysis areas were delineated based on factors such as the street pattern inside the development, the access roads to the development, and the distribution of land-use activities. The distribution of these activities is given in Table 55.

Zoning of Region

Trip-generation data for the Boise area was available for some 149 zones. The zone system was analyzed to determine how such data could be combined to provide sufficient accuracy in the application of the procedures for trip distribution and traffic assignment and yet provide a small enough number of areas to handle efficiently. The major impact of the development was anticipated in the corridor from the north to the central business district. Here, the analysis areas are required to be smaller than those farther away because with farther distances



LEGEND

Study area boundary

Proposed Foothills residential development*

Proposed Highland Square Shopping Mall

CBD

* The Footnills development includes:
- Thunder Hill Village
- Claremont

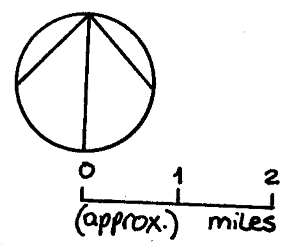


Figure 145. Boise metropolitan transportation study area, showing locations of proposed developments.

TABLE 54

LAND-USE CHARACTERISTICS OF THE NEW DEVELOPMENTS

I. Thunder Hill (Foothills Development)

A. Residential Units

Single Family	292
Townhouses	317
Apartments	550
	1159

B.1 Commercial (Village Center)

Convenience Shopping	27000 Sq. Ft.
Offices	5000 Sq. Ft.

B.2 Commercial (Near Entrance)

12000 Sq. Ft. shops, etc.

C. Park - Active Recreation - 65 acres.

II. Claremont (Foothills Development)

A. Residential Units

Single Family	531
Townhouses	370
Apartments	250
	1151

B. Commercial - None

C. Park - Active Recreation - 38 Acres

III. Highland Square Shopping Mall

A. No Residential Development

B. Commercial

Shopping	139000 Sq. Ft.
Offices	40000 Sq. Ft.

C. Park - None

TABLE 55

DISTRIBUTION OF VARIOUS ACTIVITIES BY ANALYSIS AREA

Analysis Area		Single Family	Residential Townhouses	(Units) Apartments	Commercial (Sq. Ft.)	Office (Sq. Ft.)	Recreation (Acres)
1	Thunder Hill & Claremont (Foothills)	225	0	0	0	0	15
2		210	180	0	0	0	15
3		172	287	550	39000	5000	65
4		216	220	250	0	0	8
7	Highland Square	0	0	0	139000	40000	0
TOTAL		823	687	800	178000	45000	103

less trips are anticipated, and the routing is not as critical in the assignment process.

Within the expected impact area, the street system was examined to determine if route selection would be affected by the zoning. The zoning selected as appropriate for the analysis is shown in Figure 146. The decision made in the selection of analysis areas will become more apparent as the scenario is described. For the analysis areas selected, the trip-production and trip-attraction estimates were accumulated from the estimates made by zone by the local transportation agency. (These estimates are given in Table 58, Parts A and B.)

Trip Generation—New Development

The material in Chapter Two, "Trip-Generation Estimation," was used to estimate the average daily vehicle travel for the new development. This estimate was based on the land-use characteristics and income estimates made for the new residential area, the latter developed from the dollar value of the homes to be constructed.

For single family homes in the development, the percentage distribution of such units by household income ranges (based on current dollars) was estimated as follows:

$20,000 to $25,000	45%
$25,000 and over	55%

Reference to Table 2 (urbanized area population 100,-000 to 250,000) in Chapter Two indicates corresponding average daily person trip rates of 20.4 trips/unit for the lower income and 20.6 for the higher income resulting in a weighted average of 20.5 trips per unit.

The average daily person-trip rate for townhouses was assumed to be intermediate between apartments and single family homes and estimated at 19.6 based on townhouse units/income distribution of:

$10,000 to $15,000	15%
$15,000 to $20,000	60%
$20,000 to $25,000	15%
$25,000 and over	10%

For apartments, the units/income distribution was estimated as follows:

$10,000 to $15,000	39%
$15,000 to $20,000	55%
$20,000 to $25,000	6%

The corresponding average daily person-trip rates from Table 2 are 18.0 (interpolated), 19.6, and 20.4 from low to high income, respectively. If these trip rates are weighted by the units/income distribution [$(0.39 \times 18.0) + (0.55 \times 19.6) + (0.06 \times 20.4)$] an average daily person-trip rate of 19.0 is obtained.

To obtain the trip rate by purpose for the residential development, Table 2 was entered with the appropriate income and the results weighted to obtain the distribution by trip purpose by type of housing unit. The results by purpose are given in Table 56.

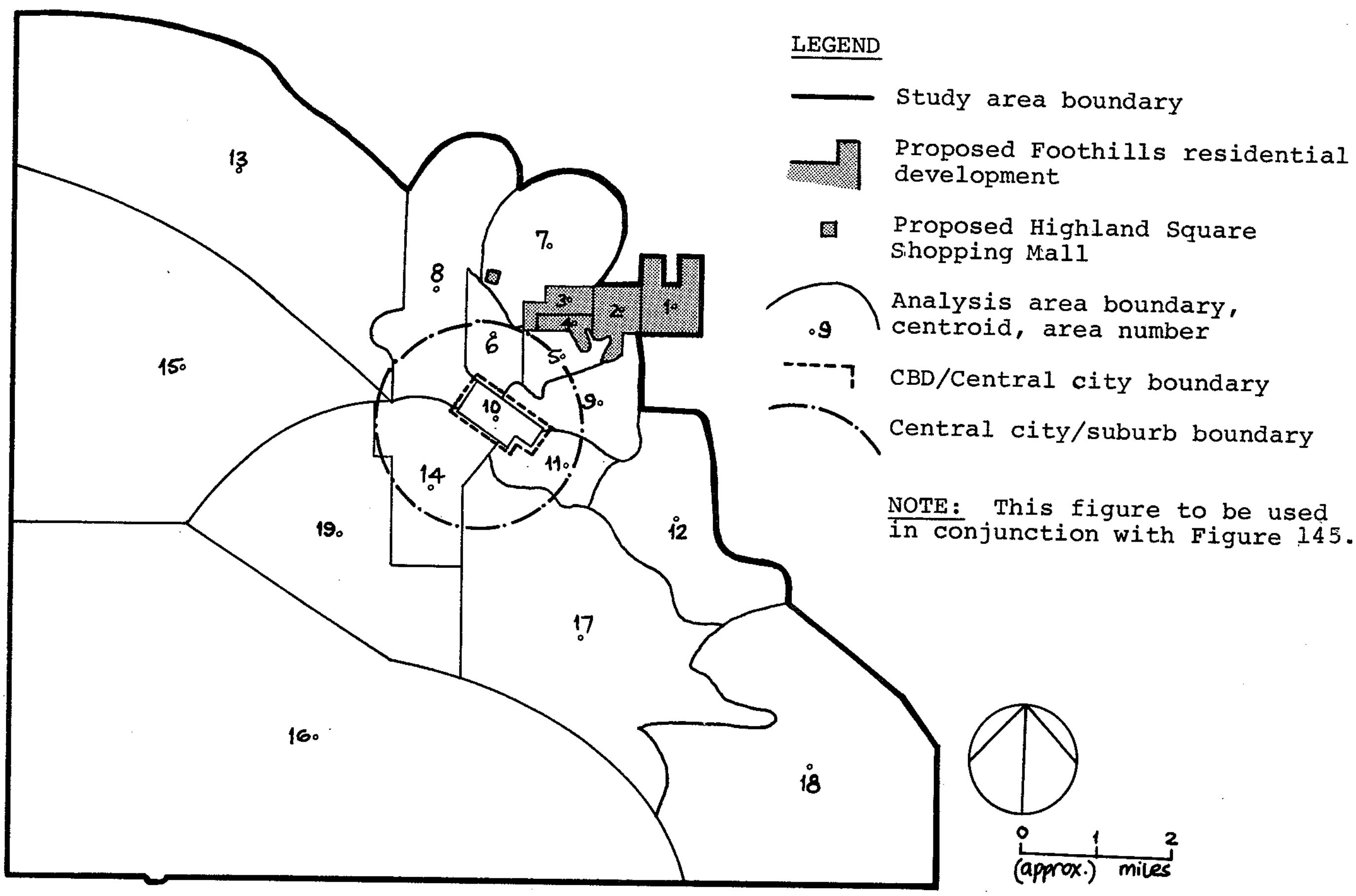


Figure 146. Boise metropolitan area, showing zoning system selected for analysis and subregional boundaries.

TABLE 56

PERSON-TRIP GENERATION RATES BY PURPOSE FOR THE RESIDENTIAL DEVELOPMENT

	Average Daily Person Trips/DU	% Person-Trips by Purpose[a]			Person-Trips/DU[b]		
		HBW	HBNW	NHB	HBW	HBNW	NHB
Single Family	20.5	18	55	27	3.7	11.3	5.5
Townhouses	19.6	19	55	26	3.7	10.8	5.1
Apartments	19.0	19	56	25	3.6	10.6	4.8

a. From Table 2, Chapter 2, "Trip Generation Estimation".
b. (Person-Trips/DU) x (% Person-Trips by Purpose).

TABLE 57

AUTO TRIP GENERATION RATES BY PURPOSE FOR THE RESIDENTIAL DEVELOPMENT

	HBW	HBNW	NHB
Single Family			
Number of Units[a]	823	823	823
Person Trips/Units[b]	3.7	11.3	5.5
Person Trips[c]	3045	9300	4527
Auto Pers.Trips as %Total Pers.Trips[d]	88%	97%	94%
Auto Occupancy[e]	1.37	1.81	1.43
Auto Trips[f]	1956	4984	2976
Auto Trips/Unit[g]	2.38	6.06	3.61
Townhouses			
Number of Units	687	687	687
Pers. Trips/Unit	3.7	10.8	5.1
Person Trips	2542	7420	3504
Auto Pers.Trips as %Total Pers.Trips	88%	97%	94%
Auto Occupancy	1.37	1.81	1.43
Auto Trips	1633	3976	2303
Auto Trips/Unit	2.38	5.79	3.35
Apartments			
Number of Units	800	800	800
Pers. Trips/Unit	3.6	10.6	4.8
Person Trips	2880	8480	3840
Auto Pers.Trips as %Total Pers.Trips	88%	97%	94%
Auto Occupancy	1.37	1.81	1.43
Auto Trips	1850	4545	2524
Auto Trips/Unit	2.31	5.68	3.16

a. From Table 55.
b. From Table 56.
c. (Number of Units) x (Person-Trips/Unit).
d. From Table 3, Chapter Two.
e. From Table 12, Chapter Two.
f. (Person-Trips) x (Auto % of Person-Trips) ÷ Auto Occupancy
g. Auto Trips/Number of Units.

The calculations made so far provide average daily *person*-trip rates by purpose for the residential development. The desired result, however, is average daily *vehicle* trips per housing unit. The calculations necessary to obtain auto vehicle trips per unit are given in Table 57. The calculations will be described for the single family case only, inasmuch as the same procedure is used for the other types of units. The number of housing units is acquired from Table 55. Person-trips/unit rates for each purpose are obtained from Table 56. Person-trips are calculated by multiplying person-trips/unit by the number of units (for home-based work (HBW) trips, this would be $823 \times 3.7 = 3{,}045$). The percent of these person-trips that are auto trips is obtained from Table 3, Part A, Chapter Two (for urbanized area population 100,000 to 250,000). Auto occupancy is obtained from Table 12, Chapter Five, "Automobile-Occupancy Characteristics," for urbanized area population 100,000 to 250,000. Auto trips are then computed by multiplying person-trips by the auto person-trips as a percent of total person-trips and dividing by auto occupancy [i.e., for HBW trips: $(3{,}045 \times 0.88) \div 1.37 = 1{,}956$]. The auto trip rate per household unit is then obtained by dividing the auto trips by the number of units (i.e., for HBW trips: $1{,}956 \div 823 = 2.38$). These rates are multiplied by the corresponding units of each type (single family, townhouses, apartments) and entered in Table 58, "Part A—Productions," as shown for analysis areas 1 to 4. For example, HBW productions for analysis area 3 are calculated as follows:

172 single family units × 2.38 trips/unit	=	409
287 townhouses × 2.38 trips/unit	=	683
550 apartments × 2.31 trips/unit	=	1,271
Average daily auto trips	=	2,363

The same is accomplished for home-based nonwork (HBNW) trip productions. Nonhome-based (NHB) trips are not necessarily related to analysis areas 1 to 4 in any production-attraction sense. Although they are made by the residents of areas 1 to 4, they may be made between other areas. This is not true of HBW and HBNW trips which by definition are produced at the home end. The handling of NHB trips is described later in this section.

For the nonresidential portion of the new development, the trip rates contained in Table 1, Chapter Two, were used. The new nonresidential development occurs in analysis areas 3 and 7 (see Table 55) for shopping areas and offices and in areas 1 to 4 for recreation.

The following calculations were made to estimate trips for the 39,000 sq ft of shopping space in analysis area 3. From Table 1, it can be seen that for a neighborhood retail generator under 100,000 sq ft gross floor area (GFA), a trip rate of 97 vehicle trips/1,000 sq ft GFA can be expected. This results in:

$$39{,}000 \text{ sq ft GFA} \times \frac{97 \text{ vehicle trips}}{1{,}000 \text{ sq ft GFA}} = 3{,}783 \text{ veh. trip ends} \quad (47)$$

It is estimated that for a shopping area of the type proposed, 2.2 employees per 1,000 sq ft can be expected, resulting in 86 employees. A regional estimate (made by the local planning agency in Boise) of vehicle HBW trips per employee of 1.82 was used to estimate HBW trips attracted to the area, resulting in $86 \times 1.82 = 156$ HBW attractions to the shopping center. To estimate the proportion of HBNW and NHB trips, the proportion found from the regional projections made by the local transportation agency was used. Thus, it was estimated that of the total HBNW trips plus NHB trips, 56 percent were HBNW and 44 percent were NHB. Therefore, for the shopping area, of a total of 3,783 attractions, 156 are HBW trips; of the remaining 3,627 trips, 56 percent or 2,031 are estimated as HBNW trips, and 44 percent or 1,596 are estimated as NHB trips.

For office space, 2,000 sq ft is expected to be used as medical office space and 3,000 sq ft as general office space. From Table 1, 63.5 vehicle trips/1,000 sq ft gross floor area (GFA) are generated by the medical office space and 11.7 vehicle trips/1,000 sq ft GFA are generated by the general office space. This results in the following trip estimates:

2,000 sq ft medical GFA × 63.5 vehicle trips/ 1,000 sq ft GFA	= 127
3,0000 sq ft general GFA × 11.7 vehicle trips/ 1,000 sq ft GFA	= 35
Average daily vehicle trips	= 162

It is expected that 17 employees will work in the office space and make 1.82 HBW vehicle trips per employee for a total of 31 trips. Therefore, of the total 162 office-related trips, 31 will be HBW trips. Of the remainder, 56 percent is expected to be HBNW trips and 44 percent NHB trips (see preceding discussion). This results in 73 HBNW trips and 58 NHB vehicle trips.

For recreation attractions in analysis area 3, a vehicle trip rate of 5.1 for county parks (Table 1) was used resulting in 332 recreation attractions (65 acres × 5.1 vehicle trips/acre). All these trips are assumed to be HBNW trips.

The trip-attraction activity estimated for analysis area 3 is summarized as follows:

	HBW	HBNW	NHB
Shopping area	156	2,031	1,596
Offices	31	73	58
Recreation	0	332	0
Total avg. daily veh. trips	187	2,436	1,654

The dwelling units (DU) in analysis area 3 also attract some HBNW and NHB trips. To estimate such attraction, the information in Table 3, Part C, was used. Based on this information, HBNW attractions per unit equals 1.0 × dwelling units and NHB trips per unit equals 0.5 × dwelling units. There are 1,009 dwelling units in area 3, thereby resulting in 1,009 HBNW attractions and 505 NHB attractions. Adding these attractions to the preceding attractions for shopping, office, and recreation, the following average daily vehicle trips are obtained:

HBW		= 187
HBNW	2,436 + 1,009	= 3,445
NHB	1,654 + 505	= 2,159

These results are entered in Table 58, "Part B—Attractions," for analysis area 3. For analysis areas 1, 2, and 4, the following results are entered in Table 58.

ANALYSIS AREA	DU'S	HBNW TRIPS AT 1.0 TRIPS/DU	NHB TRIPS AT 0.5 TRIPS/DU	RECREATION ACRES	HBNW TRIPS AT 5.1 TRIPS/ACRE
1	225	225	113	15	77
2	390	390	195	15	77
4	686	686	343	8	41

It is generally assumed that for each analysis area, NHB productions equal NHB attractions. Therefore, the productions for NHB trips in Table 58, Part A, are filled in from the NHB trips as calculated for areas 1 to 4 and entered in Table 58, "Part B—Attractions."

The remaining calculations for trip generation must be made for the Highland Square Shopping Mall. The same procedure as used for analysis area 3 for shopping areas and office space is applied here. The calculations are carried out as shown in Figure 147. The results are summarized as follows and entered for area 7 in Table 58, "Part B—Attractions."

	HBW	HBNW	NHB
Shopping area	564	3,257	2,559
Offices	235	524	411
Total avg. daily veh. trips	799	3,781	2,970

The NHB trip estimate is also entered for zone 7 in Table 58, "Part A—Productions." The results given in Table 58 are next entered into work sheets for trip distribution (as described in the next section). The trip-production estimates are entered directly into the trip-distribution table. If the total of areawide attractions differs from areawide productions, an adjustment is generally made to the individual analysis area attractions to strike a balance. Review of Table 58 will indicate the following production and attraction vehicle trip ends by purpose:

	PRODUCTIONS	ATTRACTIONS	FACTOR ADJUSTMENT
HBW	133,272	128,816	1.035
HBNW	413,396	408,657	1.012
NHB	314,651	321,191	0.980

It can be seen that a slight imbalance exists between the HBW and HBNW trips. To balance the attraction vehicle trip ends for each of the 19 analysis areas in order to match the production/attraction control totals, the adjustment factor is applied to each of the 19 attraction trip ends for both the HBW and the HBNW trips. For example, for analysis area 5, the HBW and the HBNW attraction trip ends are adjusted as follows:

HBW: 302 × 1.035 = 313 vehicle trip ends
HBNW: 2,186 × 1.012 = 2,212 vehicle trip ends

And so on for all other analysis areas. These adjustments are undertaken before entering the production/attraction trip ends in the trip distribution work sheets described subsequently.

To assess the actual clock time required to conduct the manual trip-generation procedures described previously, a time log was kept for the various steps undertaken. The time log shows that the entire trip-generation procedure required a total of 12 person-hours as follows:

PROCEDURAL STEP	TIME REQUIRED PERSON-HOURS
1. Zoning of region.	3
2. Conversion of zones to analysis areas.	1
3. Accumulation of zonal P's and A's to analysis areas.	3
4. Generation of trips for new land uses.	5
Total	12

Trip Distribution

Using the trip-generation output from the previous step, the manual trip-distribution procedure was applied to distribute trips among the 19 analysis areas established. The average daily vehicle trips by each of the three purposes (HBW, HBNW, and NHB) were distributed in turn. Trip distribution was conducted in exactly the same manner as that described in Chapter Three, "Trip Distribution." As such, the actual application process is not described here in elaborate detail, except for situations where the process deviates from that in Chapter Three.

The distribution process began by first delineating clearly district boundaries and centroids for all 19 analysis areas, in addition to laying out the significant highway network on a map of the Boise region, that is, freeways and major arterials. Also defined were subregion boundaries for the Boise CBD, the central city, and the suburbs. The CBD boundary was relatively easy to identify; the central city boundary, however, required careful judgment because this boundary also defines the inner periphery of the suburb. All these geographic and network characteristics were indicated on a large map of scale ½ in. to 1 mile. Figure 148 shows district boundaries and centroids, subregion boundaries, the highway network, and other relevant features of the Boise study area. (See also Fig. 146.)

The next step involved setting up a 19 × 19 trip-distribution matrix for each of the three purposes. For each matrix and each purpose, district numbers and the production and attraction vehicle trip ends were inserted in the appropriate cells. The completed trip distribution work sheet for HB work is shown in Figure 149. Similar computations were accomplished for HBNW and NHB trips, respectively, but are not shown. Notice that the individual attraction trip ends have been adjusted to achieve the regionwide control totals, as has been described previously.

The district-to-district travel times were then inserted in the corresponding cells of each of the matrices. (Recall that the travel time from area i to area j is assumed to remain the same as that for j to i. In effect, therefore, the travel times remain the same irrespective of trip purpose.) To develop the district-to-district travel times, the "Airline Distance vs. Travel Time vs. Distribution Factors" graphs shown in Chapter Three were used. The series of charts that applies to urbanized areas that fall in the 100,000 to 250,000 population group was used for the Boise area (Figs. 13 through 18). Recall also that construction of the travel time for any trip interchange [of which there are $(19 \times 19)/2 = 181$ trip interchanges] involves several sequential steps. First, measurement from the map of the airline distance, the corresponding over-the-road arterial-freeway mix, and an indication of the subregions that are to be traversed; that is, CBD-to-CBD, or CBD-to-suburb, central city-to-suburb, and the like. Then, using this information, the appropriate graph was entered to obtain the corresponding travel time.

As can be inferred from this discussion, construction of the travel time matrix is repetitive, tedious, and quite involved. To lessen this burden, two technicians were assigned this task, so that one could read off trip interchange information from the map, while the other could obtain the corresponding travel time from the graphs and record the same on the trip distribution work sheets.

Having obtained and tabulated travel times for all district-to-district trip interchanges, the next step was to insert distribution (friction) factors corresponding to each of these travel times and each of the purposes. Travel times and the corresponding distribution factors by trip purpose used for trip distribution are given in Table 59.

After all the basic information (i.e., productions, attractions, travel times, and distribution factors) had been compiled, the actual distribution process was undertaken in turn for each of the trip purposes. The process was applied through two iterations, yielding the final values of the 19 × 19 trip interchanges. These final results were scrutinized for reasonableness and consistency; for example, by applying systematic arithmetic checks for key calculations, by checking production and attraction trip balance, by confirming the magnitudes of selected trip interchanges, and the like. When no errors were detected, the three trip-distribution tabulations were considered to be complete.

The final auto trip interchanges (and all required steps) are shown in Figure 149 for the HBW trip purpose.

