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UTPS

AN INTRODUCTION TO URBAN TRAVEL DEMAND FORECASTING

~ A SELF-INSTRUCTIONAL TEXT ~

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DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA •

Federal Highway Administration

Urban Mass Transportation Administration

1977

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AN INTRODUCTION TO URBAN TRAVEL DEMAND FORECASTING

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U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
URBAN MASS TRANSPORTATION ADMINISTRATION

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PREFACE

This self-instructional text is part of a coordinated series of user-oriented materials designed to aid planners in understanding and applying the computer package UTPS -- the Urban Transportation Planning System. The series of materials will also include:

- audio-visual presentations,
- case study workbooks,
- computer-interactive programmed learning, and
- a UTPS general information manual.

Purpose of Text

This text is intended to provide a general introduction to the travel demand forecasting process, and as such it does not deal with specific UTPS programs. It is designed to give you some basic background information so that you can begin to understand the basis of computer programs.

General Content

The presentation is based on what is known as the traditional four-step travel demand forecasting process: trip generation, trip distribution, mode usage, and network assignment. The text is structured to teach you the "language" of travel demand forecasting and to give you an understanding of the traditional process. This information provides the foundation for continued study in travel forecasting, covering subjects that are not dealt with here -- such as sketch planning, behavioral modeling, and direct demand models. The chapter on trip generation deals only with cross-classification analysis. There are two reasons for this: limitations on the size of this book, and the feeling that cross-classification will overshadow regression analysis as the most commonly used technique. The gravity model is the only trip distribution technique discussed, for similar reasons. A list of references is given at the end of each chapter in this text. You will find these lists helpful in your continued study of topics for which you require additional information.

Who the Text is For

This text was prepared primarily for technical people who are not familiar with the urban transportation planning process. The self-instructional format was chosen so that you can learn at your own pace: you can take as much time as you need to get a thorough understanding of the subject matter. The text is in a modular form to encourage study of sections you find to be most useful. You can stop as often as you like to review or think about the section that you have just read.

This is not an ordinary textbook. There is a short quiz at the end of each section. These quizzes are not tests; they are designed so that you can gauge how well you are learning. Take the time to answer the quiz questions. They reinforce the reading and make learning much easier. The answers to each quiz are in the lower-right-hand corner of the quiz page. Keep the answers covered until you've made a reasonable attempt at answering the questions.

Since travel demand forecasting has a language all its own, an extensive glossary of terms is provided in the back of the book.

To get a better understanding of the material in this text, you should first see two audio-visual presentations included in the series of user-oriented materials: "An Overview of Urban Transportation Planning" and the audio-visual complement to this text, "An Introduction to Urban Travel Demand Forecasting." While seeing those presentations is not essential, you will find them very helpful.

Acknowledgments

This text was prepared by Dr. G. Scott Rutherford of De Leuw, Cather and Company, with assistance from Mark G. Bergstralh of Roy Jorgensen Associates, Inc., under contract DOT-FH-11-8806. The project was jointly funded by the Urban Planning Division of the Federal Highway Administration (FHWA) and the Office of Planning Methodology and Technical Support of the Urban Mass Transportation Administration (UMTA). Dr. Ricardo dePaul Dobson and Dr. Leonard Goldstein of FHWA served as contract managers. Reviews, suggestions, and technical assistance were provided by Messrs. David Gendell, James McDonnell and George Schoener, all of FHWA; and Mr. Samuel Zimmerman of UMTA. The authors are indebted to these individuals for their contribution to this text.

A substantial portion of the material for this text comes directly or indirectly from existing FHWA and UMTA publications; however, the authors take full responsibility for any errors or omissions.

Chapter One

TRAVEL DEMAND FORECASTING IN THE URBAN TRANSPORTATION PLANNING PROCESS

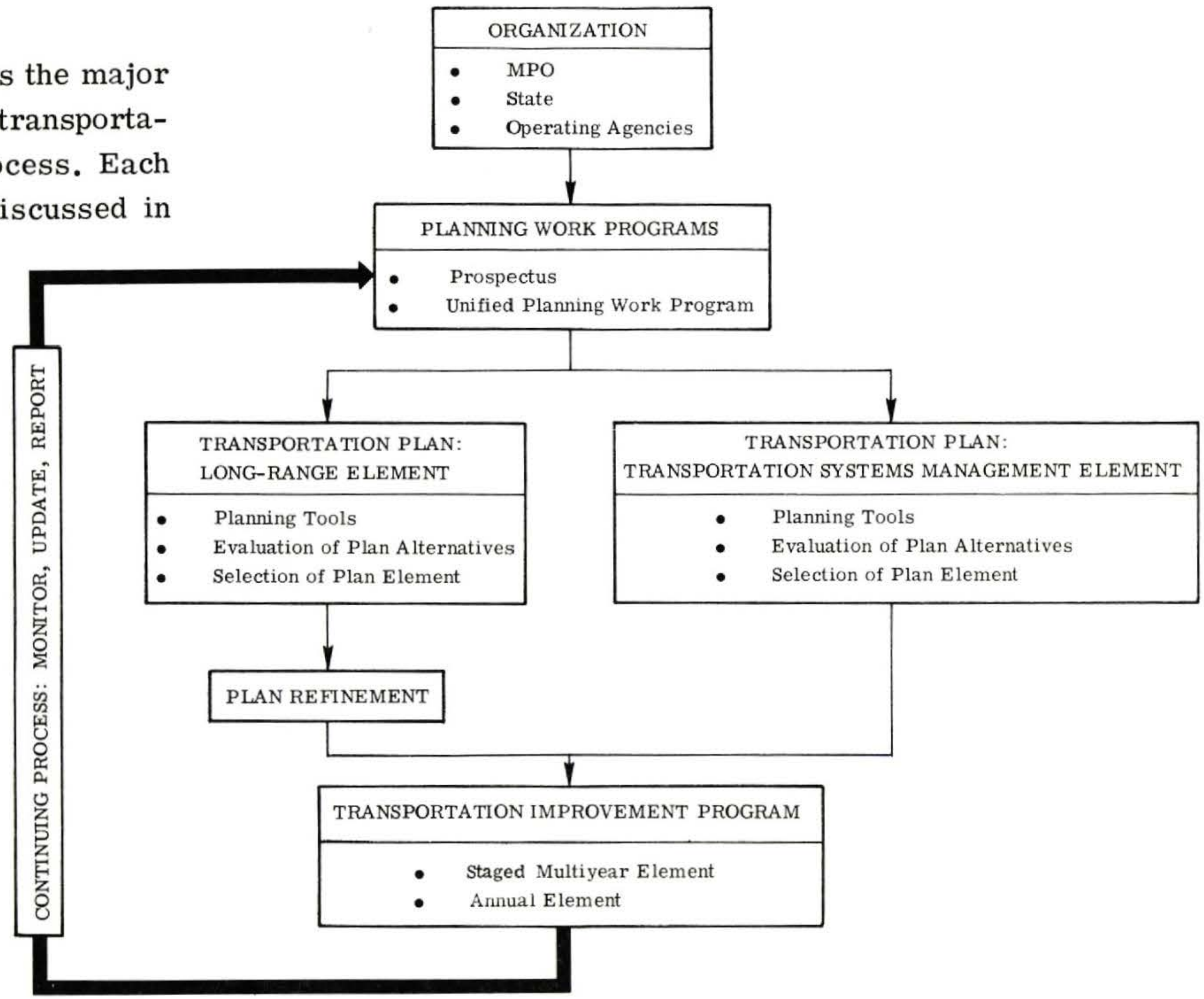
Urban transportation planning is the process that leads to decisions on transportation policies and programs. In this process, planners develop information about the impacts of implementing alternative courses of action involving transportation services, such as new highways, bus route changes, or parking restrictions. This information is used to help decision-makers (elected officials or their representatives) in their selection of transportation policies and programs.

The transportation planning process relies on travel demand forecasting, which involves predicting the impacts that various policies and programs will have on travel in the urban area. The forecasting process also provides detailed information, such as traffic volumes, bus patronage, and turning movements, to be used by engineers and planners in their designs. A travel demand forecast might include the number of cars on a future freeway or the number of passengers on a new express bus service. It might also predict the amount of reduction in auto use that would occur in response to a new policy imposing taxes on central-area parking.

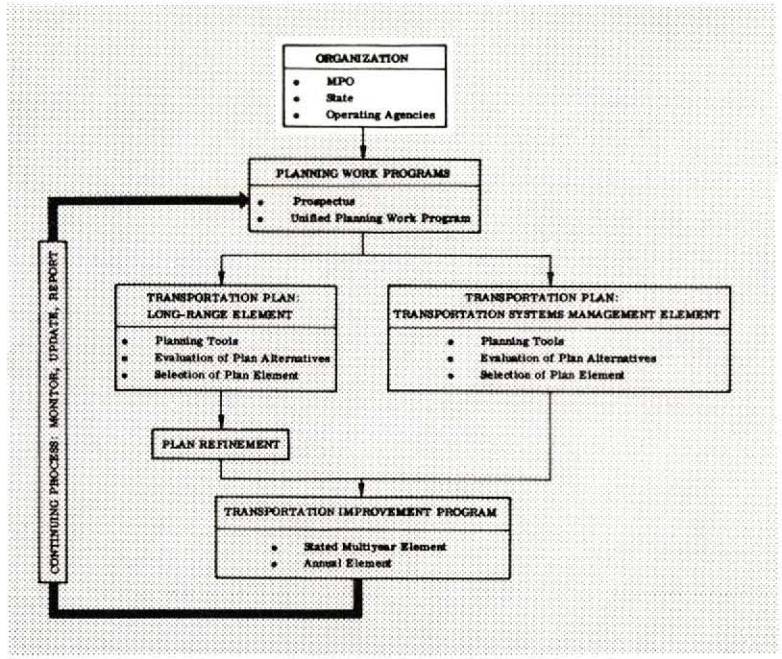
To help you understand the role of travel demand forecasting in urban transportation planning, this first chapter is divided into two sections: first, a brief look at the planning process, and then forecasting as it is applied in planning. The urban transportation planning process is discussed in the FHWA/UMTA audio-visual presentation titled "An Overview of Urban Transportation Planning." Therefore, this discussion of planning is limited.

THE URBAN TRANSPORTATION PLANNING PROCESS

This chart shows the major activities in the transportation planning process. Each step is briefly discussed in this section.



Organization



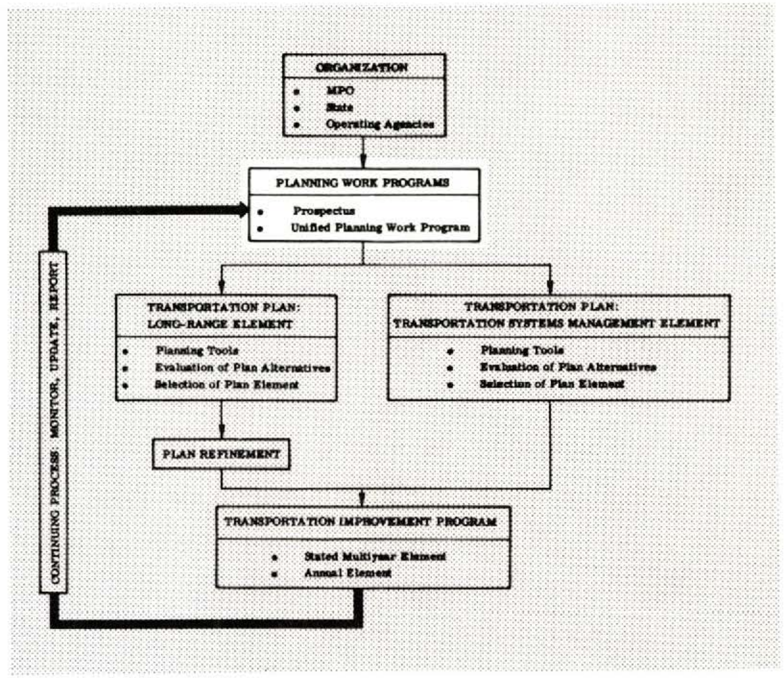
Transportation planning is an extensive undertaking. The need for an effective organization is obvious; this phase of the planning process ensures efficient direction from public officials and guidance from the citizens of the study area.

The planning process must operate within the framework of the goals and objectives of the study area. Early in the process, ways to promote interaction with public officials, public agencies and the citizens of the area must be defined to make sure that the goals and objectives reflect current community values.

The governor of each state designates a Metropolitan Planning Organization (MPO) to be responsible, with the state, for urban transportation planning. Usually, one MPO is designated for each urbanized area or group of adjacent areas.

The MPO's planning activities are carried out in cooperation with state and local agencies. The staffs of other local agencies can be contracted by the MPO for work on some of the elements of the planning process.

The organization phase, then, is designed to ensure that all available inputs are used to the fullest extent possible to organize planning to meet the needs, goals, and objectives of the community.



Planning Work Program

Planning work programs are developed to make sure that the planning is conducted efficiently and comprehensively, and that it addresses all pertinent issues. As you can see in the diagram, there are two parts to this phase: the prospectus and the unified planning work program.

The prospectus establishes a multi-year framework for the planning process. It summarizes the planning procedures, discusses the important issues that will be addressed during planning, describes the responsibilities of each agency that is participating in planning, and describes the status of all elements in the planning process.

The unified planning work program has two functions. It describes all urban transportation and transportation-related planning activities that are anticipated over the next year or two, and it documents work to be performed with federal planning assistance.

QUIZ

Urban transportation planning leads to decisions on transportation ______________ and programs. Travel demand forecasting predicts the impacts on ______________ that these policies and programs will have.

MPO stands for ______________ ______________ ______________.
It is designated by the ______________ to carry out planning activities within the state.

Planning work programs consist of two parts:

- developing a ______________, and
- developing a ______________ ______________ ______________ ______________.

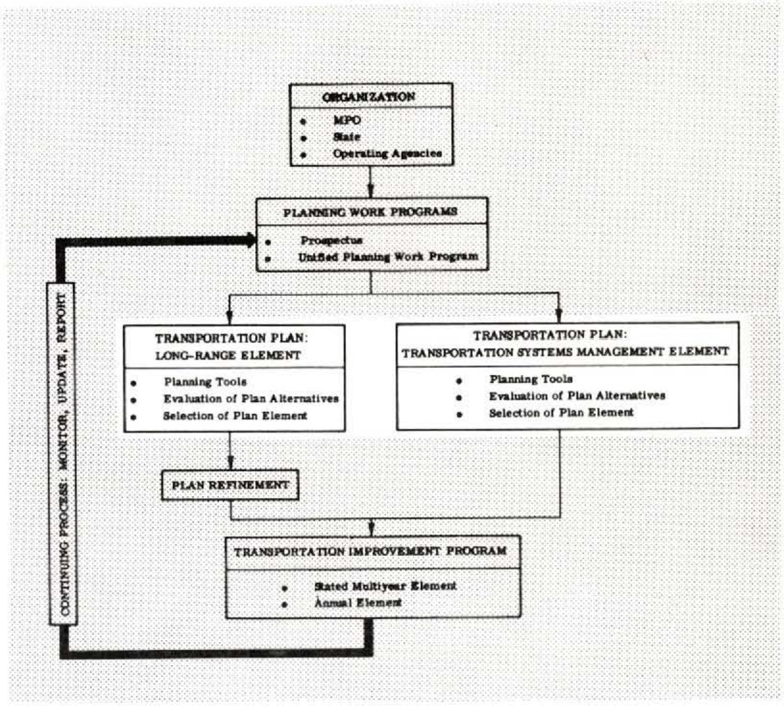
policies; travel

Metropolitan Planning Organization; governor

prospectus; unified planning work program

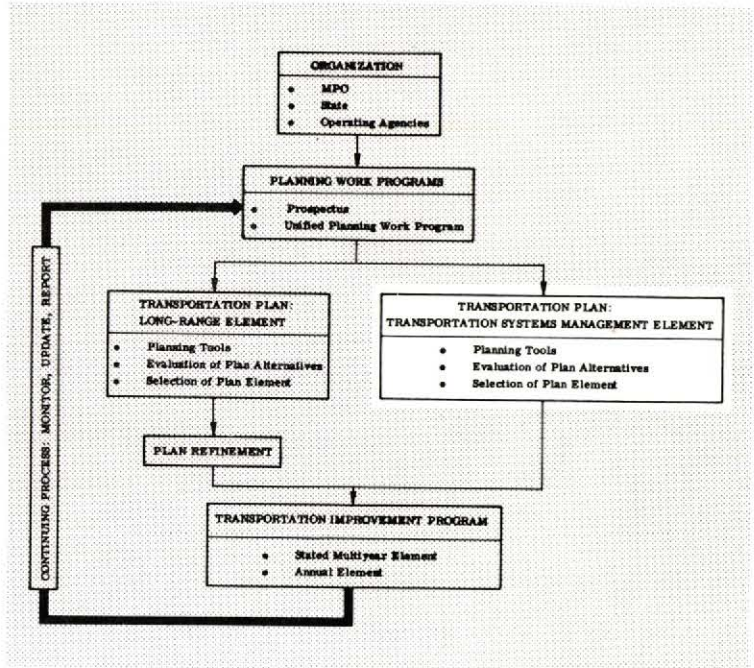
The Transportation Plan

There are two elements in the preparation of a comprehensive transportation plan to guide improvements to the transportation system. The Transportation Systems Management (TSM) element and the Long-Range element work together to formulate a transportation improvement program. Let's look more closely at these two elements.



The Transportation Systems Management Element

The key word here is management. The TSM Element is concerned with making existing systems as efficient as possible and with making provisions for an area's short-range transportation needs. Automobiles, taxis, trucks, terminals, public transit, pedestrians, and bicycles are all parts of the urban transportation system.



There are four basic categories of actions to increase the efficiency of the different parts of the system.

1. Actions to ensure the efficient use of existing road space. These actions include measures to manage and control the flow of motor vehicles. Installing reversible lanes to accommodate rush-hour traffic and improving intersection capacities are examples.

2. Actions to reduce vehicle use in congested areas. Encouraging carpooling and other forms of ride-sharing are examples.

3. Actions to improve transit service. People can be encouraged to use transit by such actions as providing park-and-ride services from fringe areas to the central business district.

4. Actions to improve internal transit management efficiency -- for example, developing management tools, such as information systems, or marketing campaigns.

To decide which actions to implement, you need a clear understanding of how each would affect the transportation system and the region as a whole. That is, what are the results of selecting a particular course of action? "Planning tools" are developed so that you can predict impacts and provide the information necessary for decision-makers to evaluate alternatives and select the best courses of action.

Travel demand forecasting tools provide input to this process by predicting travel impacts on transportation systems and their users. These predictions are one part of the planning process where travel demand forecasting plays an important role.

QUIZ

TSM means ______________________________ ____________________ __________________, with the emphasis being on __________________.

The major purpose of the TSM element is to increase the _______________ of our existing systems.

Installing exclusive bus lanes is an example of Transportation System Management. True or false? __________

Reducing vehicle use in congested areas is an example of a TSM action. True or false? ___________

Transportation Systems Management, management

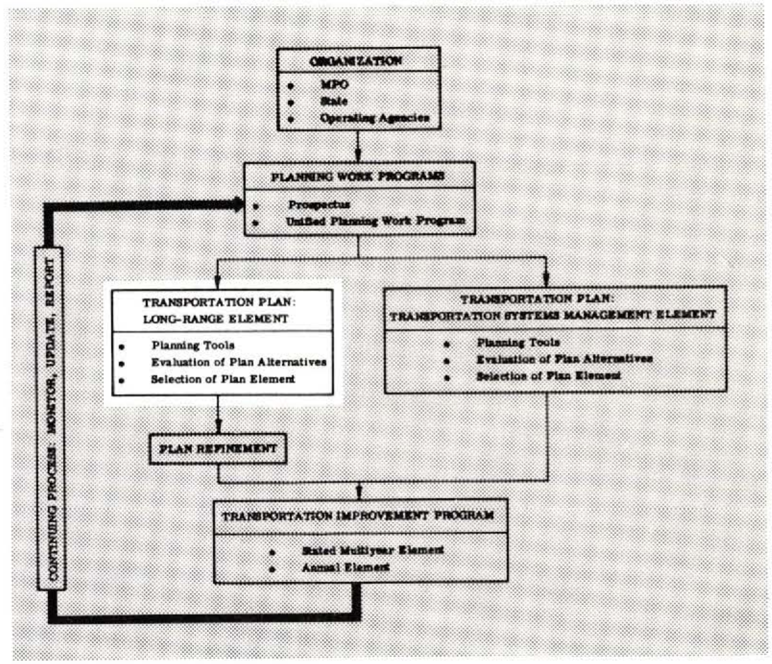
efficiency

True

True

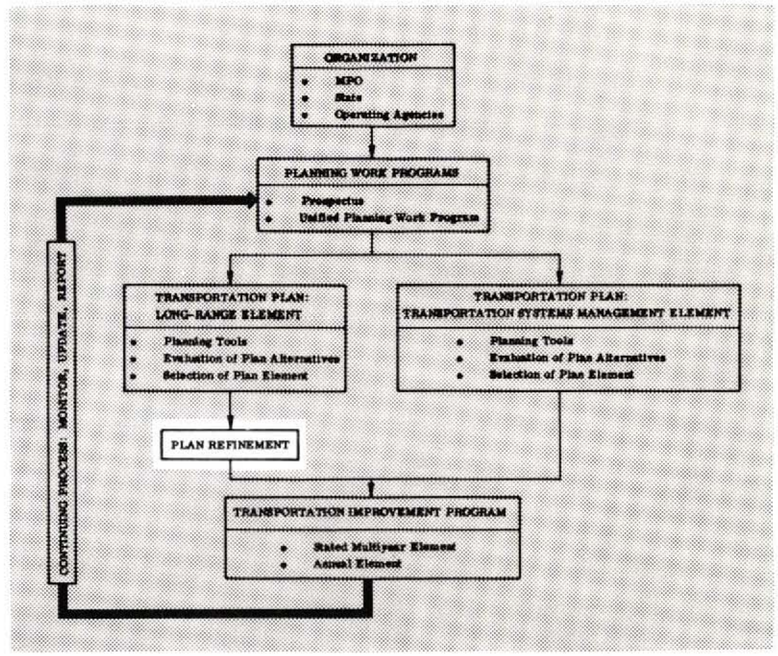
The Long-Range Element

To make provisions for the long-range transportation needs of the urban area, the long-range element identifies facilities to be constructed, major changes to be made to existing facilities, and long-range policy actions. This element of the transportation plan might, for example, consider future land development policies by adding a highway link, or installing a busway system.



As in the TSM element, many long-range alternatives must be evaluated before decisions can be made. Thus, planning tools for analysis of long-range alternatives must be developed. These tools also provide information to help decision-makers select the most promising alternatives.

Once again, travel demand forecasting plays an important role as a major contributor to the planning tools used in evaluating alternatives.



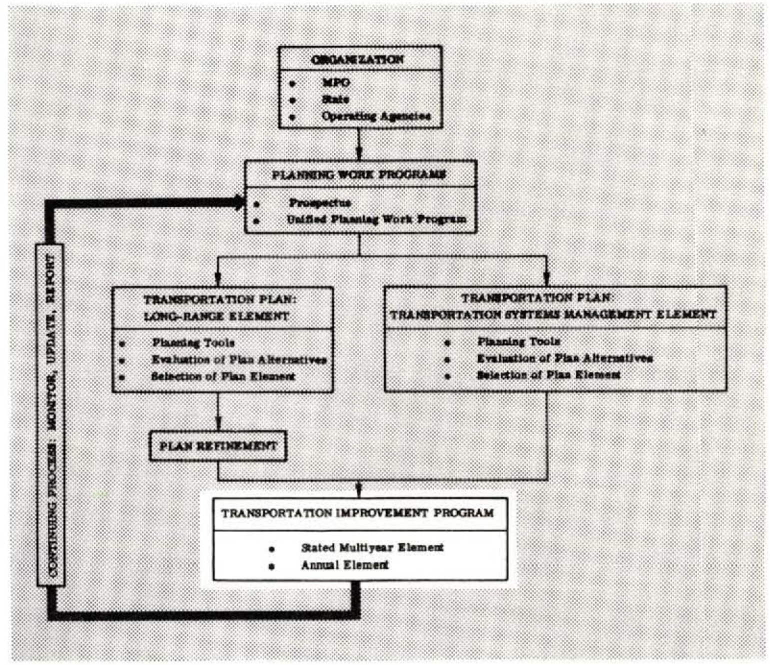
Plan Refinement

After the long-range plan elements have been selected, the plan is refined by further detailed studies. In the plan refinement stage, the corridor in which improvements are planned might be studied in detail, along with studies of various types of technology -- for example, buses versus rapid transit -- and studies to determine the proper staging (scheduling) of the planned projects.