During application of the manual trip-distribution procedure, an accurate time log was compiled, not only to monitor progress of work but also to acquire an idea of the actual time and manpower resources used. At the conclusion of the distribution process, the time log indicated the following time requirements:

PROCEDURAL STEP	TIME REQUIRED, PERSON-HOURS
1. Setting up of map (districts, highway network, etc.).	2
2. Derivation of travel distance/travel time/distribution factors.	6
3. Distribution of HBW trips.	6
4. Distribution of HBNW and NHB trips.	19
Total	33

The trip-distribution process for all three trip purposes consumed a total of 33 person-hours. Note that this total time requirement is higher than that estimated from Figure 39, Chapter Three (i.e., 24 person-hours for 19 areas). This higher time requirement can be attributed to the fact that the HBNW and NHB trip distributions were undertaken by a single clerk who had no familiarity and no prior experience with any transportation planning proce-

TABLE 58

AVERAGE DAILY VEHICLE TRIP ENDS

PART A - PRODUCTIONS

Analysis Area	HBW		HBNW		NHB	
	From Regional Zonal Forecast	Estimate as Described	From Regional Zonal Forecast	Estimate as Described	From Regional Zonal Forecast	Estimate as Described
1		536		1363		113
2		928		2304		195
3		2363		5810		2159
4		1615		3989		343
5	2272		6922		1633	
6	3850		12056		9372	
7	3371		10605		4045	2970
8	7291		22651		10881	
9	666		2083		6832	
10	526		1614		40394	
11	2070		6575		19448	
12	3672		11517		4179	
13	17594		54718		29774	
14	6841		21308		25508	
15	31330		98335		48121	
16	13169		41944		25561	
17	16879		52405		33205	
18	3325		10317		4037	
19	14974		46880		45881	
Subtotal	127830	5442	399930	13466	308871[a]	5780
TOTAL	133272		413396		314651	

PART B - ATTRACTIONS

Analysis Area	HBW		HBNW		NHB	
	From Regional Zonal Forecast	Estimate as Described	From Regional Zonal Forecast	Estimate as Described	From Regional Zonal Forecast	Estimate as Described
1				302		113
2				467		195
3		187		3445		2159
4				727		343
5	302		2186		1667	
6	3198		17318		10282	
7	830	799	5415	3781	4196	2970
8	3651		15083		11029	
9	3628		7813		6117	
10	26485		39613		38148	
11	7252		23262		16765	
12	1485		6164		10765	
13	10994		37008		4216	
14	11680		24528		30304	
15	15049		70532		25222	
16	11710		29678		51449	
17	13475		56245		26972	
18	2522		5062		33403	
19	15569		60028		44876	
Subtotal	127830	986	399935	8722	315411[a]	5780
TOTAL	128816		408657		321191	

a. The NHB productions and attractions from the regional zonal forecasts are not equal due to procedures used locally in Boise.

```
-- Shopping Area equals  139000 sq. ft. GFA

   Trip Rate equals 45.9 Vehicle Trips/1000sq.ft. (Table 2)

   Trips = 45.9/1000 x 139000 = 6380 Vehicle Trips

   Employment Estimate = 45.9 Trips/1000sq.ft. GFA  =2.23    Empl.
                         20.6 Trips/Employee             1000sq.ft.GFA
                                                          (Table 1)

                       = 2.23 x 139000 = 310 Employees
                         1000

   HBW Trips/Employee = 1.82 x 310 = 564  Average Daily Veh. Trips
   HBNW + NHB Trips   = 6380 - 564 = 5816    "      "     "     "
   HBNW               =0.56 x 5816 = 3257    "      "     "     "
   NHB                =0.44 x 5816 = 2559    "      "     "     "
```

```
-- 40,000 sq. ft. GFA Office Space

   10,000 sq. ft. Medical @ 63.5 trips/10000sq.ft.GFA    =635 Veh.Trips
   25,000 sq. ft. General @ 11.7 trips/1000sq.ft.GFA     =293    "
    5,000 sq. ft. Government @ 48.3 trips/1000sq.ft.GFA=242      "
          (Rates from Table 1)                           1170    "

   Employment Estimate
     Medical: (63.5 Trips/1000sq.ft.GFA) x 10000sq.ft.  =  25
               25 Trips/Employee
     General: (11.7/3.5) x 25                           =  84
     Government: (48.3/12) x 5                          =  20
                                 Total Employees        = 129

     HBW Trips    = 1.82 x 129          =  235 Avg.Daily Veh.Trips
     HBNW Trips   = 0.56(1170 - 235)    =  524  "    "    "    "
     NHB Trips    = 0.44(1170 - 235)    =  411  "    "    "    "
                                          1170  "    "    "    "
```

Figure 147. Calculations of trip attractions for shopping mall.

dures. The time estimates in Figure 39 apply to relatively skilled and experienced technicians.

The auto-trip interchange results obtained from this trip-distribution stage are now used as input to the trip-assignment stage. Description of the assignment procedure follows.

Trip Assignment

The actual trip-assignment process used was the all-or-nothing assignment method described in Chapter Seven, "Traffic- Assignment Procedures." Because the objective of this scenario is to investigate additional traffic impacts caused specifically by the new developments (i.e., Thunder Hill, Claremont, and Highland Square Shopping Mall), only trips to and from these new developments were considered in the assignment process. Furthermore, the area designated for study of traffic impacts was confined to analysis areas immediately adjacent to the new developments, inasmuch as this is where major impacts were anticipated.

The first step of the assignment process, therefore, involved setting out an impact boundary. Figure 150 shows a map of the new development areas and location of the impact boundary. The boundary encompasses analysis areas 5, 6, 7, and 9, and it is within these areas that the traffic impacts are to be determined.

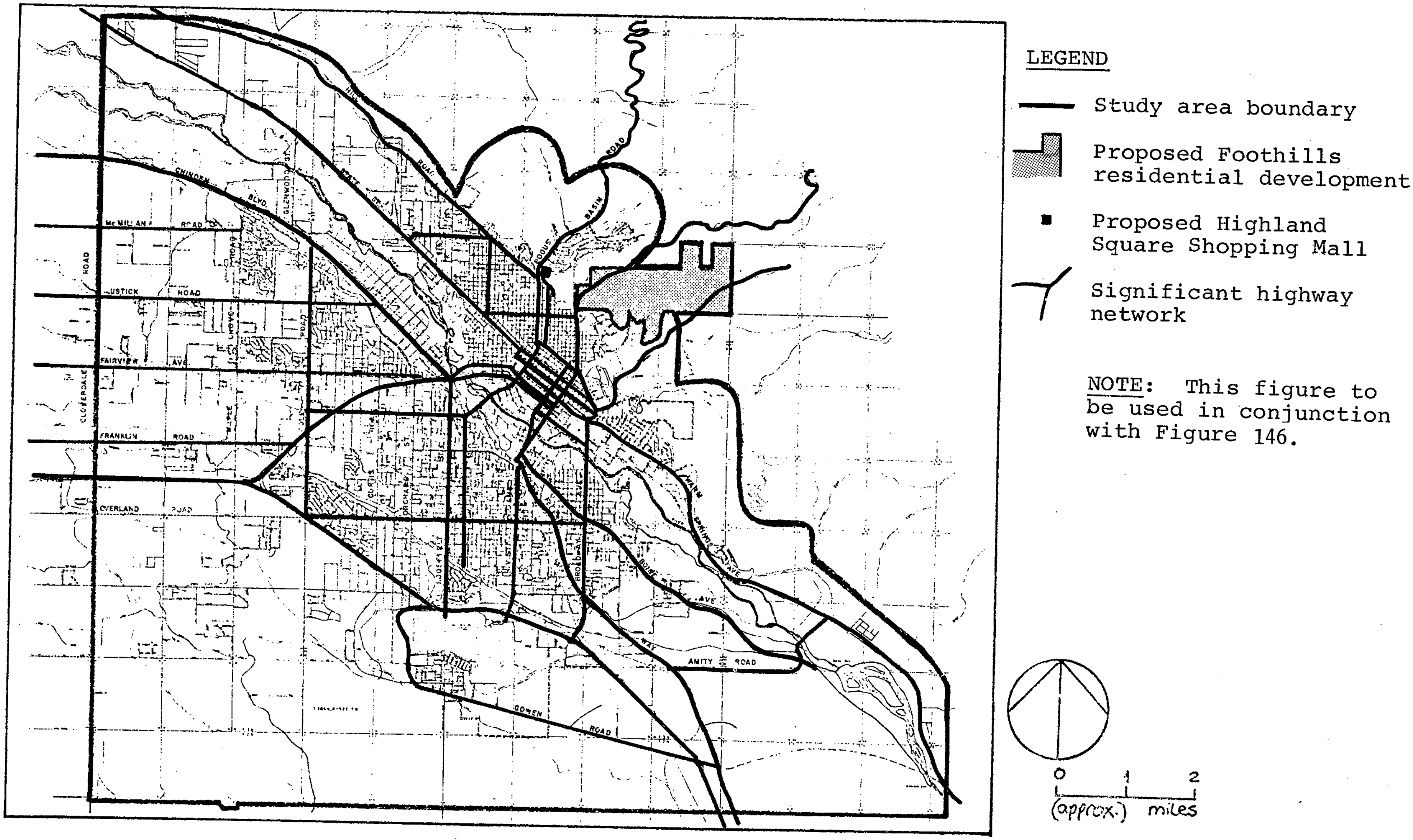


Figure 148. Boise metropolitan area, showing significant highway network.

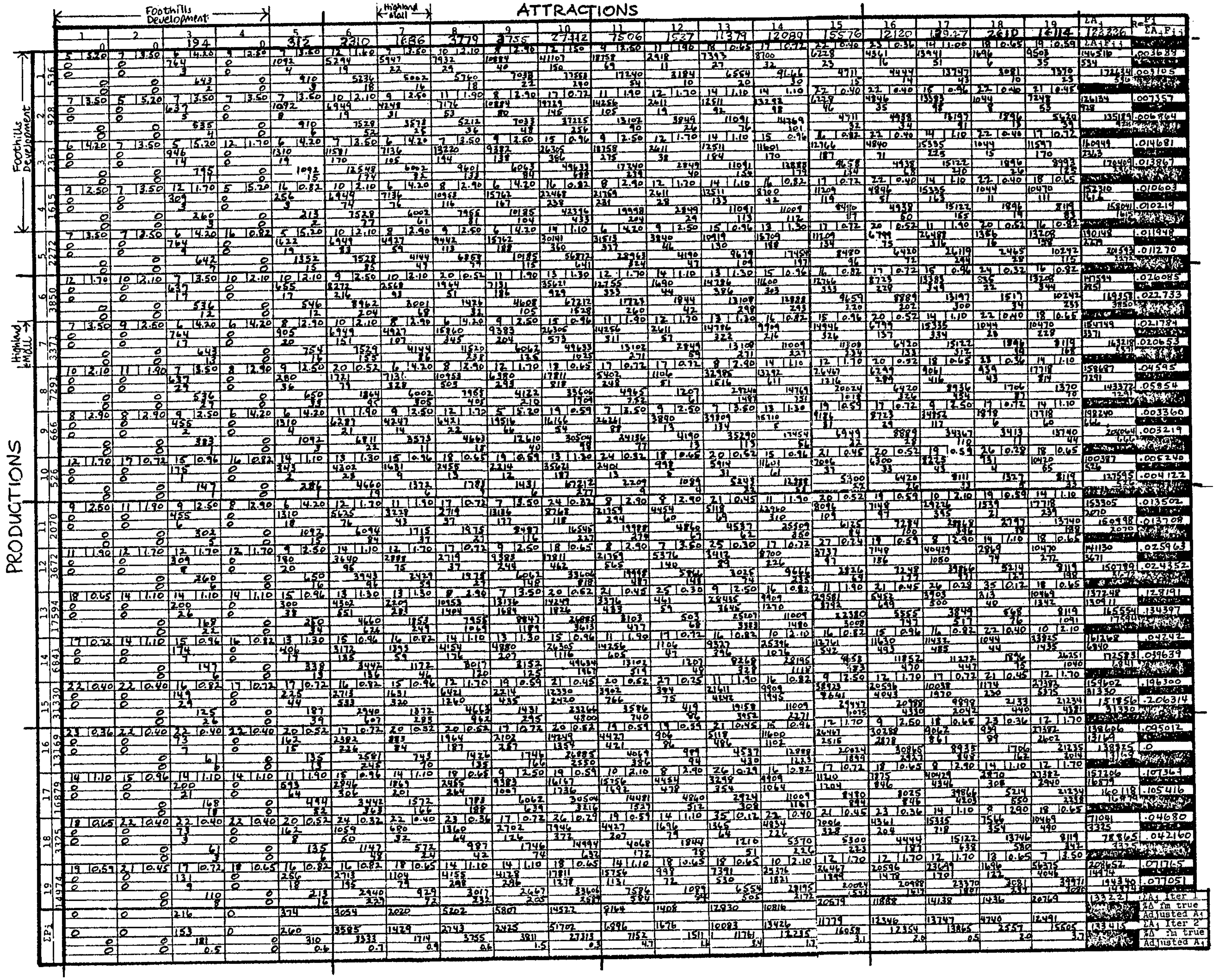


Figure 149. Trip distribution matrix work sheet for HBW vehicle trips.

TABLE 59

TRAVEL TIME AND FRICTION FACTORS BY TRIP PURPOSE USED FOR TRIP DISTRIBUTION

	FRICTION FACTORS BY TRIP PURPOSE		
TRAVEL TIME (Mins.)	HBW	HBNW	NHB
1	18.00	80.00	50.00
2	11.00	50.00	30.00
3	8.50	34.00	18.00
4	6.60	22.00	12.00
5	5.20	17.00	9.00
6	4.20	10.00	7.00
7	3.50	7.00	5.00
8	2.90	5.40	4.00
9	2.50	3.90	3.00
10	2.20	2.90	2.20
11	1.90	2.00	1.80
12	1.70	1.60	1.50
13	1.30	1.20	1.20
14	1.10	0.92	1.00
15	0.96	0.78	0.80
16	0.82	0.70	0.70
17	0.72	0.66	0.60
18	0.65	0.44	0.60
19	0.50	0.38	0.50
20	0.52	0.33	0.40
21	0.45	0.30	0.35
22	0.40	0.27	0.30
23	0.36	0.23	0.28
24	0.32	0.20	0.22
25	0.29	0.19	0.20
26	0.27	0.18	0.18
27	0.24	0.17	0.16
28	0.22	0.16	0.15
29	0.19	0.14	0.14
30	0.18	0.13	0.12
31	0.17	0.11	0.10
32	0.16	0.10	0.095
33	0.14	0.094	0.088
34	0.13	0.085	0.079
35	0.11	0.079	0.067

Next, the significant freeway-arterial network in the Boise region was laid out. It was made certain that in the identification of significant routes, all areas were provided with highway access to and from the new development areas. As for the traffic impact area itself, a slightly more detailed network was selected. In this selection process, the width, traffic capacity, and existing traffic volumes were some of the factors used to determine the significance of routes. Then, highway segments within the impact boundary were numbered in an orderly manner. The network selected for analysis is also shown in Figure 150.

The loading (stringing) of average daily vehicle trips onto the highway segments was accomplished using the tabular method described previously in Chapter Seven. Two assignments were actually carried out. The first involved loading of HBW vehicle trips, ultimately adjusted by an appropriate factor to convert the same to total vehicle trips. The second involved loading of the sum of HBW, HBNW, and NHB vehicle trips. The reason underlying this venture was to compare volumes obtained from a factored HBW trip assignment to those obtained from a total trip assignment. The primary objective here was to investigate whether trip-distribution steps for HBNW and NHB purposes can be eliminated; that is, if factored HBW trips yield results close to total trips for all purposes, the question arises whether trip distributions for other purposes are at all necessary for quick-estimate planning.

Factoring of HBW trips to total trips has seldom been used in actual transportation planning practice. However, it does take on added importance for quick-response, sketch-planning techniques, such as those described in Chapters Two through Nine, because considerable time savings could be achieved. The Boise scenario, in addition to simulating the traffic impacts of the new developments, also attempts to investigate the effectiveness and accuracy of expanded trips.

In order to obtain the expansion factor, reference should be made to Table 39, Chapter Six, "Time-of-Day Characteristics." For an urbanized area the size of Boise, the table indicates a multiplicative factor of 5.5 necessary to expand HBW trips to total trips. Hence, after assigning HBW vehicle trips, the accumulated vehicle trips for each highway segment would then be factored by 5.5 to arrive at the total vehicle trips. Trip assignments for HBW ($\times 5.5$) trips and for HBW + HBNW + NHB trips are described as follows.

Assignment of HBW ($\times$ *5.5*) *Vehicle Trips*

Unfactored, HBW auto trips were assigned to the selected highway network (shown in Fig. 150) by choosing the most reasonable routes for the following trip interchanges (with the necessary adjustments):

From area i to area j } for $i = 1, 2, 3, 4$, and
From area j to area i } $j = 5$ through 19
One-half of HBW trips from area j to area 7 } for $j = 5$ through 19

To elaborate, all HBW trips produced by the new development areas 1, 2, 3, and 4 and attracted to all the other 15 areas, and those produced by all the other 15 areas and attracted to areas 1, 2, 3, and 4 are assigned to the network. [Note, however, that the HBW trip-distribution matrix (Fig. 150) indicates that only district 3 of the new development areas 1 to 4 has any HBW trip attractions.] In addition to these trip interchanges, the Highland Square Shopping Mall in analysis area 7, although itself not producing any HBW trips, does attract one-half (½) of the HBW trips attracted by area 7 from production areas 5 through 19. The ½ factor is derived from Table 58, "Part B—Attractions," by noting that the shopping center accounts for about one-half of the total district 7 attractions. There are 830 HBW attraction trip ends due to some activity in the district, and 799 HBW trip ends due to the shopping mall itself. The ratio 799/830 + 799) is the ½ factor.

The results of the tabular HBW auto trip assignment are shown in Figure 151 with trips inserted in appropriate cells corresponding to the most reasonable route for a particular interchange. For example, for trip interchange 3-6-3, the HBW trip-distribution matrix (Fig. 149) indicates 174 average daily vehicle trips from district 3 to district 6, and 12 trips from district 6 to district 3, amounting to a total of

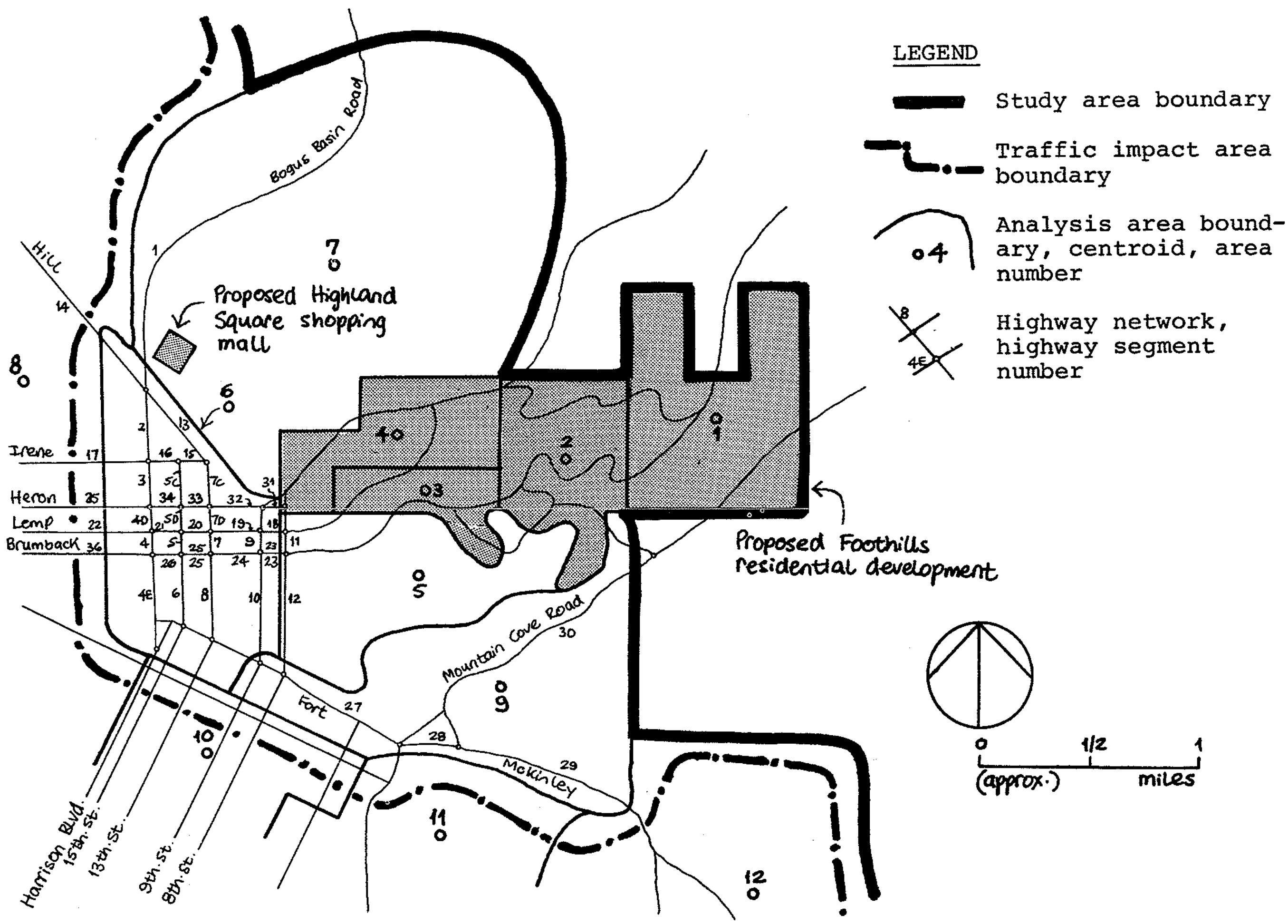


Figure 150. Traffic impact area relative to proposed developments and highway network selected for traffic assignment.

186 trips. These are inserted in cells 9, 24, 25, 26 representing the most reasonable path to and from areas 3 and 6. (See highway network in Fig. 150.)

Notice also that trips from area 5, for example, to the Highland Square Shopping Mall (district 7) are one-half of the trips indicated in the trip-distribution matrix for that trip interchange; that is, $\frac{1}{2} \times 47 = 24$ (to the nearest trip). Hence, for the districts 5 to 7 trip interchange, 24 trips are inserted in cells 12, 11, 31, 32, 7, 13, and 1 representing the minimum path.

Average daily HBW vehicle trip totals for each highway segment are shown at the bottom of Figure 151. For instance the total number of HBW trips on highway segment 4, for example, is $101 + 185 + 160 + 133 + 112 + 87 + 83 + 23 + 142 + 35 + 36 = 1{,}097$. And so on for all other highway segments.

In order to convert these HBW average daily vehicle trips to total vehicle trips, the 5.5 expansion factor as given by Table 39 was applied to the HBW trips. Thus, for highway segment 4, for example, the conversion is as follows:

Total auto trips on highway segment 4
$= 1{,}097$ (HBW vehicle trips) $\times$ 5.5 (expansion factor)
$= 6{,}034$

And so on for all other highway segments, the results of which are shown in Figure 151.

Assignment of HBW + HBNW + NHB Vehicle Trips

The sum of the average daily vehicle trips for these three purposes was assigned to the same minimum paths identified previously for the following trip interchanges (with the necessary adjustments):

For HBW, HBNW and NHB trips, the sum of trips:

From area i to area j } where $i = 1, 2, 3, 4$ and
From area j to area i } $j = 5$ through 19

For HBW trips:
One-half of HBW trips from area j to area 7
For HBNW trips:
41.1 percent of HBNW trips from area j to area 7
} where $j = 5$ through 19

For NHB trips:
41.4 percent of NHB trips from area 7 to area j
41.4 percent of NHB trips from area j to area 7
} where $j = 5$ through 19

The adjustments noted previously require some clarifications. For all three purposes, vehicle trips to and from the new development and the 15 other districts are added together to obtain the total trip interchanges. In addition

HBW x 5.5 1/3

TRIP INTERCHANGE	TRIP VOLUME	NETWORK SEGMENT #S																																			
		22ND	HARRISON			15TH		13TH		9TH		8TH		HILL		IRENE			LEMP					BRUMBACK				McKINLEY			COVE	HELEN					BRUM
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1-5-1	3												3																								
1-6-1	18																							18	18	18	18										
1-7-1	16	16						16						16						16													16				
1-8-1	18							18						18	18																		18				
1-9-1	22																														22						
1-10-1	240																											240			240						
1-11-1	54																														54						
1-12-1	10																													10	10						
1-13-1	20																							20	20	20	20										20
1-14-1	30																														30						
1-15-1	15																														15						
1-16-1	14																														14						
1-17-1	43																														43						
1-18-1	10																														10						
1-19-1	23																														23						
2-5-2	6												6																								
2-6-2	52																							52	52	52	52										
2-7-2	25	25						25				25		25																		25	25				
2-8-2	36							36				36		36	36																	36	36				
2-9-2	48																														48						
2-10-2	256								256															256	256												
2-11-2	90																														90						
2-12-2	26																													26	26						
2-13-2	76																							76	76	76	76										76
2-14-2	101				101																			101	101		101										
2-15-2	32												32																								
2-16-2	34												34																								
2-17-2	91																														91						
2-18-2	13																														13						
2-19-2	39												39																								

Figure 151. Trip assignment work sheet for HBW (×5.5) average daily vehicle trips.

TRIP INTERCHANGE	TRIP VOLUME	NETWORK SEGMENT #'S																																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
3-5-3	22											22	22																								
3-6-3	186									186															185	186	186										
3-7-3	95	95						95						95																			95				
3-8-3	160							160						160	160																		160				
3-9-3	85											85	85															85			85						
3-10-3	689								689	699															689												
3-11-3	243											243	243															243									
3-12-3	46											46	46															46	46	46							
3-13-3	176																																176	176	176	176	
3-14-3	185				185																												185	185	185		
3-15-3	160				160																												160	160	160		
3-16-3	74											74	74															74									
3-17-3	228											228	228															228									
3-18-3	29											29	29															29	29	29							
3-19-3	133				133																												133	133	133		
4-5-4	2											2	2																								
4-6-4	77																							77	77	77	77										
4-7-4	61	61						61		61				61					61														61				
4-8-4	81							81		81				81	81				81														81				
4-9-4	104												104															104			104						
4-10-4	433								433										433	433																	
4-11-4	204												204															204									
4-12-4	29												29															29	29	29							
4-13-4	113																		113	113	113	113	113														
4-14-4	112				112																			112	112	112	112										
4-15-4	87				87																			87	87	87	87										
4-16-4	50												50															50									
4-17-4	155												155															155									
4-18-4	19												19															19	19	19							
4-19-4	83				83																			83	93	83	83										

Figure 151 (continued).

HBW x 5.5 3/3

NETWORK SEGMENT #s

Trip Interchange	Trip Volume	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
5-7	24	24						24				24	24	24					
6-7	34	34	34	34															
7-7	43	43																	
8-7	153	153													153				
9-7	6							6				6	6	6					
10-7	3							3	3					3					
11-7	19							19	19					19					
12-7	30							30	30					30					
13-7	125	125	125															125	
14-7	23	23	23	23	23														
15-7	142	142	142	142	142														
16-7	35	35	35	35	35														
17-7	83							83	83					83					
18-7	12							12	12					12					
19-7	36	36	36	36	36														
HBW Segment Volumes		812	395	270	1097	0	0	669	1525	1047	0	820	1520	669	458	0	0	125	688
HBW x 5.5 (Factored)																			
=TOTAL		4466	2173	1485	6034	0	0	3680	8388	5759	0	4510	8360	3680	2519	0	0	688	3784
		Boggs	Harrison			15th		13th		9th		5th		Hill		Irene		Lemp	

Trip Interchange	Trip Volume	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
5-7	24													24	24				
6-7	34																		
7-7	43																		
8-7	153																		
9-7	6									6			6	6	6				
10-7	3																		
11-7	19									19									
12-7	30									30	30	30							
13-7	125																		
14-7	23																		
15-7	142																		
16-7	35																		
17-7	83									83									
18-7	12									12									
19-7	36																		
HBW Segment Volumes		562	113	113	113	882	1783	711	812	1656	153	183	924	91	1176	654	654	176	96
HBW x 5.5 (Factored)																			
=TOTAL		3091	622	622	622	4851	9807	3911	4466	9108	842	1040	5082	501	6468	3597	3597	968	528
		Lemp				Brumback				McKinley		Love		Heron					Brum

Figure 151 (continued).

to these interchanges, trips to the Highland Square Shopping Mall in area 7 have to be accounted for. For HBW trips, the mall does not produce but does attract one-half of HBW trips attracted by area 7 from production areas 5 through 19. [This situation is described in the preceding section, "Assignment of HBW (×5.5) Vehicle Trips."] For HBNW trips, the same is true of the mall; that is, it does attract but does not produce HBNW trips. Because 41.1 percent of the HBNW attraction trip ends in area 7 are attributed to the mall itself, trips from production area 5 through 19 to the mall have to be factored by that fraction. For NHB trips, however, the mall both produces and attracts such trips, but because 41.4 percent of the NHB production and attraction trip ends in area 7 are attributed to the mall, both trips to and from the mall and area 5 through 19 have to be adjusted by that fraction.

The 41.1 percent HBNW attraction factor and the 41.4 percent NHB attraction factor are derived from Table 58, "Part B—Attractions." For area 7, there are 5,415 HBNW trip ends due to some activity in the analysis area and 3,781 HBNW trip ends due to the shopping mall itself. The ratio 3,781/(5,415 + 3,781) is the 41.1 percent HBNW factor. Similarly, the NHB factor is given by the ratio 2,970/(4,196 + 2,970) = 41.4 percent.

The results of the tabular HBW + HBNW average daily vehicle trip assignment are shown in Figure 152. Trips have been inserted in cells corresponding to minimum paths identified in the previous assignment. The assignment was carried out in a manner similar to that described for the HBW assignment.

The HBW + HBNW + NHB vehicle trip totals for each highway segment are shown at the bottom of Figure 152. For instance, the total number of HBW + HBNW + NHB trips on highway segment 4 is 289 + 649 + 1,148 + 688 + 312 + 442 + 250 + 388 + 1,125 + 306 + 407 = 6,004. And so on for all other highway segments.

The two trip assignments for additional traffic from the new developments (analysis areas 1, 2, 3, and 4 and the mall in area 7) are now complete. It can be seen from the previous discussion that trips to and from area 7 required certain adjustments depending on the magnitude of attractions to the mall. All these adjustments could have been avoided by creating a special zone for the mall itself, for example, area 7A. This alternative approach would have meant an extra zone for trip distribution and trip assignment, but then the factoring would have been eliminated.

At this juncture, the reader must be reminded that the results of the preceding trip assignments (for additional traffic) are based on the all-or-nothing method. This method, although simple in application, often yields unrealistic traffic volumes because it does not explicitly consider the numerous factors that influence the driver's choice of routes. In most computerized assignment packages, capacity restraint functions are available to adjust and balance such unrealistic traffic volumes. For this scenario, a manual post-assignment redistribution technique developed by R. H. Pratt Associates (*72*) was used. This technique has been described in Chapter Seven in the section entitled, "Distribution of Assigned Volumes Among Available Facilities." This adjustment constitutes the final step of trip assignment.

Post-Assignment Redistribution of Assigned Volumes

The highway network selected for post-assignment redistribution was that contained in analysis area 6. Figure 153 shows the actual network, the existing 1976 traffic volumes, and level-of-service "C" capacities for district 6. (The existing volumes exclude the additional traffic generated by the new Foothills and Highland Square developments.) Figure 153 also shows the 10 horizontal cutlines across which the all-or-nothing assignment volumes are to be redistributed. Figure 154 shows the highway network in analysis area 6 and the eight vertical cutlines used for redistributing the assigned volumes.

Figure 155 shows the computations necessary for the assignment of volumes obtained from HBW (×5.5) trip assignment for the horizontal cutlines (A-A through J-J). Computations for the vertical cutlines (K-K through S-S) are not shown herein, but were conducted in a manner similar to that for the horizontal cutlines. Although not shown, assignment redistribution computations similar to those aforementioned, were also completed for the HBW + HBNW + NHB trips.

It must be pointed out that complete data on base-year traffic and capacities for all links in the highway network were not available. In several instances, therefore, certain traffic conditions were assumed—primarily, the proportion of traffic flow across any cutline was assumed to be constant anywhere along the corridor for the horizontal cutline adjustments (Fig. 155). For vertical cutline adjustments, most of the basic data were not available—as a result, it was not possible to conduct the assignment adjustments in their entirety.

In conclusion, the unadjusted and adjusted traffic volumes for both the HBW (×5.5) and the HBW + HBNW + NHB trip assignments are given in Table 60; these results (for selected links in the network) are compared against results projected by the local Boise transportation agencies. Note that the traffic results given in Table 60 are derived by adding traffic volumes by link from the trip assignments to that already existing in the base year. For example, consider highway link 10 for which the existing volume is 3,600. The various traffic projections are as follows:

- Boise local transportation agencies—link 10:
  Additional traffic due to new developments = 1,530
  Existing traffic = 3,600
  Total 5,130
- HBW (×5.5) assignment—link 10 (adjusted):
  Additional traffic due to new developments (Fig. 155, Column h) = 3,762
  Existing traffic = 3,600
  Total 7,362
- HBW + HBNW + NHB assignment—link 10 (adjusted):
  Additional traffic due to new developments (data not shown) = 3,401
  Existing traffic = 3,600
  Total 7,001

HBW + HBNW + NHB 1/3

Trip Interchange	Trip Volume	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1-5-1	47												47																								
1-6-1	97																							97	97	97	97										
1-7-1	168	168						168						168						168													169				
1-8-1	119							119						119	119																		119				
1-9-1	72																														72						
1-10-1	926																											926			926						
1-11-1	267																														267						
1-12-1	48																													48	48						
1-13-1	69																							69	69	65	69										69
1-14-1	86																														86						
1-15-1	70																														70						
1-16-1	37																														37						
1-17-1	175																														175						
1-18-1	28																														28						
1-19-1	75																														75						
2-5-2	102												102																								
2-6-2	420																							420	420	420	420										
2-7-2	230	230						230				230		230																		230	230				
2-8-2	199							199				199		199	199																	199	199				
2-9-2	178																														173						
2-10-2	738								738															738	738												
2-11-2	387																														387						
2-12-2	100																													100	100						
2-13-2	316																							316	316	316	316										316
2-14-2	289				289																			289	289		289										
2-15-2	157												157																								
2-16-2	110												110																								
2-17-2	381																														381						
2-18-2	40																														40						
2-19-2	136												136																								

Figure 152. Trip assignment work sheet for HBW+HBNW+NHB average daily vehicle trips.

TRIP INTERCHANGE	TRIP VOLUME	NETWORK SEGMENT #S 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
3-5-3	423											423	423																								
3-6-3	2161									2161															2161	2161	2161										
3-7-3	1529	1529						1529						1529																			1529				
3-8-3	1697							1697						1697	1697																		1697				
3-9-3	341											341	341															341			341						
3-10-3	1963								1963	1963															1963												
3-11-3	1607											1607	1607															1607									
3-12-3	253											253	253															253	253	253							
3-13-3	967																																967	967	967	967	
3-14-3	649				649																												649	649	649		
3-15-3	1148				1148																												1148	1148	1148		
3-16-3	310											310	310															310									
3-17-3	1100											1100	1100															1100									
3-18-3	115											115	115															115	115	115							
3-19-3	688				688																												688	688	688		
4-5-4	16											16	16																								
4-6-4	530																							530	530	530	530										
4-7-4	705	705						705		705				705					705														705				
4-8-4	586							586		586				586	586				586														586				
4-9-4	413												413															413			413						
4-10-4	1116								1116										1116	1116																	
4-11-4	1124												1124															1124									
4-12-4	120												120															120	120	120							
4-13-4	411																		411	411	411	411	411														
4-14-4	312				312																			312	312	312	312										
4-15-4	442				442																			442	442	442	442										
4-16-4	144												144															144									
4-17-4	565												565															565									
4-18-4	51												51															51	51	51							
4-19-4	250				250																			250	250	250	250										

Figure 152 (continued).

HBW + HBNW + NHB 3/3

TRIP INTERCHANGE	TRIP VOLUME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
7-5-7	217	217						217				217	217	217					
7-6-7	545	545	545	545															
7-7-7	508	508																	
7-8-7	2253	2253													2253				
7-9-7	206							106				206	206	206					
7-10-7	799							799	799					799					
7-11-7	576							576	576					576					
7-12-7	207							207	207					207					
7-13-7	1125	1125	1125															1125	
7-14-7	388	388	388	388	388														
7-15-7	1125	1125	1125	1125	1125														
7-16-7	306	306	306	306	306														
7-17-7	776							776	776					776					
7-18-7	99							99	99					99					
7-19-7	407	407	407	407	407														
TOTAL																			
SEGMENT VOLUMES		9506	3896	2714	6004	0	0	8113	6274	5548	0	5017	7557	8113	4854	0	0	1125	2818

TRIP INTERCHANGE	TRIP VOLUME	19	20	21	22	23	24	25	26	27	28	29	30	31	32	32	34	35	36
7-5-7	217													217	217				
7-6-7	545																		
7-7-7	508																		
7-8-7	2253																		
7-9-7	206									206			206	206	206				
7-10-7	799																		
7-11-7	576									576									
7-12-7	207									207	207	207							
7-13-7	1125																		
7-14-7	388																		
7-15-7	1125																		
7-16-7	306																		
7-17-7	776									776									
7-18-7	99									99									
7-19-7	407																		
TOTAL																			
SEGMENT VOLUMES		1696	411	411	411	3463	7587	4597	4886	8983	746	894	3830	852	9108	3452	3452	367	385

BOGUS | ← HARRISON → | ← 15TH → | ← 13TH → | ← 9TH → | ← 8TH → | ← HILL → | ← TREVER → | ← LEMP → | ← BRUMBACH → | ← MCKINLEY → | ← TILTON → |

Figure 152 (continued).

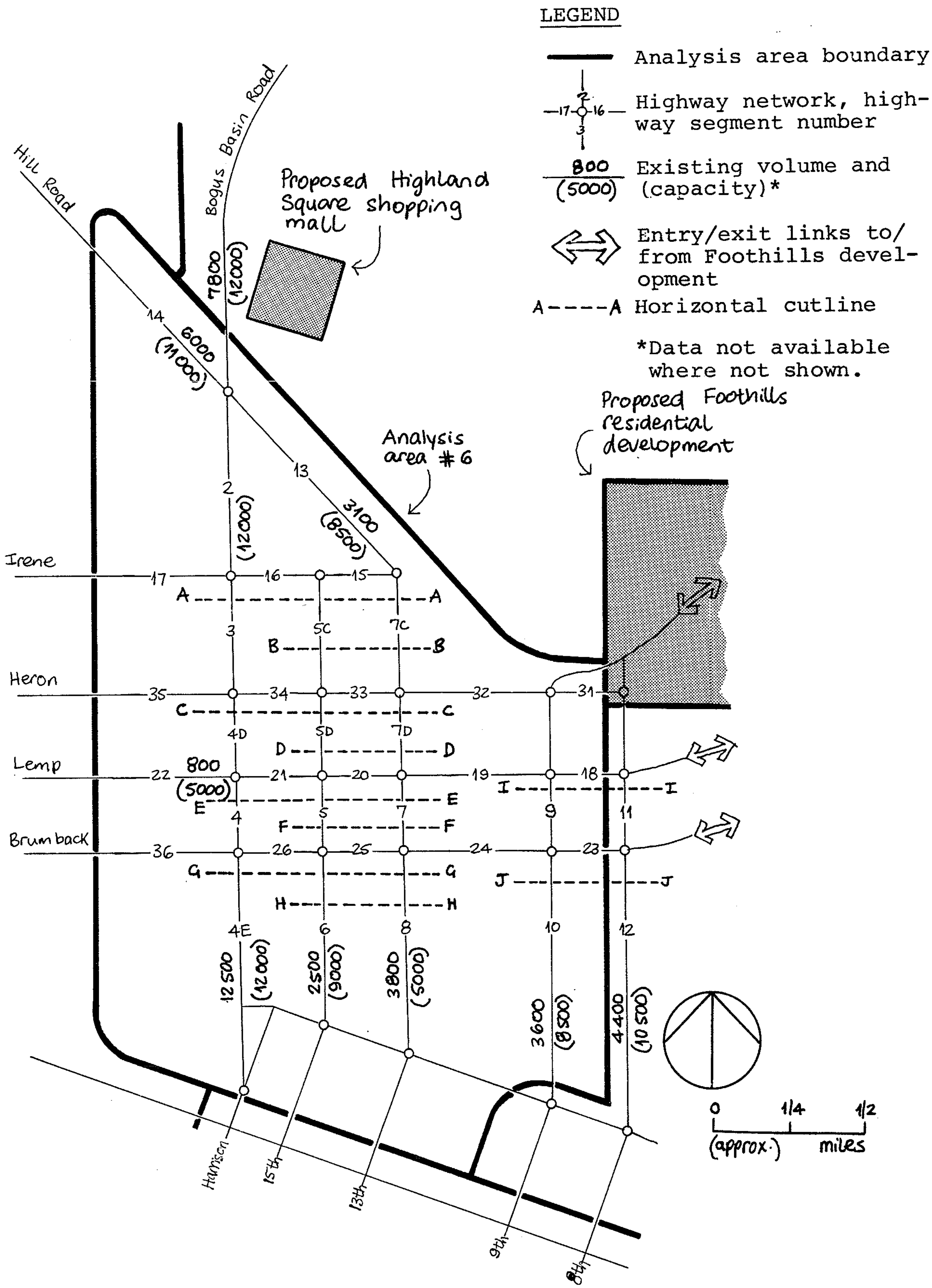


Figure 153. Highway network in analysis area 6 and horizontal cutlines for post-assignment redistribution.

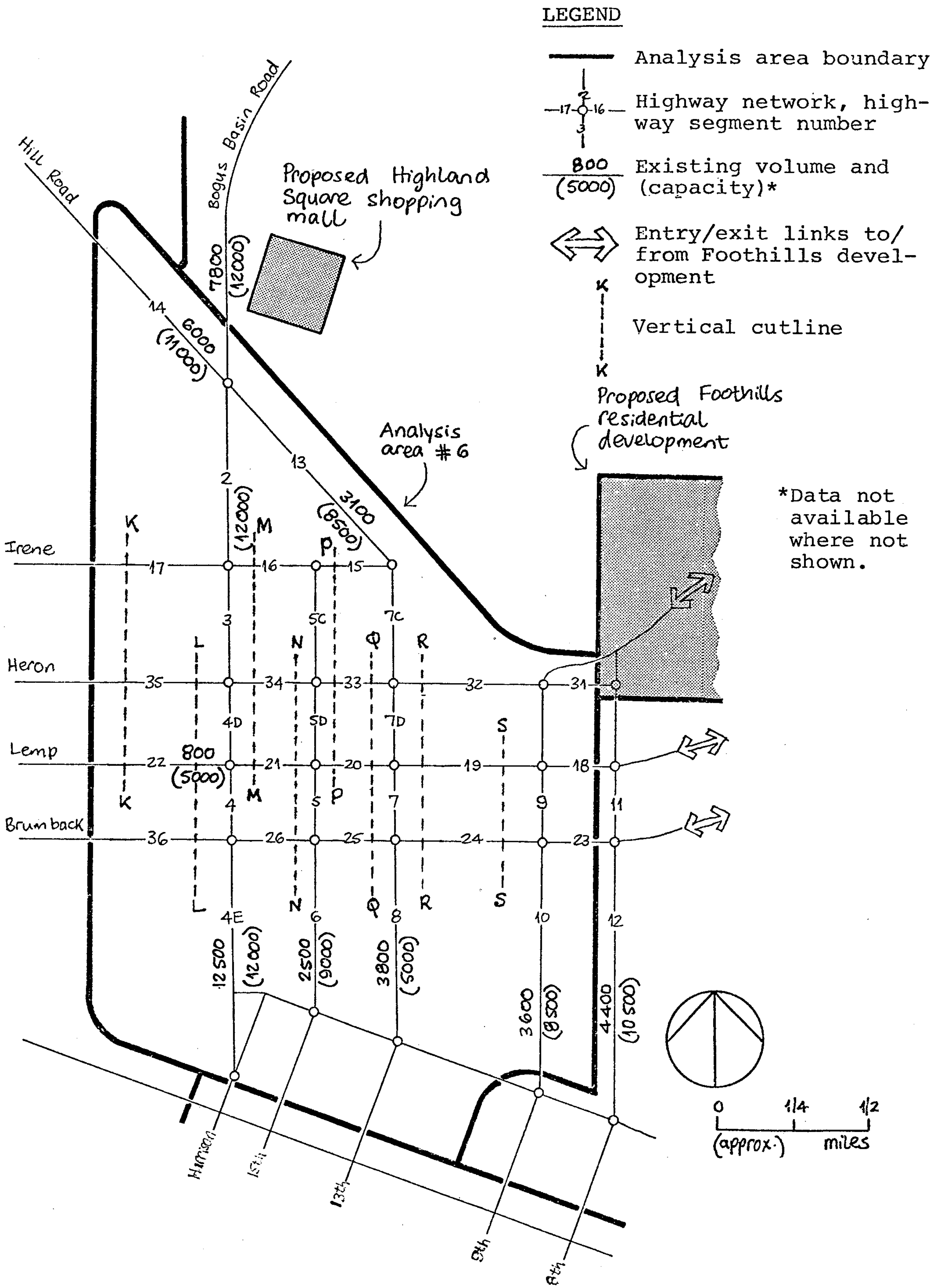


Figure 154. Highway network in analysis area 6 and vertical cutlines for post-assignment redistribution.

CUTLINE	LINK DESCRIPTOR	a BASE YEAR VOLUME	b % BASE YEAR VOLUME ON CUTLINE	c CAPACITY	d % OF TOTAL CAPACITY ON CUTLINE	e FORECAST YEAR ASSIGNMENT VOLUME	f CAPACITY-ASSIGNMENT ADJUSTMENT	g=Σ(e) x b VOLUME ASSIGNMENT ADJUSTMENT	h=f+g TOTAL ASSIGNMENT ADJUSTMENT
A-A	3		(66.5)		no new facilities proposed across cutlines. ∴ calculations not necessary for this column.	1485	see note in column d.	3435	3435 *
	5C	Δ	(13.3)	+		0		687	687
	7C		(20.2)			3680		1043	1043
Σ			100.0			5165		5165	5165
B-B	5C	Δ	(39.7)	+		687		687	687 *
	7C		(60.3)			1043		1043	1043 *
Σ			100.0			1730		1730	1730
C-C	4D		(66.5)			6034		6460	6460 *
	5D	Δ	(13.3)	+		0		1292	1292
	7D		(20.2)			3680		1962	1962
Σ			100.0			9714		9714	9714
D-D	5D	Δ	(39.7)	+		1292		1292	1292 *
	7D		(60.3)			1962		1962	1962 *
Σ			100.0			3254		3254	3254
E-E	4					same as for cutline C-C			6460 *
	5	Δ		+					1292
	7								1962
Σ									9714
F-F	5	Δ		+		same as for cutline D-D			1292 *
	7								1962 *
Σ									3254
G-G	4E	12500	66.5	12000	no new facilities proposed across cutlines. ∴ calculations not necessary for this column.	6034	see note in column d.	9591	9591 *
	6	2500	13.3	9000		0		1918	1918
	8	3800	20.2	5000		8388		2913	2913
		18800	100.0	26000		14422		14422	14422
H-H	6	2500	39.7	9000		1918		1918	1918 *
	8	3800	60.3	5000		2913		2913	2913 *
		6300	100.0	14000		4831		4831	4831
I-I	9	Δ	(45.0)	+		5759		4621	4621 *
	11		(55.0)			4510		5648	5648 *
			100.0			10269		10269	10269
J-J	10	3600	45.0	8500		0		3762	3762 *
	12	4400	55.0	10500		8360		4598	4598 *
		8000	100.0	19000		8360		8360	8360

a. All traffic data is due to the new developments; the volumes are 2-directional and measured in average daily traffic (ADT).