Travel demand forecasting plays a role here in refining estimates of such things as patronage, market areas, congestion and turning movements.

The Transportation Improvement Program

After selections have been made in the Transportation Systems Management and Long-Range elements, and after plan refinement, a Transportation Improvement Program is developed. This program ensures that the transportation plan will be implemented in an orderly, efficient manner and represents a statement as to how the transportation system will improve in the next few years. The program has two major elements: the staged multi-year element and the annual element.



The staged multi-year element describes the general aspects of the program over the next three to five years. This element indicates priorities among the projects identified for implementation, groups projects into appropriate staging periods, and makes estimates of costs and revenues for the program period.

The annual element identifies the details of projects that will be implemented within the next year. For each project, the annual element contains:

- a basic description,
- costs involved,
- revenue sources, and
- the local agency that is responsible for implementation.

QUIZ

The long-range element of the transportation plan is primarily concerned with capital-intensive improvements. True or false? ____________

Adopting development policies that complement efficient transportation systems is an example of the long-range element. True or false? ____________

In plan refinement, we are concerned with specific ____________________ in which improvements are planned.

The ____________________ ____________________ ____________________ is a statement of improvements to the transportation system in the next few years.

True

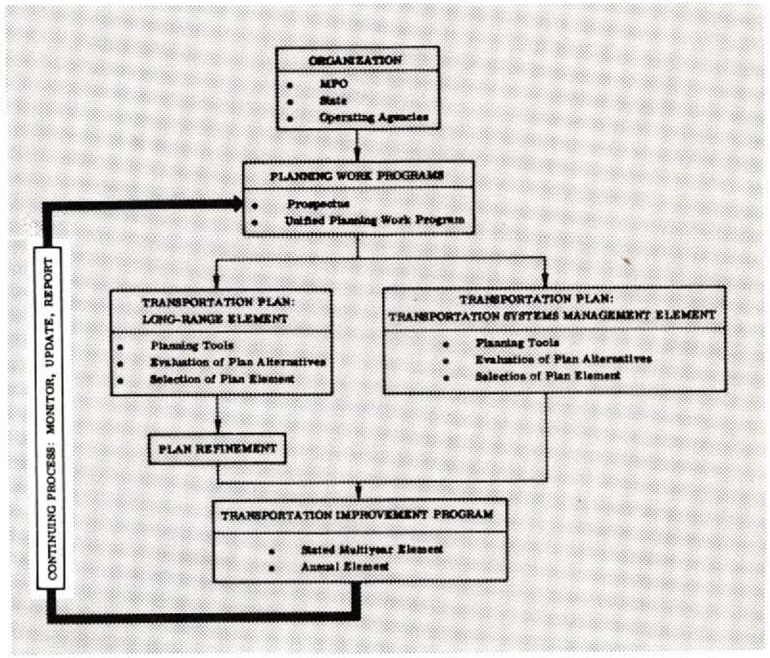
True

corridors

Transportation Improvement Program

The Continuing Process

The continuing process (the stage that most urban areas are in now) consists of monitoring changes that could make it necessary to modify the transportation plan, updating the data that serve as a base for planning, updating the methods used in transportation planning -- including those for travel forecasting -- and reporting on activities and findings.



Transportation studies have been made in all areas with populations over 50,000. Planners have made inventories of the characteristics that affect travel in urban areas. These inventories, which make up the data base, include:

- population,
- land use,
- economic activity,
- transportation systems,
- travel,
- laws and ordinances,
- financial resources, and
- community values.

In the continuing process, one task is to update these inventories as necessary to make sure that the data base for planning is complete and accurate. This update is done using secondary sources, such as the census or small sample surveys. Complete large-scale surveys are no longer feasible due to their high cost.

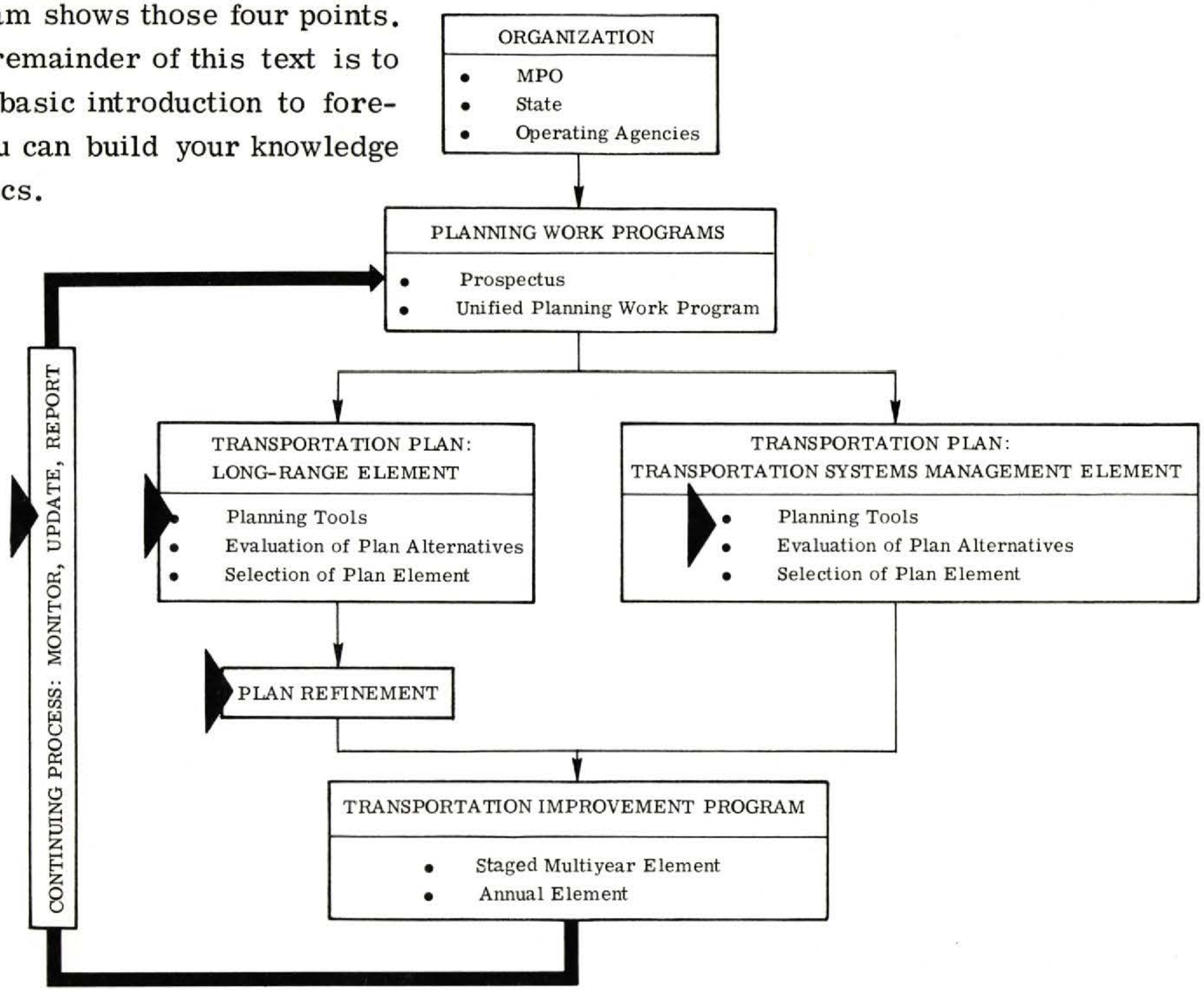
Monitoring changes is extremely important. You can imagine how a decision to install a major shopping center or sports arena near your city would affect transportation and the transportation plan. In the continuing process, we monitor both the transportation system and its performance.

In addition to monitoring changes and updating the data base, the continuing process provides information to interested local agencies in the form of reports and technical assistance as required.

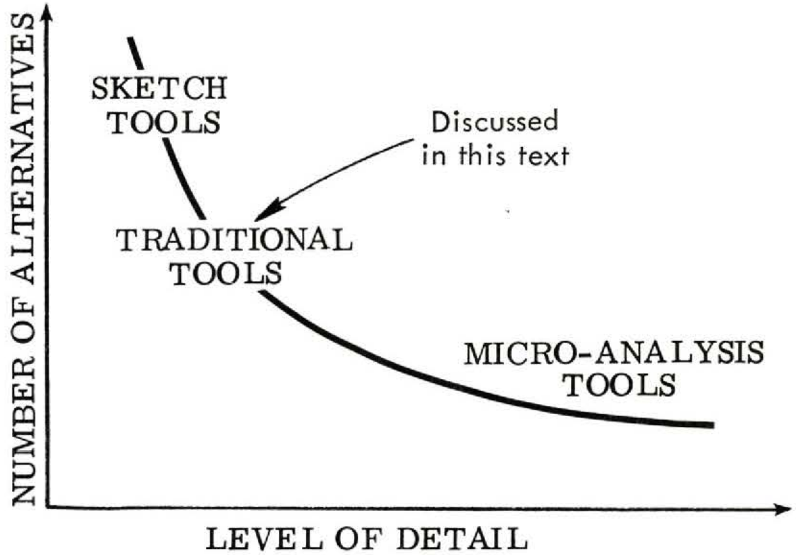
Through careful studies of data on people's travel behavior, relationships have been developed to predict how many trips people will make, where they will go, by which mode of transportation, and by which specific route. These relationships are the basis for travel demand forecasting and must be reviewed and reevaluated, if necessary, in the continuing process.

The continuing process ensures that the transportation plan will respond to the area's transportation needs -- needs that are constantly changing. The level of effort involved in the continuing process will depend on the size of the urban area and the complexity of its problems.

Travel demand forecasting was mentioned four times during the discussion of the planning process. This diagram shows those four points. The purpose of the remainder of this text is to provide you with a basic introduction to forecasting on which you can build your knowledge to include other topics.



There are several different techniques for travel demand forecasting from which to choose, depending on the requirements of the analysis. These techniques differ in complexity, cost, level of effort, sophistication and accuracy, but each has its place in travel forecasting. The graph at right shows the general relationship of these planning tools to their most likely applications. Each tool is explained briefly below.



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

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

TRADITIONAL TOOLS: Traditional tools treat the kind of detail appropriate to tactical planning; they deal with many fewer alternatives than sketch tools, but in much greater detail. Inputs include the location of principal highway facilities and delineated transit routes.

At this level of analysis the outputs are detailed estimates of transit fleet size and operating requirements for specific service areas, refined cost and patronage forecasts, and level-of-service measures for specific geographical areas. Household displacements, noise, and aesthetic factors can also be evaluated.

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

MICRO-ANALYSIS TOOLS: Micro-analysis tools are applicable as the time to implement a project grows near. They are the most detailed of all planning tools. At this level of analysis, one may wish, for example, to make a detailed evaluation of the extension, rescheduling, or repricing of existing bus service; to analyze passenger and vehicle flows through a transportation terminal or activity center; or to compare possible routing and shuttling strategies for a demand-activated system. Final analysis at this level is prohibitively expensive except for subsystems whose implementation is very likely, and whose design refinements would bring substantial increases in service or significant reductions of cost. It is most effective in near-term planning when a great many outside variables can be accurately observed or estimated. It is sometimes necessary, however, to use micro-analysis tools to supplement the output of traditional longer-range planning.

Although traditional tools are the focus of this text, we should keep in mind their relationship to sketch and micro-analysis tools.

QUIZ

The continuing planning process is a process of monitoring,________________, and__________________.

Travel demand forecasting provides important inputs to the TSM element, to the ______________element, in plan refinement, and in the ______________process.

To quickly investigate a large number of alternatives, the most appropriate method for travel forecasting is_________ _____________.

updating, reporting

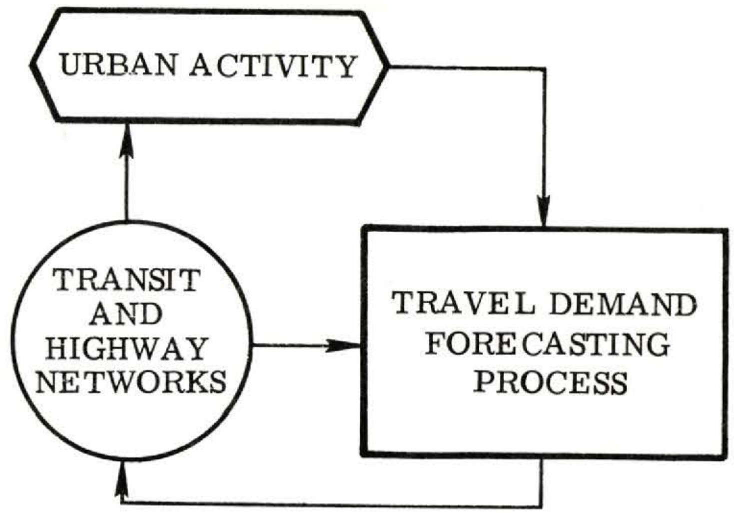
long-range, continuing

sketch planning

That was a brief look at urban transportation planning. Now, go on to a summary of the Traditional Travel Demand Forecasting Process, a short discussion on one method planners use to forecast the amount and character of travel. This material will introduce you to the entire process, after which its components are discussed in some detail.

A SUMMARY OF THE TRADITIONAL TRAVEL DEMAND FORECASTING PROCESS

In general, travel demand forecasting attempts to quantify the amount of travel on the transportation system. Demand for transportation is created by the separation of urban activities. The supply of transportation is represented by the service characteristics of highway and transit networks. These basic relationships are shown in the diagram at right.



There are many methods available to forecast travel demand. A discussion of all forecasting is beyond the scope of this text; our major objective is to provide a basic foundation for the process. Therefore, what has become known as the "traditional four-step process" will be discussed.

The process considered here has been developing over the past 25 years for forecasts of urban travel. In terms of the planning process, this discussion will focus on planning tools for the long-range element of the transportation plan, as modified and updated in the continuing process. Understanding the traditional approach will greatly help your understanding of other aspects of travel demand forecasting. However, this presentation is <u>not</u> intended to endorse any particular method for doing travel forecasting -- it only represents an example of how several agencies have done travel forecasting in the past.

There are four basic phases in the traditional travel demand forecasting process.

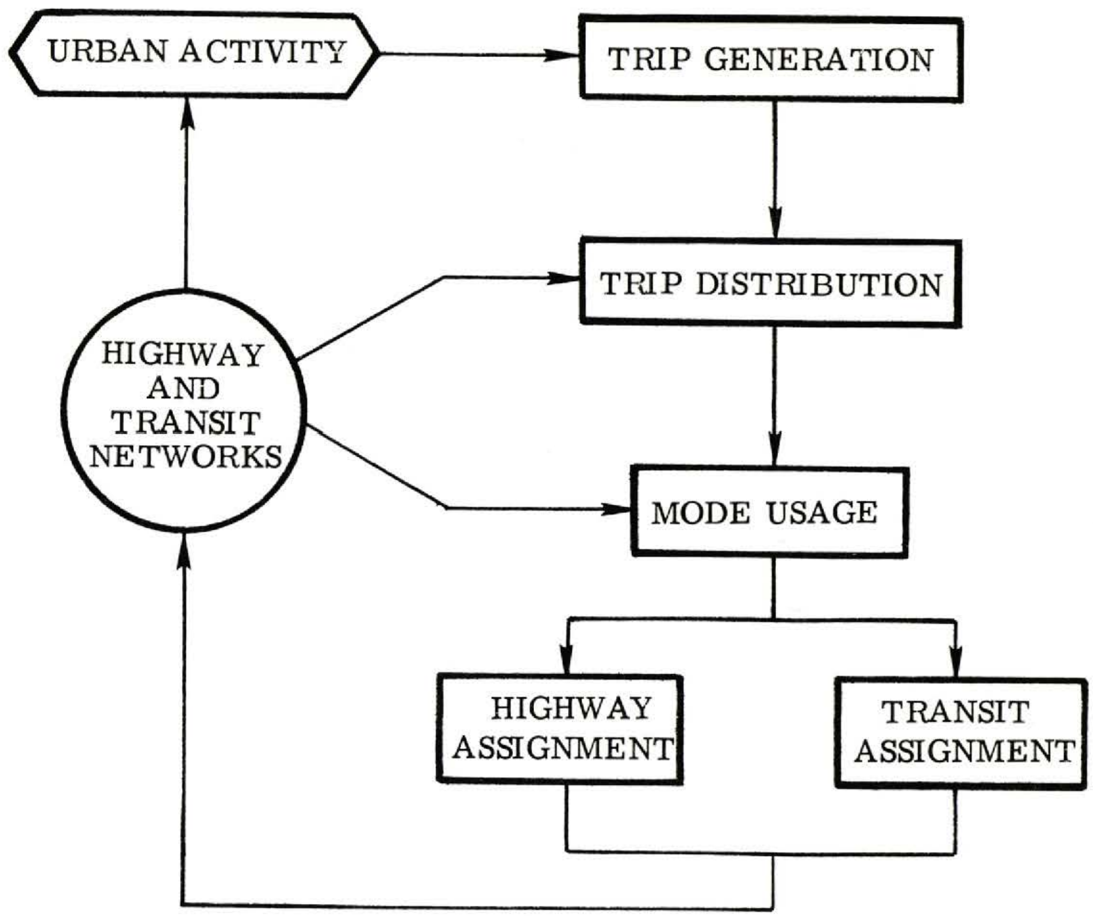
- Trip Generation forecasts the number of trips that will be made.
- Trip Distribution determines where the trips will go.
- Mode Usage predicts how the trips will be divided among the available modes of travel.
- Trip Assignment predicts the routes that the trips will take, resulting in traffic forecasts for the highway system and ridership forecasts for the transit system.

The following page shows how these phases fit together into the forecasting process.

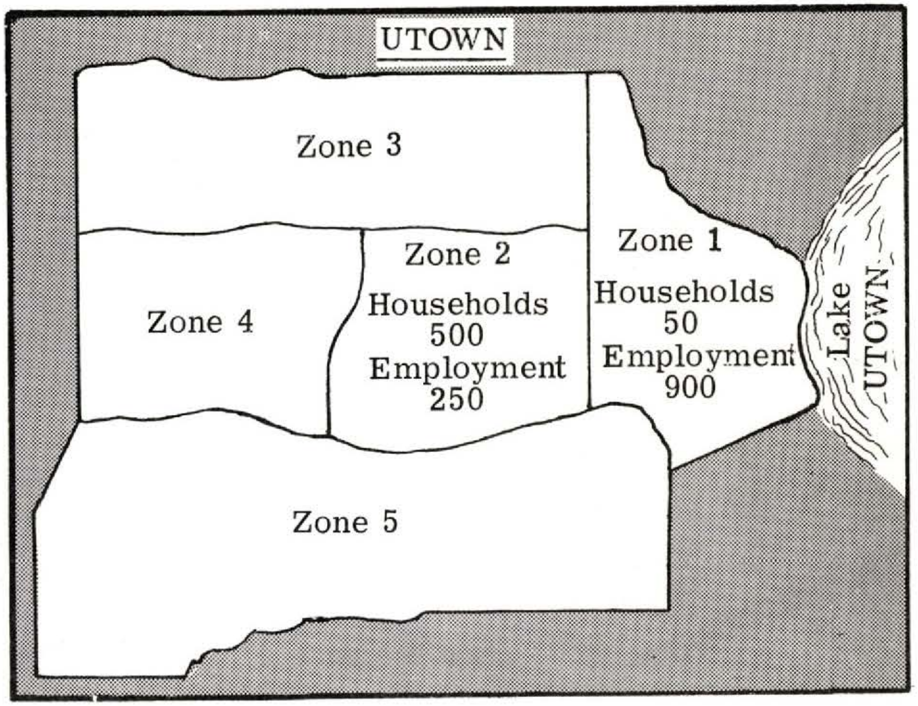
Urban activity forecasts provide information on the location and intensity of future activity in an urban area and provide primary input to trip generation.

Descriptions of the highway and transit networks provide the information necessary to define the "supply" of transportation in the area; the four phases predict the travel "demand."

The feedback arrows shown represent checks of earlier assumptions made on travel-times and determine if adjustments are necessary. If not, the process is complete.



Urban Activity Forecasts



Urban activity forecasts provide estimates of where people will live and where businesses will locate in the future. These forecasts also include the intensity of activity, such as the number of households and number of employees of businesses. The figure on the right shows the number of households and employment for two zones of the mythical 5-zone town known as UTOWN. An actual forecast might include several additional factors and considerably more detail, such as employment by type and households by socioeconomic group.

These forecasts are done for small parcels of land called zones. Zones vary in size, with the smallest about the size of a block in the downtown area and the largest on the urban fringe being several square miles. More about establishing zones will be described in the next chapter.

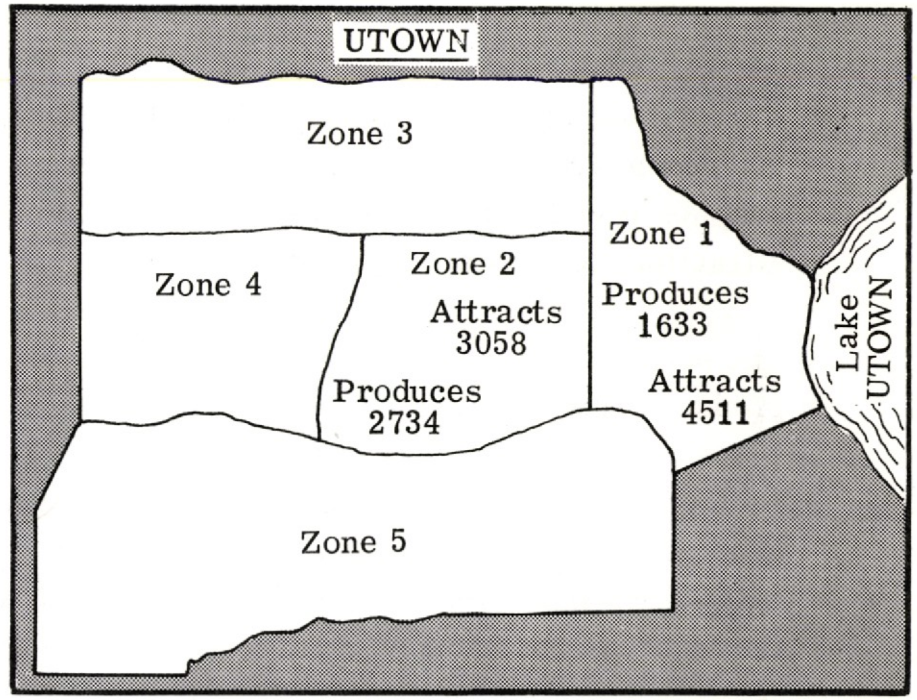
Zonal urban activity forecasts are based on the following:

- total urban area population and employment estimates;
- location behavior of people and businesses; and
- local policies regarding land development, transportation, zoning, sewers, etc.

These activity forecasts are direct inputs to the next stage of the process, trip generation analysis.

Trip Generation

Trip generation is the process by which measures of urban activity are translated into numbers of trips. For example, the number of trips that are generated by a shopping center is quite different from the number of trips generated by an industrial complex that takes up about the same amount of space. In trip generation, the planner attempts to quantify the relationship between urban activity and travel.



The inventory data discussed earlier is the analyst's input for trip generation analysis. Surveys of travelers in the study area show the numbers and types of trips made; by relating these trips to land use patterns, the analyst is able to forecast the number of trips that will be made in the future, given forecasts of population and other urban activity.

Here's a simplified example. The UTOWN survey data show that Zone 1 has employment of 900 people and, from the figure above, attracts 4,511 trips. By dividing the trips by employees, we find about 5 trips attracted per employee. This rate can then be used to predict attractions for future employment levels.

The output of trip generation analysis is a table of trip ends -- the number of trips that are produced and the number that are attracted.