Δ Base year traffic volumes not available, but the proportion of traffic across any cutline has been assumed to be the same throughout the corridor - such percentages are shown in parentheses (xx.x) in column b.

+ Data on capacity not available (not needed, however, for calculations above).

* Final, balanced volumes as a result of traffic redistribution.

Figure 155. Adjustment computations for HBW (×5.5) assignment volumes (horizontal cutlines).[a]

TABLE 60

COMPARISON OF TRIP ASSIGNMENT RESULTS (ALL-OR-NOTHING AND ADJUSTED VOLUMES) VS. DATA FROM LOCAL TRANSPORTATION STUDIES

			ADDITIONAL TRAFFIC DUE TO NEW DEVELOPMENTS			ADDITIONAL TRAFFIC DUE TO NEW DEVELOPMENTS					
			UNADJUSTED, ALL-OR-NOTHING			ADJUSTED			TOTAL TRAFFIC = EXISTING + ADJUSTED ADDITIONAL TRAFFIC		
CUTLINE	LINK #, STREET NAME	EXISTING (BASE YEAR) VOLUMES	BOISE	HBW (x5.5) ASSIGNMENT	HBW+HBO+NHB ASSIGNMENT	BOISE	HBW (x5.5) ASSIGNMENT	HBW+HBO+NHB ASSIGNMENT	BOISE	HBW (x5.5) ASSIGNMENT	HBW+HBO+NHB ASSIGNMENT
A-A, B-B	3 (Harrison)	–	–	1485	2711	assignment volumes not adjusted	3435	7198	–	–	–
	5c (15th)	–	–	0	0		687	1440	–	–	–
	7c (13th)	–	–	3680	8113		1043	2186	–	–	–
C-C, D-D	4D (Harrison)	–	–	6034	6004		6460	9388	–	–	–
	5D (15th)	–	–	0	0		1292	1877	–	–	–
	7D (13th)	–	–	3680	8113		1962	2852	–	–	–
E-E, F-F	4 (Harrison)	–	–	6034	6004		6460	9388	–	–	–
	5 (15th)	–	–	0	0		1292	1877	–	–	–
	7 (13th)	–	–	3680	8113		1962	2852	–	–	–
G-G, H-H	4E (Harrison)	12500	5500	6034	6004		9591	8165	18000	22091	20665
	6 (15th)	2500	2000	0	0		1918	1633	4500	4418	4133
	8 (13th)	3800	700	8388	6274		2913	2480	4500	6713	6280
I-I	9 (9th)	–	–	5759	5548		4621	4754	–	–	–
	11 (8th)	–	–	4510	5017		5648	5811	–	–	–
J-J	10 (9th)	3600	1530	0	0		3762	3401	5130	7362	7001
	12 (8th)	4400	1870	8360	7557		4598	4156	6270	8998	8556
source:	Figure 153	Figure 153	Local agency	Figure 151	Figure 152		Figure 155	Computations not shown			

Traffic for the other selected links given in Table 60 was similarly calculated. A review of Table 60 indicates that post-assignment redistribution of traffic does indeed make significant adjustments to the all-or-nothing traffic assignment volumes. Furthermore, traffic volumes obtained for the HBW (×5.5) trip assignment compared satisfactorily with those derived from the HBW + HBNW + NHB trip assignment. A certain degree of confidence can be attributed to the expansion factor of 5.5 and, for quick sketch planning projects, it would seem possible to rely on expanded/factored trips, rather than undergo separate assignments for the various purposes.

The time log for the trip-assignment process indicated the following time was expended:

PROCEDURAL STEP	TIME REQUIRED, PERSON-HOURS
1. Setting up of networks, assignment table	3
2. HBW (×5.5) trip assignment	2
3. HBW + HBNW + NHB trip assignment	3
4. Redistribution/adjustment of all-or-nothing assignment (2) volumes	3
Total	11

Estimating Potential Transit Use

The material in Chapter Four, "Mode-Choice Analysis," enables estimation of potential transit use for the new Foothills residential development. Because most transit trips will be work-oriented, system improvements are generally based on work travel. For this scenario work travel to and from the CBD generated by the Foothills development is assessed.

A review of the HBW trip-distribution matrix (Fig. 149) indicates that the following HBW trips between the new development (analysis areas 1 to 4) and the CBD (analysis area 10) are made by auto driver:

INTERCHANGE	TRIPS
1—10	240
2—10	256
3—10	688
4—10	433

Instead of using the nomograph (Fig. 74) provided in Chapter Four, computations more specific to the situation are used to illustrate how the mode-choice methodology may be tailored to a specific situation. Table 61 gives the pertinent auto and transit measures for travel between the analysis areas.

The mode-choice analysis is based on the equation:

$$\% \text{ Transit} = \frac{(\text{Impedance, auto})^2}{(\text{Impedance, auto})^2 + (\text{Impedance, transit})^2} \times 100 \qquad (48)$$

The generalized equation for impedance is:

$$\text{Impedance} = (1.0 \text{ vehicle time}) + (2.5 \times \text{excess time}) + \frac{\text{Trip cost}}{\text{Income factor}} \qquad (49)$$

where income factor = ⅓ × annual income ($) ÷ 120,000.

To illustrate for interchange 1 to 10:

$$\text{Impedance, auto} = (1 \times 12) + (2.5 \times 5) + (55/4.72) = 36.2$$

where income is estimated at $17,000 per year and therefore income factor = ⅓ × 1,700,000 ÷ 120,000 = 4.72
and

$$\text{impedance, transit} = (1 \times 24) + (2.5 \times 22) + (50/4.72) = 89.6$$

TABLE 61

AUTO AND TRANSIT CHARACTERISTICS FOR MODE-CHOICE ANALYSIS FOR NEW DEVELOPMENT

Zonal Pair	Road Distance[b] (Miles)	Auto Time @ 25 mph (minutes)	Excess Auto Time (minutes)	Total Auto Time (minutes)	Auto Cost[a] (¢)	Transit Veh. Time @ 12.5 mph (minutes)	Average Transit walk O + D[b] (miles)	Excess Time[c] (minutes)	Fare (¢)
1-10	5.0	12.0	5	17.0	55	24.0	0.4	22	50
2-10	3.5	8.4	5	13.4	49	16.8	0.7	27	50
3-10	2.3	5.5	5	10.5	45	11.0	0.4	22	50
4-10	1.8	4.3	5	9.3	43	8.6	0.3	20	50

a. Cost at 5¢/mile plus 1/2 daily parking cost of $1.00/car occupancy.
Car occupancy assumed at 1.37.

b. Estimated from a map (Figure 150).

c. A 30-minute headway was assumed
Excess time = 1/2 headway + walk distance @ 3.5 mph.

$$\% \text{ Transit} = \frac{36.2^2}{36.2^2 + 89.6^2} \times 100 = 14\% \qquad (50)$$

Similar calculations are carried out for interchanges 2 to 10, 3 to 10, and 4 to 10 resulting in 10-, 11- and 12-percent transit use, respectively.

The assumption used in developing this scenario was that approximately 12 percent of HBW trips would be by transit and that auto occupancy is 1.37. (See Table 3, Part A, in Chapter Two and Table 12 in Chapter Five.) The auto driver trips presented previously can be converted to person-trips by applying the following factors:

INTERCHANGE	AUTO TRIPS		PERSON-TRIPS
1—10	240 × 1.37 ÷ (1 − 0.12)	=	374
2—10	256 × 1.37 ÷ 0.88	=	399
3—10	688 × 1.37 ÷ 0.88	=	1,071
4—10	433 × 1.37 ÷ 0.88	=	674

Transit trips would be calculated as using results of the mode-choice estimation as follows:

INTERCHANGE	PERSON-TRIPS		TRANSIT TRIPS
1—10	374 × 0.14	=	52
2—10	399 × 0.10	=	40
3—10	1,071 × 0.11	=	118
4—10	674 × 0.12	=	81
			291

The number of trips in each direction would be ½ of the preceding (i.e., ½ in AM and ½ in PM). The total trips *to* and *from* work by transit can be expected to be 146.

The foregoing calculations were based on a $0.50 transit fare, ½ hour headway, and $1 parking. It is a simple and rather quick process to develop alternatives; for example, if a 10-min headway was to be tested, excess time by transit in each movement would decrease by 10 min (30/2-10/2). The new percent transit and absolute trips would be estimated as follows:

INTERCHANGE	% TRANSIT	TRANSIT TRIPS
1—10	24	90
2—10	18	72
3—10	22	236
4—10	26	175
		573

Assuming the original conditions except that a $0.25 fare for transit is to be used, the following trips would result:

INTERCHANGE	% TRANSIT	TRANSIT TRIPS
1—10	16	60
2—10	11	44
3—10	13	139
4—10	14	94
		337

Again, assuming the original conditions except that a $2 daily parking fee was imposed at the CBD end for automobiles, the following trips would result:

INTERCHANGE	% TRANSIT	TRANSIT TRIPS
1—10	21	79
2—10	16	64
3—10	20	214
4—10	22	148
		505

Each set of the foregoing calculations based on the changes to the original assumptions can be completed in about 30 min using an electronic calculator.

SUMMARY

A scenario was conducted for the Boise metropolitan area to determine the traffic impacts of a residential development in the Foothills area and the Highland Square Shopping Mall. Techniques used to quantify these impacts were those described in the preceding chapters. Application of such techniques was entirely manual and required nothing more sophisticated than an electronic desk calculator. The scenario was simluated through various steps—primarily trip generation, trip distribution, and trip assignment. Additionally, manual techniques for determining auto occupancy, volume-capacity adjustments, and modal split were also applied. Generally, the results of the manual application of the travel-estimation techniques were satisfactory, and the complete scenario was conducted in approximately 60 person-hours. A breakdown of the time requirements by the major steps follows (only time for assigning the total of all trips is given):

MAJOR STEP	TIME REQUIRED, PERSON-HOURS
1. Trip generation	12
2. Trip distribution	33
3. Trip assignment	9
4. Modal Split	3
5. Miscellaneous	3
Total	60

If the approach of handling only HBW trips was used (and then expanding to total trips), considerable time savings would have been realized. The trip-generation step would have been reduced to about 10 hr, the trip-distribution step to about 14 hr, and the trip-assignment step to about 8 hr. The entire scenario would have taken about 38 hr.

CHAPTER ELEVEN

SCENARIO FOR CORRIDOR ANALYSIS: COLUMBUS, OHIO

INTRODUCTION

Application of the user's guide procedures in Columbus, Ohio, represents an appropriate example of corridor analysis. Typically, such an analysis could be required in any urbanized area. Its appropriateness can be attributed to the location of the corridor under investigation—it is located just outside the existing Columbus transportation study area. In the past, the corridor has been treated as an external location.

The corridor is a 5-mi stretch running along state route (SR) 256 between Pickerington and Reynoldsburg. It is located along the eastern border of the Columbus study area and is oriented in a north-south direction between two major highways—US 33 and US 40. Figure 156 shows the corridor within the Columbus area.

Today, the area adjacent to SR 256 is largely rural with a few small residential subdivisions along its length. The route itself is a 2-lane rural road 18 ft in width with an undulating alignment. It has short vertical sight distances but, because of its rural location, it has an operating speed of 48 mph.

Proposals have been submitted to concentrate development in the eastren part of Columbus and in the SR 256 corridor during the next 20 years. The population of the area is expected to increase to 54,545 in the year 2000, and employment for the same year is estimated at 21,599 jobs, compared to expected totals in Franklin County (the existing Columbus transportation study boundary) of 1,259,817 people and 613,702 jobs.

Data for the SR 256 corridor are not available for the 1974 base year; however, virtually all growth outside the Reynoldsburg and Pickerington corporate limits will be new development. By contrast, Pickerington and Reynoldsburg are well-established communities and will experience a minor portion of the total growth.

Assessment of significant growth impacts within a corridor area external to an existing transportation planning study area can be quite time-consuming using existing computerized models and procedures. Such an effort would require expansion of the study area cordon to include the corridor and the development of system networks for the area. Except for the quantification of significant land-use variables, other major efforts, such as detailed network analysis, were not required for application of the manual procedures.

To assess the impacts of the new development on SR 256, the following information was provided by the Ohio Department of Transportation and the Mid-Ohio Regional Planning Council.

1. Land-use data for 1974, by traffic analysis zone, for Franklin County.
2. Year 2000 land-use control totals for Franklin County.
3. Year 2000 land-use data, by traffic analysis zone, for the SR 256 corridor outside Franklin County.
4. Highway travel characteristics, including existing networks for Franklin County.
5. General development plan for the SR 256 corridor area.

The following sections describe the steps taken to apply the manual techniques and the conclusions reached on the development impact on SR 256.

Summary of Steps Undertaken for Scenario

Application of the user's guide procedures required the following major steps, which also include those tasks necessary as preparation for application of the procedures.

Step 1: Analysis districts that would be used in the Columbus study area were defined.

Step 2: Year 2000 land-activity data were organized by analysis districts as preparation for applying trip-generation procedures.

Step 3: Trip-generation procedures were applied to estimate the productions and attractions of the study area for the year 2000. This step included areas within Franklin

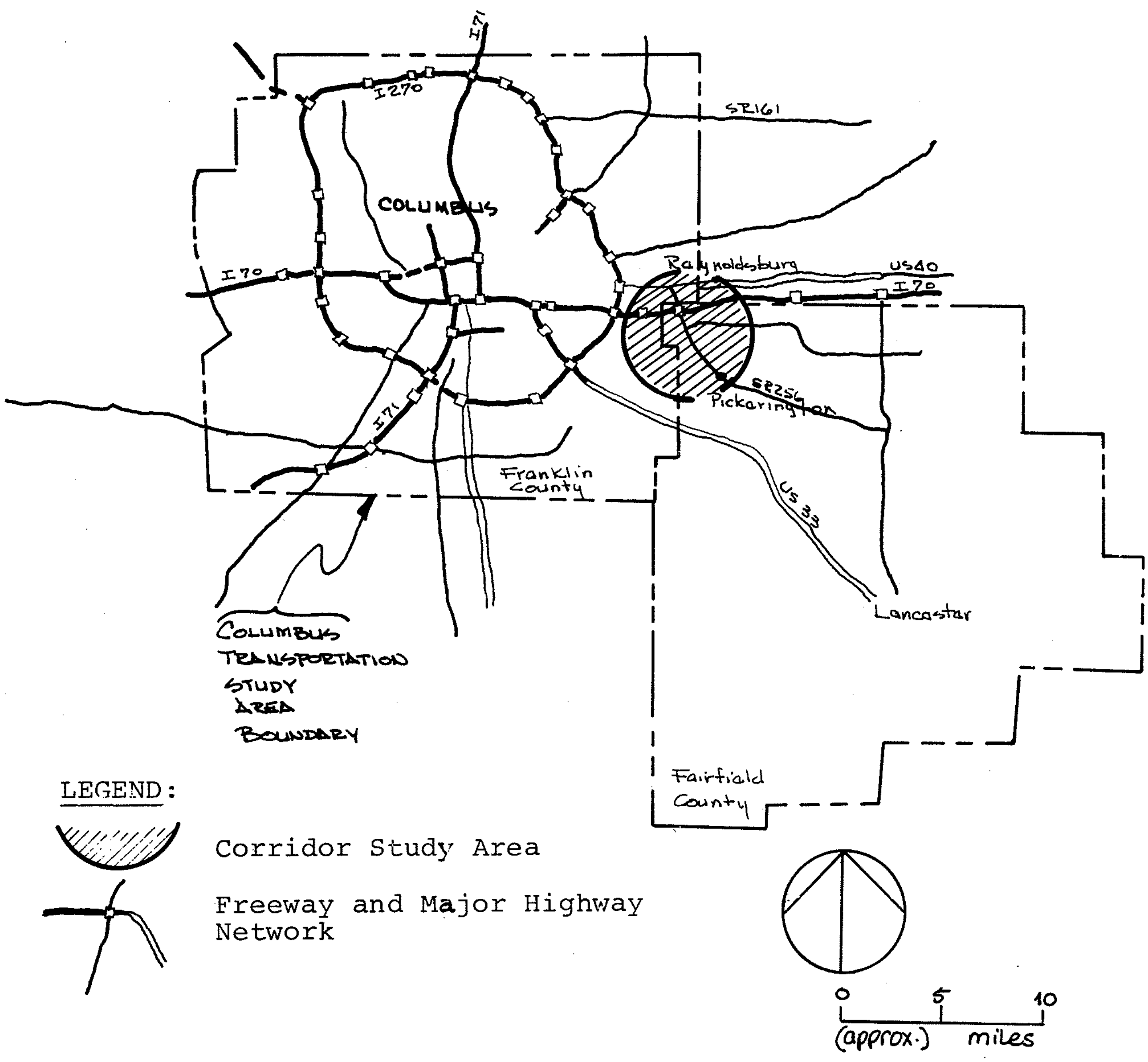


Figure 156. Columbus, Ohio, transportation study area, showing location of corridor under investigation.

County and appropriate sections of Fairfield County. After application of the procedures, attractions were balanced against productions, by trip purpose, as preparation for the trip-distribution phase.

Step 4: A year 2000 vehicle trip table was developed through application of the trip-distribution procedures. Trip tables were developed for the HBW and HBNW person-trip purposes and converted to vehicle trips.

Step 5: Vehicle trips were assigned along SR 256. Because of the lack of competing facilities, an all-or-nothing technique was used *without* further redistribution of trips, by facility, after assignment.

Step 6: Volume/capacity ratios were calculated to analyze conditions anticipated to occur with the proposed year 2000 development plan.

SCENARIO DETAILS

The following sections describe in detail the steps undertaken to analyze the SR 256 corridor for the year 2000.

Determination of Analysis Areas

The Franklin County study area includes 814 traffic analysis zones and, for the year 2000 analysis, the cordon was expanded to include an additional 39 traffic analysis zones for a regionwide total of 853 zones. Because only the SR 256 corridor was to be subjected to impact evaluation, the zones outside the corridor were aggregated into large analysis areas (districts). Zones within the SR 256 corridor were also aggregated, but not as extensively.

The study region was aggregated into a total of 18 analysis districts comprising the SR 256 corridor. The analysis districts inside the corridor are shown in Figure 157. For each of the analysis districts, an existing (contained) traffic analysis zone was selected to represent the analysis district. The representative zone was selected as a compromise geographic- and land-activity centroid of the district.

Aggregation of Year 2000 Land-Activity Variables

Land-activity variables, necessary for the generation of trip productions and attractions, required partial development as well as aggregation by the 18 analysis districts. Within Franklin County, detail land-activity data were available for 1974, but only countywide control totals were available for the year 2000. Year 2000 data for Franklin County were derived by:

- Aggregating 1974 traffic analysis zone data according to the 18 analysis districts.
- Factoring each variable of each analysis district by its countrywide growth rate.

The procedure assumed there would be proportionally uniform growth throughout the county over the 26-year period. Obviously, the distribution of development and growth will not be uniform, but the error of the assumption should not have a significant impact on the analysis because the analysis zones affected are outside the SR 256 corridor.

For Franklin County and areas outside the county within the SR 256 corridor, year 2000 land activity was available by traffic analysis zone and required only a retabulation of the data by analysis district. The variables necessary to apply the trip-generation procedures, for all 18 analysis districts, are given in Table 62.

Application of Trip-Generation Procedures

The first step in applying trip-generation procedures was to develop productions for each analysis district. The areawide population for year 2000 is anticipated to exceed 750,000 persons; therefore, Table 2, in Chapter Two, "Trip Generation Estimation," was selected for use. A summary of the analysis district productions is given in Table 63.

Generation factors (col. 3) were determined using the autos per household (col. 2) by interpolation using the average autos per household given in Table 2. For example, using traffic analysis district 0023, the autos/household (HH) figure is 1.13 which lies between 1.06 and 1.16 in Table 2; average daily person trips/HH for these figures is 6.5 and 7.2, respectively. Interpolation resulted in a generation factor of 7.0 daily internal plus internal-external person-trips per household for district 0023.

The second stage of determining analysis district productions was to stratify the total productions (col. 4) by trip purpose (col. 5, 6, and 7). This was accomplished by using the percent average daily person-trips by purpose data from Table 2.

Because of the small variation in trips by purpose owing to changes in auto ownership, the percentages used were not interpolated. Instead, percentages corresponding to the nearest average autos/HH rate were used.

The second phase of trip generation was the calculation of trip attractions by analysis district. Tables 64 through 66 are the attraction development work sheets for the three trip purposes—HBW, HBNW, and NHB.

The trip productions previously developed were transcribed to the attraction work sheets so that the areawide attractions could be balanced with the productions—a requirement to complete trip distribution.

The trip-attraction estimating relationships in Chapter Two, Table 3, Part C, were used to develop the attractions for each analysis district by trip purpose. The equations were applied to the land-activity variables given in Table 62 to calculate each component's contribution (as specified by the equations) to the total attractions of the analysis district. In the case of the HBW trip purpose, the only attraction contribution was from total employment (TOTE) where as HBNW and NHB trip attractions were determined by retail employment, nonretail employment, and dwelling units.

After the attraction contributions were summarized for each trip purpose, the total attractions for each purpose were compared to its appropriate total productions. A factor was determined by dividing the attractions by the productions and applying it to the attractions of each analysis district to obtain a set of balanced attractions for each trip purpose. It can be seen from Tables 64, 65, and 66 that the adjustments made to the raw attractions to arrive at balanced attractions were minor.

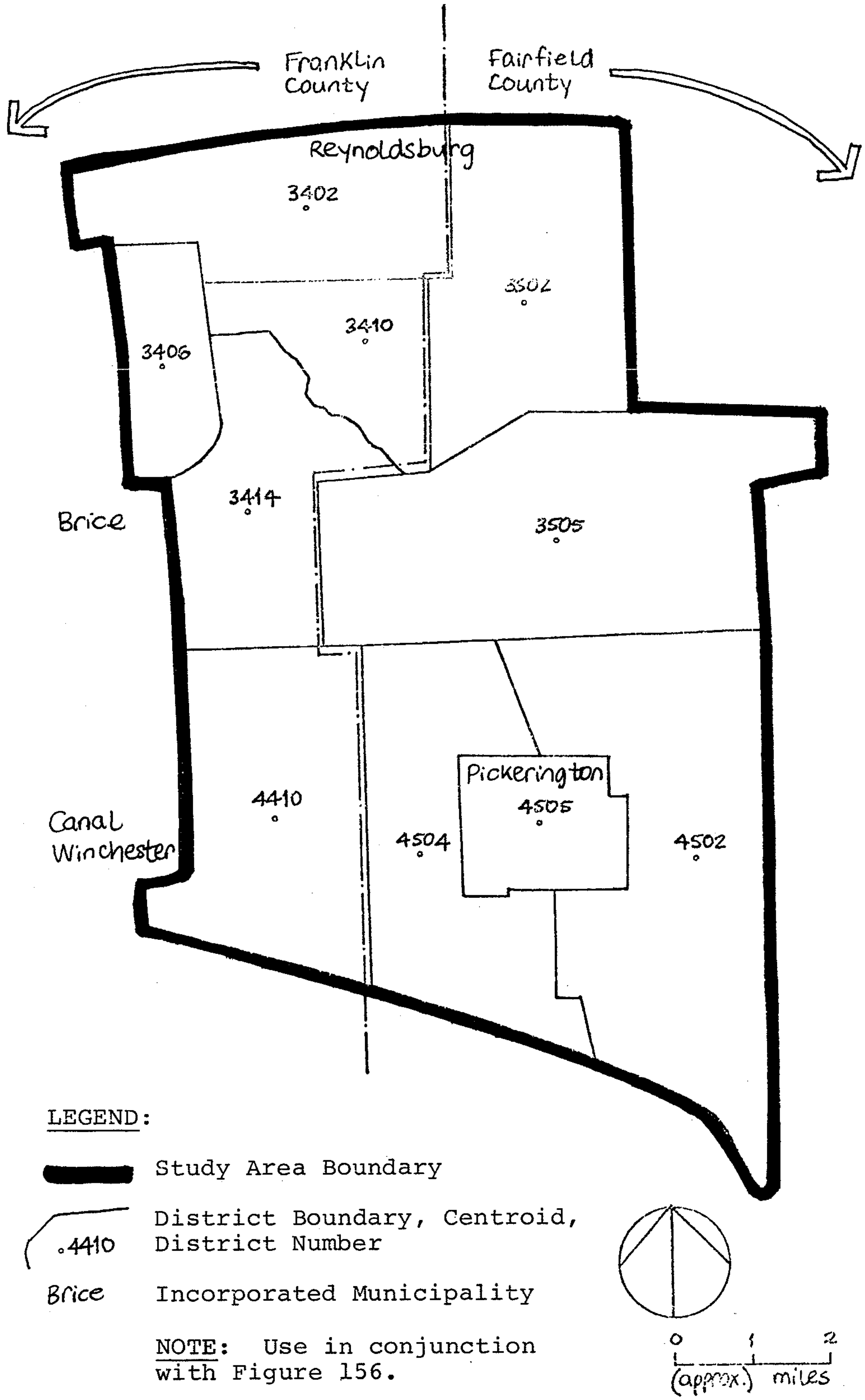


Figure 157. SR 256 (Ohio) corridor analysis districts.

TABLE 62

LAND-USE DATA FOR COMPRESSED ZONE STRUCTURE (YEAR 2000)

Traffic Analysis District	Cars (a)	Population POP (b)	Dwell. Units DU (c)	Average Income INC (d)	Total Employ. TOTE (e)	Retail Employ. COMSH (f)	Non-Retail Employ. TOTE-COMSH (g=e-f)
0023	7,708	11,560	6,835	13,973	137,049	23,031	114,018
1332	177,459	286,134	117,395	28,767	78,469	27,675	50,794
2103	166,628	352,241	151,509	19,281	138,156	26,644	111,512
3402	784	1,068	474	27,972	12,859	63	12,796
3406	6,854	9,759	4,162	28,904	1,430	1,167	263
3410	5,462	8,258	3,313	27,344	1,227	569	658
3414	5,879	8,450	3,567	29,736	2,891	1,022	1,869
3502	5,525	9,980	3,611	28,152	1,640	524	1,116
3505	3,635	6,750	2,376	28,950	595	209	386
4306	75,147	124,424	51,867	24,904	54,028	17,057	36,971
4410	343	500	214	21,886	200	145	55
4502	1,718	3,200	1,123	29,018	220	121	99
4503	2,253	4,196	1,472	29,018	403	121	282
4504	1,280	2,384	837	29,018	134	63	71
4507	3,495	6,532	2,284	29,119	519	163	356
5118	67,703	133,858	56,506	22,577	52,965	10,113	42,852
7312	100,364	148,736	63,895	29,552	65,270	17,300	47,970
9110	123,539	213,893	87,992	23,330	91,153	21,704	69,449
TOTALS:	755,776	1,331,923	559,432	26,195	639,208	147,691	491,517

TABLE 63

PERSON-TRIP PRODUCTIONS BY TRIP PURPOSE (YEAR 2000)

Traffic Analysis District (1)	Autos/HH (2)=a/c[a]	Gen. Factor (Table 2) (3)	Total Productions (Int + Int/Ext) (4)	HBW (5)	HBNW (6)	NHB (7)
0023	1.13	7.0	47,845	12,918	25,358	9,569
1332	1.51	9.0	1,056,555	264,139	559,974	232,442
2103	1.10	6.8	1,030,261	278,171	546,038	206,052
3402	1.65	9.5	4,503	1,126	2,386	991
3406	1.65	9.5	39,539	9,885	20,956	8,698
3410	1.65	9.5	31,474	7,869	16,681	6,924
3414	1.65	9.5	33,887	8,472	17,960	7,455
3502	1.53	9.1	32,860	8,215	17,416	7,229
3505	1.53	9.1	21,622	5,405	11,460	4,757
4306	1.45	8.7	451,243	117,323	239,159	94,761
4410	1.60	9.4	2,012	503	1,066	443
4502	1.53	9.1	10,219	2,555	5,416	2,248
4503	1.53	9.1	13,395	3,349	7,099	2,947
4504	1.53	9.1	7,617	1,904	4,037	1,676
4507	1.53	9.1	20,784	5,196	11,016	4,572
5118	1.20	7.4	418,144	112,899	221,616	83,629
7312	1.57	9.3	594,224	148,556	314,939	130,729
9110	1.40	8.5	747,932	194,462	396,404	157,066
TOTALS		N.A.	4,564,116[b]	1,182,947	2,418,981	962,188

a. See Table 62.
b. Control total.

With the completion of the attraction work sheets, the trip-generation phase was completed. The most time-consuming task for estimating productions was the consolidation and factoring of the land-activity data in preparation for applying trip-generation procedures. Data factoring and compression required three person-days whereas application of trip-generation procedures, including generation-factor development, required only one person-day.

Trip Distribution

With the balanced productions and attractions in hand, the next step was to develop trip tables for each of the three generation purposes—HBW, HBNW, and NHB. As explained later herein, it was necessary only to develop trip tables for the first two purposes.

The initial step required was to develop a matrix of airline travel distances between districts and to estimate freeway/arterial mix for the travel path between each district pair. The facility mix is necessary for estimating the travel time between analysis districts. This step of the trip-distribution phase is necessary in order to use the appropriate "Airline Distance vs. Travel Time vs. Distribution Factors" graphs (Figs. 25 through 30 in Chapter Three).

TABLE 64

HBW PERSON-TRIP PRODUCTIONS AND ATTRACTIONS (YEAR 2000)

Traffic Analysis District	Productions	Attr. Contrb. Tot. Empl.	Total Attractions	Balanced Attractions
0023	12,918	253,719	253,719	253,629
1332	264,139	145,270	145,270	145,219
2103	278,171	255,768	255,768	255,676
3402	1,126	23,806	23,806	23,798
3406	9,885	2,647	2,647	2,646
3410	7,869	2,272	2,272	2,271
3414	8,472	5,352	5,352	5,350
3502	8,215	3,036	3,036	3,035
3505	5,405	1,102	1,102	1,102
4306	117,323	100,022	100,022	99,987
4410	503	370	370	370
4502	2,555	407	407	407
4503	3,349	746	746	746
4504	1,904	248	248	248
4507	5,196	961	961	961
5118	112,899	98,054	98,054	98,019
7312	148,556	120,834	120,834	120,791
9110	194,462	168,752	168,752	168,692
TOTALS:	1,182,947	1,183,366	1,183,366	1,182,947

TABLE 65

HBNW PERSON-TRIP PRODUCTIONS AND ATTRACTIONS (YEAR 2000)

Traffic Analysis District	Productions	Attr. Contributions			Total Attract.	Balanced Attract.
		Retail Emp.	Non-Rtl. Emp.	Dwelling Units		
0023	25,385	244,129	60,430	7,245	311,804	311,798
1332	559,974	293,355	26,921	124,439	444,715	444,706
2103	546,038	282,426	59,101	160,600	502,127	502,116
3402	2,386	668	6,782	502	7,952	7,952
3406	20,956	12,370	139	4,412	16,921	16,921
3410	16,681	6,031	349	3,512	9,892	9,892
3414	17,960	10,833	991	3,781	15,605	15,605
3502	17,416	5,554	591	3,828	9,973	9,973
3505	11,460	2,215	205	2,519	4,939	4,939
4306	239,159	180,804	19,595	54,979	255,378	255,373
4410	1,066	1,537	29	227	1,793	1,793
4502	5,416	1,283	52	1,190	2,525	2,525
4503	7,099	1,283	149	1,560	2,992	2,992
4504	4,037	668	38	887	1,593	1,593
4507	11,016	1,728	189	2,421	4,338	4,338
5118	221,616	107,198	22,712	59,896	189,806	189,802
7312	314,939	183,380	25,424	67,729	276,533	276,528
9110	396,404	230,062	36,808	93,272	360,142	360,135
TOTALS:	2,418,981	1,565.524	260,505	592,999	2,419,028	2,418,981

Figure 158, "District-to-District Airline Distance/Travel Time," is a sample of the work sheets used for tabulating the travel time between analysis districts. It represents the characteristics between analysis district 1 and all other districts. It is assumed that the travel characteristics from *i* to *j* are equal to the characteristics from *j* to *i*.

The first column lists, in parentheses, the zone that represents each analysis district. The next three columns are tabulations of airline mileage between representative zones (analysis district centroids). The distribution factor graphs (Figs. 25 through 30) require segregation of travel by subregion (i.e., CBD, central city, suburb) because of the varying speed characteristics within each subregion. Two numbers are shown in each cell of each of the mileage columns. The first is the airline distance in whole miles; the second (circled number) is the percentage of travel, for the highway trip between analysis districts, estimated to occur on arterials. The total mileage column was used only to ensure that the measured calculations were correct.

The second set of columns in Figure 158 represent the time required to travel each component of the recorded distance. These quantities were determined by using Figures 25 through 30. For example, the traffic analysis district 1-to-district 1 time was determined using Figure 25. After each subregion's (CBD, central city, suburb) travel time contribution was determined, the components were summed to determine total travel time; and the distribution factor was then read from the graphs.

TABLE 66

NHB PERSON-TRIP PRODUCTIONS AND ATTRACTIONS (YEAR 2000)

Traffic Analysis District	Productions	Attr. Contributions Retail Emp.	Non-Rtl. Emp.	Dwelling Units	Total Attract.	Balanced Attract.
0023	9,569	24,459	152,042	1,823	178,434	178,435
1332	232,442	29,523	67,733	31,309	128,565	128,565
2103	206,052	28,424	148,700	40,407	217,531	217,532
3402	991	67	17,063	126	17,256	17,256
3406	8,698	1,245	351	1,110	2,706	2,706
3410	6,924	607	877	884	2,368	2,368
3414	7,455	1,090	2,492	951	4,533	4,533
3502	7,229	559	1,488	963	3,010	3,010
3505	4,757	223	515	634	1,372	1,372
4306	94,761	18,196	49,300	13,833	81,329	81,329
4410	443	155	73	57	285	285
4502	2,248	129	132	300	561	561
4503	2,947	129	376	393	898	898
4504	1,676	67	95	223	385	385
4507	4,572	174	475	609	1,258	1,258
5118	83,629	10,788	57,143	15,070	83,001	83,001
7312	130,729	18,455	63,967	17,041	99,463	99,463
9110	157,066	23,154	92,610	23,467	139,231	139,231
TOTALS:	962,188	157,554	655,432	149,200	962,186	962,188

TO: TRAFFIC ANALYSIS DISTRICT	AIRLINE DISTANCE (MILES) CBD	CENTRAL CITY	SUBURB	TOTAL AIRLINE DISTANCE MILES	TRAVEL TIME (MINUTES) CBD	CENTRAL CITY	SUBURB	TOTAL TRAVEL TIME (MINUTES)
1(0023)	1 (100)			1	17			17
2(1332)	1	4 (100)	3 (100)	8	5	14	7+9	35
3(2103)	1	2 (80)		3	5	6+10		21
4(3402)	1	4 (0)	5 (20)	10	5	7	8+9	29
5(3406)	1	4 (0)	4 (30)	9	5	7	6+9	27
6(3410)	1	4 (0)	6 (20)	11	5	7	11+9	32
7(3414)	1	4 (0)	5 (40)	10	5	7	9+9	30
8(3502)	1	4 (0)	8 (50)	13	5	7	17+9	38
9(3505)	1	4 (0)	8 (30)	13	5	7	16+9	37
10(4306)	1	6 (0)	1 (50)	8	5	12	1+9	27
11(4410)	1	5 (0)	6 (30)	12	5	10	11+9	35
12(4502)	1	5 (0)	10 (60)	16	5	10	22+9	46
13(4503)	1	5 (0)	8 (70)	14	5	10	19+9	43
14(4504)	1	6 (0)	7 (60)	14	5	12	14+9	40
15(4501)	1	4 (0)	13 (60)	18	5	7	27+9	48
16(5118)	1	2 (100)		3	5	6+10		21
17(7312)	1	4 (80)	3 (80)	8	5	12	6+9	32
18(9110)	1	2 (80)		3	5	6+10		21

Figure 158. District-to-district airline distance/travel time (from: origin analysis district 1).

Distribution factors, for each trip purpose, were recorded directly on the trip matrix form (not shown) along with each district's productions and attractions. Note that trip matrices were only developed for HBW and HBNW trip purposes. Trip productions and trip attractions were tabulated by analysis district and a sample (5 row) NHB trip distribution matrix was completed to investigate the relationship between NHB trips and the other two trip purposes. The production and attraction tabulations showed a consistent relationship between HBW and NHB trips. HBW trips were related to HBW plus NHB trips by a ratio of 1 to 1.82—see Table 67. The same relationship held true for the sample NHB trip distribution.

TABLE 67

ANALYSIS OF TRIP-GENERATION INTERRELATIONSHIPS BY TRIP PURPOSE

Analysis District	% OF TOTAL PRODUCTIONS			% OF TOTAL BALANCED ATTRACTIONS		
	HBW	HBNW	NHB	HBW	HBNW	NHB
0023	27.0	53.0	20.0	34.1	41.9	24.0
1332	25.0	53.0	22.0	20.2	61.9	17.9
2103	27.0	53.0	20.0	26.2	51.5	22.3
3402	25.0	53.0	22.0	48.6	16.2	35.2
3406	25.0	53.0	22.0	11.9	76.0	12.1
3410	25.0	53.0	22.0	15.6	68.1	16.3
3414	25.0	53.0	22.0	21.0	61.2	17.8
3502	25.0	53.0	22.0	18.9	62.3	18.8
3505	25.0	53.0	22.0	14.9	66.6	18.5
4306	26.0	53.0	21.0	22.9	58.5	18.6
4410	25.0	53.0	22.0	15.1	73.2	11.6
4502	25.0	53.0	22.0	11.7	72.3	16.1
4503	25.0	53.0	22.0	16.1	64.5	19.4
4504	25.0	53.0	22.0	11.1	71.6	17.3
4507	25.0	53.0	22.0	14.7	66.2	19.2
5118	27.0	53.0	20.0	26.4	51.2	22.4
7310	25.0	53.0	22.0	24.3	55.7	20.0
9110	26.0	53.0	21.0	25.3	53.9	20.8
AVERAGE VALUE	25.9	53.0	21.1	25.9	53.0	21.1

Note that the ratio % HBW/%(HBW + NHB) = 25.9/(25.9 + 21.1) = 1/1.82, or %NHB = 0.82(% HBW).

In the interest of saving analysis time it was decided *not* to develop a NHB trip but instead, to factor the HBW trip table by 1.82 so that it could represent both trip purposes. This was done after the HBW trip table had been completed and while the total vehicle trip table was being created.

The total vehicle trips were calculated by factoring the HBW trips, adding the HBNW trips and dividing the sum by an auto-occupancy rate. The formula for determining the quantity of vehicles for each interchange was:

$$\text{Total vehicles (internal + internal/external)} = \frac{\text{Total person-trips}}{1.51} \qquad (51)$$

where

$$\text{Total person-trips} = \text{HBW trips} + \text{HBNW trips} + 0.82\ (\text{HBW trips}).$$

The third quantity 0.82 (HBW trips) is the quantity of trips determined to represent the NHB trips within the system.

Trip-distribution results show that 3,022,611 average daily internal plus internal-external vehicle trips are expected to occur within the expanded Columbus region. Before proceeding with further analysis, the vehicle trip table was subjected to several reasonableness checks, such as trip rates per household, trip rates per capita, and the like. It is recommended that potential users of these manual techniques review the consistency between land-use and transportation variables as well as the reasonableness of the application of these procedures. The trip table was found to be consistent with the procedures that had been applied.

Traffic Assignment

The method used for traffic assignment was the all-or-nothing technique described in Chapter Seven. The volumes assigned by the procedure were not subjected to the assignment-volume redistribution procedures because of the lack of facility competition within the SR corridor.

Using the analysis district map, a cordon (study area limit) was constructed and the roadway network within the study area defined; the network is shown in Figure 159. Twenty-five highway links and five entry stations were defined as being of interest to traffic assignment and corridor analysis. The only route that could be considered to parallel SR 256 is Brice Road (links 9, 10, 11) which was included for its potential for decreasing the demand on SR 256. Facilities transverse to SR 256 were not to be analyzed in great depth. Only those links that intersect SR 256 were considered in the assignment.

Printouts of existing (1974) travel paths were used for determining the logical path of travel and, subsequently, accumulating trips by link. The assignment of vehicle trips is shown via a sample of the assignment work sheets as shown in Figure 160. Note that all interchanges are not included on the work sheets. Travel between many of the analysis district pairs do not impact the study area. For example, trips between downtown Columbus and a northern analysis district would not impact the SR 256 corridor.

Summing the columns (links) of the assignment work sheets yields the total volume estimated to occur on each link of interest. The volumes determined from the work sheets have been posted on the appropriate links of Figure 161.

Normally the volumes determined from the all-or-nothing assignment would be subjected to the assignment-volume redistribution procedures described in Chapter Seven; however, because of the lack of facility competition with SR 256 and because the primary interest was in SR 256, the assignment volumes were posted as summarized.

A review of the link volumes indicates severe traffic impacts on the major routes (Wright Road, Refugee Road, etc.) feeding into SR 256. In fact, much of the traffic generated by the development in the east is likely to travel westward, away from SR 256, and to use Brice Road to get to either US 33 or I-70 and, ultimately, towards the downtown.

In this case it appears that the location details of the new development are a critical key in the selection of a travel path. The access point to the arterial system will significantly influence the path of travel. For the all-or-nothing assignment it has been assumed there would be access to all arterial routes. Consequently, the volumes accumulated on links 9, 10, 11, 21, 22, and 23 (Brice and

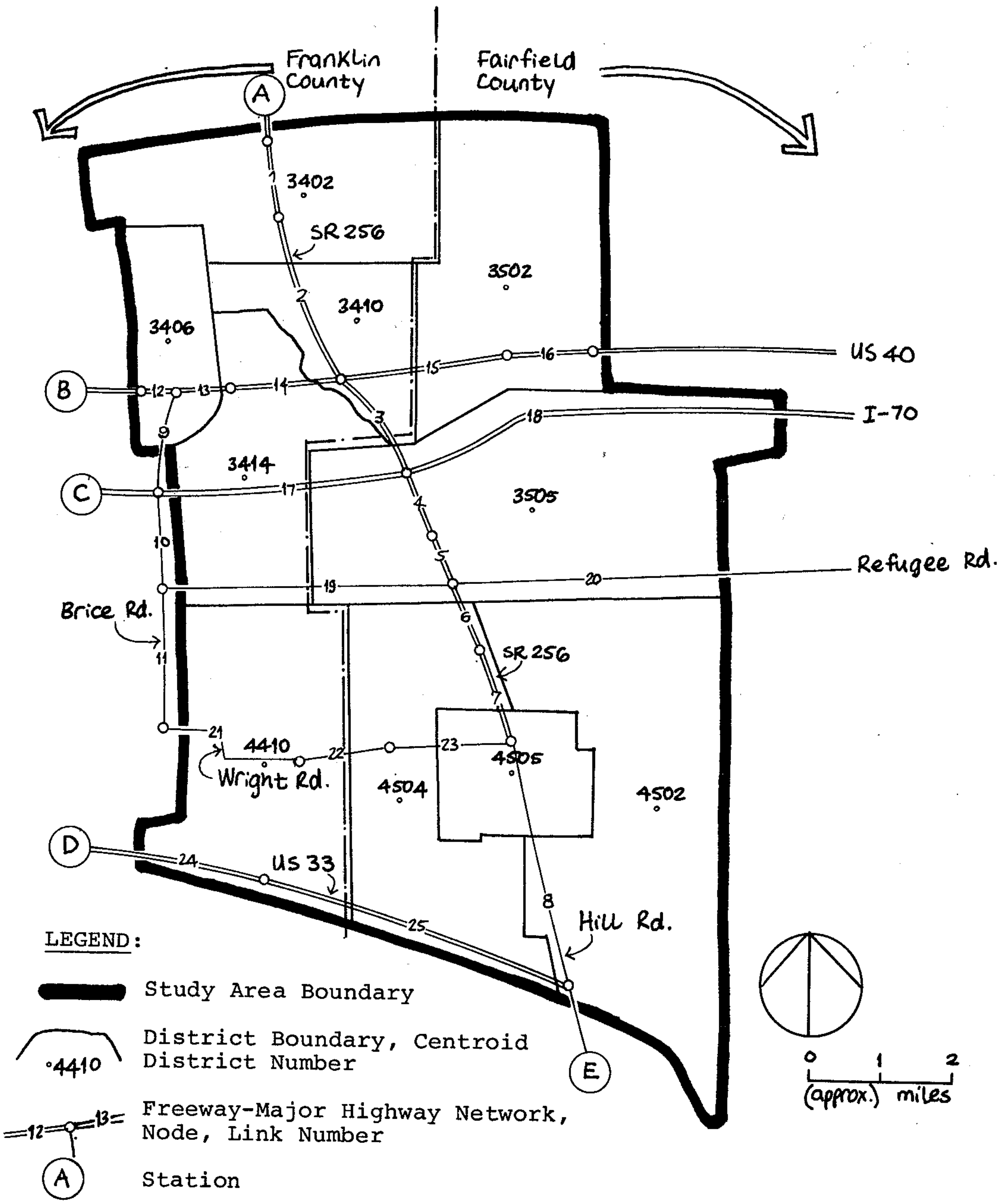


Figure 159. SR 256 (Ohio) corridor analysis network.