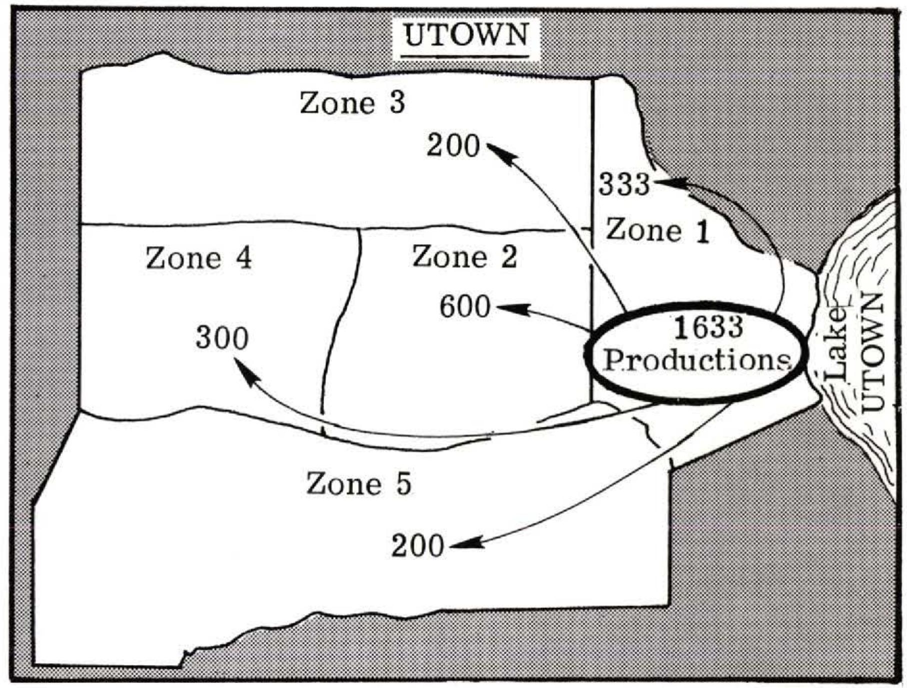
As mentioned earlier, the study area is divided into zones for analysis purposes. After trip generation analysis, the planner knows how many trips are produced by each zone, and how many are attracted by each zone. In addition, the planner knows the purposes for the trips -- the trips are put into several categories, like trips from home to work, or home to shop.

There are basically two tools for trip generation analysis: multiple linear regression and cross-classification. In this text, you'll see the use of cross-classification because this procedure is easy to understand and update, and because it produces reliable results.

Trip Distribution

After trip generation, the analyst knows the numbers of trip productions and trip attractions each zone shown below will have. But, where do the attractions in Zone 1 come from and where do the productions go? What are the zone-to-zone travel volumes?

Trip distribution procedures determine where the trips produced in each zone will go -- how they will be divided among all other zones in the study area. The output is a set of tables that show the travel flow between each pair of zones. The figure on the right shows where Zone 1's trip productions are distributed.



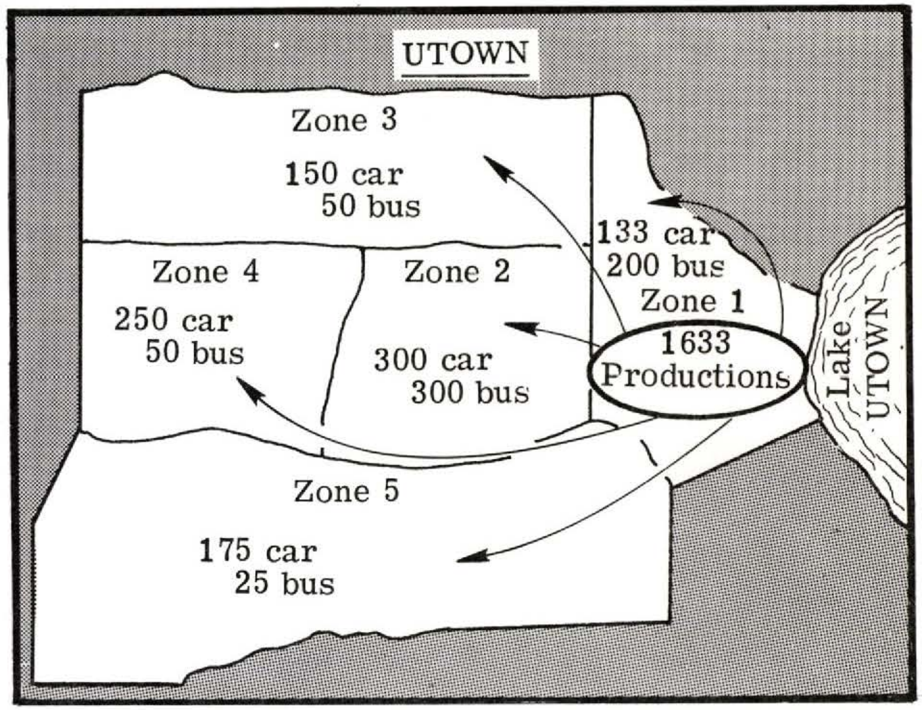
The decision on where to go is represented by comparing the relative attractiveness and accessibility of all zones in the area -- a person is more likely to travel to a nearby zone with a high level of activity than to a distant zone with a low level of activity.

There are several types of trip distribution analyses: the Fratar method, the intervening opportunity model, and the gravity model. In this text, we will discuss only the gravity model, because it is the most widely used method.

Mode Usage

In this phase of travel demand forecasting, we analyze people's decisions regarding mode of travel -- auto, bus, train, etc.

In our flow chart of the travel demand forecasting process, mode usage comes after trip distribution. However, mode usage analyses can be done at various points in the forecasting process. Mode usage analyses are also commonly done within trip generation analyses.



The most common point is after trip distribution, since the information on where trips are going allows the mode usage relationship to compare the alternative transportation services competing for users.

Before we can predict how travel will be split among the modes available to the traveler, we must analyze the factors that affect the choices that people make. Three broad categories of factors are considered in mode usage:

- the characteristics of the tripmaker,
- the characteristics of the trip, and
- the characteristics of the transportation system.

The planner looks at how these characteristics interact to affect the tripmaker's choice of mode. When the relationships have been discovered, the planner can predict how the population of the future will choose from among the modes that will be available.

Generally, at this point in the forecasting process some consideration is given to predicting the number of occupants in autos for those choosing that mode. This consideration of auto occupancy can either be included in the mode usage relationship with each level of occupancy being considered a separate mode, or a separate relationship might be developed.

Trip Assignment

Trip assignment is the procedure by which the planner predicts the paths the trips will take. For example, if a trip goes from a suburb to downtown, the model predicts which specific roads or transit routes are used. The trip assignment process begins by constructing a map representing the vehicle and transit network in the study area. The network maps show the possible paths that trips can take.

The intersections (called nodes) on the network map are identified, so that the sections between them (called links) can be identified. After the links are identified by nodes, the length, type of facility, location in the area, number of lanes, speed, and traveltime are identified for each link. If transit is available, additional information, which identifies fares, headways (time between vehicles), and route descriptions, is included on a separate network. This information allows the computer to determine the paths that the traveler might take between any two points on the network and to assign trips between zones to these paths.

The output of trip assignment analysis shows the paths that all trips will take, and therefore the number of cars on each roadway and the number of passengers on each transit route.

Using these analyses of trip generation, trip distribution, mode usage, and trip assignment, the planner can obtain realistic estimates of the effects of policies and programs on travel demand. Once travel demand is known, the planner can assess the performance of alternative transportation systems and identify various impacts that the system will have on the urban area, such as energy use, pollution, and accidents. With information on how transportation systems perform, and the magnitude of their impacts, planners can provide decision-makers with some of the information they need to evaluate alternative methods of supplying a community with transportation services.

QUIZ

Urban activity forecasts are a major input to the_______ ____________ phase.

Mode usage analyzes the characteristics of the traveler, the trip, and the ____________________ ___________.

Trip generation is the process by which the analyst predicts the ________ __________ that will be made in the future.

Trip distribution forecasts the ____________________ of the trip productions.

Mode usage is always analyzed after the trip generation analysis. True or false? ____________

trip generation

transportation system

trip ends or productions and attractions

destinations

false

One of the first steps in trip assignment is the preparation of a

____________________ _________________.

The trip assignment step predicts the _________________ trips will take through the network and hence the ________________________ of travel on various segments of the network.

Checking initial assumptions about travel times between zones is a task known as _______________________.

network map

paths, volumes

feedback

SPECIFICATION, CALIBRATION, VALIDATION AND FORECASTING

Before forecasting travel, a considerable effort must be made to analyze inventory data and establish relationships among travel choices and several other variables. Discovering the reasons for making travel decisions, such as where or how to travel, is done in two steps. First, the types of models to be used and their variables are specified; and second, those models are calibrated to reproduce observed travel. Follow the figure on page 1-36 to see how these steps relate to one another.

In model specification, a choice must be made among several mathematical formulations and many possible variables. Research has shown which formulations and variables will probably yield the best results; therefore, the task is somewhat simplified to testing a few options. During this step, the level of analysis for the models must be specified; that is, a decision must be made whether to model individual travel behavior or that of a larger group, such as a zone.

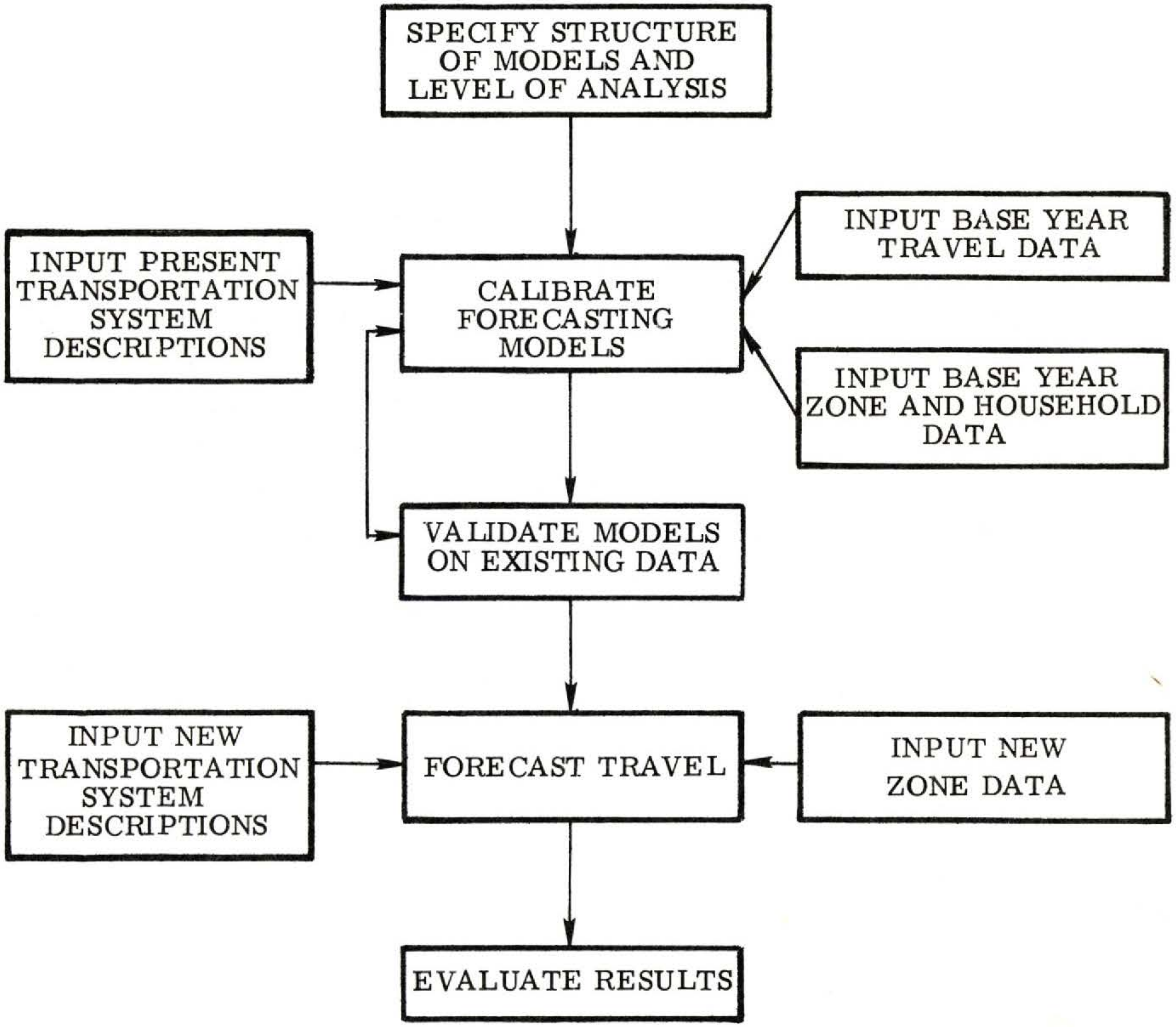
The calibration process is basically an attempt to duplicate travel for the year in which calibration data is available. The year for which data is available is termed the "base year." Surveys are taken to see how people travel in the study area; base year data is used to calibrate the trip generation, trip distribution, mode usage, and trip assignment relationships separately. The calibration process also includes intuitive tests of models to see if the variables and their coefficients are reasonable. The important point to remember in the calibration process is that the output of each model is compared individually to base-year data.

After the models are calibrated they should go through a validation process by applying these calibrated models sequentially in the base year. These models are applied in exactly the same way as they would be applied in the forecast year. This is necessary to see if the procedure produces reasonable comparisons to the base year observed data. For example, if models are calibrated using household information (income, family size, access time to bus, parking costs, etc.), they should be validated at the same level of aggregation to be used in forecasting (average zone income, average zone access time to bus, etc.). This validation will show how well the entire chain of calibrated models can forecast observed travel in the same way they will be used to forecast future travel. If the series of models cannot produce traffic volumes and transit riderships similar to what is observed on roadways and bus lines, then the models must be reevaluated and appropriate adjustments made.

The validation process can continue in future years by comparing measured traffic volumes with model estimates. This continued reappraisal of the travel forecasting models assures that forecasts will remain as accurate as possible.

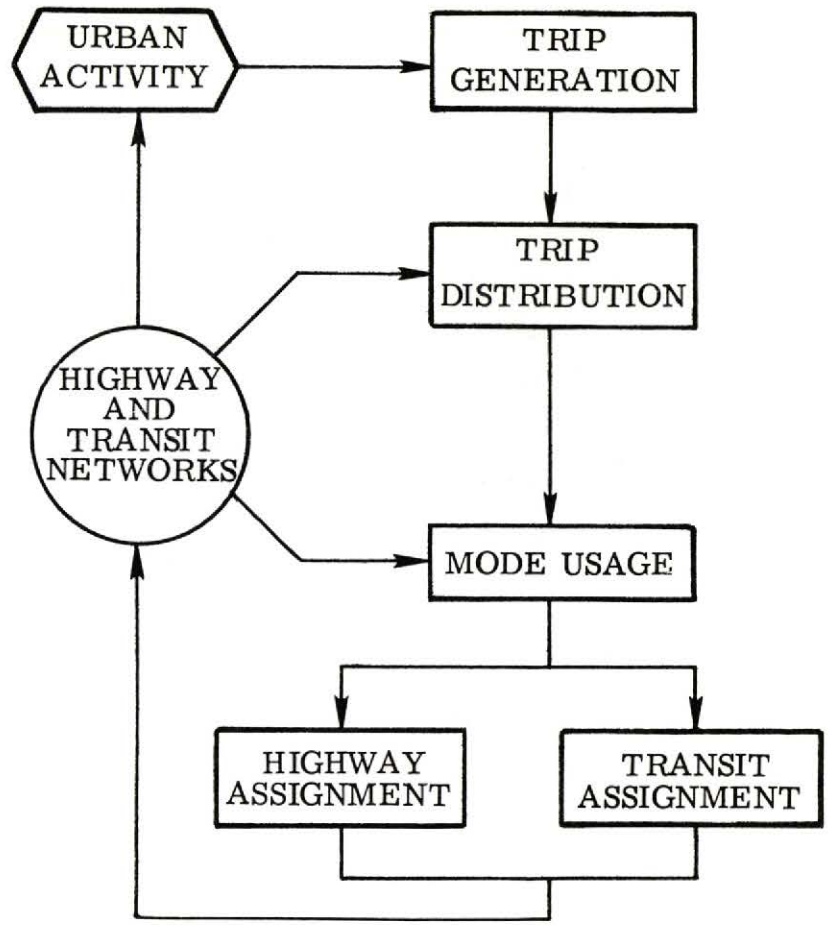
In the forecasting process, estimates of new levels of activity in the zones and/or alternative transportation system descriptions are used. Then, the calibrated models produce estimates of travel on the alternative systems to be tested.

This diagram shows the specification, calibration, validation and forecasting process.



Before proceeding, you should be aware that the travel demand forecasting process is not without problems.

You will notice after studying the diagram at right that the feedback to the Highway and Transit Networks implies that these networks are updated and the process begins again with new forecasts of Urban Activity and Trip Generation based on the results of Highway and Transit Assignments. This seems logical. The pattern of urban activities should be influenced by the transportation system. In fact, this update seldom takes place, because of time and budget constraints. The process, as practiced, therefore implies that the location and intensity of activities and trip generation are independent of the transportation system. Clearly, this is not the case.



The forecasting process has also come under criticism because of its sequential nature; first, a decision to make a trip is modeled, then a destination, then a mode, and finally a path. Is this the way people make travel decisions? Some analysts have thought not, and have attempted with varying degrees of success to place the entire process within a single model.

The forecasting techniques are being improved continually in terms of their theoretical basis and ability to respond to changing requirements. Recent research is aimed at overcoming the problems mentioned and enhancing the capabilities to represent travel behavior accurately.

In spite of some criticisms, the current forecasting process has been shown to work quite well over extensive periods of time with major changes in the amount of activity in the area, rising affluence of households, and changes to the transportation system.

QUIZ

Specification decides which model formulation will be used in the forecasting process. True or false? ___________

The process of working with the models to reproduce travel behavior is known as ___________________.

To use the calibrated models for forecasting, new levels of activity and/or alternative_________________ _________ __________________are input.

True

calibration

transportation system descriptions

This section completes Chapter One. If you feel you have a general knowledge of urban transportation planning and how travel forecasting relates to planning, go on to the next chapter. If you are unsure, go back and review this chapter.

For further study on introductory transportation planning or forecasting, review the following documents:

Introduction to Urban Travel Demand Forecasting, UMTA, March 1974. "Summary" - NTIS - PB 236-847/AS \$3.75. "Volume I - Demand Modelling." - NTIS - PB #236-848/AS \$9.25. A comprehensive instructional text on modern demand modeling approaches.

Computer Programs for Transportation Planning - PLANPAC/BACKPAC General Information, FHWA, April 1977. Reprint available from FHWA, HHP-22, Washington, D.C. 20590. This reference provides very useful technical information on several phases of the analytical planning process.

UTPS Users Guide (on UTPS tape), Chapter II - "Planning Technical Review." This tape provides a terse outline form review of planning steps useful as a refresher but not as a basic instructional text.

A Review of Operational Urban Transportation Models, DOT, April 1973. NTIS - PB #222-109 \$6.75. This provides a good review of models of land use, travel demand, network analysis and some evaluation aspects.

Chapter Two

INFORMATION NEEDS FOR TRAVEL DEMAND FORECASTING

INTRODUCTION

Prior to embarking on the forecasting process as outlined in Chapter One, a significant amount of work is necessary to accumulate the information that drives the forecasting process.

These information needs include broad items like defining the area for which forecasting will be done and specific items such as identifying detailed information about streets and bus routes. In order to understand the travel forecasting process and its terminology, a brief exposure to its information requirements is essential. For the purpose of this discussion, information needs have been divided into four broad categories, as follows:

- the study area,
- urban activites,
- transportation system, and
- travel.

With knowledge of these four categories of information, the transportation planner has the data necessary to begin the travel demand forecasting process.

THE STUDY AREA

Defining the Boundaries

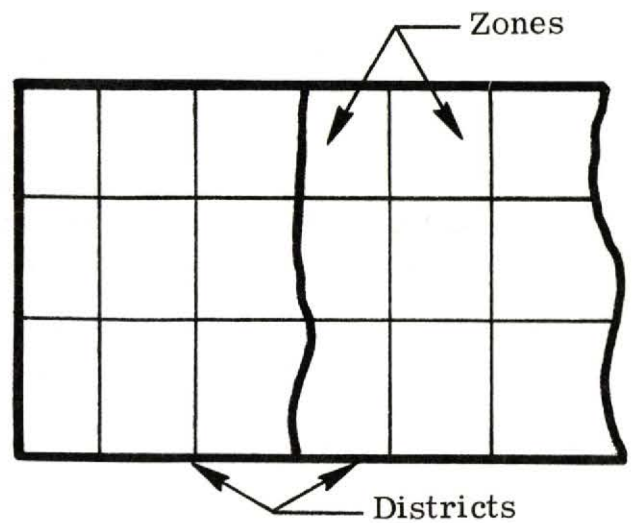
Obviously, before forecasting travel for an urban area, the planner must clearly define the exact area to be considered. This planning area generally includes all the developed land plus the undeveloped land that the urban area will encompass in the next 20 to 30 years.

The boundary of the planning area is known as the cordon line. In addition to considering future growth, the establishment of the cordon line might take into account political jurisdictions, census area boundaries, and natural boundaries. The cordon should intersect a minimum number of roads to save on subsequent interview requirements.

Subdividing the Area for Forecasting

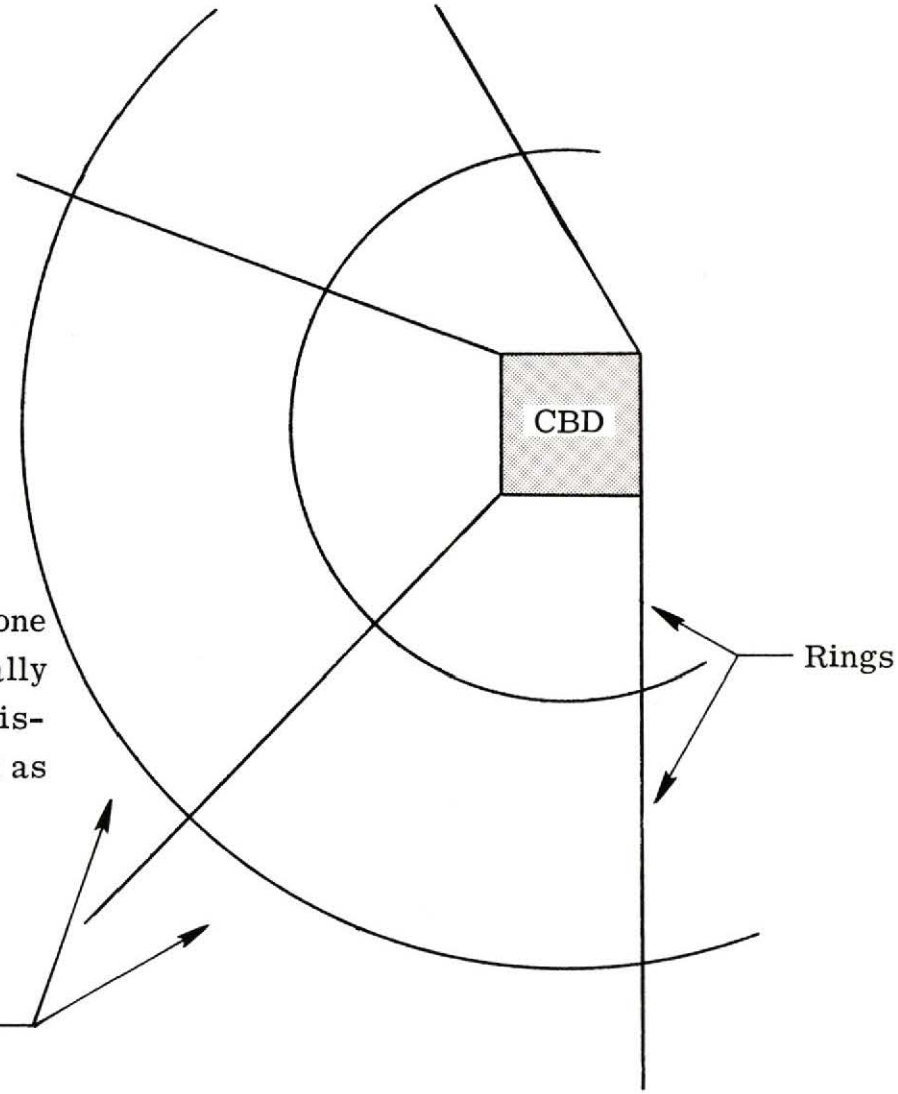
The study area must be divided into analysis units to enable the planner to link information about activities, travel, and transportation to physical locations in the study area.

The transportation analysis units are known as zones. These zones vary in size depending on the density or nature of urban development. In the central business district (CBD), zones may be as small as a single block, and in the undeveloped area they may be as large as 10 or more square miles. An area with a million people might have 600 to 800 zones, and an area of 200,000 people might have 150 to 200 zones. The zones attempt to bound homogeneous urban activities; that is, a zone may be all residential, all commercial, all industrial, etc. Zones also should consider natural boundaries and census designations.



An important consideration in establishing zones is their compatability with the transportation network to be used. As a general rule, the network should form the boundaries of the zones.

Zones are usually grouped into larger units known as districts. Districts might contain 5 to 10 zones, and a city of a million might have about 100 districts. Districts often follow travel corridors, political jurisdictions, and natural boundaries such as rivers.



The downtown area is usually defined as one district. Groups of districts moving radially from the CBD are known as sectors. Districts in circumferential groups are known as rings.