Wright Roads) are excessively high. The travel desire would be to use Brice Road, *not* SR 256, to get to the freeway system. Thus, permitted access is a critical issue.

Capacity Analysis

It was originally intended that the capacity analysis focus on SR 256, but the magnitude of the assignment volumes on the links comprising Brice Road and Wright Road mandate their discussion.

Table 68 gives the links considered in the capacity analysis and the peak-hour volumes calculated using the time-of-day procedures described in Chapter Six. SR 256 and Brice Road were classified as suburban, cross-town routes and Refugee Road and Wright Road were classified as collectors. From the Chapter Six time-of-day characteristics, an 8.5 percent average daily traffic (ADT) peak factor for suburban cross-town arterials and a 9.5 percent ADT factor for suburban collectors were obtained. Because of the current lack of land-use planning detail, the directional split was not considered. The factors were applied to arrive at the peak-hour volumes given in Table 68.

Capacities for each link were determined using the table of generalized capacities (Table 51, Chapter Eight) assuming a 0.50 G/C ratio. For example, SR 256 has a 9-ft approach width in each direction. Because the tables do not allow for an approach width of 9 ft, the base-capacity value for an approach width of 20 ft was factored (interpolated between 0 and 20 ft) to represent a 9-ft approach width. The calculation resulted in a two-directional

from district	to analysis dist.	veh trips	NETWORK SEGMENTS: SR-256								BRICE			US 40		I-70		REFUGEE		WRIGHT			US 33		
			1	2	3	4	5	6	7	8	9	10	11	14	15	17	18	19	20	21	22	23	24	25	13
4503	0023	805				805	805	805	805							805									
	1332	491				491	491	491	491							491									
	2103	1165				1165	1165	1165	1165							1165									
	3402																								
	3406																								
	3410																								
	3414																								
	3502																								
	3506																								
	4306	3098																		3098	3098	3098			
	4410																								
	4502																								
	4504	408																				408			
	4507	140								140															
	5118	543																		543	543	543			
	7312	297								297													297	297	
	9110	315										315	315							315	315				
4504	0023	582				582	582	582	582							582									
	1336	257				257	257	257	257							257									
	2103	664										664	664							664	664				
	3402																								
	3406																								
	3410																								
	3414																								
	3502																								
	3505																								
	4306	2052																		2052	2052	2052			
	4410																								
	4502																								
subtotal			1103	3707	[illegible]	2320	1604	1333	1327	1302	3371	2302	1070	1704	2046	3733				8054	8802	1603	314	314	2494

Figure 160. Sample assignment work sheet for SR 256 (Ohio) corridor.

capacity of 1,060 vehicles per hour (VPH), derived as follows:

$$\text{Approach width capacity} = 1{,}700 \times \frac{9\text{ ft}}{20\text{ ft}}$$
$$= 765$$
$$\text{Net capacity} = 765 \times (\text{urbanized area pop. adj. factor}) \times (\text{area type adj. factor}) \times (G/C\text{ ratio})$$
$$= 765 \times 1.11 \times 1.25 \times 0.5$$
$$= 531\text{ VPH}$$

Doubling the net capacity yields a two-directional hourly capacity for SR 256 of 1,060 VPH. The other quantities were determined in a similar manner.

Figure 162 shows a "facilities stress diagram" for SR 256. The vertical axis represents the calculated volume/capacity ratios (Table 68) and the horizontal axis represents the length of SR 256 from the northern study boundary to the southern boundary. A horizontal datum has been drawn at a level of service equal to "C" (V/C = 0.8) to determine which segments are over capacity at that level of service. A second datum (dashed horizontal line) is shown, also, to evaluate those portions of SR 256 that might be considered over capacity at level-of-service "D" (V/C = 0.9). In this instance, the exercise is academic inasmuch as the entire length of SR 256 would be ex-

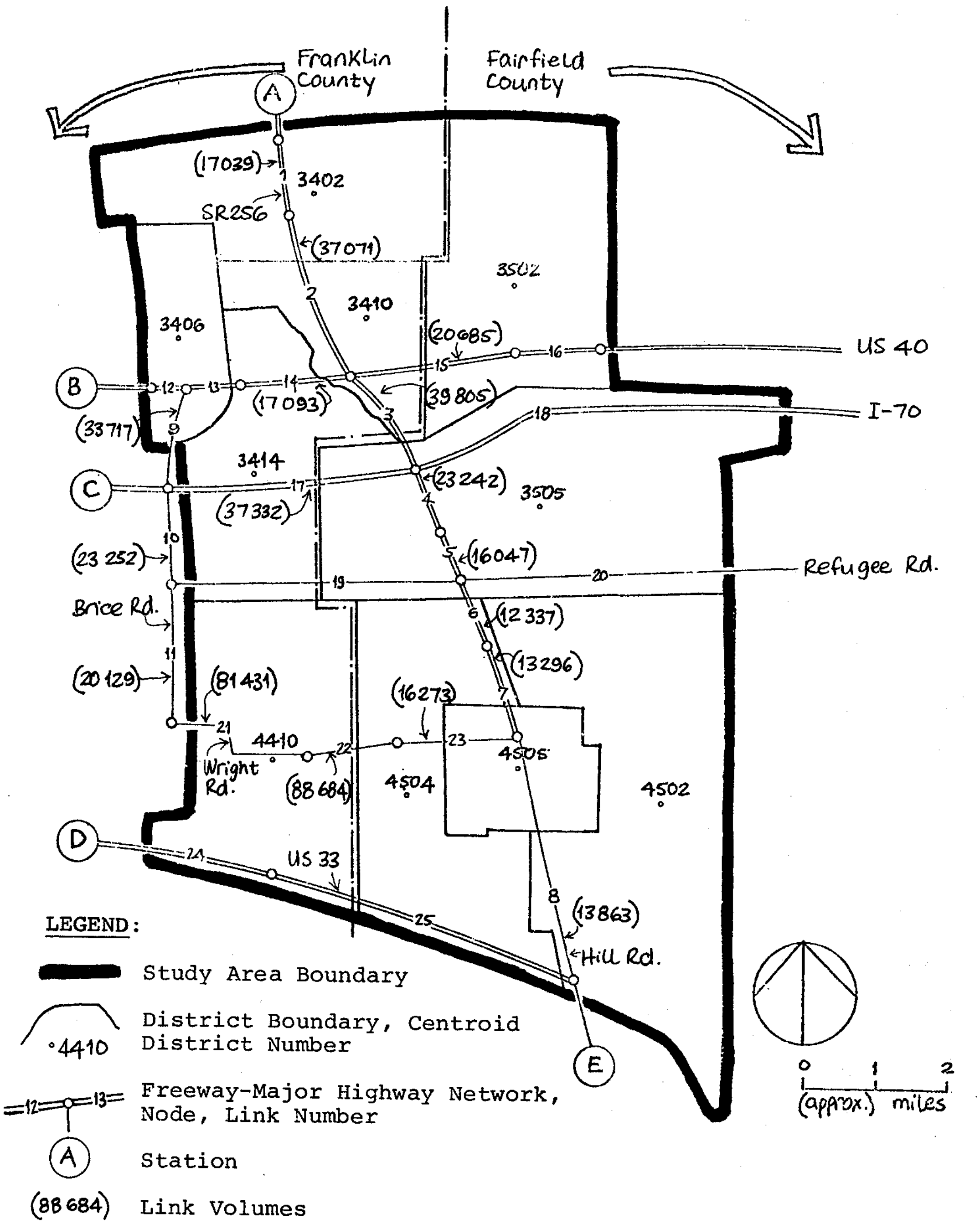


Figure 161. SR 256 (Ohio) corridor analysis network with link volumes.

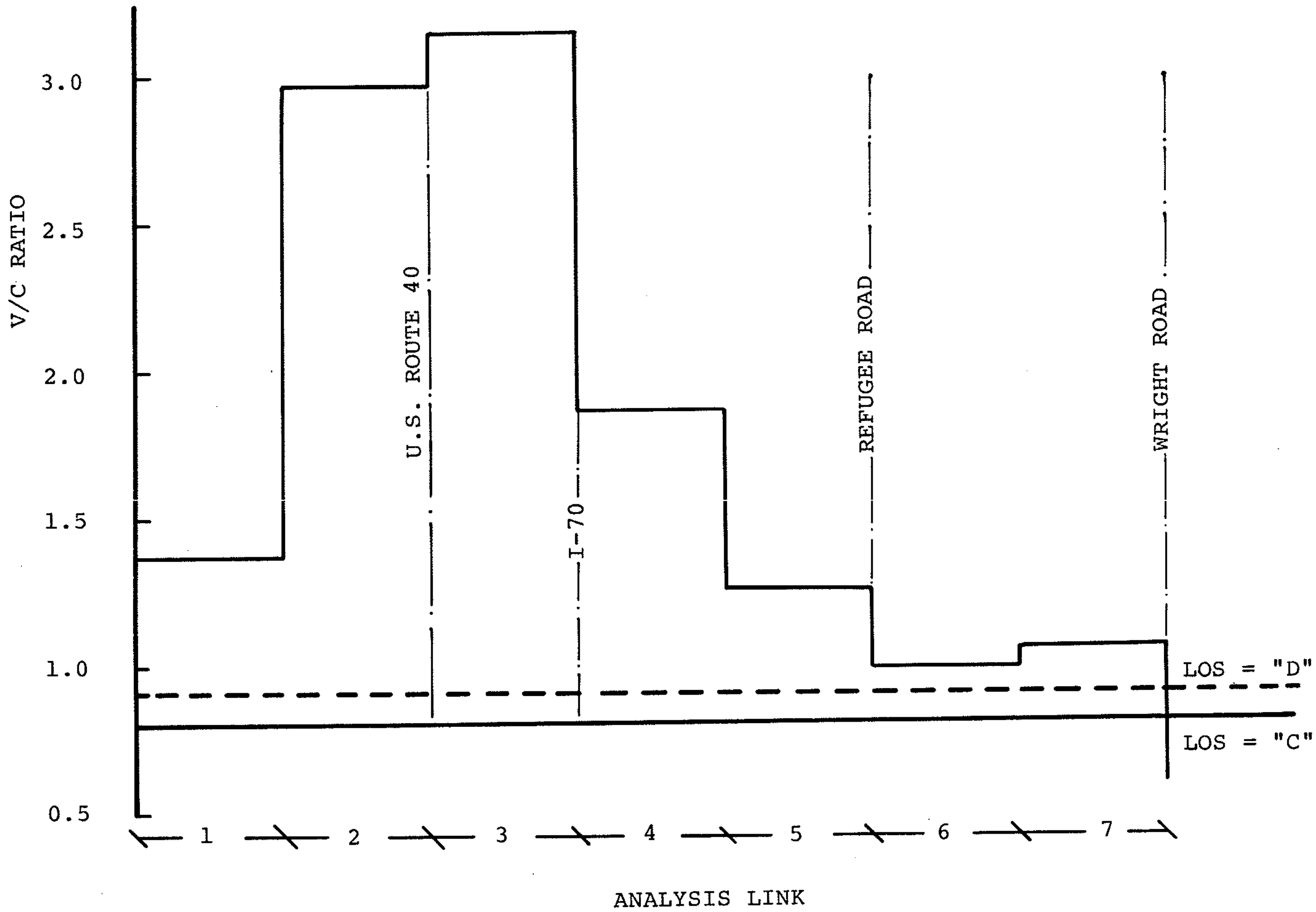


Figure 162. Facilities stress diagram for SR 256 (Ohio) corridor.

periencing excess travel for its current cross-sectional configuration. It would be better to estimate an approach width that could accommodate the estimated future traffic volumes.

A required aproach width can be calculated by reversing the volume/capacity determination procedure. For example, link 4 has a V/C ratio of 1.86 (Table 68) at level-of-service "E." Therefore, the V/C ratio for level-of-service "C" can be calculated:

V/C (at LOS = "C") = 0.8; and V/C (at LOS = "E") = 1.86

Therefore, for link 4:

$$V/C_{LOS=C} = \frac{1.86}{0.8} = 2.325 \qquad (52)$$

The capacity necessary to handle the peak-hour volume can be determined by multiplying the existing capacity by the new V/C ratio.

$$\text{Capacity}_C = (1{,}060)(2.325) = 2{,}465 \text{ VPH} \qquad (53)$$

The 2,465 VPH represents net capacity and requires adjustment for urbanized area population and location and G/C ratio (G/C = 0.5) to obtain possible capacity in order to determine the two-dimensional approach width. The approach width will be estimated for one direction and doubled. The base capacity is determined from Table 51.

$$\text{Base Capacity} = \frac{2{,}465}{2(1.11)(1.25)(\text{G/C ratio})} = 1{,}776 \text{ VPH} \qquad (54)$$

Interpolating the base capacity for two-way, no-parking facilities between 20 and 25 ft yields an approach width of 21 ft or 42 ft of cross-section approach width.

Therefore, SR 256 in the area between I-70 and Refugee Road needs to be reconstructed as a 4-lane facility with appropriate turning lanes at major intersections. Similar calculations can be made for other sections of SR 256.

The user might observe that the highest V/C ratio along SR 256 is on link 3 (V/C = 3.19). A calculation similar to the preceding one indicates that a 6-lane (approach width, 36 ft) facility is needed for the area between I-70 and US 40. Constructing 6 lanes of facility between two major highway intersections would not necessitate 6 lanes of facility for the full length of SR 256 through Pickerington. Other calculations show that a 4-lane facility is needed along SR 256 south of I-70.

It was felt that because of the capacity and volume relationships estimated to exist along Wright Road, conclusions could not be drawn without further analysis. Obviously, the impacts caused by development within the

TABLE 68

SUMMARY OF YEAR 2000 OPERATING CONDITIONS FOR SR 256 CORRIDOR

Link	Descriptor	Pk. Hr. Volume	Approach Width	2-Direction Hourly Capacity[a]	V/C Ratio
1	SR 256	1448	9'	1060	1.37
2	SR 256	3151	9'	1060	2.97
3	SR 256	3383	9'	1060	3.19
4	SR 256	1976	9'	1060	1.86
5	SR 256	1364	9'	1060	1.29
6	SR 256	1048	9'	1060	0.99
7	SR 256	1130	9'	1060	1.07
8	Hill Road	1178	9'	1060	1.11
9	Brice Road	2866	36'	4578	0.63
10	Brice Road	1976	36'	4578	0.43
11	Brice Road	1711	36'	4578	0.37
19	Refugee Road	-0-	9'	1060	-0-
21	Wright Road	7736	12'	1457	5.31
22	Wright Road	8425	12'	1457	5.78
23	Wright Road	1546	12'	1457	1.06

a. Represents capacity at Level of Service = "E".

Wright Road vicinity are serious and will require not only more roadway facilities but also a careful investigation of the development anticipated. Also, the development should be analyzed carefully with regard to highway access in an effort to divert some of the new central-city bound traffic to US 33. Any diversion of traffic to SR 256 as a path to US 40 or I-70 will require further expansion of SR 256. There does appear to be available capacity along Brice Road that could be used to get to the major width routes.

SUMMARY

In addition to the general capacity requirements determined and the conclusions noted previously, the scenario has pointed out several issues that could be further investigated using procedures in this user's guide:

- The current highway facilities within the SR 256 corridor cannot accommodate the travel desired as dictated by the development plan.
- The facilities plan should not depend solely on SR 256 to satisfy the travel desires of the area. Travel should be encouraged to distribute between the major arterials provided.
- The land-activity plan, particularly in the area west of SR 256 between Refugee Road and US 33, should be evaluated in more detail with regard to level of development and access to area arterials.

Application of the procedures from the user's guide in the Columbus scenario required 66 person-hours of computation and analysis (exclusive of documentation). A summary of person-hours, by major task is given in Table 69.

Most of the first block of time (Tasks A, B, and C) involved summarization and expansion of land-activity data to the year 2000. It would be possible, depending on available data, for this time to be slightly reduced. Unfortunately, when situations occur where decisions must be made on such matters as the distribution of land activity, clerical assistance cannot supplant the analyst. In those cases where data exists in a satisfactory organization, data manipulation time can be minimized.

It was found that trip-distribution time requirements decreased as experience was gained with the data work sheets and the various graphs as is evidenced by the 3-hr time reduction between developing the HBW trip table and the HBNW trip table. It also was noted that the entire trip-distribution procedure can be applied by clerical staff with a minimum of professional supervision.

The trip-assignment procedure application was accomplished by professional staff primarily because of the path selection that had to be made while the "stringing" of trips was accomplished. It is also felt that the familiarity gained by manipulating the data is beneficial for subsequent analyses.

TABLE 69

PERSON-HOURS REQUIRED FOR SR 256 CORRIDOR ANALYSIS

	TASK	PERSON-HOURS
A	Develop analysis districts	4
B	Summarize land activity data	13
C	Develop productions and attractions	6
D	Develop travel time matrix	4
E	Develop HBW purpose trip table	16
F	Develop HBNW purpose trip table	13
G	Develop total trip table	5
H	Assign trips to network	3
I	Capacity analysis	2
	Total	66

In general, the manual procedures were found to be easily applied. Considering the characteristics of this particular scenario with its major focus being outside the existing study area, it is also felt the total elapsed time to complete the manual application would be less than that required to process the information by computer within an existing transporation planning procedural framework.

CHAPTER TWELVE

SCENARIO FOR LAND-USE/HIGHWAY SPACING ANALYSIS: FAIRFAX, VIRGINIA

INTRODUCTION

The area selected to test an application of the development density/highway spacing relationships developed is Fairfax County, Virginia, a growing suburban county in the Washington, D.C. metropolitan area. Present population exceeds 500,000 persons and is expected to increase by at least 50 percent to more than 750,000 persons in the next 20 years. There is extensive commuting from Fairfax County to other counties in the Washington metropolitan area and into the downtown area of the District of Columbia.

Fairfax County had been divided into 11 analysis areas by local planners for planning purposes. These areas vary considerably in density and type of development. In the portion of the county nearest the center of the region, mixed residential and commercial areas can be found. Along the Shirley Highway corridor, residential development is concentrated in high-rise apartment units. High-income, single-family residential areas can be found in the northern portion, along with new office-type research parks. Farther out, past the Capitol Beltway, the new town of Reston, as well as rural (agricultural) areas exist. There are several major regional shopping centers in the county as well; thus, in one county, a wide variety of land-use patterns exists.

Presently, the county is served by a major radial freeway, the Shirley Highway, a parkway, and the circumferential Capitol Beltway as well as arterial highways (state routes). Although transit service is today limited to bus, express service on exclusive lanes exists on the Shirley Highway, and special service exists from Reston to the center of Washington, D.C.

Rail rapid transit is planned in two corridors and is under construction along the right-of-way of a new radial freeway, I-66. Use of this latter freeway is to be limited to car pool and bus service only in peak-travel periods. The beltway is currently being widened from 4 to 8 lanes. From this background information, it can be seen that a wide variety of transportation services exists and is planned, including major high-type facilities.

The scenario selected for application in Fairfax County was:

1. To determine the base-year level of service being provided by the highway system in Fairfax County.
2. To determine the level of service that would be provided by a planned transportation system for the county in a future year.

In both cases, the only inputs required were a measure of land activity and of the transportation system. The methodology described in Chapter Nine was then used to determine present and future travel in the county, allocate this travel by subarea to freeway and arterial facilities, and to compute the resulting level of service.

If desired, the information obtained could also be used to indicate where present and future deficiencies exist, where improvements are indicated, and the magnitude of improvements required to reach a desired level of service.

Summary of Steps Undertaken for Scenario

The steps undertaken in applying the density/spacing methodology were:

1. Dividing the county into analysis areas (i.e., districts) averaging 16 sq mi in area.
2. Obtaining existing and future land-use activity data on households and jobs by those areas.
3. Obtaining maps of existing and future transportation systems for the county. This included planned transit improvements for the future year.
7. Computing travel time by future transit facilities from analysis areas to areas of employment, and using an existing method to estimate changes in transit use.
8. Going through the computation steps as previously outlined in Figure 128, Chapter Nine.

SCENARIO DETAILS

The following sections describe in detail the steps undertaken to evaluate the base-year levels of service.

Step 1: Computation of vehicle trip ends. Both Method I and Method II, as described in Chapter Nine, were used in the application to Fairfax County for existing-year data; however only method I was used in computing the future year. As described previously, Method I uses the number of households and total employment by subarea to compute daily vehicular trip ends by multiplying these totals by an appropriate *one-way* trip generation rate.

Rates by type of land use were obtained from Table 1, Chapter Two, and are as follows:

RESIDENTIAL	TOTAL VEH. TRIP ENDS DAILY/DU	ORIGINATING VEH. TRIP ENDS DAILY/DU
Single-family	10	5
Townhouses	7	3.5
Apartments	6	3

NONRESIDENTIAL	TOTAL VEH. TRIP ENDS DAILY/JOB	ORIGINATING VEH. TRIP ENDS DAILY/JOB
Office	3.5	1.75
Retail	20.0	10.00
Manufacturing	3.0	1.50
Other	10.0*	5.00
Military	2.5*	1.25

* Estimated from local sources.

For Method I, an over-all rate for residential dwelling units was created by weighting by the number of units in each group. For 1968, the total one-way vehicle trips are as follows:

84,000 Single-family	× 5.0 =	420,000
4,400 Townhouses	× 3.5 =	15,400
30,500 Apartments	× 3.0 =	91,500
Total		526,900

Dividing this by a total of 118,900 units gave an over-all residential trip rate of 4.4 originating daily vehicle trips per dwelling unit. A similar procedure was used to obtain an average rate for all jobs. This resulted in a rate of 4.0 trips per job.* These rates were then multiplied by the number of dwelling units and jobs in each subarea. If employment data are unavailable, rates per unit of floor area, or per acre can be used.

For Method II, the individual rates were used for each subarea to obtain total daily originating vehicle trips. Only Method I was used to compute 1985 originating vehicle trips given future households and jobs. The base-year rates were used for 1985. If substantially different distributions of activities exist in the future, new rates should be computed.

Step 2: Computation of transit use and auto-occupancy adjustments. Although the vehicular trip rates used assume a nominal use of transit, transit plans for rapid rail and commuter rail service necessitated revisions to the initial vehicle-miles of travel estimate for 1985. To estimate the effect of these planned services, a simplified trip-end modal split curve was used to modify the 1985 vehicular trip estimates before computing future VMT. This relationship had been derived from a prior transit improvement study in the county. The relationship is shown in Figure 163. The curve relates the percentage of regional employment reached within 45 min by bus for a given area. By making similar estimates for each subarea in 1985, a percentage figure was derived from each subarea. Figure 164 shows the transit system assumed. Bus access time was estimated to each station by measuring the airline distance from the subarea centroid to the station and assuming a 15 mph speed. Station-to-station times were added as were an initial walk and wait time of 8 min, a transfer and wait time of 2 min, and a walk at the subarea of destination of 1 min. In subareas with direct access to a station, an access time of 8 min was used. Regional, not just local, jobs should be accessed.

The modal split percentage derived and the modal split percentage assumed in the vehicular trip-generation rates † were used with an auto occupany of 1.4 to calculate a percent change in auto driver trips. (See Chapter Nine, Fig. 131 and *Step 2: Computation of transit use and auto-occupancy adjustments.*) This percent change is used to reduce the trips calculated in Step 1 in this chapter.