Dividing the area into zones, districts, sectors, and rings is a great help to the transportation planner in organizing information and interpreting forecasting results.

QUIZ

The study area boundary is known as the ____________ ______________.

The study area is divided into small analysis units known as ____________.

Zones can be grouped to form ________________.

cordon line

zones

districts

URBAN ACTIVITIES

Once the study area has been divided into appropriate analysis units (zones and districts), information about activities in these areas can be gathered. Knowledge about the forecasting procedure is essential at this point, since only data relevant to the calibration and forecasting process need be gathered. Collecting data that is not eventually used is a wasteful practice.

In Chapter One, urban activity forecasting was briefly mentioned as the source of information on activities that might influence travel in the urban area. These activity forecasts are done on a zonal basis, providing the intensity and characteristics of activities in each zone in the study area. The results of a typical activity analysis provide the planner with present levels of activities in zones to help in predicting future levels that provide a basis for forecasting.

Zone activity information might appear as follows for a few sample zones.

Zone 39:	Heavy industry Employment -- 400 blue collar 123 white collar
Zone 3:	Central Business District Employment -- 623 retail 1200 non-retail
Zone 136:	Suburban shopping center Parking spaces -- 700 Employment -- 120 retail 43 non-retail
Zone 89:	Residential Population -- 1200 Households -- 400 Average Income -- $12,000

More detailed information might be required depending on the modeling requirements. However, the trend is to base models on the simplest information possible from which reasonable forecasts of the information can be made and the models applied to these future forecasts.

TRANSPORTATION SYSTEM

The transportation system allows the urban activities to communicate with one another; that is, people travel to work, to shop, and to visit friends. This communication takes place on streets, highways, subways, and bus routes.

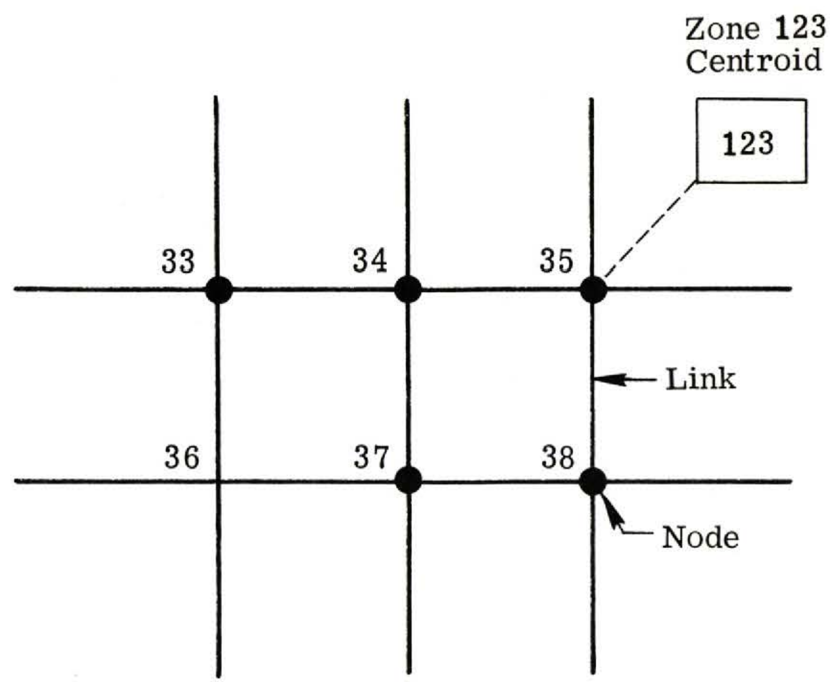
If an urban area were a flat plane with no obstacles to movement, the transportation system could be described quite easily. In cities, this is clearly not the case; some areas are not directly connected, some roads are faster than others, and some areas have no transit service. This variation in accessibility requires the planner to describe the transportation system in terms of its geometry (what's connected with what) and its level of service (how well points are connected).

Network Geometry

The transportation system consists of networks that represent the available modes (auto, bus, etc.). The network description is an abstraction of what is actually on the ground, and as such does not include every local street or collector street in the area. A network description is developed to describe auto and truck travel, with a separate description for transit, if transit is a consideration. These descriptions could include the geometry of the transportation system.

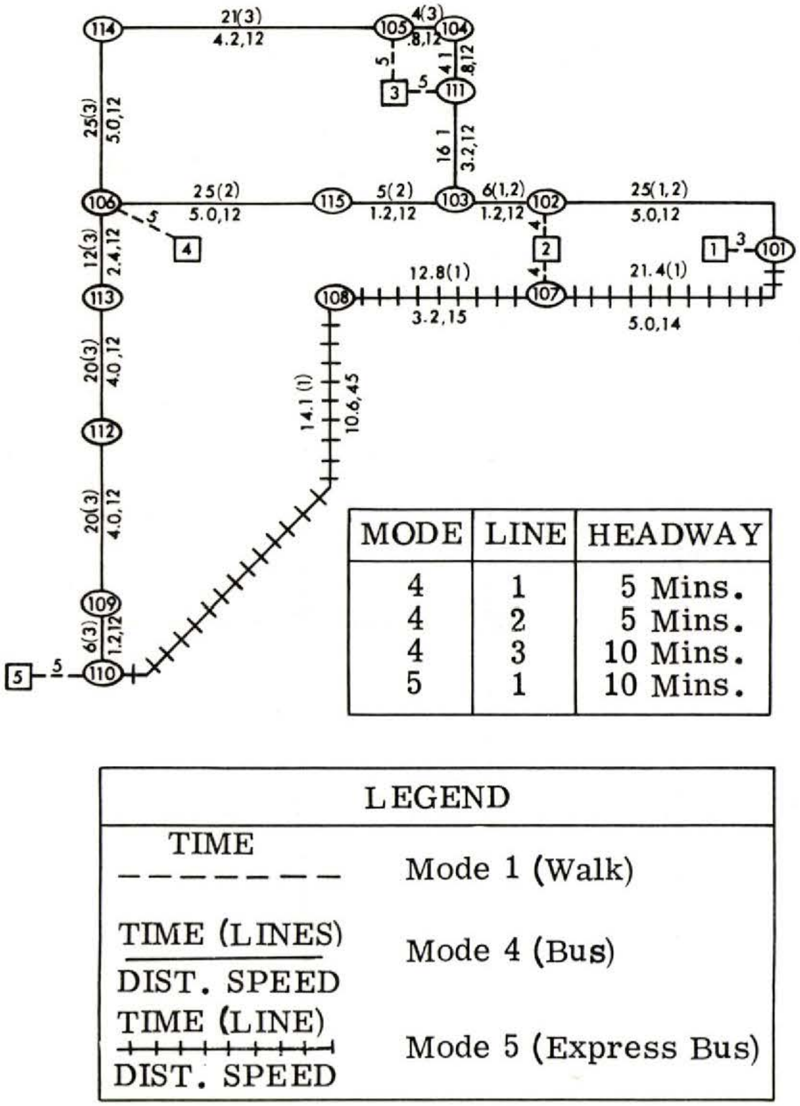
Network geometry includes numbering the intersections (called nodes for assignment purposes). Numbering the nodes allows us to identify the segments between them (called links). In transit networks we also identify groups of links over which specific routes pass (called lines). This geometric description of the transportation network shows all possible ways that travel can take place between points in the area.

In the illustration at right, link 34-37 is defined by its nodes; if link 34-37 is a two-way street, link 37-34 would also be defined.



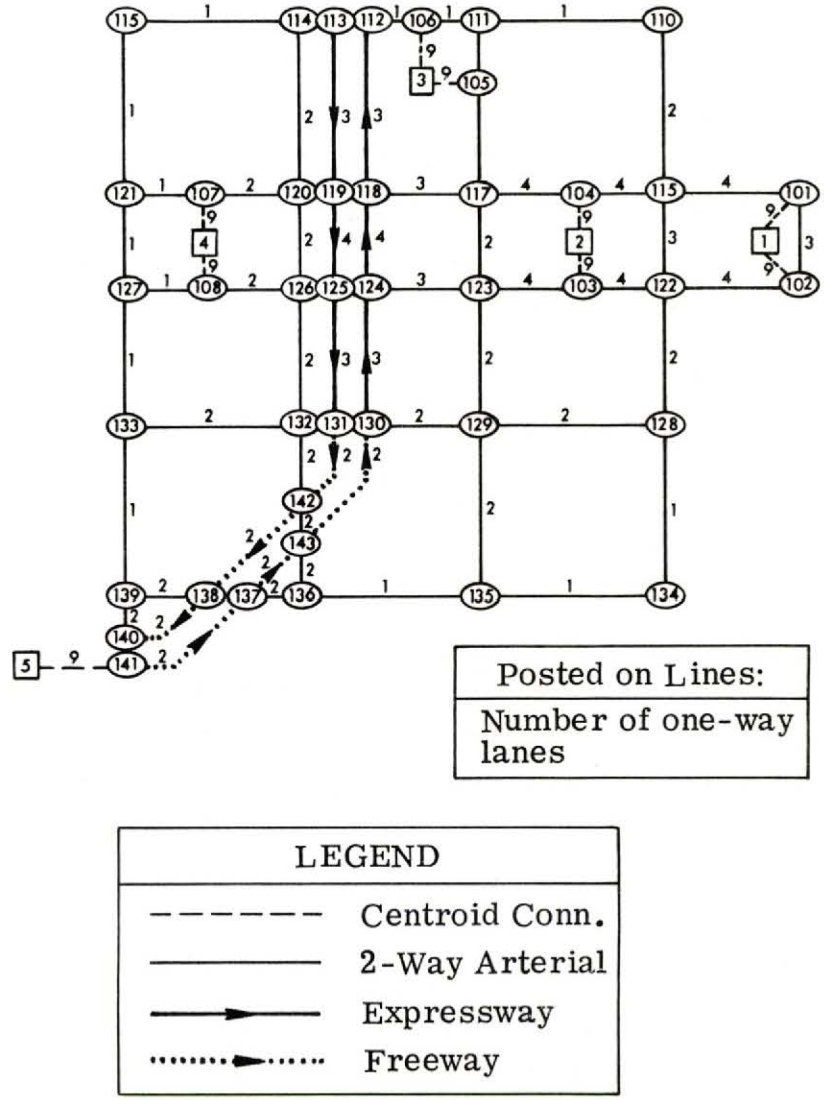
In the network description, zone centroids (centers of activity) are identified; they are connected to nodes by imaginary links called centroid connectors. Centroids are used as the points at which trips are "loaded" onto the network.

Sample vehicle and transit network maps are shown on the next page for the mythical UTOWN.



MODE	LINE	HEADWAY
4	1	5 Mins.
4	2	5 Mins.
4	3	10 Mins.
5	1	10 Mins.

UTOWN TRANSIT NETWORK DISTANCES, SPEED, TIMES, AND HEADWAYS



UTOWN HIGHWAY NETWORK

Level of Service

Once the transportation network has been described in terms of how points can be connected, it is necessary to quantify the ease with which these connections are made. Whether two zones are connected by an arterial street or freeway is an important distinction in travel forecasting. Travel speeds and link capacity on the freeway would probably be greater than on the arterial street; this level of service difference must be quantified and included as part of the transportation system description.

For the vehicle network description, specific items must be collected to determine the level of service on each link. These requirements include physical items such as the link length and number of lanes, whether the type of facility under consideration is a freeway, arterial, etc., and where in the urban area the link is located.

For the transit network, the description needs some additional information about the service characteristics of the system. The transit network is different from the vehicle network in that both the links and the sequence of links to establish routes (lines) must be identified. In that both links and lines must be represented, the network description is two-tiered. The first level is a system of links that define the segments of travel facilities between nodes. Traveltimes, speeds, and distances are required for links. The second level -- the network of lines -- overlays the links and defines the fixed routes. This requires that each line be identified individually along with its service headways and the series of links over which it travels.

With these items of information about the highway and transit networks, the planner can determine how each zone in the area is connected in terms of time and cost to all other zones and hence the level of service the transportation system provides.

The measures of time and cost can usually be expressed in terms of a general measure known as impedance, which represents a "generalized cost" of traversing a particular link.

QUIZ

Once zones have been estalished, information about the character and intensity of ____________________ is gathered.

The transportation system is usually described in terms of its ________________ and level of service.

Numbering the ________________ on the network provides definitions of _________ between the nodes.

Time and/or cost of travel between zones is an indicator of the ____________ ____ ____________ provided by the transportation system.

A transit ______________ describes a specific route in the transit network.

__________________ is a combination of time and cost used to describe the difficulty in using any link.

activities

geometry

nodes, links

level of service

line

impedance

TRAVEL INFORMATION

Information on how, when, and where people are currently traveling is of obvious importance in the forecasting process. This information is studied to determine the underlying factors causing people to make certain travel decisions so that models can be calibrated and used to forecast how people will travel in the future or in response to changing conditions now.

Origin-Destination Data

To be able to analyze trip-making, the planner needs information on where trips come from, where they go, by what mode, for what purpose, and characteristics about the tripmaker and activities at the origin and destination of the trip. This information is termed origin-destination data.

Origin-destination survey data are generally available in sufficient detail and of proper statistical stability to allow accurate estimates of the model parameters. The home interview survey provides the most complete and accurate information for computing the parameters. However, since home interviews have been done in all large cities and are extremely expensive, they are no longer done for large samples. Small-sample surveys are now done to update past surveys.

Although the best data are collected through person-to-person interviews, other techniques can provide satisfactory results. Telephone interviews, on-board transit surveys, mailed questionnaires, and pick-up postal cards are sometimes used.

No matter which technique is used, the data must be reliable: they must be complete and unbiased.

The following information is typical of that collected about each household that is contacted in home interviews:

- address of household,
- number of persons who live there,
- number of cars available to the residents,
- occupation of the head of the household, and
- income of the household.

For each trip made by a member of the household, the following information is usually collected:

- identification of the person who made the trip,
- address of the origin of the trip,
- address of the destination of the trip,
- time at which the trip started,
- time at which the trip ended,
- purpose at the origin,

- purpose at the destination,
- mode of transportation,
- type of activity at the origin, and
- type of activity at the destination.

In addition to home interview surveys, truck-and-taxi surveys and external cordon surveys are generally made to provide a complete picture of travel in the study area.

Counts of vehicle traffic and transit ridership are also made at various locations throughout the urban area. They can be used to check on the accuracy of the surveys and, later, to check on the functioning of the models.

Initial Decisions

Before proceeding with the processing of travel data, some decisions must be made. Here are two:

- whether to use vehicle trips or person trips in the analysis, and

- how to stratify trip purpose classifications.

Vehicle Trips or Person Trips

Deciding whether to use vehicle trips or person trips is one of the first decisions the planner must make. The decision is directly related to the needs and objectives of the study. Areas with significant public transit issues, regardless of size, require mode usage models to be developed making person trip models for trip generation and trip distribution necessary.

Stratification of Trip Purpose Classifications

The planner must decide how many and which trip purpose classifications to use.

The use of classifications ranges from only one to nine or more, depending on the size of the study area and the scope and objectives of the study.

The number of trips in each classification should be considered. The home interview survey data can be studied to make sure that enough trips are recorded in each classification used to allow accurate forecasting.

The amount of data preparation time, computer time, and analysis time should also be considered in deciding on the stratification.

The trip purpose breakdown in most widespread use is as follows.

1. Home-based work -- trips between a person's home and place of employment for the purpose of working.

2. Home-based other -- trips between a person's home and any other destination for any other purpose.

3. Non-home-based -- trips that have neither end at home, regardless of purpose. These may include truck and taxi trips.

4. Internal-external trips -- trips with one end inside the study area and one outside the study area.

5. Through trips -- trips that have neither end in the study area but pass through it.

6. Truck and taxi trips -- if required, but often included as part of non-home-based trips.

Defining Productions and Attractions

It is generally felt that household characteristics related to travel are easier to identify and forecast. For this reason, planners use the home as a base to predict travel. This convention requires a distinction in the terms origin, destination, production, and attraction, which often cause confusion in transportation planning. A trip origin is always the beginning point of the trip, and a trip destination is always the ending point. This doesn't hold true for productions and attractions, however. Here are a few rules to follow.

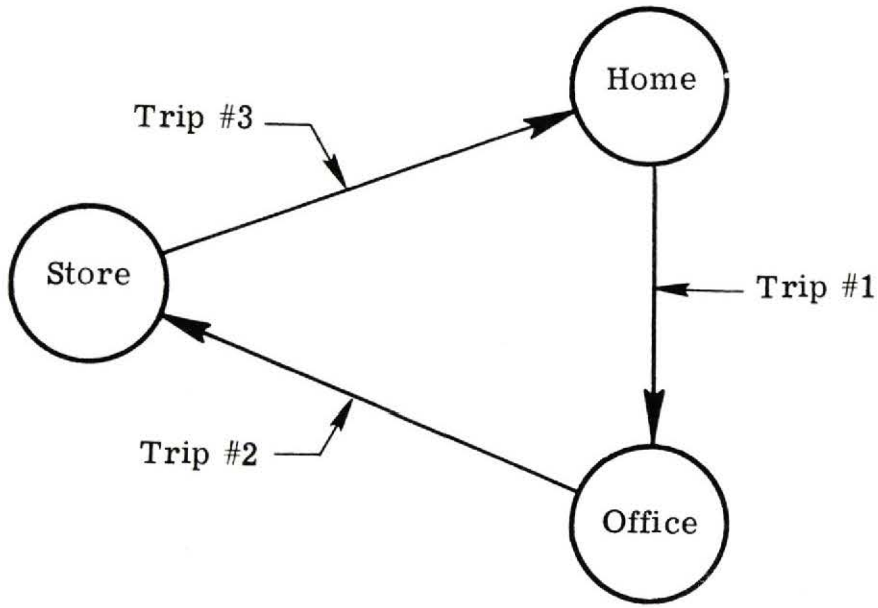
Rule 1: Trips that either begin or end at the traveler's home are produced at the home end.

Rule 2: Trips that either begin or end at the traveler's home are attracted to the non-home end.

Rule 3: Trips that begin at a non-home location and end at another non-home location are produced at the origin and attracted to the destination.

The example on the next page should help.

A traveler goes from home, to the office, to a store, then back home.



Trip number 1 was produced at home and attracted to the office -- Rules 1 and 2 -- therefore a home-based work trip.

Trip number 2 was produced at the office and attracted to the store -- Rule 3 -- therefore a non-home-based other trip.

Trip number 3 was produced at home and attracted to the store -- Rules 1 and 2 -- therefore a home-based other trip.

Processing Travel Data

Developing Calibration Files

From the edited trip information, a file that includes an entry for each trip surveyed can be developed. Each entry represents a complete description of one trip; this description includes information about the trip maker along with where the trip was produced, where it was attracted, its purpose, mode. etc.

The calibration file can then be used in various phases of the forecasting process to provide the observed travel information against which models are calibrated.

Developing Trip Tables

The calibration file just mentioned provides the basic data to generate what is called a trip table. A trip table is simply a matrix showing how many trips are interchanged between the various zones in the study area. A simple three-zone trip table is shown at right. This table indicates that 10 trip productions from Zone 1 stay in Zone 1, 30 go to Zone 2, 20 to Zone 3, etc. The sum of the rows of the trip table is equivalent to zone trip productions, and the sum of the columns is zone trip attraction. For example, the table shows Zone 1 produces 60 trips and attracts 70 trips.

Production Zone \ Attraction Zone	1	2	3	
1	10	30	20	Σ=60
2	20	15	35	
3	40	56	74	
	Σ=70			

A trip table is produced for each trip purpose category defined.

Developing Initial Travel Impedances

You will recall from Chapter One that the travel forecasting process relies on feedback to check initial assumptions on traveltimes. Initial traveltimes are best derived by loading the trip tables produced by the calibration file onto the network that provides estimates of zone-to-zone traveltimes.

The network assignment procedure will be discussed in detail in Chapter Six. This brief description is provided because impedance estimates are required in trip distribution and mode usage analysis, which are discussed prior to network assignment.

QUIZ

Travel information allows the planner to ______________________ the necessary travel models.

Extensive home interviews are now required to obtain travel data. True or false?

____

A trip from a person's office to home is a non-home-based trip. True or false?

____

calibrate

Internal-external trips have one end inside the area and the other end ________________ the area.

False

False

A ______________________ file is used to establish travel models.

outside

calibration

For a production/attraction trip table, the row sums are the zone __________ ______________________.

trip productions

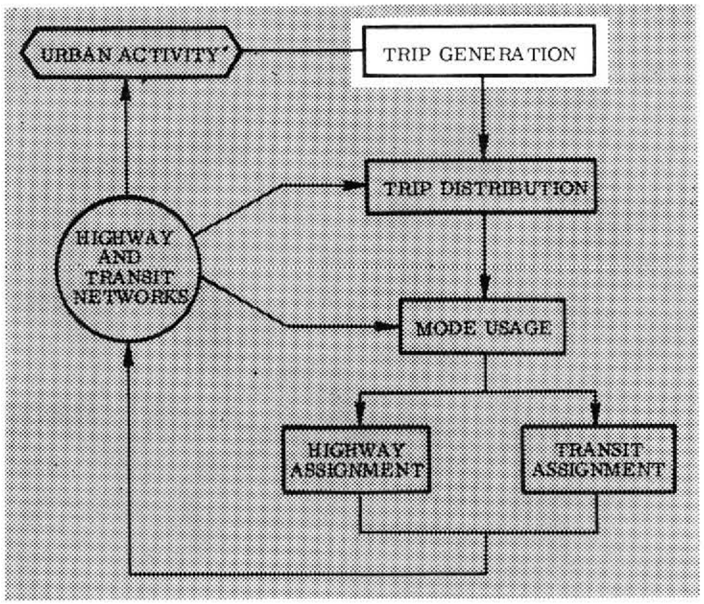
For further reading about surveys and information needs, refer to the following:

Urban Origin-Destination Surveys, 1973. Available from FHWA, HHP-20, Washington, D.C. 20590.

Urban Mass Transportation Travel Surveys, FHWA, August 1972. Available from Government Printing Office, Stock No. 5001-0037, $2.10.

Chapter Three
TRIP GENERATION ANALYSIS

INTRODUCTION



To predict the amount of travel that will take place in the forecast year, or to analyze current travel, the planner must understand -- and quantify -- the relationship between present urban activity and present trip-making. If the urban activity forecasts are accurate and the relationship between urban activity and trip-making does not change, then predictions based on these relationships will also be accurate.

In the trip generation phase of transportation planning, the planner is concerned only with the number of trip ends. A trip end is defined as the beginning or ending of a trip; therefore, a trip from home to work has two trip ends. The other characteristics of trips -- destinations, modes and paths -- are considered in other phases.

Trip generation, then, is the process by which the transportation planner predicts the number of trip ends.

Urban activity, as it affects trip generation, is usually described in terms of amount of activities and character of activities. Measures of amount and character are provided by the urban activity forecasts and are input to the trip generation phase. Transportation system variables, from the descriptions of the highway and transit networks, can also be used in trip generation; however, they have not generally been included in practice, since strong relationships have not yet been discovered.

BASIC CONSIDERATIONS IN TRIP GENERATION

Amount of Urban Activity

Relationships obviously exist between the amount of activities and travel. All else being equal, a zone with a larger number of households or employees will generate more trips than a zone with a smaller number. Establishing the amount of activity is, therefore, a key element in analyzing trip generation.

The amount of activity is usually stated in terms of a measure like the number of employees, households, or retail sales in a zone.

Character of Urban Activity

Measures of the amount of activity usually are not enough to develop a good relationship between activities and travel. The character of the activities is important, too.

For residential land uses, character is described in terms of socioeconomic variables like family size, family income, and car availability. Generally, high-income or large families make more trips than low-income or small families. And obviously, three-car families generally make more trips than one-car families.

For nonresidential activities, character reflects the type of activity; for example, industrial, retail, and commercial. As you can imagine, the number of trips that are generated by a major shopping center is usually higher than the number of trips that are generated by a warehouse of the same size.

Other Considerations

It certainly seems logical that the level of service provided by the transportation systems would affect the trip generation rates. You might expect areas with excellent freeways and high-quality bus service to generate more trips than areas with poor facilities. The fact is that strong relationships between trip generation and the quality of transportation have not been shown; and therefore variables to describe the transportation system are seldom included in trip generation analysis.

Trip generation relationships are often developed with location of activities as a consideration, especially when considering the generation rates for retail activities in the downtown area as opposed to other shopping areas.

Special Generators

Areawide trip generation analysis must be somewhat general in the treatment of a wide diversity of activities in an urbanized area. There are some concentrations of activities of such size or unusual nature to warrant special consideration in trip generation analysis. Such generators might include airports, sports stadiums, hospitals, military bases, large regional shopping centers, and suburban office complexes.

Special generators are usually handled separately from the areawide analysis using special surveys and generation rates specific to each activity or group of similar activities, such as large shopping centers.

Special generators are relatively few in number in any urban area, but may represent a significant portion of trips and therefore justify separate treatment. Their influence on nearby arterials and highways could not be adequately captured without separate analysis.

QUIZ

Trip generation is the process by which the planner attempts to understand and quantify the relationship between ____________ ________________________ and ________________________________.

Measures of ________________ and ___________________ of urban activities are input to trip generation.

Special generators represent large or unusual concentrations of trip ends. True or false? ______________

urban activity, trip-making

amount, character

True

SPECIFYING THE TRIP GENERATION MODEL

While there are several general alternative structures for specifying trip generation models, the procedure called Cross-Classification Analysis has become most widely accepted and will be the only one discussed in this text. This procedure is based on household trip making as its level of analysis.

A great deal of research has established a recommended procedure for using cross-classification for trip generation analysis. The procedure provides the planner a basic model structure. This structure can be altered for local situations by substituting or adding variables. There are separate recommended model structures for each type of trip as follows:

- trip productions,
- trip attractions, and
- internal-external trip generations.

Trip Production Model Structure

The forecasting of trip productions is based on relating trip making to various household characteristics such as income, auto availability, or household size. The matrix below shows a possible trip production model structure with household trip rates cross-classified by income and auto availability.

	Auto Availability		
Household Income Level	0	1	2+
1			
2	(Trip productions per household)		
3			
4			
5			

In actual use, the above table might have additional income categories or additional variables, depending on data availability and results obtained when using the relationship.

Trip Attraction Model Structure

In contrast to trip production modeling, which focuses on household characteristics, the trip attraction model structure is directed toward the activities that might attract the trip productions. These activities might be households, stores, offices, factories, etc.

In order to analyze trip attractions, the number of trips attracted to certain activities is related to a measure of the amount of that activity. For example, the number of trips attracted might be related to the number of employees in a factory or the number of employees in a store.

The structure of the trip attraction model relates trip ends by purpose to the amount, character, and in some cases location of the activities as shown below:

	Attraction Activity			
	Household	Non-Retail Employment	Downtown Retail Employment	Other Retail Employment
Home-based work				
Home-based other	(Trip attractions per unit of activity)			
Non-home-based				

In the attraction model structure, the amount of activity is reflected in the rate per unit measure, the character of activity by the type of activity, and the location by the downtown versus other retail employment classification.

Internal-External Trip Generation

So far in this chapter, only internal trips -- trips that begin and end within the boundary of the study area, the "cordon line" -- have been discussed. Internal trips generally account for 80 to 90 percent of all travel within a study area, so 10 to 20 percent of the travel in the area remains to be analyzed. As a matter of fact, trips without both origins and destinations within the study area run as high as 50 percent of travel in smaller urban areas. Trips that have one end outside the cordon line are called internal-external trips, and trips that go through the study area but neither begin or end within the cordon line are called through trips.

Through trips are generally handled by a factoring process. Growth factors are developed, based upon forecasts of transportation facility development that may add to or subtract from the attractiveness of travel through the study area. Population and economic activity in the regions from which the through trips began are also analyzed and forecast. In this section, the concern is mainly with internal-external trips -- those that begin or end inside the study area.

There are several ways to handle internal-external travel. The recommended way is to group internal-external trips so that they are "produced" at the cordon line and "attracted" to internal zones. The number of attractions is a function of the character of the internal zone. As a rule, more trips are attracted to the central business district than to the outlying zones of the study area.

Usually there are not enough internal-external trips for them to be analyzed alone. Therefore it is suggested that the planner treat the internal ends of internal-external trips as a proportion of all other trips.

The following ratio, calculated by zone, forms the basis for this approach.

$$\frac{\text{Number of internal ends of internal-external trips/zone}}{\text{Number of all other internal trip ends/zone}}$$

After these ratios have been determined, the averages of the zonal ratios can be calculated and analyzed, by rings, from the central business district. If no pattern is apparent, an alternative is to average the zonal ratios by districts and then examine those ratios for a pattern. If a large traffic generator attracts a significant amount of external traffic, it should be analyzed separately.

In forecasting, the ratios are applied by area type (central business district, fringe business, central city, suburbs, etc.) to the forecasted internal trip ends to yield forecasts of internal-external trip attractions.

At the cordon line station -- the production end of internal-external trips -- the forecast of future trip ends should be based upon a growth factor that reflects the expected growth within the travel corridor of the external station, including the area beyond the cordon.

QUIZ

The recommended approach to trip generation analysis is called ____________-
________________.

Trip production forecasting is based on ____________________characteristics.

The trip attraction model relates trip ends to units of
________________.

Trip ends that have one end outside the cordon line are known as ___________-_____________ trips.

Trip productions for internal-external trips are estimated at the _______________ _______________.

cross-classification

household

activity

internal-external

cordon line

TRIP GENERATION MODEL CALIBRATION

Introduction

Model calibration is the process in which the relationships between travel and variables influencing travel are quantified. In trip generation analysis, trip productions and attractions are related to urban activities and their characteristics.

Developing Trip Production Rates

In this section, you'll see some examples of how a cross-classification matrix is developed for trip production rates. The purpose here is to show you the process for developing rates.

Consider the development of trips per household, stratified by auto availability and income. In this example, there are 20 households in the sample for cross-classification analysis. Naturally, in practice there would be many more households included in the sample.

The table on the next page shows the data that might have been collected in home interviews.

In this table, you see the numbers of trips, the family incomes and numbers of autos available to the twenty families in the sample.

Household	Trips	Income	Autos
1	2	4,000	0
2	4	6,000	0
3	10	17,000	2
4	5	11,000	0
5	5	4,500	1
6	15	17,000	3
7	7	9,500	1
8	4	9,000	0
9	6	7,000	1
10	13	19,000	3
11	8	18,000	1
12	9	21,000	1
13	9	7,000	2
14	11	11,000	2
15	10	11,000	2
16	11	13,000	2
17	12	15,000	2
18	8	11,000	1
19	8	13,000	1
20	9	15,000	1

A matrix is established, based upon family income and auto availability. The numbers inside the matrix below represent the household sample numbers.

INCOME ($ 000's)	Autos Available: 0	1	2 or more
≤ 6	1,2	5	--
6-9	8	9	13
9-12	4	7,18	14,15
12-15	--	19,20	16,17
> 15	--	11,12	3,6,10

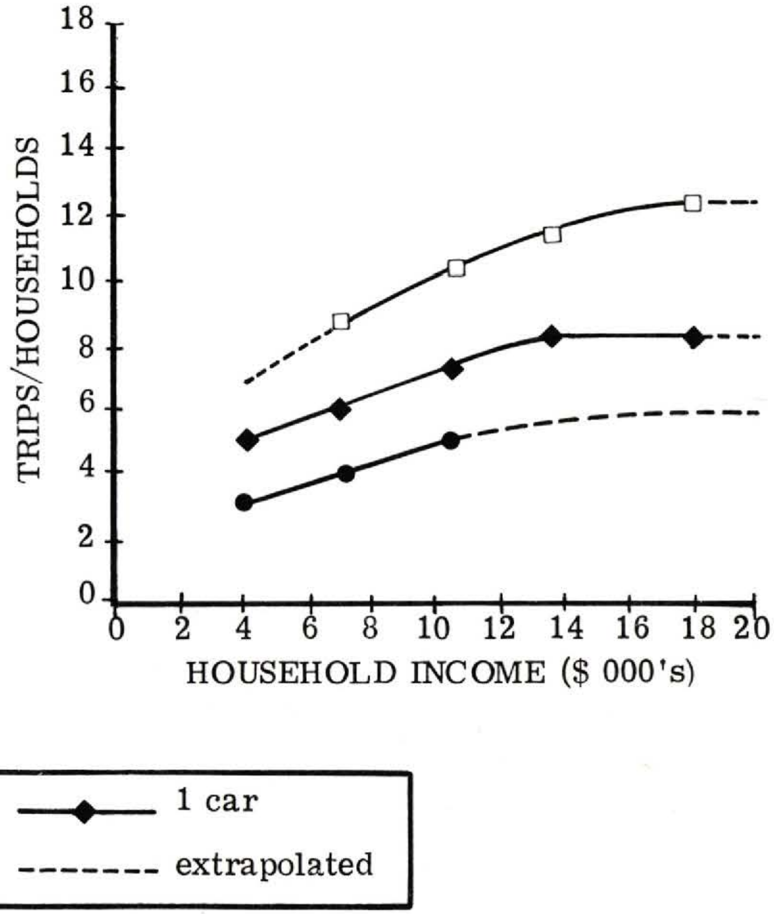
← households 3, 6 and 10 from table on preceding page.

Now, the average of the number of trips for the households in each cell of the matrix above is obtained. For example, the average trip rate for households with 2 or more autos and an income between $12,000 and $15,000 is 11.5 -- households 16 and 17 made a total of 23 trips, so 23 is divided by 2 to arrive at the average rate of 11.5 trips. These averages are then substituted for the household numbers in the matrix, as shown below.

INCOME ($ 000's)	Autos Available: 0	1	2 or more
≤ 6	3.0	5.0	--
6-9	4.0	6.0	9.0
9-12	5.0	7.5	10.5
12-15	--	8.5	11.5
> 15	--	8.5	12.7

The data from the second matrix can now be plotted on a graph, as shown at right.

The plotted points are fit with smooth curves, and the lines are extended -- extrapolated -- based on the shape of the curves and logic. The curve values are then used to develop a completed matrix, which can be used to make forecasts of trips. For example, on the basis of information from the graph, we can predict that families that have an income of $10,000 and one auto will make about 7 trips per day. When used in forecasting, incomes are corrected for inflation and represented in constant dollars.



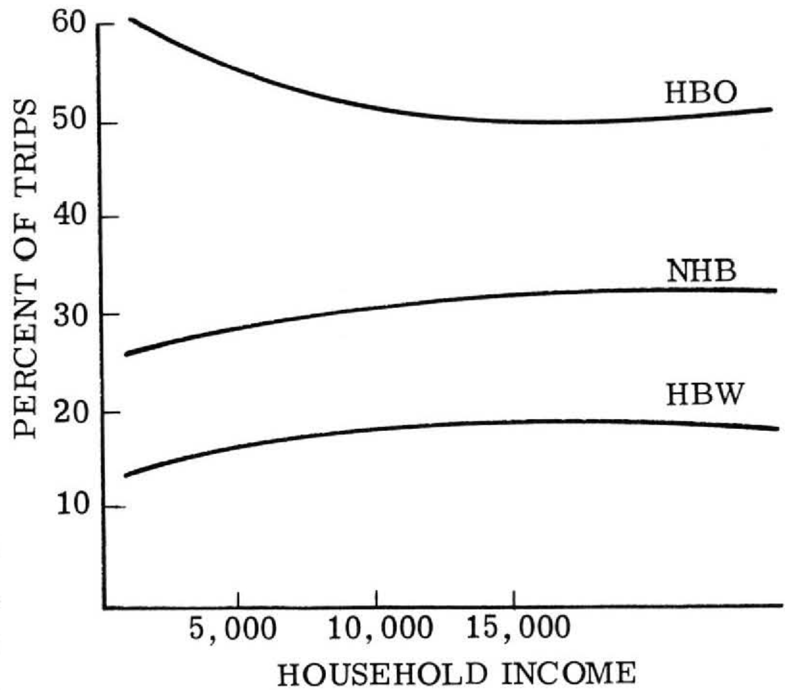
An additional relationship is necessary for the trip production process. Generally in transportation planning, we are interested in trip making associated with some specific purpose and therefore the total trip productions must be split by trip purpose.

Most urban areas can use three categories of trip purpose:

home-based work (HBW),
home-based other (HBO), and
non-home-based (NHB).

Additional categories may be justified, depending on local needs.

Using survey data, the relationship at right can be developed from cross-classification tables. These curves relate the expected split of trips into various purpose categories to household income. Once again, these relationships can be borrowed from similar areas if no data are available, or if the available data are found inadequate.



Developing Trip Attraction Rates

In the previous section, you saw the development of trip production rates based on household characteristics. We now turn our attention to the attraction end of the trip. Attraction rates are developed by analyzing the urban activities that attract trips.

Trips are attracted to various locations, depending on the character, location, and amount of activities taking place. For example, a high-rise office building that employs thousands of people will attract more trips than a small dress shop.

Trip attraction rates might be borrowed from other urban areas or developed from survey data relating the number of trip attractions to activity character, location, and amount. For example, we might discover that retail stores in the central business district employ 1,000 people and attract 9,700 trips. Using this information, we can make the following calculation:

CBD Retail Trips per Employee = 9,700 trips/1,000 employees = 9.7 trips/employee.

If we refine the calculations further and establish a separate rate for each trip purpose and for various types of urban activities, we might end up with the following table:

	Attractions per Household*	Attractions per Non-Retail Employee	Attractions per Downtown Retail Employee	Attractions per Other Retail Employee
Home-based work	negligible	1.7	1.7	1.7
Home-based other	1.0	2.0	5.0	10.0
Non-home based	1.0	1.0	3.0	5.0

Using these trip rates and estimates of future households and employment in each zone, the planner can forecast trip attractions for the area. An example application of this table will follow later in the chapter.

This concludes our discussion of trip generation model calibration. After the quiz, which follows, go on to the application example.

* Note: These trips would be made to households other than the residence of the tripmaker.

QUIZ

The purpose of model calibration is to ________________ the relationship between travel and appropriate variables.

Trip production models use cross-classification to develop relationships between trip making and ____________________ characteristics.

Trip production and attraction rates can be developed from travel surveys or ____________________________________.

quantify

household

borrowed from similar areas

TRIP GENERATION MODEL APPLICATION

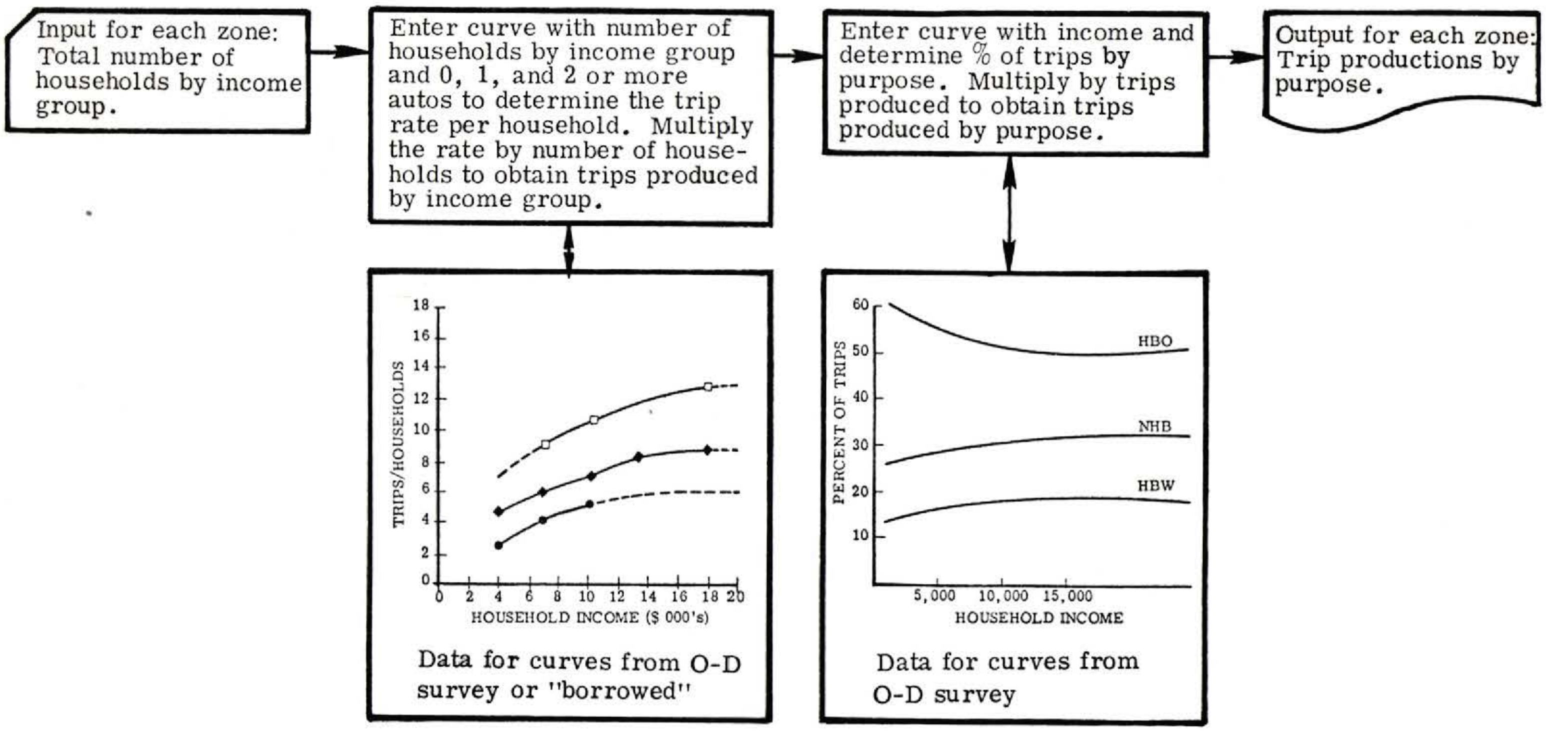
In order to understand how the production and attraction models are used, the remainder of this chapter is devoted to a single example.

To simplify the example, three household income groups are used -- low, medium and high. In actual applications, more income groups might be used or other variables included, such as household size or location in the urban area.

The trip production example is shown first, followed by trip attractions.

Trip Production Model Application

The diagram below outlines the trip production forecasting procedure, showing how the three components are interrelated. Study this diagram carefully and then go onto a UTOWN example.



As can be seen on the preceding page, the process begins with inputs of the number of households cross-classified by income and auto availability (or other variables, as provided for in the calibration process). These inputs can be obtained in several ways.

First, the urban activity forecasting procedure might produce estimates of households by income and auto availability for each zone. If this is the case, the required data is at hand and can be used directly.

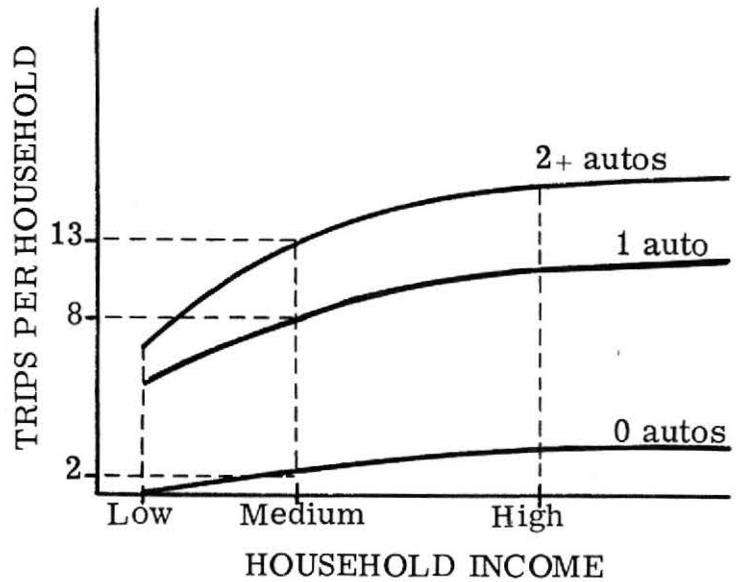
The FHWA publication "Trip Generation Analysis" describes a procedure for deriving the number of households by income and auto availability using functions relating the average zone income to distribution of household income and auto availability.

Alternatively, the planner might assume that zones already developed will maintain their current breakdown of households by income and auto availability or, if the zone population is changing, the percent of households in each income/auto category would remain constant. Zones being developed could be related to existing zones of similar socioeconomic status and their households divided into income/auto categories using the similar existing zones as a basis. For example, if a zone is being developed in a similar manner to an existing one, and the existing zone has 50% of its households with high incomes and two or more autos, then the new zone will likely have 50% of its households in the same income/auto category. For long-range forecasts corrections to account for real increases in income might be necessary. Clearly the planner must exercise a good deal of judgment to obtain the desired information.

Any of the three methods just described could yield estimates of the number of households by income and auto availability for each zone in the area. The table below shows an example for zone #1 of UTOWN.

	Auto Availability		
Income Group	0	1	2
Low	3 households	2 households	0 households
Medium	1 household	14 households	9 households
High	1 household	9 households	21 households

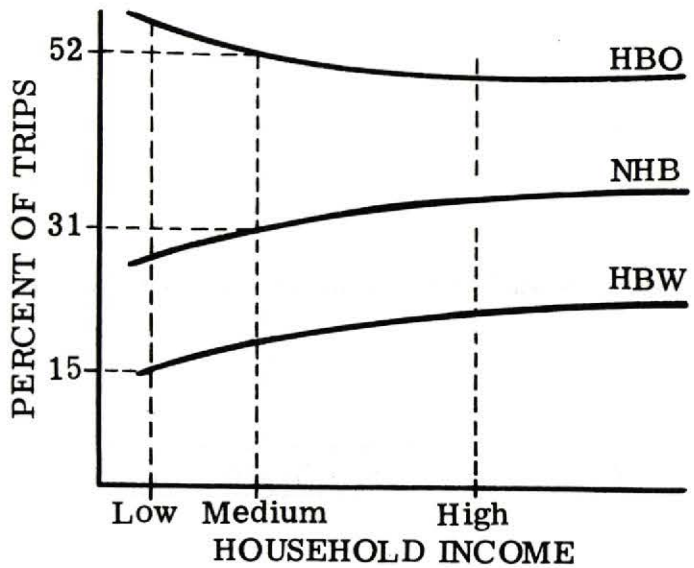
Using the information about households from the previous page, the trip production relationships shown at right can be applied to obtain the number of trip productions.



The calculations for Zone 1 are as follows:

	Auto Availability			
Income Group	0	1	2	Total
Low	3 households x 1 trip/household = 3 trip ends	2 households x 6 trips/household = 12 trip ends	0 households x 10 trips/household = 0 trip ends	15
Medium	1 household x 2 trips/household = 2 trip ends	14 households x 8 trips/household = 112 trip ends	9 households x 13 trips/household = 117 trip ends	231
High	1 household x 3 trips/household = 3 trip ends	9 households x 9 trips/household = 81 trip ends	21 households x 15 trips/household = 315 trip ends	399

Next, with estimates of trip productions by zone and household income, the curves at right can be entered to split the trips by trip purpose.



The calculations for Zone 1 are as follows:

Zone 1:

Trip Productions	Household Income Group	Percent by Purpose	Trip Productions by Purpose
15	Low	15% HBW	2
		57% HBO	9
		28% NHB	4
231	Medium	17% HBW	39
		52% HBO	120
		31% NHB	72
399	High	18% HBW	72
		50% HBO	199
		32% NHB	128

Summary Zone 1: 113 Home-Based Work Productions
328 Home-Based Other Productions
204 Non-Home-Based Productions

Similar calculations for other zones yield the following:

Zone #	Trip Production		
	Home-Based Work	Home-Based Other	Non-Home Based
1	113	328	204
2	404	1395	747
3	602	1726	1079
4	263	821	478
5	428	1213	766
Total	1810	5483	3274

This completes the forecast of trip productions for UTOWN. The next task is to estimate trip attractions.

Trip Attraction Model Application

With estimates of the number of households and employment levels in each zone, and with the calibrated trip attraction rates, forecasts of trip attractions can be made.

TRIP ATTRACTION RATES

Trip Purpose	Attractions per Household	Attractions per Non-Retail Employee	Attractions per Downtown Retail Employee	Attractions per Other Retail Employee
Home-based work	negligible	1.7	1.7	1.7
Home-based other	1.0	2.0	5.0	10.0
Non-home-based	1.0	1.0	3.0	5.0

The calculations for UTOWN Zone #1 follow.

Zone 1 (downtown): Home Based Other Attractions

60 households x 1 trip end/household	=	60 attractions
220 downtown retail employees x 5 trip ends/employee	=	1100 attractions
650 non-retail employees x 2 trip ends/employee	=	1300 attractions
Zone 1 home-based other attractions	=	2460 attractions

Similarly, calculations for other purposes for Zone 1 yield:

Home-based work attractions = 1479

None-home-based attractions = 1370

The attractions for the remainder of UTOWN zones calculated in a similar manner show the following:

Zone #	Home-Based Work	Home-Based Other	Non-Home-Based
1	1479	2460	1370
2	144	1750	1075
3	104	650	495
4	64	500	370
5	112	680	450
Total	1903	6040	3760

The total number of trip productions and trip attractions should be in balance for any given area. Given the approximate nature of these rates, the likelihood of a close balance is not great. The comparison for the UTOWN example is as follows:

	Total Trip Productions	Total Trip Attractions	Productions/ Attractions
Home-Based Work	1810	1903	1810/1903 = 0.95
Home-Based Other	5483	6040	5483/6040 = 0.91
Non-Home-Based	3274	3760	3274/3760 = 0.87

As you can see, the productions and attractions do not balance; and, therefore, adjustments must be made. If these totals were off more than 20%, the entire procedure would have to be investigated. Since the trip productions are based on household data, they are felt to be more reliable and therefore act as control totals for trip generation. The trip attractions by zone are multiplied by the ratio of total productions over total attractions so that the totals will be equal. If work trip productions and attractions do not balance, a special analysis should be undertaken since the attractions are based on employment and therefore should be quite accurate.