Any trip-end modal split method could be used to derive an estimate of future modal split. Or, as previously noted, Figure 131 can be used if a policy figure or goal is to be achieved.

The curve used in the Fairfax County scenario can provide an approximation of modal split in other areas if the number of minutes used to determine percentage employment accessibility via transit (45 min in the example) is calibrated to the urbanized area population. In general,

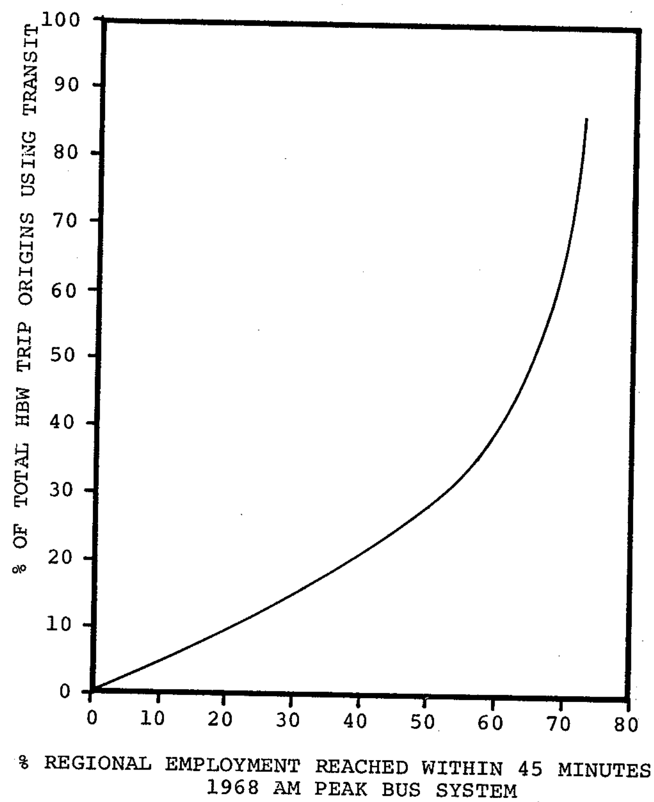


Figure 163. Modal split relationship for the Washington, D.C., area. Source: Metropolitan Washington Transportation Planning Board (1968).

* If military employment was excluded, this rate increased to 4.8. The district containing the majority of military employment still required special adjustment, and, despite this additional correction, did not agree with observed data. Special types of generators require more specific local information.

† This would, of course, vary by urbanized area population between 2 and 13 percent. For the area used, it was 6 percent, based on local data. If local data are not available, the values in Table 1, Chapter Two, might be used for a gross approximation.

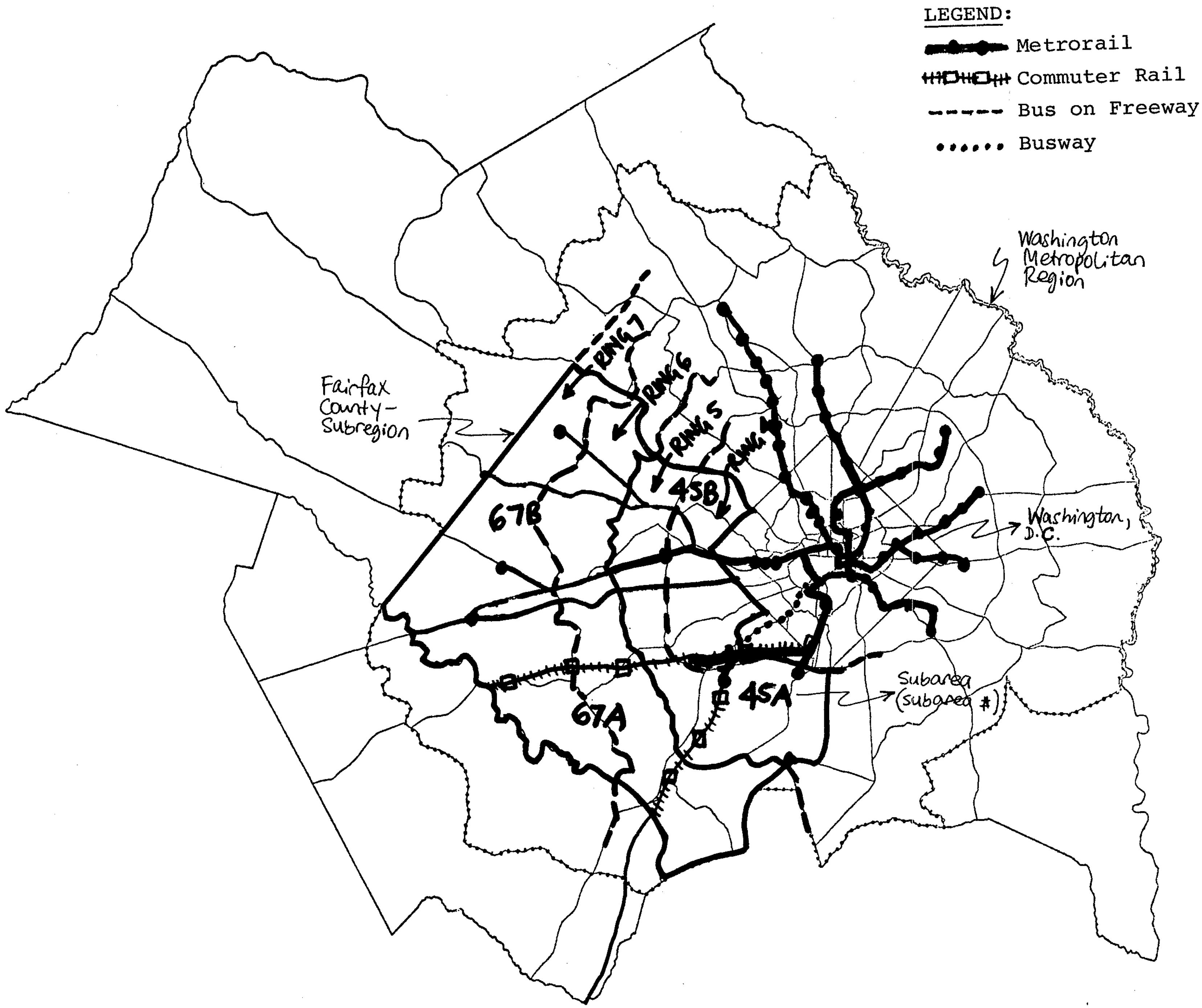


Figure 164. Future assumed transit service for Washington, D.C., and metropolitan region.

the number of minutes should represent the time within 90 percent of all HBW trips in the area that can be completed by all modes, including auto. For most areas, this figure will approximate the mean HBW trip length in minutes plus 50 percent.

If an average door-to-door airline HBW trip speed of 15 mph is assumed along with the fact that HBW trips are 50 percent longer than the average trip, Figure 133 can be used to estimate the average HBW trip length in minutes for different urbanized area populations.

The average work trip length in minutes for areas of 500,000 population would be 24 min; for areas of 2,000,000, 27 min; and for areas of 5,000,000, 33 min. Corresponding values to be used with Figure 163 would then be 50 percent higher, or approximately 35, 40 and 50 min. Higher speeds could be assumed for smaller urbanized areas yielding lower travel time values, and lower speeds assumed in larger areas yielding higher travel time values. If data are available, the curve could be checked and/or calibrated.

Figure 165 shows the 1985 modal split obtained from the curve versus that obtained from a trip-interchange model used by the transportation planning agency. For the most part, the results parallel the results of the more complex, computerized procedure. It is, however, consistently below the regional forecast because auto access to transit stations was *not* considered in the short-cut method used, whereas auto access was allowed in the computerized regional forecasts. Had auto access been considered, the percent modal split would have increased. It was not allowed, however, because vehicles traveling to stations should be accounted for as part of the vehicular travel demands to be estimated in this case.

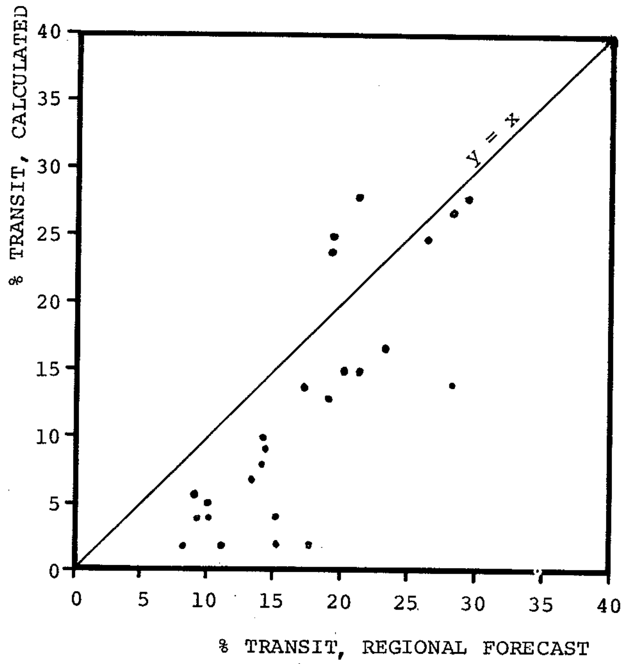


Figure 165. Comparison of calculated modal split vs regional forecast of modal split (from computer trip interchange method).

Step 3: Computation of vehicle-miles of travel; and

Step 3A: Computation of external vehicle-miles of travel. Using Figure 133, it was determined that the average airline trip length was 5 mi in 1968 and would be 5.2 mi in 1985 when the population of the metropolitan region would have increased from 3 to 4 million. A 5-percent improvement in speed was also assumed, resulting in an additional 7.5 percent in work-trip length (see Fig. 134). Because HBNW travel would remain roughly constant, an over-all 1985 trip length of 5.5 mi was selected. (See Chapter Nine for the method of weighting HBW and HBNW trip lengths to calculate an over-all trip length.)

Inasmuch as these figures are airline distances, it is necessary to multiply them by an over-the-road conversion factor. A value of 1.3 was used for the Fairfax County area. This resulted in a figure of 6.5 mi per trip in 1968 and 7.2 in 1985. Originating vehicle trips in each subarea were then multiplied by the trip lengths to obtain daily vehicle-miles by subarea.

A significant amount of commuting into the Fairfax County area occurs from areas to the west. It was found that this was not adequately accounted for by internal trip ends alone. External station * volumes were used to obtain adjustments for peripheral districts, as described in Chapter Nine, and to calculate an external VMT to be added to the subarea containing the station.

Because traffic count data were available,† a comparison could be made between Methods I and II and actual subarea VMT. If the county is divided into rings (as shown in Fig. 164), the ratio of the estimated to actual VMT is given in Table 70. A comparison graph of differences between Method I and actual VMT by district is shown in Figure 166. As shown, Method I appears to give better results than Method II, the more detailed method.‡ Both methods are consistent in that no bias seems to be introduced by distance from the center. A similar methodology was followed for 1985. Actual daily VMT for 1968 totaled 6,497,000.

Step 4: Computation of vehicle-miles of travel on freeways and arterials. Following the adjustment for improved transit service in 1985, future vehicle-miles of travel in that year was computed to be 16,394,750. It was estimated that without improved transit, the estimate would have been 1,165,900 VMT's higher.

The next step is to estimate the amount of travel that will be accommodated on freeway facilities. Using the freeway spacing formula discussed previously, the average volume per mile of route and freeway VMT by area were computed for the present and future. Only small additions to the existing freeway system were included in the future plan, but widenings of existing freeways are planned to accommodate increased traffic volumes. The future trans-

* Freeway facilities were excluded as described in Chapter Nine.

† A factor was added to include VMT on local streets.

‡ If military employment is excluded from Method I in computing the average trip rate used, Method I results would also be approximately 10 percent higher and similar to Method II. It is believed that the average trip rates used are somewhat higher than Washington, D.C., area trip rates. Where local trip rates are available, they should be used whenever possible.

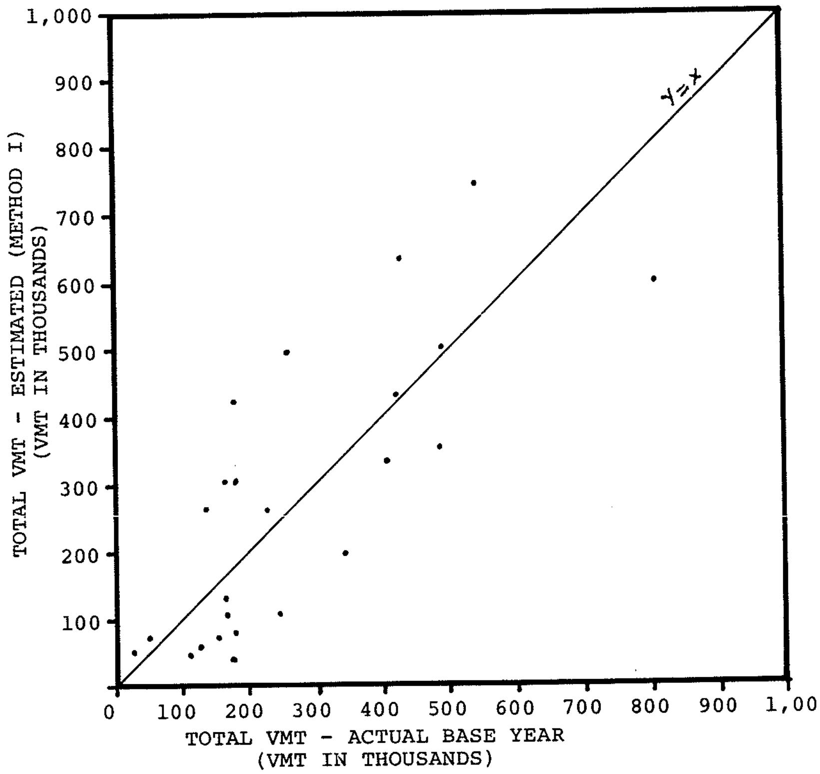


Figure 166. Comparison of estimated total VMT (Method I) vs actual total VMT (by district).

portation plan for Fairfax County is shown in Figure 167. Present freeway lengths were measured by groups of districts; that is, subareas (see Figs. 138 and 139) and spacing, Z, calculated as follows:

$$Z=\frac{2\ (\text{Subarea size in sq mi})}{\text{Miles of route}}=\frac{2A}{L} \qquad (55)$$

Arterial spacing was also computed and input along with vehicle trip origin density (the same as previously computed, plus nonresidential origins) and the average over-the-road vehicle trip length.

Again, because traffic count data for the base year were available, a comparison could be made between calculated and estimated results. The comparison is given in Table 71. (Also given are the future year freeway VMT estimates.) These freeway VMT's were then expressed as a ratio (or percentage) of the total VMT previously computed. The residual arterial and local VMT in each district was then calculated by reducing the total VMT by that percentage. In addition, a further reduction of 8.4 percent was made in each district for local street VMT. The arterial VMT estimate by district was obtained by relating the residual arterial VMT by district computed for 1985 to that computed for 1968 and dividing to obtain a VMT growth factor by subarea. This VMT growth factor was then applied to actual 1968 arterial VMT data by district to obtain 1985 arterial VMT. In the absence of actual base-year district arterial VMT data, the estimated data could be used directly. If such base-year information is available, as it was in this case, the growth factor estimation may be preferable inasmuch as it tends to correct for errors in estimation. Actual and estimated arterial VMT is shown in Figure 168 for the base year.

Step 5: Computation of average arterial volumes per lane and level of service. Given the base and future year arterial VMT by district, the last step was to divide by the number of equivalent lane-miles of arterials in each district for the existing system and future plan. As noted previously, each multilane arterial lane was converted to equivalent lanes so as to equate single-lane and multilane capacity. The average volume per equivalent lane was then computed and is given in Table 72. To compute the level of service provided, the average volume per equivalent lane was then used to determine the percentage of VMT in each district currently operating above level-of-service "C." Figure 141 shows this relationship (along with VMT over levels-of-service "D" and "E" as well). The arterial level of service by subarea is shown for the base and future years in Figure 169.

If desired, the average freeway volume can also be used to get an indication of freeway system performance. The freeway volume can be related to level of service and speed (see Table 53 in Chapter Nine).

Figure 129 relates the percentage of arterial VMT over level-of-service "C" to the average peak hour and daily speed in the subarea. A good indication of the total level of service provided can be obtained from the following relationship:

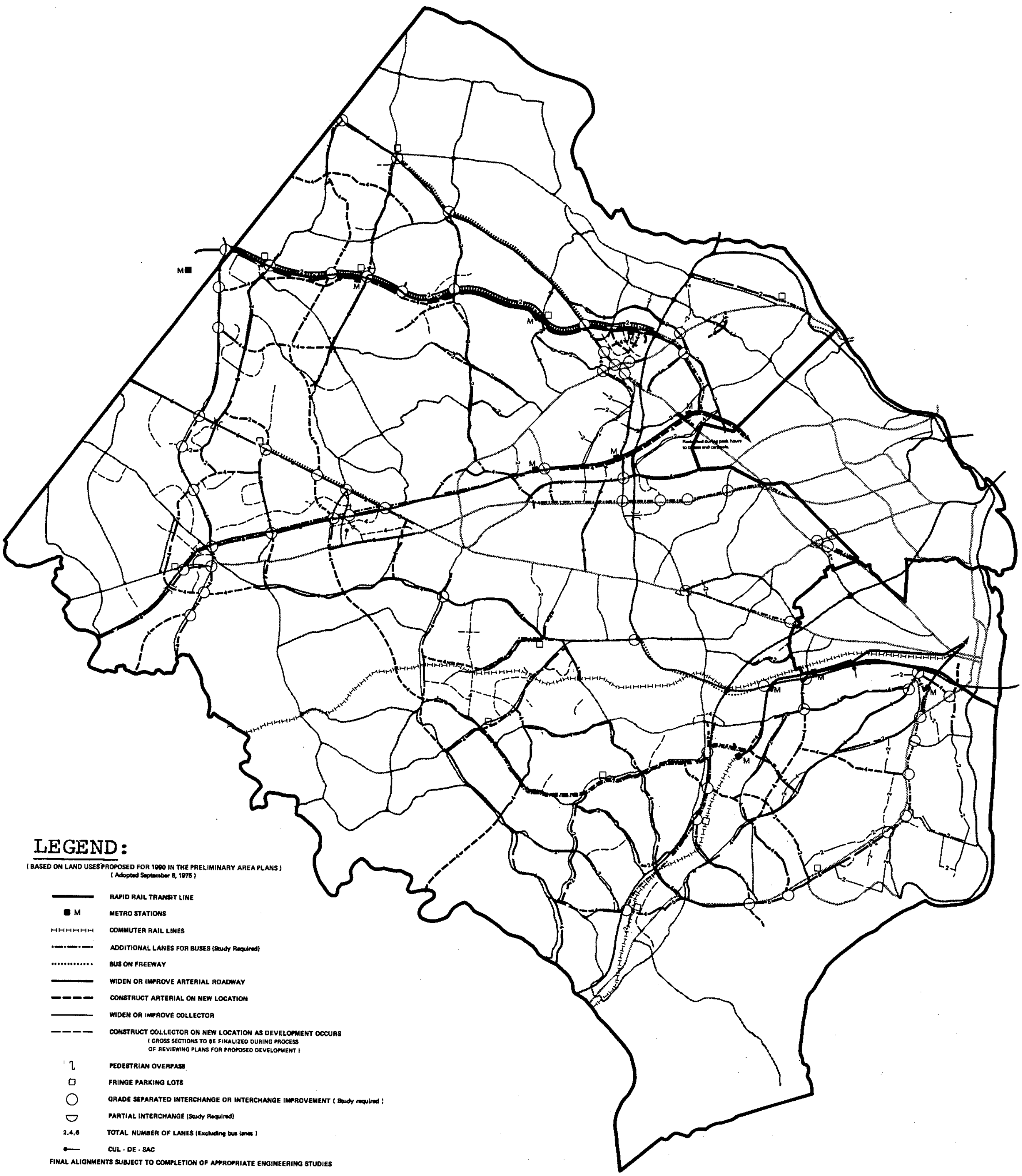


Figure 167. Future transportation plan for Fairfax County, Va.

TABLE 70

RATIO OF ESTIMATED TO ACTUAL VMT (1968)

Ring[a]	Method I	Method II
4	1.18	1.23
5	0.84	0.97
6	1.25	1.30
7	0.84	0.91
Total	1.02	1.10

a. See Figure 164.

TABLE 71

RATIO OF ESTIMATED TO ACTUAL VMT ON FREEWAYS

	BASE YEAR			FUTURE YEAR
SUBAREA[a]	ACTUAL	ESTIMATED	RATIO[b]	ESTIMATED
45A	1,164,430	1,184,720	1.02	2,408,110
45B	730,050	783,180	1.07	1,637,230
67A	227,590	142,560	0.63	338,010
67B	309,620	198,480	0.64	1,071,350
TOTAL	2,431,690	2,308,940	0.95	5,454,700

a. See Figures 138 and 164.
b. Ratio = Estimated VMT/Actual VMT.

TABLE 72

BASE AND FUTURE YEAR ARTERIAL VMT AND AVERAGE EQUIVALENT LANE VOLUME

ANALYSIS DISTRICTS AND RINGS[a]	VMT		AV. VOLUME PER EQUIV. LANE	
	BASE YEAR[b]	FUTURE YEAR[c]	BASE YEAR[b]	FUTURE YEAR
70	8,750	20,388	3,500	8,155
71	299,725	536,508	4,976	7,394
72	391,655	466,069	5,975	4,175
73	293,620	252,513	5,097	3,589
74	123,640	207,715	4,016	3,746
75	172,850	274,832	4,012	4,992
RING 4	1,290,240	1,758,025	4,967	4,783
91	155,930	205,836	3,392	1,626
92	382,810	1,048,899	4,042	3,515
93	161,475	271,278	6,061	2,899
94	201,630	522,222	4,459	8,270
95	209,230	518,890	3,115	4,983
96	88,843	744,504	2,373	10,325
97	58,608	235,018	2,114	6,021
RING 5	1,258,526	3,546,647	3,649	4,450
112	89,897	157,320	1,767	2,264
113	56,920	751,017	841	1,526
114	147,200	228,160	2,466	1,428
115	135,896	95,127	2,602	1,484
116	54,693	784,584	1,124	6,812
117	80,556	530,864	2,009	13,785
RING 6	565,162	2,547,072	1,770	3,164
123	25,828	222,379	1,195	10,289
124	15,126	107,697	351	1,414
125	104,817	619,468	1,561	3,468
126	102,263	918,322	1,165	4,137
127	95,008	946,280	1,648	5,047
128	108,105	486,473	2,093	3,025
RING 7	451,147	3,300,619	1,371	3,898
TOTAL	3,565,075	11,152,363[c]		

a. See Figure 139 for districts; see Figure 164 for rings.
b. Actual condition.
c. Based on factoring existing VMT by district. A direct estimate of future arterial VMT was 9,679,418.

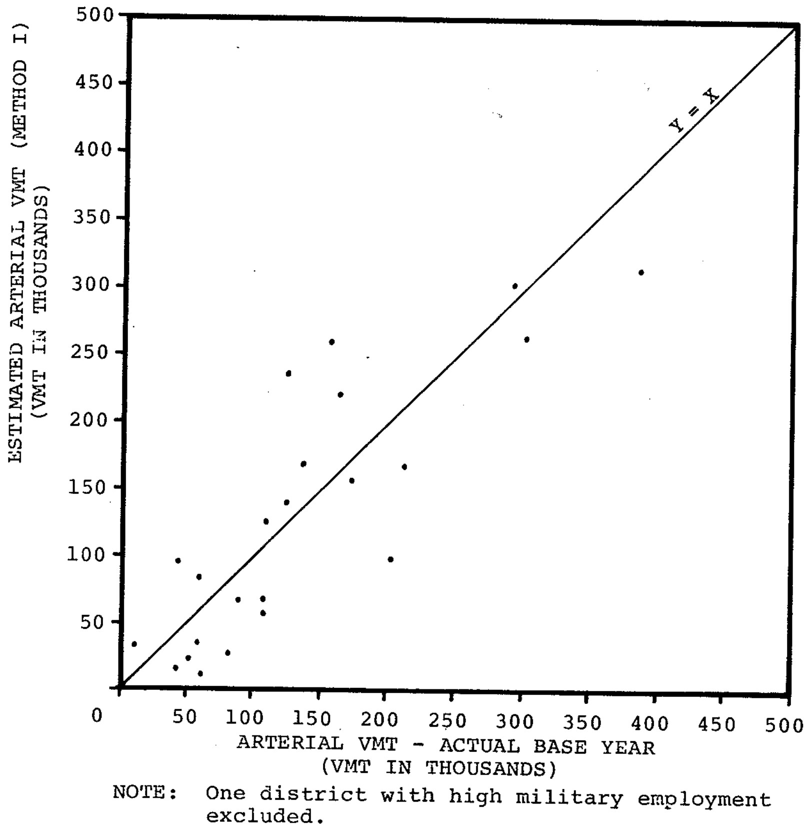


Figure 168. Comparison of estimated arterial VMT (Method I) vs actual arterial VMT (by district).

Average Speed = % VMT on freeway × (Freeway speed at level of service . . . .)
+
% VMT on arterial × (Arterial speed at level of service . . . .)
+
% VMT on local × (Local Speed at level of service . . . .)

Note: To apply this formula, "speed" must be expressed with distance in the denominator, as in min/mi.

Peak and off-peak conditions can be weighted if desired, as well.

An examination of least-cost solutions indicates that the volumes shown in Figure 130 should be obtained for new and widened facilities. These volumes lie between levels-of-service "C" and "D." New or widened arterials can be provided to reduce equivalent lane volumes to the standard desired.

SUMMARY

A method for estimating the level of service provided by a transportation system has been developed and tested using data from a suburban county. Although the scenario tested dealt with determination of the level of service provided by an existing and planned future transportation system, it would have been simple to estimate the additional facilities needed to maintain or increase existing levels of service. Adding lanes (facilities) would have reduced the equivalent lane volumes and increased the level of service. In addition, the land use assumed could have been revised to reduce VMT and modify the equivalent lane volumes so as also to increase the level of service found. Other strategies outlined in the section on "Feedback" in Chapter Nine could have been considered as well.

The method provides reasonable results although only average data from urbanized areas were used. The use of local data has the potential to improve accuracy. It is, however, like most planning tools, most useful in a relative sense when comparing alternative plans or proposals. Because the method can be applied entirely without the use of computers and in a short period of time (the scenario application took approximately 22 person-hours, the bulk of which—13 hr—involved adjustment for future transit), many alternatives can be developed. (Choosing a "policy level" modal split and using Figures 131 and 132 can greatly reduce the time and effort required.) One potential use is in deciding where improvements should be made or in choosing between two improvements if limited funds are available.

The method is also limited by the data input developed from current travel behavior. Should that behavior change because of energy constraints, pricing restraints, or through the imposition of public policies restricting use of the automobile, new input data will need to be provided. (Some indicated changes in VMT due to policy changes are given in Table 7 of the companion report entitled, "Travel Estimation Procedures for Quick Response to Urban Policy Issues" *NCHRP Report 186* (*73*).)

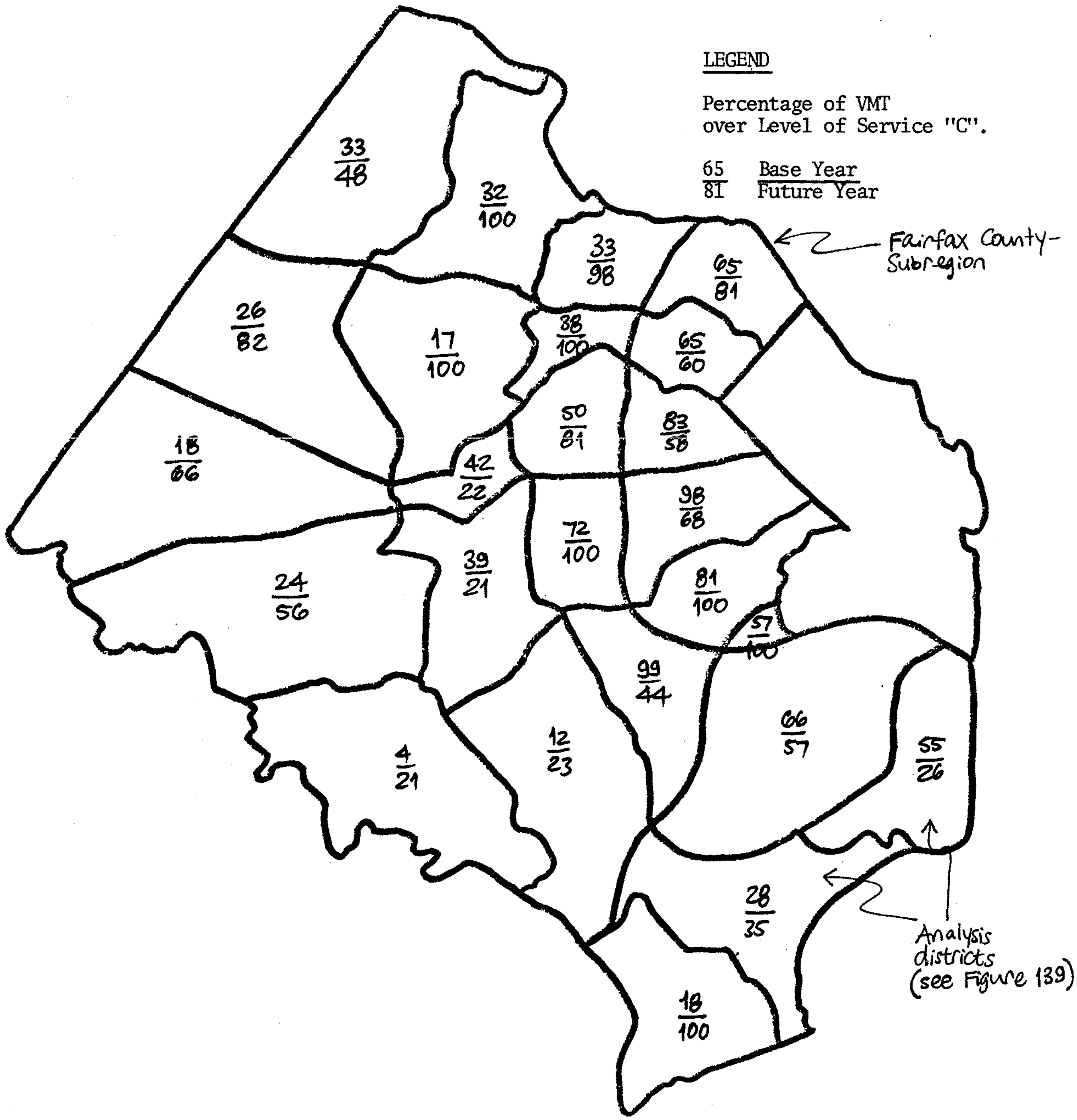


Figure 169. Computed arterial level of service, by analysis district, for Fairfax County, Va.

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GLOSSARY

This glossary provides definitions for many of the technical terms used in this user's guide. Generally, these terms are consistent with the terminology used in common transportation planning practice. In some instances, however, the definitions might vary from ordinary usage. Such variations have been deemed necessary in order to develop explanations of terms specific to those employed in the user's guide.

ACCESSIBILITY—The potential to reach certain opportunities within a given travel time. This potential can be quantified by the accessibility index.

ACCESSIBILITY INDEX—A measure of the ability to reach a certain number of opportunities in a given travel time. Mathematically, for an analysis area in question, this index is given by the sum of the products of all trip attractions in the study area and the friction factors corresponding to those attractions; i.e., $\Sigma A_j F_{ij}$. This term forms the denominator of the gravity model formula.

ACCESS TIME—The total time from origin or destination to the primary mode of travel. May include walking time, waiting time, time in another type of vehicle, or terminal time.

AIRLINE DISTANCE—The shortest (straight-line) distance in miles between two points (usually centroids) in a study area. Airline distance is typically measured from a map using a straightedge between the two points in question.

ALL-OR-NOTHING ASSIGNMENT—The process of allocating the total number of trips between each pair of analysis areas to the path or route with the minimum travel time.

ANALYSIS AREA, ANALYSIS UNIT—The basic geographical entity or portion of a study area delineated for transportation analysis. In the context of the user's guide, the smallest area/unit is the zone, whereas the largest could be a subregion.

ANNUAL AVERAGE WEEKDAY TRAFFIC—The average number of vehicles passing a specified point on an average weekday; i.e., Monday through Friday.

ARTERIAL—A class of street serving a major movement of traffic not served by a freeway.

ATTENUATION—The characteristic related to trips where the number of trips to or from a generator decreases with increasing distance from the generator.

AUTO DRIVER TRIPS—Trips made as a driver in an automobile. Auto driver trips are also called auto trips.

AUTO PASSENGER TRIPS—Trips made as a passenger in an automobile.

AUTO PERSON-TRIPS—Trips made as a driver or a passenger in an automobile. Thus, auto person-trips constitute the sum of auto driver and auto passenger trips.

AVERAGE DAILY TRAFFIC (ADT)—The average number of vehicles passing a specified point during a 24-hr period. Some examples are as follows:
ANNUAL AVERAGE DAILY TRAFFIC (ADDT)—Denotes daily traffic averaged over one calendar year.
ANNUAL AVERAGE WEEKDAY (AAWDT)—Denotes that the specified period includes only weekdays, Monday through Friday.

BASE YEAR—The year selected to which the major portion of the data are related. It is usually taken as the year of the survey.

CALIBRATION—The procedure used to adjust travel models to simulate base-year travel.

CAPACITY—The maximum number of vehicles that can pass over a given section of a lane or roadway in one direction (or in both directions for a 2-lane or 3-lane highway) during a given time period under prevailing roadway and traffic conditions. It is the maximum rate of flow that has a reasonable expectation of occurring. The terms "capacity" and "possible capacity" are synonymous. In the absence of a time modifier, capacity is an hourly volume. Capacity would not normally be exceeded without changinng one or more of the conditions that prevail. In expressing capacity, it is essential to state the prevailing roadway and traffic condition under which capacity is applicable. Refer to the revised edition of the *Highway Capacity Manual* for more detail.

CAPACITY RESTRAINT—The process by which the assigned volume on a link is compared with the practical capacity of that link and the speed of the link adjusted to reflect the relationship between speed, volume, and capacity. The procedure is iterative until a realistic balance is achieved.

CENTRAL BUSINESS DISTRICT (CBD)—Usually the downtown retail trade area of a city, or generally an area of high land valuation, traffic flow, and concentration of retail business, offices, theaters, hotels, and service businesses. The CBD forms the smallest subregion of a study region (in the context used in the user's guide).

CENTRAL CITY—Generally, the residential/commercial subregion of a metropolitan region between the suburb and the CBD. In the user's guide, the central city has been delineated, in some cases, as that area other than the CBD, lying inside a circumferential highway; for example, a beltway.

CENTROID—An assumed point in a zone that represents the origin or destination of all trips to or from the zone. Generally, it is the center of trip ends rather than a geometrical center.

CIRCUITY FACTOR—A directionless number used to convert airline distance to over-the-road distance. This number varies from 1.20 to about 1.40.

COLLECTOR-DISTRIBUTOR STREET—An auxiliary roadway, separated laterally from, but generally parallel to, the expressway or thru roadway, which serves to collect and distribute traffic from several access connections between selected points of ingress to, and egress from, through traffic lanes.

CORDON LINE—An imaginary line enclosing a study area, along which external interviews are conducted.

COUNT—A volume counted on the street, which may be used for comparison with the present traffic volume assigned to the corresponding link. The count may be directional or total two-way, peak hour—morning and/or afternoon—and/or a 24-hr value.

CUTLINE—An imaginary line placed at a strategic location to intercept all the links in an identified corridor. Traffic counts and trips assigned to the corridor are compared as a check of survey accuracy or model calibration.

DESIRE LINE—A straight line connecting the origin and destination of a trip. A desire-line map is made up of many such desire lines, the width of which represents the volume of trips moving between the origins and destinations.

DESTINATION—The location at which a trip terminates.

DIRECTIONALITY—The directional distribution orientation of trips emanating from a land-use activity. (See GEOGRAPHIC ORIENTATION.)

DISTRIBUTION—The process by which movement of trips between zones is estimated. Distribution may be measured or estimated by a growth factor process or by a synthetic model.

DISTRIBUTION FACTOR—A factor identical to the friction factor, but for the user's guide, it was not derived empirically; instead, a set of normalized friction factors have been provided.

DISTRICT—A conglomeration of contiguous zones for transportation analysis. The area of a district may vary from about 3 sq mi to about 100 sq mi depending on the type of study to be conducted.

DIVERSION—The process of allocating trips between two possible routes on the basis of measurable parameters.

DWELLING UNIT—A room or group of rooms occupied or intended for occupancy as separate living quarters, by a family or other group of persons living together or by a person living alone.

EQUIVALENT LANES—The expression of lanes in terms of some base condition. For example, a lane of a 4-lane arterial has a capacity equal to 1.6 times the capacity of a lane on a 2-lane arterial.

EXPRESSWAY—A divided arterial highway for through traffic with full or partial control of access and generally with grade separations at intersections.

FREEWAY—A divided arterial highway designed for the safe nonimpeded movement of large volumes of traffic, with full control of access and grade separations at intersections.

FRICTION FACTOR—See DISTRIBUTION FACTOR.

GREEN-TO-CYCLE (G/C) RATIO—The fraction of cycle time that a specific through traffic movement has a green signal light. It is calculated as the same amount of green time divided by the time from the instant the signal turns green until it completes one full cycle and turns green again.

GEOGRAPHIC ORIENTATION—The movement of trips to and from a generator as related to direction in terms of east, west, southeast, and the like.

GRAVITY MODEL: A mathematical model of trip distribution based on the premise that trips produced in any given area will distribute in accordance with the accessibility of other areas and the opportunities they offer.

GROWTH FACTOR—A ratio of future trip ends divided by present trip ends.

HOME-BASED NONWORK (HBNW) TRIP—A trip, for the purpose of shopping, or for a social-recreational purpose, or for any other purpose other than work, with one end at the residence of the trip-maker.

HOME-BASED TRIP—A trip with one end at the residence of the trip-maker.

HOME-BASED WORK (HBW) TRIP—A trip, for the purpose of work, with one end at the residence of the trip-maker.

IMPEDANCE—The total "time cost" incurred by an individual when making a trip. It includes travel time in the vehicle, time spent getting to and from the vehicle, and any perceived cost associated with the trip converted to minutes.

INTERZONAL TRAVEL TIME—The total travel time between different zones consisting of the terminal times at each end of the trip plus the driving time.

INTERZONAL TRIP: A trip with its origin and destination in different zones.

INTRAZONAL TRAVEL TIME: The average travel time for trips beginning and ending in the same zone, including the terminal time at each end of the trip.

INTRAZONAL TRIP—A trip with both its origin and destination in the same zone.

IN-VEHICLE TIME—That portion of the total trip time spent in any major mode vehicle—generally an auto or a bus.

LAND USE—The purpose for which land or the structure on the land is being used.

LEVEL OF SERVICE—The quality of service provided by a facility under a given set of operating conditions. Refer to the revised edition of the *Highway Capacity Manual* for more detail.

LOCAL STREET—A street intended only to provide access to abutting properties. In traffic assignment, any link having a centroid as one node.

MINIMUM PATH—That route of travel between two points which has the least accumulation of time, distance, or other parameters to traverse. This path is found by path-building programs (BUILDVN, UPATH, UROAD) or manually.

MODAL SPLIT—The division of person-trips between public and private transportation. The process of separating person-trips by mode of travel.

MODE OF TRAVEL—Means of travel such as auto driver, vehicle passenger, mass transit passenger, or walking.

MODEL—A mathematical formula that expresses the actions and interactions of the elements of a system in such a manner that the system may be evaluated under any given set of conditions; i.e., land-use, economic, socioeconomic, and travel characteristics.

NETWORK—A system of links describing a transportation system for analysis.

NONHOME-BASED (NHB) TRIP—A trip that takes place between two points, neither of which is the home end of the trip-maker.

ORIENTATION—The directional distribution of trips relative to the compass; i.e., the northern sector, or the eastern sector, and so forth. (See GEOGRAPHIC ORIENTATION.)

ORIGIN—The location of the beginning of a trip or the zone in which a trip begins.

OUT-OF-VEHICLE TIME—Time spent while making a trip that is not in any type of vehicle (e.g., walking time, waiting time, and terminal time). Generally out-of-vehicle time is assessed a penalty factor because it is perceived as more of a deferment than is in-vehicle time.

OUTPUT—Information produced by some calculation whether accomplished by computer or manually.

OVER-THE-ROAD DISTANCE—The distance in miles actually traveled from point of origin to point of destination.

PEAK HOUR—The 60 min observed during either the AM or PM peak period that contains the largest amount of travel.

PEAK-HOUR FACTOR—The fraction of the average daily traffic volume occurring during the highest volume 60-min period during the day.

PEAK HOUR-PEAK DIRECTION—The travel direction which, during the 60-min peak hour, contains the highest percentage of travel.

PEAK PERIOD—The two consecutive AM or PM 60-min periods which collectively contain the maximum amount of AM or PM travel. Peak period can be associated with person-trip movement, vehicle trip movement, or transit trips.

PERSON-TRIPS—The sum of trips made as passengers of an automobile, bus, taxi, truck, and the like, plus as an automobile driver. Auto person-trips are trips made as a driver or passenger in an automobile. Car occupancy is calculated by dividing automobile person-trips by automobile driver trips.

PLANPAC—That portion (dataset) of the FHWA battery containing a "core" set of computer programs for dealing with urban transportation planning.

PRIMARY DIRECTION OF FLOW—Direction of maximum flow on a facility during some time period.

REGION—The entire metropolitan or urbanized region. Aggregated subregions form a region.

ROUTE—That combination of street and freeway sections connecting an origin and destination. In traffic assignment, a continuous group of links connecting centroids that normally require the minimum time to traverse.

SCREENLINE—An imaginary line, usually along a physical barrier, such as a river or railroad tracks, splitting the study area into a few parts. Traffic counts and possibly interviews are conducted along this line, and the crossings are compared to those calculated from the interview data as a check of survey accuracy.

SITE—A location containing a land-use activity, such as a shopping center or a stadium, or a location proposed to contain some activity.

SPACING—The average distance between like facilities in a transportation system. For example, average distance (spacing) between arterials of 1.2 mi.

SPECIAL GENERATOR—A land-use activity that generates a high volume of traffic, such as a shopping center, an airport, or a university.

SQUARE TRIP TABLE—A table of zone-to-zone trips showing trips by direction between each pair of zones.

SUBAREA—A conglomeration of districts, such as a large residential project of a transportation corridor delineated for analysis.

SUBREGION—A portion of the metropolitan region. For the user's guide, the term subregion is used to describe the CBD, the central city, and the suburb. A number of subareas aggregated form a subregion.

SUBURB—Generally, the residential subregion of a metropolitan region. In the user's guide, the suburb has been described in some cases as that area lying outside a circumferential highway; for example, a beltway.

TERMINAL TIME—The time, associated with an auto trip, required to get from the point of origin to the auto and from the auto to the final destination. In the CBD it may be the time to get from a parking garage to the office.

TRAFFIC ASSIGNMENT—The process of determining route or routes of travel and allocating the zone-to-zone trips to these routes.

TRANSIT HEADWAY—The time between consecutive transit vehicles operating on the same line at a given point on a transit route. In the case of a route that has more than one transit line with similar destinations, the transit headway can be calculated as the time between transit vehicles, at a point along the route, for those lines collectively.

TRIP—A one-direction movement which begins at the origin and ends at the destination. For example, a trip movement from a residence to a work place is a trip from home to work.

TRIP ATTRACTIONS—The number of home-based trip ends at the nonresidence end of the trip-maker; for example, all work trips to and from the work place are considered as attractions at the work place. A location which has no residences will, therefore, have no trip productions. All trips to, plus from the locations, will be attractions. For all nonhome-based trips, attractions are synonymous with productions.

TRIP DISTRIBUTION—The process by which the movement of trips between zones is estimated. The data for each distribution may be measured or estimated by a growth factor process or by a synthetic model.

TRIP END—A trip origin or a trip destination. Trip ends for a location are the summation of origins *and* destinations. A trip has two ends, the origin and the destination. A site which has over some period of time, 2,000 trips entering and 1,800 trips leaving, has 3,800 trip ends associated with it. The 3,800 total trips to and from the site represent a total of 7,600 trip ends. Of these, 3,800 occur at locations other than the site in question.

TRIP GENERATION—A general term describing the analysis and application of the relationships that exist between the trip makers, the urban area, and the trip making. It relates to the number of trip ends in any part of the urban area.

TRIP LENGTH—The length of a trip measured in miles; may be airline distance or over-the-road distance.

TRIP-LENGTH FREQUENCY DISTRIBUTION—The array which relates the trips or the percentage of trips made at intervals of various trip distances.

TRIP PRODUCTIONS—The number of home-based trip ends at the residence end of the trip maker; for example, all work trips to and from the residence are considered as home-based work productions at the residence. If three home-to-work trips and two work-to-home-trips are associated with a residence, it is considered to produce five home-based work trips. For all nonhome-based trips, productions are synonymous with origins.

TRIP PURPOSE—The reason for making a trip; normally, for one of ten possible purposes. Each trip may have a purpose at each end; for example, home to work.

TRIP TABLE—A table showing trips between zones—either directionally or total two-way. The trips may be separated by mode, by purpose, by time period, by vehicle type or other classification. (See SQUARE TRIP TABLE.)

URBANIZED AREA—An urbanized area contains a city (or twin cities) of 50,000 or more population (central city) plus the surrounding, closely settled incorporated area which meets certain criteria of population size or density.

UTPS—The FHWA/UMTA Urban Transportation Planning System distributed by UMTA. A combined FHWA/UMTA package of computer programs for aiding in urban transportation planning.

VMT—Vehicle-miles of travel" is generally used as an areawide measure. May be calculated by summing data on a link basis or by multiplying average trip length (in miles) times the total number of vehicle trips.

ZONE—Geographically, the smallest analysis area for transportation analysis. A zone might vary from less than 1 sq mi to about 10 sq mi depending on the study area.