You will recall from Chapter Two that non-home-based trips represent true beginnings and endings and therefore must be in balance by zone. The non-home-based trip productions act only as control totals, since the production equations have no way of knowing where these trip ends are produced. Therefore, the non-home-based trip ends from the attraction forecasting procedure represent productions and attractions for each zone. These trip ends are factored to equal the total number of non-home-based trips estimated in the trip production procedure.

To adjust the attractions for Zone #1 of UTOWN, the following procedure is followed:

Home-Based Work --	UTOWN Zone #1 Attractions	=	1479
	Total UTOWN HBW Attractions	=	1903
	Total UTOWN HBW Productions	=	1810
	Total Productions/Total Attractions	=	0.95

Therefore, to adjust Zone #1 attractions: 1479 x 0.95 = 1407

Similarly:

Home-Based Other: 2460 x 0.91 = 2233

None-Home-Based: 1370 x 0.87 = 1192

The summary for Zone #1 now reads:

Zone #1:

Purpose	Productions	Attractions	Adjusted Attractions
HBW	113	1479	1407
HBO	328	2460	2233
NHB	~~204~~ 1192	1370	1192

Note that the adjusted non-home-based attractions are set equal to productions.

By continuing this process for all zones, the following final estimate of trip generation is produced:

Zone	Home-Based Work		Home-Based Other		Non-Home-Based	
	Productions	Attractions	Productions	Attractions	Productions	Attractions
1	113	1407	328	2233	1192	1192
2	404	137	1395	1592	935	935
3	602	99	1726	591	431	431
4	263	61	821	455	322	
5	428	106	1213	619	392	392
Total	1810	1810	5483	5490	3272	3272

The total productions and attractions are now in close balance (round-off errors cause some minor discrepancies), and the trip generation process is complete. Internal-external trip ends and special trip generators will not be developed into examples in this text.

The next phase of travel demand forecasting now begins -- the distribution of these trip ends throughout the area.

For additional information about trip generation analysis, consult the following documents:

Guidelines for Trip Generation Analysis, FHWA, June 1967. (Reprinted April 1973) Available from FHWA, HHP-22, Washington, D.C. 20590.

Trip Generation by Land Use, Maricopa Association of Governments, Maricopa County, Arizona, April 1974. A synthesis of trip generation rates for differing land uses. Useful in developing synthetic models, checking models or site planning. Available from FHWA, HHP-22, Washington D.C. 20590.

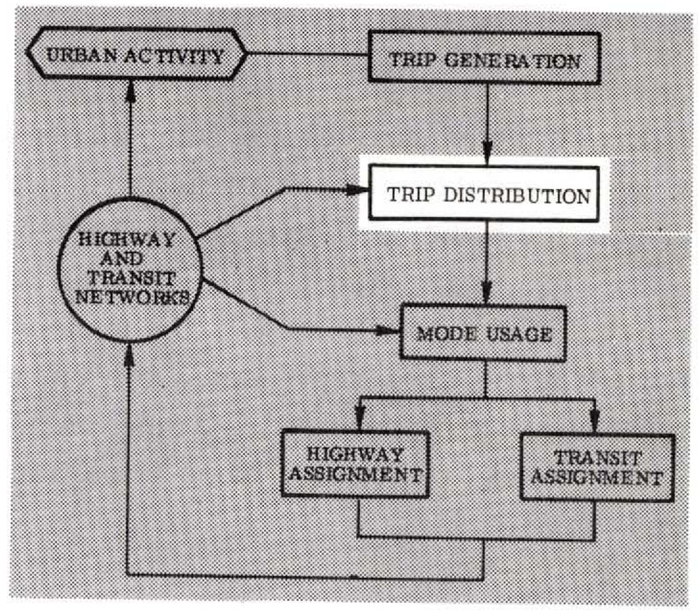
Trip Generation Analysis, FHWA, August 1975. Available from FHWA, HHP-20, Washington, D.C. 20590.

Trip Generation, Institute of Transportation Engineers, 1976. Available from ITE, members $15/nonmembers $18.

Chapter Four
TRIP DISTRIBUTION ANALYSIS

INTRODUCTION

As you saw earlier in this text, our forecasts begin with urban activity forecasts -- how much activity will there be, and how will it be allocated to the various zones in the study area?



The trip generation phase of planning uses the data from urban activity forecasts, and other related studies, to forecast the number of trips that will be "generated" in each zone.

Trip distribution is the process by which the planner determines where the generated trips will be attracted. That is, each zone's trip productions are connected to all the zones to which they are attracted.

There are several methods of distributing trips. Although other techniques supply accurate results, in this text we will discuss only the development of the most widely used technique, the Gravity Model.

BASIS FOR THE GRAVITY MODEL FORMULA

The gravity model derives its name and basic premise from Isaac Newton's law of gravity. Newton's law states that the attractive force between any two bodies is directly related to the masses of the bodies and inversely related to the distance between them.

Similarly, in the gravity model, the number of trips between two areas is directly related to activities in the area represented by trip generation and inversely related to the separation between the areas represented as a function of traveltime. Therefore, areas with large amounts of activity tend to exchange more trips and areas farther from each other tend to exchange fewer trips.

The gravity model formula appears as follows:

$$T_{ij} = \frac{P_i \, A_j \, F(t)_{ij}}{\sum_{j=1}^{n} A_j \, F(t)_{ij}}$$

where:

T_{ij} = the number of trips produced in zone i and attracted to zone j
P_i = the trips produced to zone i
A_j = the trips attracted to zone j
$F(t)_{ij}$ = the friction factor for interchange i j (based on traveltime between i and j)
i = origin zone
j = destination zone
n = number of zones in the study area.

At first, this formula might look elaborate and confusing, but it's really quite simple. Let's look at each part of the formula.

The gravity model states that the trips produced in zone i --

$$P_i$$

will be distributed to each other zone j --

$$T_{ij}$$

according to the relative attractiveness of each zone j --

$$\frac{A_j}{\Sigma A_j}$$

and the relative accessibility of each zone j --

$$\frac{F(t)_{ij}}{\Sigma F(t)_{ij}}$$

and, that's it.

Here's what the formula means.

$$\text{Trips between i and j} = \text{trips produced at i} \times \frac{\text{attractiveness and accessibility characteristics of j}}{\text{attractiveness and accessibility characteristics of \underline{all} zones in the area.}}$$

Thus, zone j gets a portion of zone i's trip productions according to its characteristics as compared to the characteristics of all other zones in the study area. This leads to the term "share model" often applied to the gravity model and other models having these characteristics.

In practice, a separate gravity model is developed for each trip purpose, since different trip purposes have different distribution characteristics -- a person who travels from one side of the city to the other for work might not go so far to see a movie or to go shopping.

In this text, we will not discuss the derivation or the proof of this model -- our purpose is to show you how to use the model as a tool in distributing trips. For more information about the formula itself, refer to the references at the end of the chapter.

Before the number of trip interchanges can be computed, several parameters must be defined.

GRAVITY MODEL PARAMETERS

The first two parameters that must be considered for the gravity model are trip productions and attractions for each zone.

Trip Productions and Attractions

Estimating trip productions and attractions, you recall, is the purpose of trip generation. Let's review the definitions of production and attraction. The gravity model distributes trips from production zone to attraction zone. To define productions and attractions, it is necessary to classify all trips as either home-based or non-home-based.

Home-based trips are always considered to be produced at the home end and attracted at the non-home end, whether the trips begin at the home end or the non-home end. A trip from work to home is produced at home and attracted at work. Does this sound unreasonable? It's not -- the traveler probably began at home, went to work, and returned home. The attraction for both trips was work. By the same token, a trip from home to a shopping center and the return trip home would be classified as home-based -- both trips are produced at home and attracted at the shopping center.

Non-home based trips are always produced by the origin zone and attracted by the destination zone.

In actual gravity model applications, the trip attraction parameter gives way to a term called the "attraction factor." This factor is a product of a balancing procedure to ensure that the number of trips sent to a zone by the gravity model is equivalent to its trip attractions estimated by the trip generation procedure. More about this procedure can be found in the references at the end of the chapter.

Friction Factors

Newton's gravity theory states that the force of gravity is inversely proportional to the distance between two bodies. The effect of distance between zones on the amount of travel between zones isn't so neatly defined -- if you were going to go shopping at one of the two identical shopping centers described below, which would you choose?

Shopping Center A -- 7 miles away/8 minutes by freeway
Shopping Center B -- 5 miles away/20 minutes by city street

You'd probably choose shopping center A, because the trip takes less than half as long as a trip to shopping center B even though B is closer. Of course, this example is for travel by automobile; the gravity model can distribute transit trips as well.

Friction factors represent the effect that various levels of traveltime have on travel between zones. These factors are determined in the calibration process.

Traveltime between each pair of zones in the study area is determined by the trip assignment process.

A more general term than traveltime for the separation of zones is "impedance." Impedance can represent traveltime, cost, distance, or a combination of factors. Generally, impedance is a weighted sum of various types of times (walking, waiting, riding) and types of cost (fares, operating cost, tolls, parking cost). In the past, traveltime was used in the gravity model to measure separation and to develop friction factors. We now have the capability to include other factors, such as tolls and operating cost, in the impedance function, which more accurately represent the separation between zones.

Socioeconomic Adjustment Factors

Another parameter that can be used reflects the unique socioeconomic characteristics of the various zones -- characteristics that are not otherwise accounted for -- and how these characteristics affect the travel patterns in the study area.

These adjustment factors affect the number of trip interchanges determined by the model.

Although the gravity model provides for these adjustments, few cities have found it necessary to use them -- but, where they are used, they show the effect of certain social and economic conditons that otherwise are not accounted for. Like the friction factors, socioeconomic factors are determined in the calibration process. They should be used with extreme caution and only when justified to account for an area's unique characteristics.

If socioeconomic factors are found necessary, they appear as the K_{ij} parameters in the gravity model, as follows:

$$T_{ij} = \frac{P_i A_j F(t)_{ij} K_{ij}}{\sum_{j=1}^{n} A_j F(t)_{ij} K_{ij}}$$

QUIZ

The gravity model distributes trips from the ____________ zone to the ____________ zone.

Home-based trips are always produced at the ____________ end and attracted to the ____________ end.

Non-home based trips are always produced by the zone of ____________ and attracted by the zone of ____________.

The gravity model is the only acceptable method of distributing trips. True or false? ____________

The most often used measure of the separation of zones is ____________.

A more general term, which also represents the separation of zones, is ____________.

Traveltime is determined in conjunction with the ____________ process.

production, attraction

home, non-home

origin, destination

False

traveltime

impedance

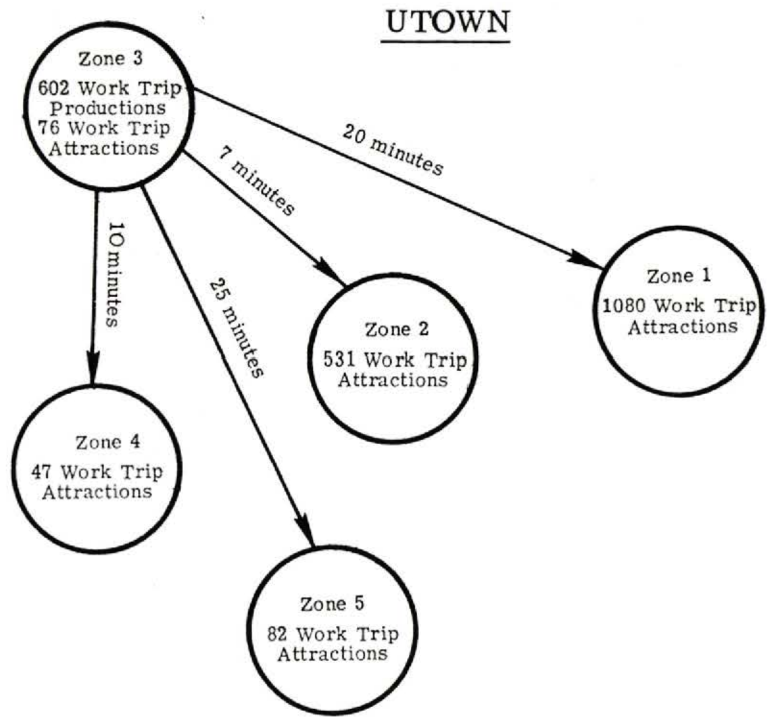
trip assignment

SAMPLE PROBLEM

The simplified sample problem using UTOWN that follows is designed to show you how the gravity model distributes trips.

We will distribute the 602 work trip productions from Zone 3 to Zones 1, 2, 4 and 5 at right. The numbers of work trip productions and attractions are determined in the trip generation phase.

Socioeconomic (K_{ij}) factors are not used in this problem.



The number of attractions in each zone is used as the estimate of the zone's attractiveness. You would expect more of zone 3's 602 trips to go to zone 1 than to zone 4. But, the travel impedance to zone 4 is 10 minutes, compared with zone 1's 20 minutes. The shorter traveltime affects the drivers in zone 3. The gravity model is designed to take both attractiveness and traveltime into account in distributing trips from zone 3.

The first thing to do is to list the zones, with their attractions, to show the relative attractiveness of each zone:

Zone	Attractions A_j
1	1080
2	531
3	76
4	47
5	82

On the basis of this tabulation, you'd expect zone 1 to get most of zone 3's 602 trips, followed by zone 2, then zone 5, then zone 3 (intrazonal trips), and zone 4.

Now we look at traveltime, which represents the separation between zones. Let's add these times to the table:

From Zone	To Zone	Attractions A_j	Impedance (minutes)
3	1	1080	20
3	2	531	7
3	3	76	5*
3	4	47	10
3	5	82	25

*Naturally, even trips that begin and end in the same zone take time, so they also must be assigned an impedance.

The next step is to enter the friction factors for each zone. These factors are determined from origin-destination data, and reflect the areawide effect of traveltime on drivers' willingness to drive to various destinations. Obtaining these factors is the principal operation of gravity model calibration, which is discussed in later sections of this chapter. The chart at right shows some friction factors for our sample study area. The friction factors represent accessibility -- with higher values being greater accessibility.

Friction Factors for Sample Problem

Traveltime (minutes)	Friction factor $F(t)_{ij}$
3.0	87
5.0	45
7.0	29
10.0	18
15.0	10
20.0	6
25.0	4
30.0	3
40.0	2

The product of the attractions and the friction factor represents each zone's relative attractiveness and accessibility -- as shown in the far-right column. This product is usually referred to as the "accessibility index" of a zone.

From Zone	To Zone	Attractions A_j	Impedance (minutes)	$F(t)_{ij}$	$A_j F(t)_{ij}$
3	1	1080	20	6	6480
3	2	531	7	29	15399
3	3	76	5	45	3420
3	4	47	10	18	846
3	5	82	25	4	328

We now have all of the information that is necessary to distribute zone 3's 602 trips.

Let's take another look at the gravity model formula:

$$T_{ij} = \frac{P_i \, A_j \, F(t)_{ij}}{\sum_{j=1}^{n} A_j \, F(t)_{ij}}$$

The socioeconomic adjustment factor (K_{ij}) was not used in this sample problem. Let's "plug in" the values that we already have, for trips going from zone 3 to 2.

Trips produced in zone 3

$A_j F(t)_{ij}$ for zone 2

$$T_{ij} = \frac{(602)\ (15,399)}{\Sigma A_j \, F(t)_{ij}}$$

Number of trips distributed from zone 3 to zone 2.

The sum of the $A_j F(t)_{ij}$'s for all zones in the study area. From the table on the next page, we see that this is 26,473.

The rest is simple mathematics:

$$\text{Trips distributed from zone 3 to zone 2} = \frac{(602)\ (15,399)}{26,473} = 350.18, \text{ rounded to } 350.$$

The numbers of trips from zone 3 to the other zones are calculated in the same manner. Here's the calculation for intrazonal trips -- trips that remain in zone 3:

$$T_{ij} = \frac{(602)\ (3,420)}{(26,473)} = 77.8, \text{ rounded to } 78.$$

Here's the completed table:

From Zone	To Zone	Attractions A_j	Impedance (minutes)	$F(t)_{ij}$	$A_j\ F(t)_{ij}$	T_{ij}
3	1	1080	20	6	6480	147
3	2	531	7	29	15399	350
3	3	76	5	45	3420	78
3	4	47	10	18	846	19
3	5	82	25	4	328	8
				Totals	26473	602

Zone 3's 602 trips will be distributed as follows: 78 intrazonal trips; 147 trips to zone 1; 350 trips to zone 2; 19 trips to zone 4; and 8 to zone 5.

As you can see, the computations in even a very simple situation can be complex and cumbersome. In an actual situation, several more steps are necessary, such as balancing attractions to assure the gravity model does not distribute more trips to a zone than it attracts according to trip generation analysis. These complex computations led to the use of computers in using the gravity model. The computer will do these computations for you -- the purpose of this example was merely to show you how the model works.

CALIBRATING THE GRAVITY MODEL

Calibration of the gravity model -- making sure that it accurately describes the travel patterns of the study area -- is accomplished by developing friction factors and, if found necessary, developing socioeconomic adjustment factors.

Developing Friction Factors

Friction factors, you will recall, attempt to show the effect that traveltime or impedance has on trip making. It is necessary to go through a trial-and-adjustment process to fit the model to the specific area that is being studied. Friction factors determined by this process are empirical measures of the effect of time or impedance on travel, and are "tailored" to each urban area.

One way to begin the trial-and-adjustment process for determining the friction factors is to use the factors from a past study in a similar urban area.

Friction factors from other areas can be used as a substitute for calibrating the gravity model if not enough information is available for a traditional calibration. An FHWA handbook of typical friction factors is referenced at the end of this chapter.

Three items are used as input to the gravity model for calibration:

1. production-attraction trip tables for each trip purpose;

2. traveltimes for all zone pairs, including intrazonal traveltimes (impedance would be substituted if combinations of costs and times are used); and

3. initial friction factors for each increment of traveltime (optional -- if none are input, initial estimates are provided analytically).

QUIZ

Friction factors attempt to show the effect of ____________________ on trip interchange.

One way to estimate the initial friction factors is to use the factors from a previous study in a similar area. True or false? ______________

In order to calibrate the gravity model, two items are required inputs:

__________________________, and

__________________________.

traveltime (or impedance)

True

trip tables, traveltimes (or impedances)

In order to calculate the friction factors, let's take another look at the gravity model formula. We'll leave out the socioeconomic adjustment factors again.

$$T_{ij} = \frac{P_i A_j F(t)_{ij}}{\sum_{j}^{n} A_j F(t)_{ij}}$$

where: T_{ij} = the number of trips produced at i and attracted to j;

P_i = the trip production at i;

A_j = the attractions at j;

$F(t)_{ij}$ = the friction factor for interchange i j (based on traveltime between zones);

i = an origin zone;

j = a destination zone; and

n = the number of zones in the study area.

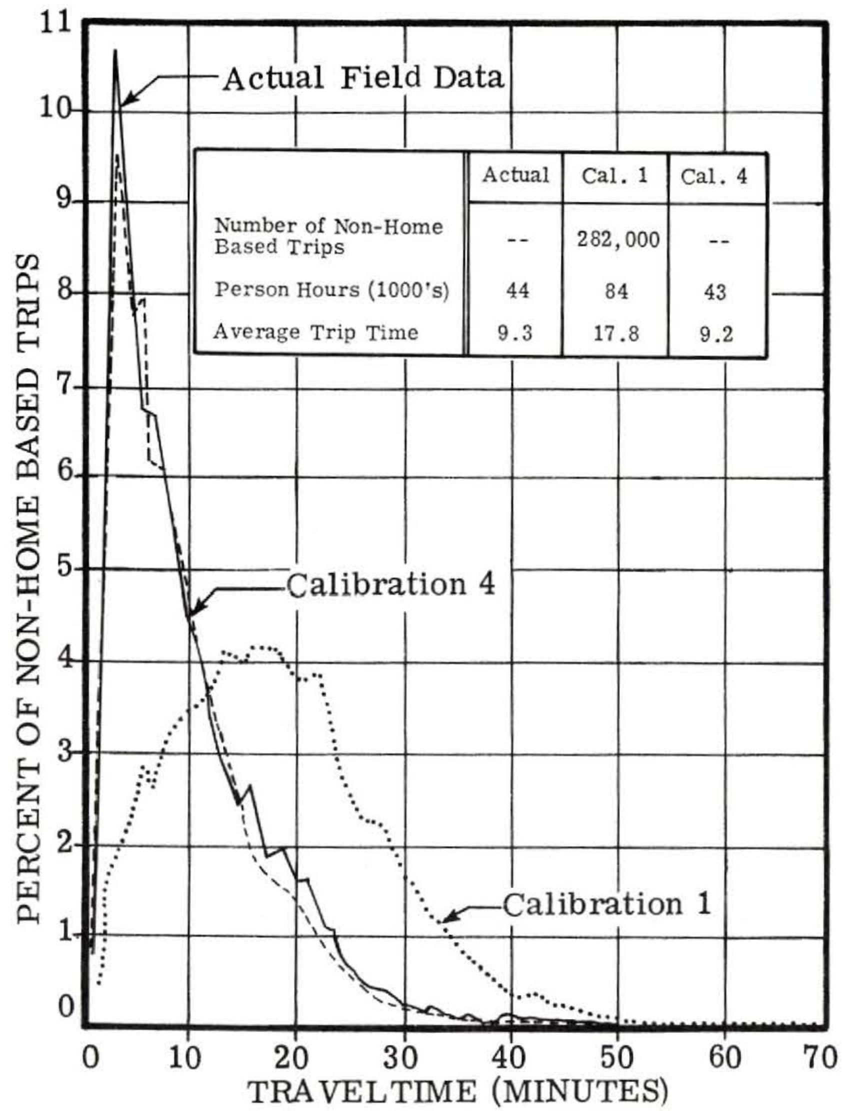
The trip production values P_i and trip attraction values A_j are obtained from the input trip tables (from the survey data). The initial friction factors can be based on judgment, obtained from similar areas, or calculated by the program.

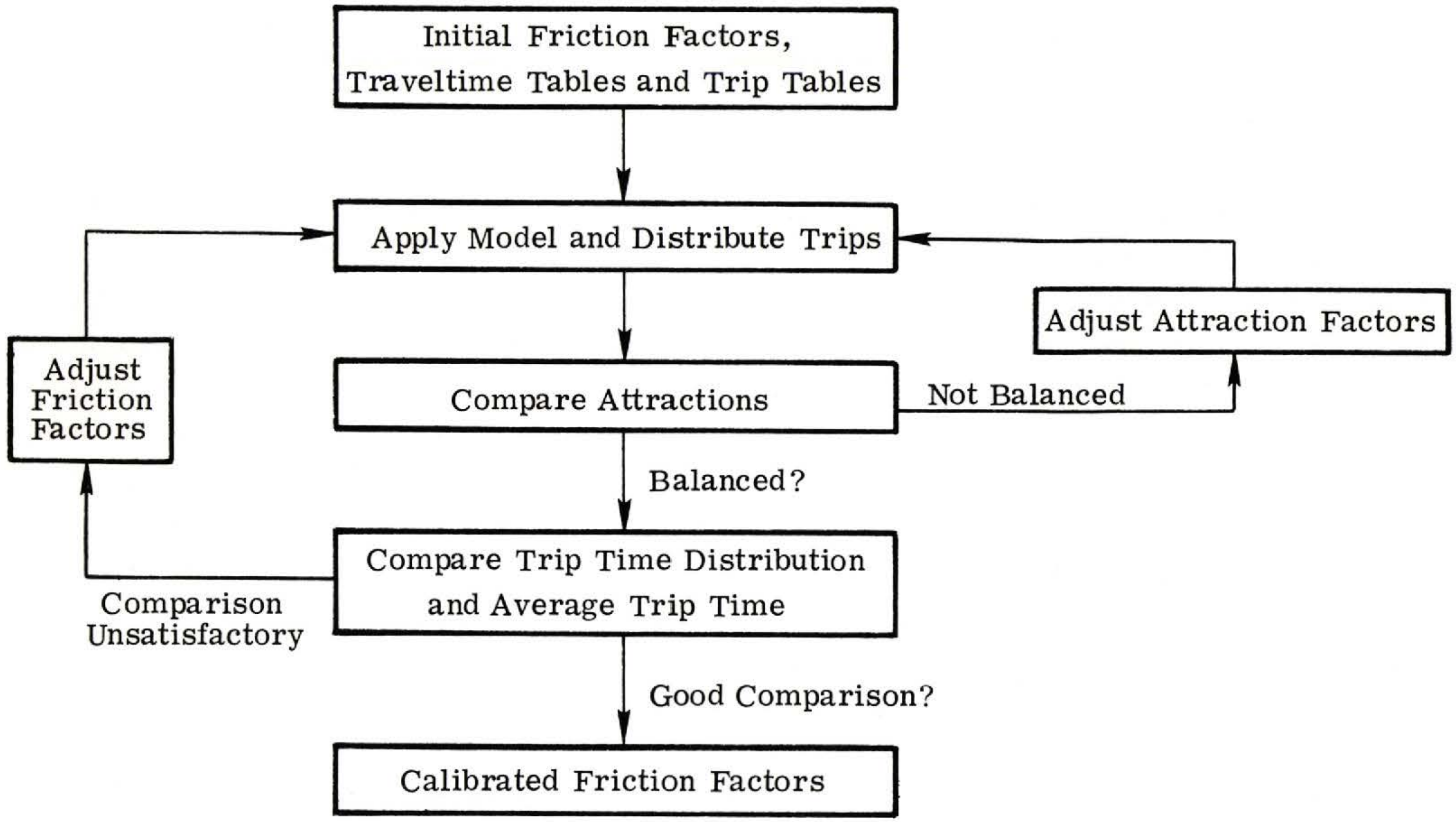
The calibration process involves adjusting the friction factor parameter until the planner is satisfied that the model adequately reproduces the trip distribution as represented by the input trip table (until the model's trip table substantially agrees with the table from the survey data using indications such as trip time frequency distribution and average trip time).

The process begins by using the gravity model to distribute trips based on initial inputs. Then, the total trip attractions at all zones j, as calculated by the model, are compared to those obtained from the input "observed" trip table. If this comparison shows significant differences, the attraction A_j is adjusted for each zone where a difference is observed. The model is rerun until the calculated and observed attractions are reasonably balanced. While these adjustments are being made, the friction factors F (t) are not changed.

After the trip attractions are reasonably balanced, the model's trip table and the input traveltime table can be used for two calculations: the trip time frequency distribution and the average trip time. These values can be compared to the values from the input trip table; if there are significant differences, the friction factors are adjusted, and the process begins again. The figure at right shows the plot of the observed traveltime distribution along with plots for an initial calibration and after four calibration runs.

Each time the friction factors are adjusted, the attractions must be compared again -- and, if necessary, the attraction factors are adjusted. The basic process for adjusting the friction and attraction factors is shown on the next page; study it carefully.





As you can see from the diagram above, the model adjusts the attractions and the friction factors until the output trip table balances with the input table -- the factors that are produced can be used to estimate future trip distributions.

Establishing Socioeconomic Adjustment Factors

There may be factors other than travel impedance that affect the travel patterns of an area. The effect of social and economic conditions can be accounted for in the gravity model using the K factors that we mentioned earlier.

In smaller urban areas, K factors usually aren't needed, but in larger areas, these factors are sometimes necessary in order to get accurate results from the gravity model program. For example, friction factors are developed for each trip purpose; since trips between all zones in the area are used to develop these factors, they represent the average area-wide effect of traveltime on trip making. However, there is some evidence that indicates that friction factors vary from zone to zone, depending on the characteristics of the people in each zone. Socioeconomic adjustment factors are intended to account for any factors, other than traveltime and trip purpose, that affect travel patterns. For example, if low-income people live near the central business district, the model may incorrectly distribute many of their trips because they are close to the CBD. K factors would adjust the interchanges so that this won't happen. However, this problem might be solved better by having separate trip distributions for various types of employment, income, or other factors.

These K factors are determined during the calibration of the gravity model. It's done after the attractions are adjusted, and after the final friction factors are obtained. Of course, adding K factors to the calibration process results in revised interchange estimates -- we add adjustment factors for interchanges that would not otherwise be adequately estimated. It must be strongly emphasized that K factors should be used only when their use can be adequately explained by some specific circumstances. They should not be used simply because the gravity model might show unreasonable values for some trip interchanges.

QUIZ

The output of the gravity model calibration is a set of ______________ ________.

If the output attractions don't balance with the input attractions, the attractions are adjusted and the model is ______________.

If the trip time frequency distribution and average trip time inputs and outputs don't compare satisfactorily, the ________________factors are adjusted.

The inputs to calibration for friction factors consist of:

________________________________;

________________________________; and

________________________________.

K factors balance the effect that unique ___________________ conditions have on trip interchange.

friction factors

rerun

friction

initial friction factors; traveltime tables; trip tables.

socioeconomic

APPLICATION OF THE CALIBRATED GRAVITY MODEL

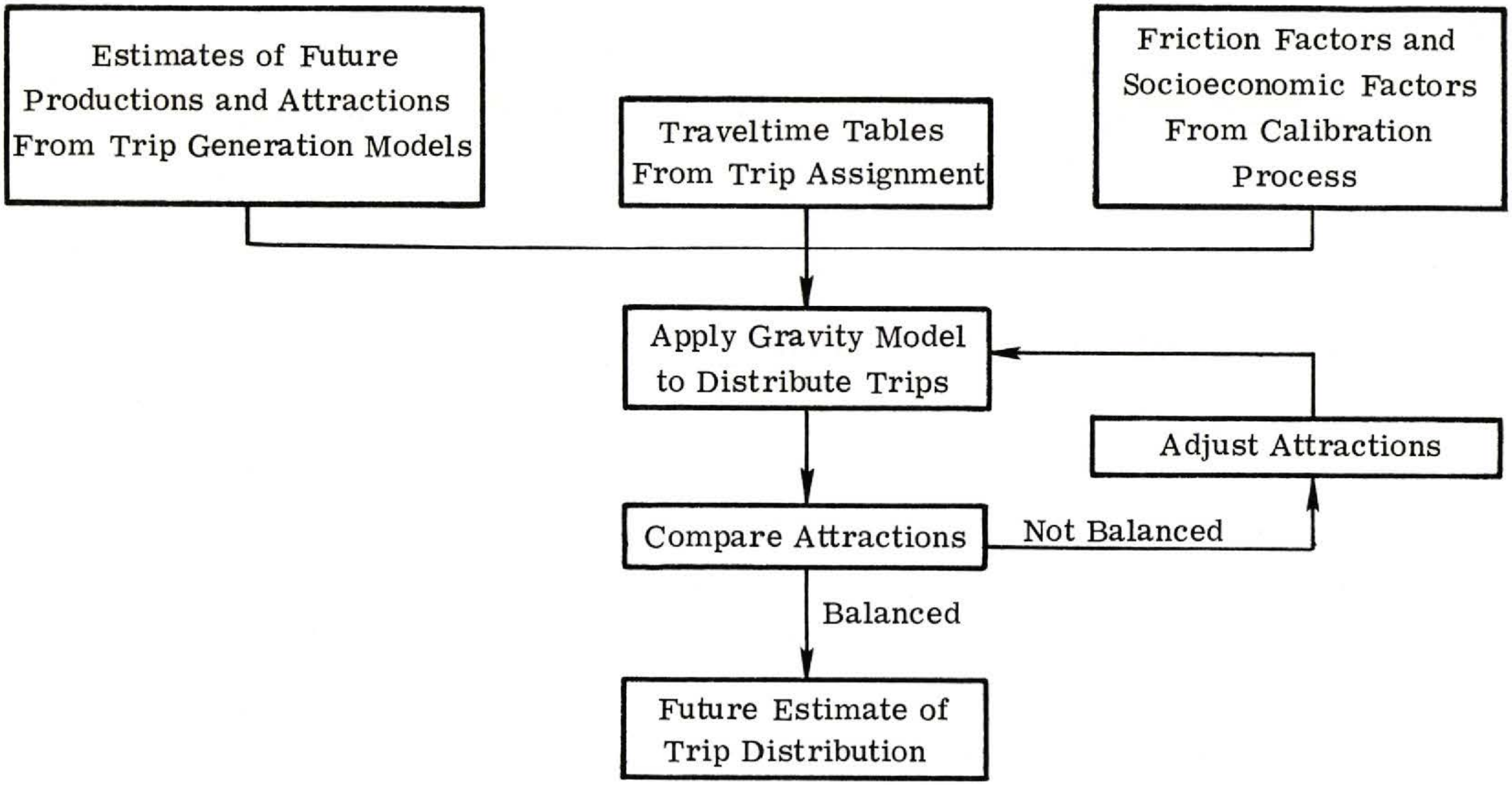
Once we have a calibrated gravity model -- a model that adequately reproduces the observed trip interchanges -- the application process is rather straightforward.

The calibration process provides friction factors that relate the effect that various levels of traveltime have on willingness to travel. The process also provides socioeconomic adjustment factors if found necessary.

The trip generation models provide estimates of future zonal productions and attractions.

Future zone-to-zone traveltimes are provided by the trip assignment process.

These inputs provide the information that is necessary to use the gravity model for estimating future trip distribution. The diagram on the next page shows how the model is applied.



Notice that in the application of the model, the trip attractions estimated by the model are compared with the attractions predicted by trip generation equations. If this comparison shows significant differences, the attractions are adjusted and the model is rerun.

Remember, the gravity model is run for each trip purpose -- therefore, a separate trip table is produced for each.

QUIZ

Friction factors and socioeconomic adjustment factors are determined during the ____________________ process.

Zone-to-zone traveltimes are determined in _______________ __________________.

Estimates of future zonal productions and attractions are made in the _________ __________________ phase.

The gravity model is run separately for each _______ _________________.

calibration

trip assignment

trip generation

trip purpose

For additional information about trip distribution analysis, consult the following documents:

Calibrating and Testing a Gravity Model for Any Sized Urban Area, FHWA, October 1965. Available from FHWA, HHP-20, Washington, D.C. 20590.

"Urban Trip Distribution Friction Factors," FHWA, November 1974. A Synthesis of Gravity Model Friction Factors for Various City Sizes and Trip Purposes. Useful in Developing Synthetic Models or as Starting F's for Gravity Model Calibration. Available from FHWA, HHP-20, Washington, D.C. 20590.

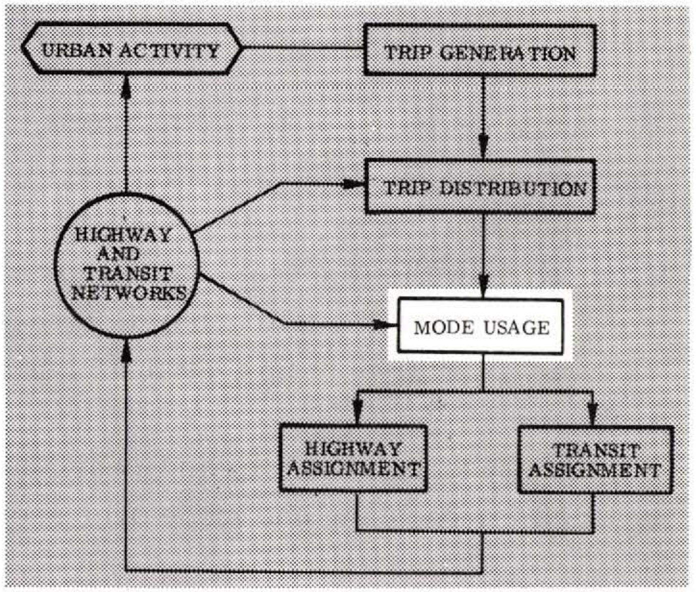
"Computer Programs for Transportation Planning -- PLANPAC/BACKPAC General Information," FHWA, April 1977. Has a chapter devoted to trip distribution. Available from FHWA, HHP-20, Washington, D.C. 20590.

Chapter Five

MODE USAGE ANALYSIS

INTRODUCTION

In our discussion of the travel forecasting process, we've looked at trip generation-- the number of trips that will be made -- and trip distribution -- where those trips will go. In this chapter, we'll discuss the modes of transportation chosen for making trips -- predicting how people decide whether to travel by car or by public transportation.



Mode usage analysis, also known as mode choice or mode split analysis, is the process by which the analyst determines the amount of travel that will be made by using each available mode of transportation in the urban area.

Mode usage analysis is, of course, a very important step in travel forecasting -- the projected demand for each mode will be a major factor in determining the amount of each mode to supply. The number of freeway lanes to add, or the number of bus lines to implement may depend to a great degree on the projected demand for those facilities; however, in these days of limited resources, we may not be able to meet projected demand. If the unlimited supply of a particular mode is unrealistic, such as extensive freeways in urban areas, we might apply mode usage analysis to determine how to shift demand from cars to public transportation.

The mode usage analysis can be done at various points in the travel forecasting process. The most common points at which the analysis is done are:

- within the trip generation phase;
- after the trip generation phase; and
- after the trip distribution phase.

We'll discuss these later, and provide examples. Right now, though, let's look at the basic reasons for choosing one mode over another.

FACTORS THAT AFFECT MODE USAGE

Before we can predict how travel will be split among the modes available, we must analyze the factors that affect choice of mode. The first two factors that come to mind are the relative costs and traveltimes of the available modes -- certainly, a fast, inexpensive mode is more attractive to travelers than a slower, more expensive one. But, there are other factors that may be important and should be considered in the mode usage analysis. These factors, including time and cost, can be grouped into three broad categories.

- characteristics of the traveler -- the tripmaker;
- characteristics of the trip; and
- characteristics of the transportation system.

Characteristics of the Tripmaker

What characteristics does the tripmaker have that might affect his or her choice of mode? The number of cars in a family -- and the number of people competing for the use of those cars -- would be important. Occupation and income could affect mode usage. People in high-status jobs with high incomes are generally less likely to ride buses. The age and sex of the tripmaker might affect the decision to use a particular mode. Thus, there are several tripmaker characteristics to consider; among the important ones are:

- family income,
- number of automobiles available,

- education level,
- family size,
- family's age distribution,
- type of dwelling,
- residential density, and
- distance from tripmaker's dwelling to the central business district.

Of course, many of these characteristics are interrelated; for example, people who live in high-density residential areas generally have fewer cars and fewer people per family than people in the suburbs.

Using a large number of characteristics to estimate mode usage would be impractical, so discovering the characteristics that best explain mode choice behavior is very important. Income and auto availability have been used widely in past studies to classify tripmakers.

Characteristics of the Trip

Trips can be made for several different purposes -- to go to work, to go shopping, to go to school, for recreation, and so on. A person who rides a bus to work every day might not want to take a bus to see a movie on a Friday night date.

Trip distance, the time of day, and the orientation of the trip within the urban area might also help to explain the reasons for choosing one mode over another.

The most widely used trip characteristic for developing mode usage relationships is trip purpose.

Characteristics of the Transportation System

Certainly, it is of the utmost importance to consider how well each of the available transportation systems meets our travel needs. If there are no bus routes to a person's desired destination, another mode must be chosen.

Automobiles have certain characteristics, and buses and trains have different characteristics. What characteristics might be important? Traveltime and the cost of travel were mentioned earlier -- let's take a closer look at traveltime.

Traveltime is usually divided into two groups:

- Riding time is the amount of time spent in the vehicle; and
- Excess time is the amount of time spent outside the vehicle (walking, parking, waiting, transferring, etc.).

This separation is made because people dislike the excess time involved in traveling much more than the riding time. That is, excess time affects choice of mode more than riding time does.

There are other characteristics of the transportation system that might affect mode usage. Reliability is important -- can you count on getting to your destination on time? Is the system comfortable to use? Comfort might include the availability of seating, proper temperature control, or shelters for bus passengers. Understanding how to use the system might be important -- if bus schedules and routes confuse you, you might prefer to take a taxi. Using a system without fear of an accident or concern for personal safety could affect choices. Some people might base their mode choice on prestige -- feeling that some modes are less prestigious than others.

There are probably many more characteristics of the various modes of transportation that affect people's choices. Again, however, using a large number of characteristics to estimate mode usage would be impractical -- traveltime and cost of travel are the characteristics most widely used to represent the nature of the service provided by the various available modes.

O.K. -- analyzing how people select a mode from the available alternatives involves consideration of the characteristics of the traveler, of the trip, and of the different modes available for use. The planner must decide which characteristics to choose to represent the mode usage decisions. The choices are made following a thorough analysis of various combinations of characteristics.

QUIZ

Mode usage analysis is most commonly done at one of three points within the travel forecasting process:

- during the ________ ________________ phase;
- after the ________ ________________ phase; or
- after the ________ ________________ phase.

trip generation

trip generation

trip distribution

There are three broad categories of factors that affect mode usage.

- characteristics of the ________________;
- characteristics of the __________; and
- characteristics of the ________________ ____________.

tripmaker

trip

transportation system

QUIZ, continued

The most commonly used characteristics of the tripmaker are _______________ and ________ ____________________.

The most commonly used characteristic of the trip is __________ ______________.

The most commonly used characteristics of the transportation systems are _________________________ and ____________.

income, auto availability

trip purpose

traveltime, cost

MODELS FOR ESTIMATING MODE USAGE

At the beginning of this chapter, we identified three types of mode usage models, according to the position of the analysis in relation to the travel forecasting process:

- analysis during the trip generation phase;
- analysis after the trip generation phase; and
- analysis after the trip distribution phase.

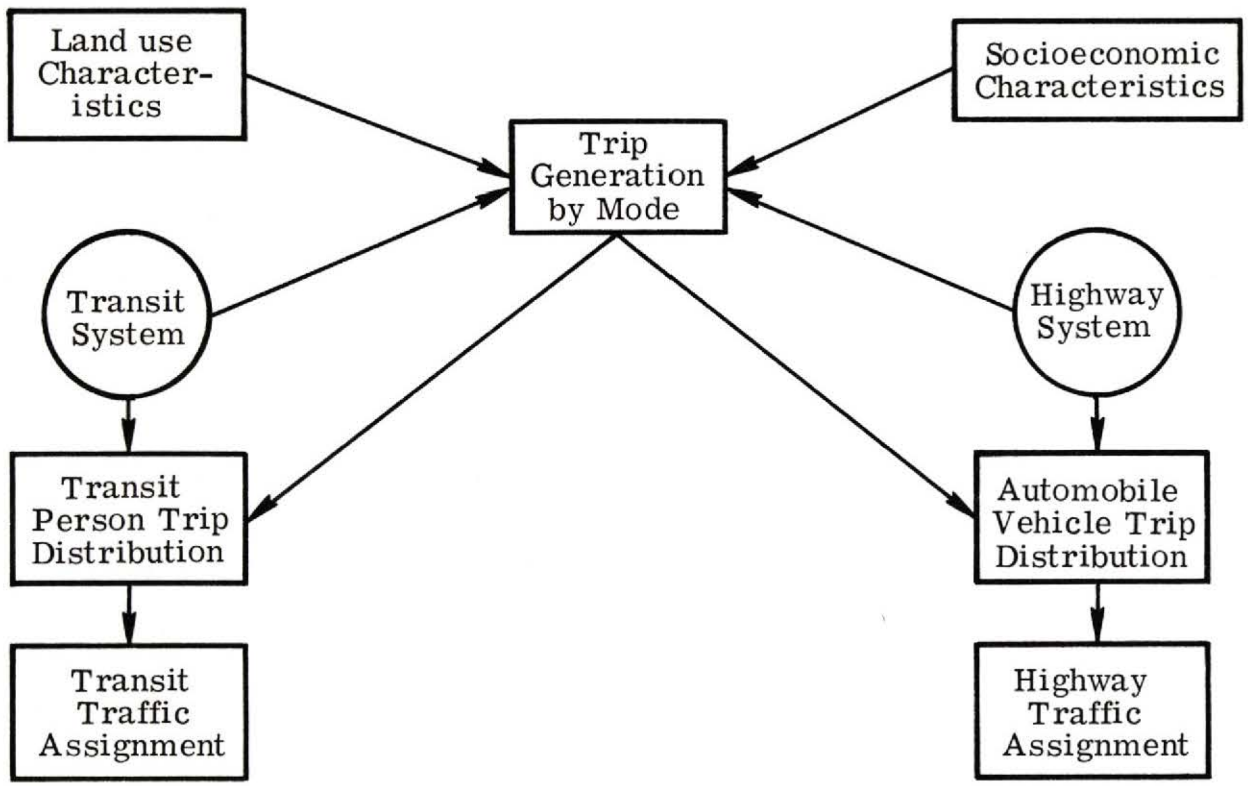
When the analysis is done within the trip generation phase, the resulting models are called direct generation models because the trips are generated, by mode, in one step. Instead of generating the total number of trips, as was done in our discussion of trip generation, trips are generated by mode -- the number of auto trips, bus trips, etc.

Mode usage models that are used after trip generation and before trip distribution are called trip end mode usage models because the trip generation phase supplies trip ends to the analysis. Because these models are rarely used, they will not be discussed in this text.

Trip interchange usage models are used after the trip distribution phase. The trip interchanges were obtained in the distribution phase, so the mode usage analysis is based on the interchanges of trips between pairs of origins and destinations.

Direct Generation Usage Models

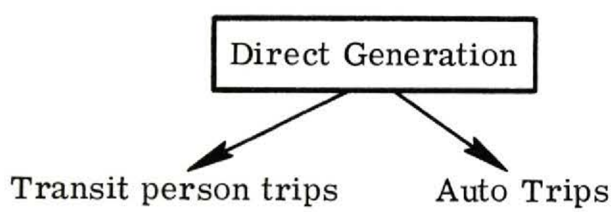
This illustration shows how direct generation works in a two-mode situation -- generation of auto trips and transit trips. The trips generated by mode are distributed to their destinations, and are assigned to highway and transit networks. This approach is generally appropriate to smaller urban areas without major transit service.



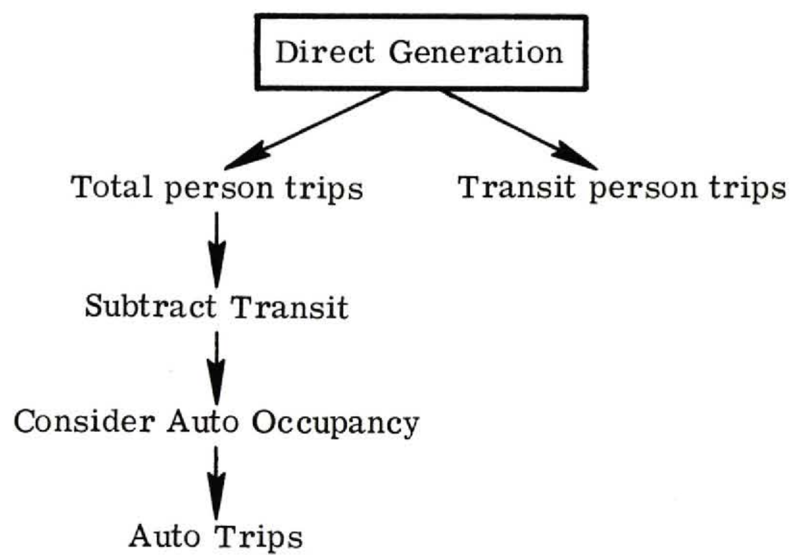
The direct generation process generates trips for two or more modes. We'll discuss generation of auto trips and transit trips.

There are two ways to generate auto and transit trips. Figure A below shows direct generation of auto trips using one set of models and generation of transit trips using another set. Figure B shows direct generation of transit trips and total person trips. If this procedure is used, transit trips must be subtracted from the total, and an auto occupancy factor must be applied to arrive at the number of auto trips.

A



B



The procedures for developing direct generation models are basically the same as the trip generation procedure that we discussed in Chapter Three. Cross-classification can be applied to direct generation by mode just as easily as it is applied to the generation of total trips. The cross-classification tables can be developed in the same manner as they were for generation of total trips, except that some consideration for the accessibility of the transit (or other non-auto) mode is included.

Accessibility can be included in cross-classification is several different ways. The simplest way is to use trip generation models that generate total trips, then develop cross-classification tables for the areas that are served by the non-auto mode. "The areas that are served" can mean areas that are within a certain distance of the service -- say, one-half mile.

One of the trip tables that we discussed in Chapter Three is shown below.

Total Person Trips Per Household

INCOME ($000's)	Autos Available: 0	1	2 or more
≤ 6	3.0	5.0	-
6-9	4.0	6.0	9.0
9-12	5.0	7.5	10.5
12-15	-	8.5	11.5
> 15	-	8.5	12.7

A table that estimates transit trips can be developed using cross-classification for the areas that are served by transit:

Total Transit Trips Produced Per Household in Areas With Transit Service

INCOME ($000's)	Autos available 0	1	2+
≤ 6	2.1	0.7	0.4
6-9	1.3	0.4	0.3
9-12	0.5	0.2	0.1
12-15	0.2	0.1	0.0
> 15	0.1	0.0	0.0

These tables can then be used to estimate auto and transit trips by a process similar to the process described in Chapter Three.

The estimates of transit ridership can be used for short-range transit planning, and to account for the effect of transit on long-range highway planning.

Remember, direct generation is generally appropriate in smaller urban areas with no major transit systems. Trip interchange mode usage models are more appropriate to large areas.

QUIZ

The approach to developing direct generation mode usage models is similar to trip generation and is known as ______________________________ _________________.

In developing cross-classification tables for direct generation, some consideration must be included for the ___________________________ of transit.

Direct generation models are appropriate only to ______________________ urban areas with limited ____________________ service.

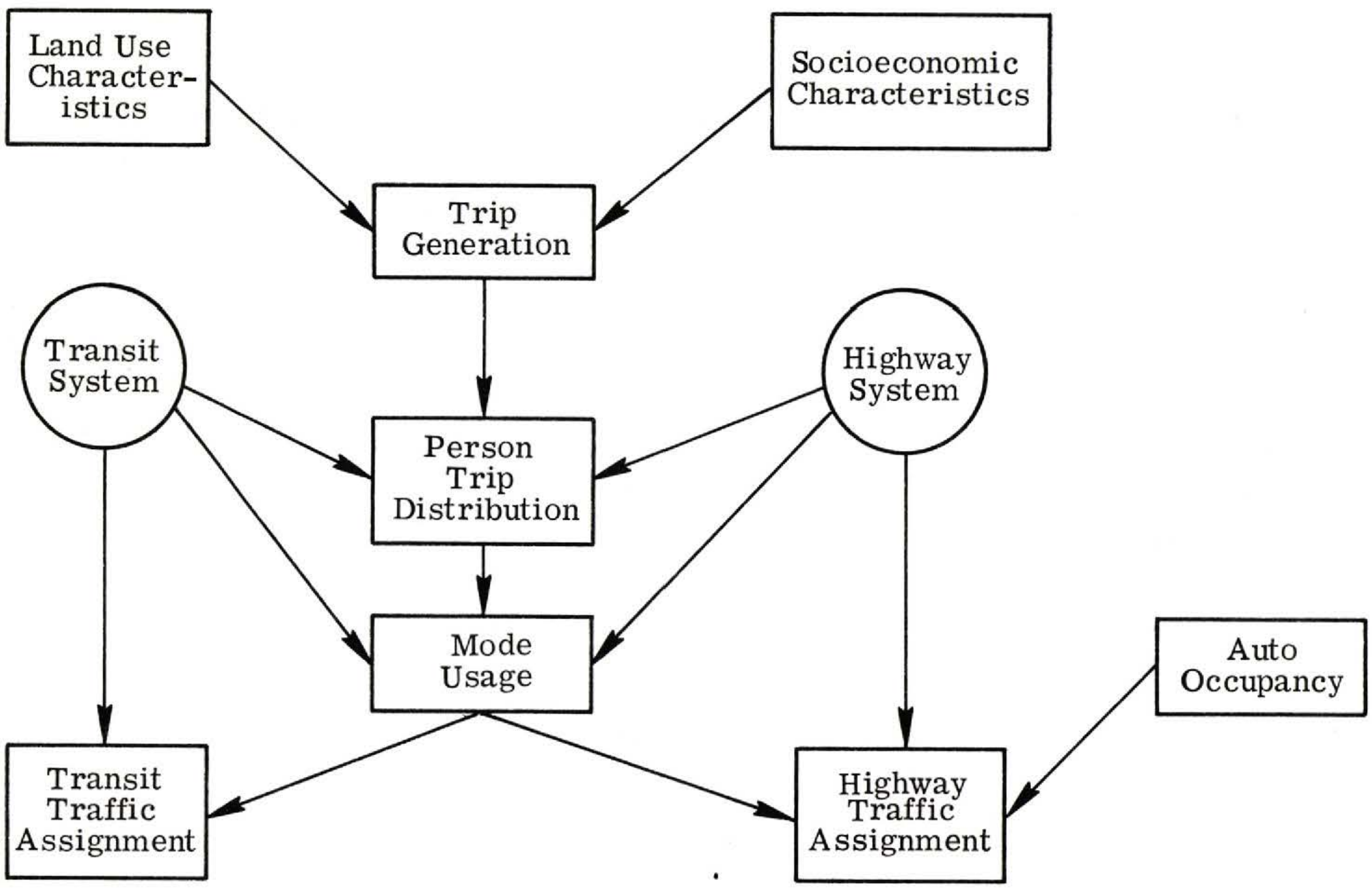
cross-classification analysis

accessibility

smaller, transit

Trip Interchange Mode Usage Models

The illustration below shows trip interchange models in the travel forecasting process.



Trip interchange mode usage models are used after the trip distribution phase. The trip interchanges were obtained in the distribution phase, so the mode usage analysis is based on the interchanges of trips between pairs of origins and destinations.

Income, auto availability and trip purpose are widely used in trip interchange mode usage models. And, since these models deal with specific zone-to-zone movements, the analyst has much stronger measures of the characteristics of the transportation systems. The measures might be in terms of the relative traveltimes or costs of travel between each pair of zones. This means that the level of service that each mode provides for each possible trip can be compared in greater detail.

The following example is typical of recent trip interchange type mode usage models.

San Diego Trip Interchange Mode Usage Model

In this model, income was used for the tripmaker characteristic. Trip purpose and trip orientation (whether the trip was in the central business district or outside it) were used as the characteristics of the trip. The characteristics of the transportation system were described in terms of the differences in cost, in-vehicle time and excess time for each pair of zones in the study area. The illustration on the next page shows some of the relationships that resulted from the study. The figure represents central business district work trips made by people with a household income of $10,000.

Here's an example of how the figure is read. Where:

- automobile in-vehicle time is 15 minutes less than transit in-vehicle time (difference = -15),

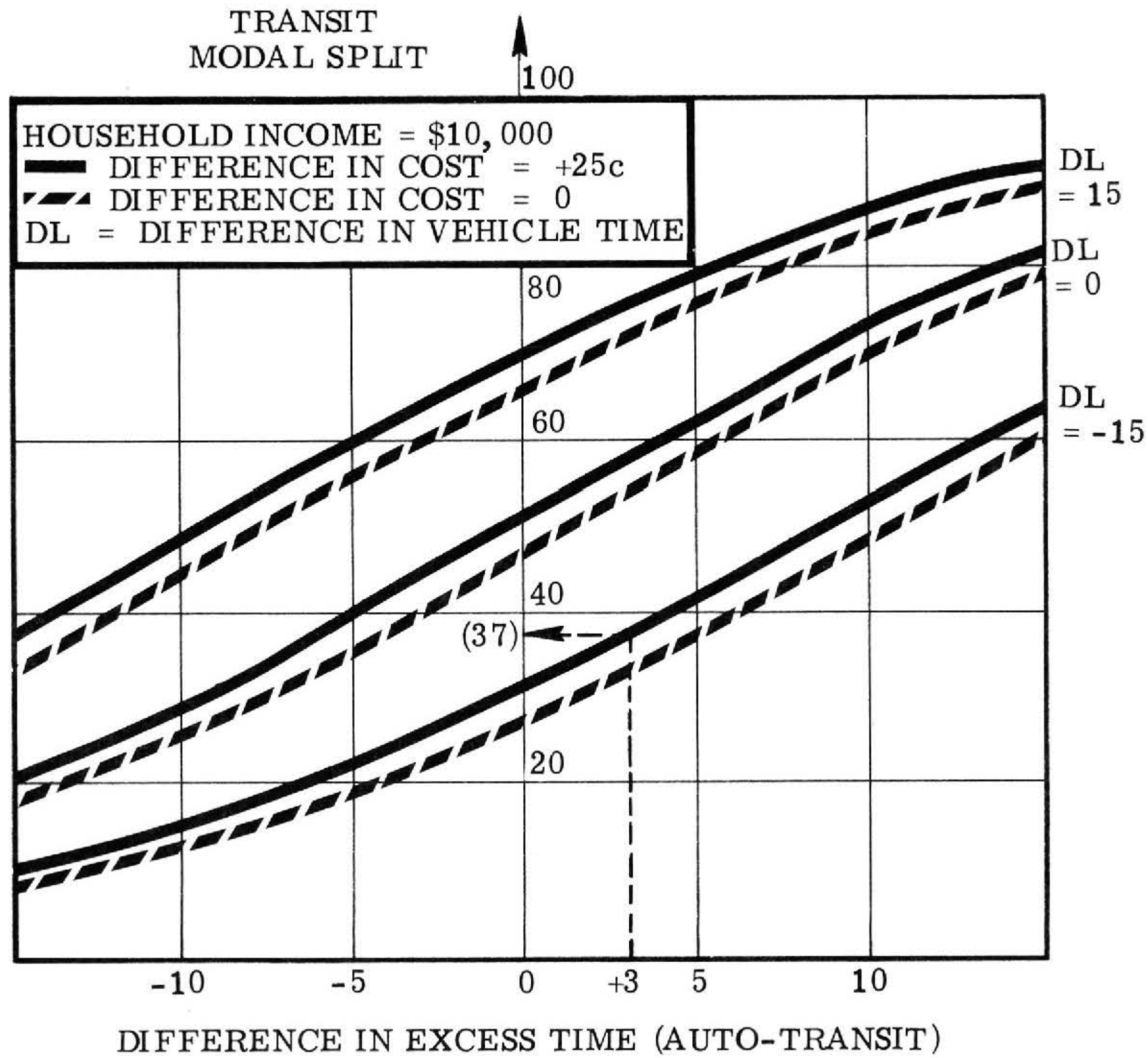
- automobile usage costs 25 cents more than transit usage (difference in cost = +$.25), and

- the excess time for auto is 3 minutes more than transit (difference = +3),

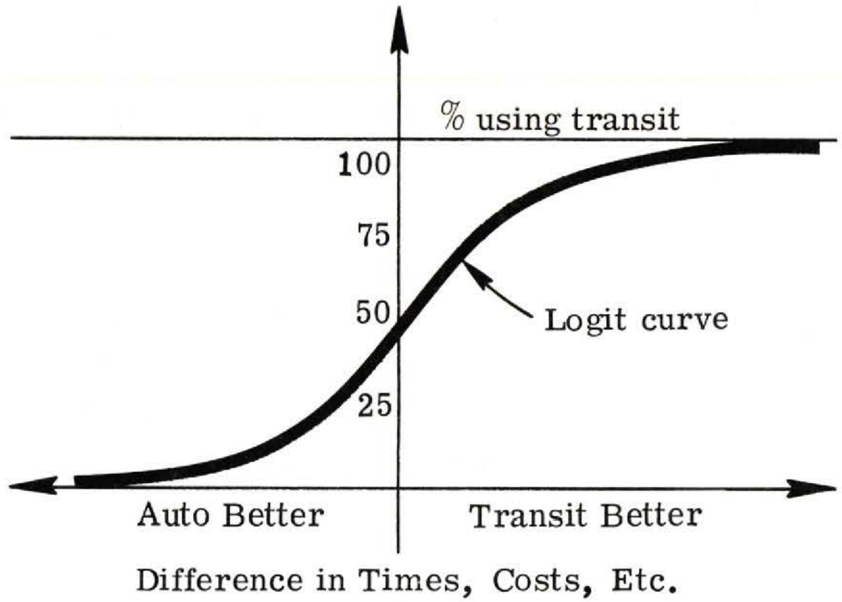
thirty-seven percent of the trips will be by transit.

Remember, this is for CBD work trips made by people with a household income of $10,000. Non-CBD trips, trips, trips with other purposes, and trips made by people with different incomes would have different curves.

The trip interchange mode usage model is appropriate for any size urban area, with any level of transit usage. It is most appropriate in larger urbanized areas with an appreciable level of transit usage, at least in some areas.



The San Diego model is an example of a family of models using a "logit" formulation. The term logit refers to the S-shaped logit curve shown at right, used to fit the model to the data.



The logit formulation is a share model (as was the gravity model) that divides the persons between the various modes depending on each mode's relative desirability for any given trip. Modes are said to be relatively more desirable if they are faster, cheaper, or have other more favorable features than competitive modes.

The better a mode is, the more utility it has for the potential traveler. The logit model takes the following form to trade off the relative utilities of various modes:

$$\text{Probability of using mode i} = \frac{e^{(\text{utility of mode i})}}{\sum_{n=1}^{\text{all modes}} e^{(\text{utility of mode n})}}$$

The exponential function "e" gives the characteristic logit curve as shown in the figure for the two-mode case. Additional modes can be considered but cannot be represented by a two-dimensional plot as shown. This logit formulation is being used in many recent studies of mode usage.

The logit formulation and other mode usage models have been used extensively in recent years to test contemporary transportation policies. For example, as air pollution became an issue, mode usage models were used to test alternative parking cost and gas tax policies. Now that energy is a major issue, mode usage models are again testing similar policies to see the impact of various energy conservation programs.

Consideration of Auto Occupancy

In order to determine the number of automobiles that will be traveling on the highway network, some consideration must be given to the number of people who will share rides. This consideration can be accomplished in several ways, depending on the mode usage procedure used.

For direct generation models:

1. As shown earlier in this chapter, auto trips can be generated directly; that is, the direct generation model predicts the number of auto driver and transit usage trips directly in one step.

2. If the direct generation model predicts auto person trips, then a relationship must be established to translate auto person trips to auto driver trips. This might be done by relating auto occupancy to the trip purpose, auto availability, and transit accessibility.

For trip interchange models:

1. The trip interchange mode usage model can be calibrated with each level of auto occupancy (1 person, 2 persons, etc.) considered a separate mode. Therefore, we might have a model in which the modes considered are transit, drive alone, 2-person auto, 3-person auto, etc. Sometimes the data base cannot support the division of travel into so many modes.

2. Alternatively, we might develop a separate auto occupancy relationship that estimates auto occupancy as a function of trip purpose, auto availability, trip end density at the destination, parking cost at the destination, and possibly traveltime if special carpool lanes are available.

Regardless of the method employed, the end result is the number of autos that must travel through the highway network. For additional information, consult the reference on auto occupancy at the end of the chapter.

QUIZ

Trip interchange mode usage models are used during the trip generation phase. True or false? ____________

In dealing with specific zone-to-zone movements, the planner has much stronger measures of the characteristics of which one of the following?

___A. tripmaker;

___B. trip, or

___C. transportation systems.

False

The San Diego mode usage model is an example of a ____________ formulation.

C

logit

autos

Consideration of auto occupancy provides estimates of the number of ____________ that will be traveling on the highway network.

For additional reading regarding mode usage analysis, consult the following documents:

"Modal Split, Documentation of Nine Methods for Estimating Transit Usage," FHWA, December 1966. Out of print. This has been widely distributed and should be available from colleagues or a library.

"Introduction to Urban Travel Demand Forecasting," UMTA, March 1974. "Volume I - Demand Modelling" - NTIS - PB #236-848/AS, $9.25. An instructional text on modern demand modelling methods.

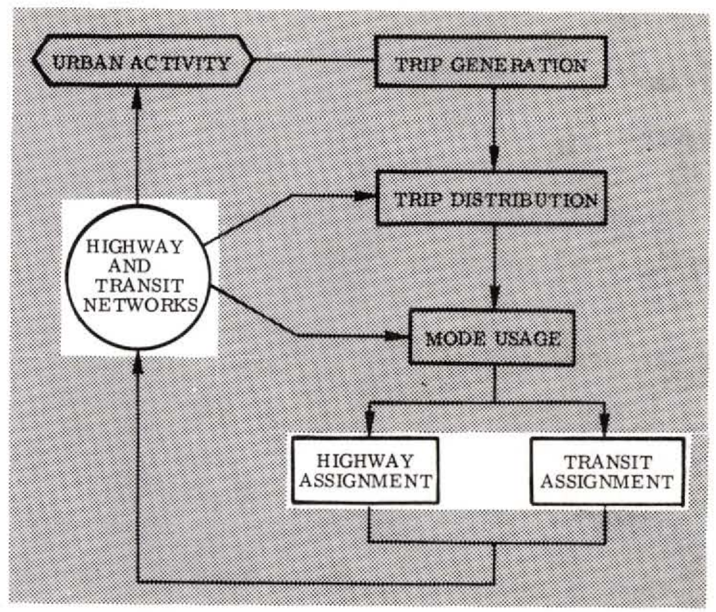
"Applications of New Travel Demand Forecasting Techniques to Transportation Planning - A Study of Individual Choice Models," Bruce D. Spear, FHWA, March 1977. A recent review of mode usage models with an emphasis on logit type formulations. Available from FHWA, HHP-22.

"Estimating Auto Occupancy, A Review of Methodology," FHWA, 1972. Available from U.S. Government Printing Office, Stock No. 5001-0035, $0.95.

Chapter Six
TRIP ASSIGNMENT ANALYSIS

INTRODUCTION

Trip assignment is the process by which we estimate the volume of travel on each individual component of the transportation system.



In this process, we can simulate volumes on the existing system or forecast volumes on alternative future systems in conjunction with the models we discussed earlier. These volumes can be the number of cars on a particular roadway, the number of passengers on a transit route, the number of passengers on a subway line, etc.

Trip assignment has many uses. Here are a few:

- developing and testing alternative transportation systems or projects;
- establishing short-range priorities for implementing transportation facilities;
- analyzing alternative locations for facilities;
- providing the necessary input and feedback for other planning tools; and
- providing design volumes for facility sizing.

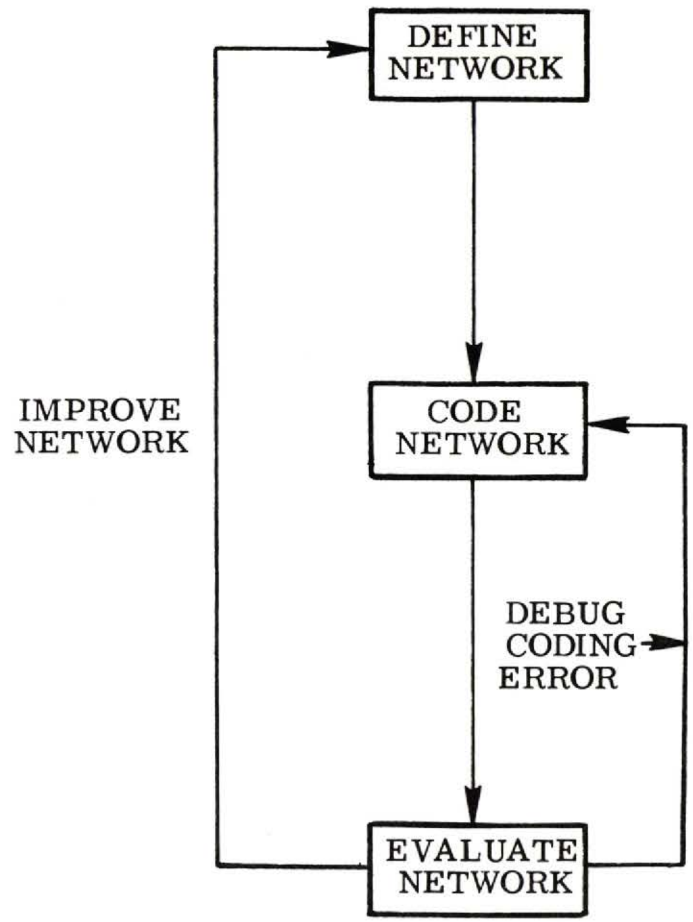
In trip generation, we forecast the number of trips that will be made; those forecasted trips are given destinations and modes by trip distribution and mode usage, respectively. Assigning the trips to specific routes and establishing volumes on links is the last phase of the forecasting process that we'll discuss in this text; this step is known as trip assignment.

The trip assignment process is preceded by what's called the network file development process. The network file development process is summarized in the figure at right and basically involves the following steps:

1. Using maps of the transportation system and a good deal of judgment, we create an abstract network representation of the actual transportation system;

2. Then the network is coded by transferring a map to a form that can be processed by computer programs; finally,

3. The coded network is evaluated in two ways: first, it is necessary to make sure the coding was done without error; and second, the network itself is evaluated to see if it adequately represents the transportation system.



Separate network files are developed for highway and transit systems. This chapter will briefly look at the development and use of these network files in the trip assignment phase of the travel demand forecasting process. You may want to review the section of Chapter Two that deals with the transportation system before you go on with this chapter.

HIGHWAY TRIP ASSIGNMENT

Highway Network File Development

It is very important to give careful attention to how the transportation system is represented for the trip assignment process. The highway network file development process can be subdivided into a series of steps, as follows:

Defining the Network

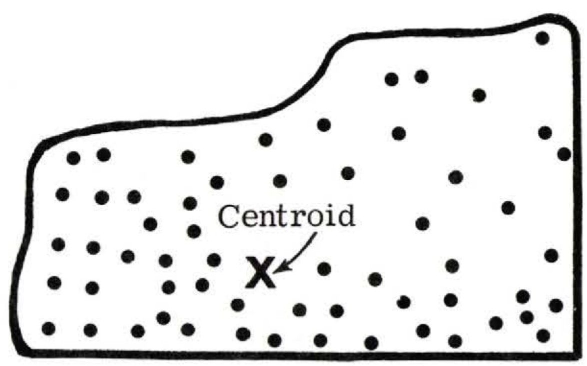
Review of Inventories and Summaries

An inventory of the existing street and highway network is one of the first studies to be undertaken in the comprehensive planning process. The results of this inventory provide the information for describing the street and highway system to the computer. The information required for each link used in the traffic assignment highway system includes items such as the link speed or traveltime, the link distance, number of lanes, type of facility, and the density of the area the link traverses.

Establishing Zones and Centroids

When establishing zones, one should consider the requirements for the traffic assignment procedure as well as the requirements for data collection. In addition, planning areas, census tracts, and the requirements with regard to traffic forecasting areas should be recognized. As a general rule, the zones should also be bounded by the highways to be included in the network.

In a trip assignment, all trips are assumed to be loaded on the higway network from a single point established for each zone. The point of loading for each zone, defined as a centroid or loading point, should be located at the center of activity for the zone. For a completely residential zone, the center of activity would be the center of gravity of the zone's population. For example, consider the following typical zone.



Assuming each spot represents 100 persons, the center of population -- or centroid -- would be established approximately as shown.

For mixed land use zones, such as residential and commercial, the location of the centroid is determined to a large extent by judgment based on expected trip ends. There is one centroid for each zone.

Establishing the Network

Judgment and a thorough knowledge of how the network is to be used are the major criteria for the selection of a network for trip assignment purposes. In selecting the network, the street classification map, traffic volumes, street capacities, and a general knowledge of the area are needed.

In general, the functional classification of the highway system plays an important role in network definition. For large areas the network may include only freeways and major arterials, while in smaller areas we might include collector streets. The decision on what to include is based on a trade-off between information requirements and cost. Including too many streets in a large urban area might result in prohibitive costs when processing the network by computer. For quick, inexpensive sketch planning we might develop a very coarse network; for subarea traffic studies, our network might be very detailed for the subarea under analysis.

The assignment procedure does not assign intrazonal trips since all trips are loaded to and from a single point, that point being the zone centroid. Therefore, if all streets are included in the system, the assigned volume would tend to be lower than the actual volume counts. On the other hand, if too few streets are included in a network, they would tend to be overloaded. This emphasizes the importance of having the network compatible with the zone system.

Connecting the Centroids

Each loading point or centroid must be connected to the street system. Because of computer program restrictions, a centroid can have no more than four connections to the system.

Locating, Defining and Numbering the Nodes

A circle or small dot is placed at each intersection in the system. These are the nodes. One of the limitations imposed by most computer programs is that there may be no more than four connections to a node. When intersections of more than four connections are encountered, it is necessary to add extra nodes at the intersection in such a way that none of them has more than four connecting links.

Coding the Network

Defining Link Parameters

Information is associated with each link in the network, to aid in determining its service characteristics and to aid in the evaluation of the highway network. These network parameters for the highway system are as follows:

- Node A -- number identifying one end of the link;
- Node B -- number identifying the other end of the link;

- Distance -- the link length;
- Time or Speed -- the time it takes to traverse the link or the average speed on the link;
- Directional Count -- the one-way count of vehicles on the link for the assignment period (e.g., peak or daily);
- Number of Lanes -- the one-way number of traffic lanes;
- Type Facility -- the physical type of facility (e.g., freeway, two-way arterial, centroid connector);
- Type Area -- the density of the area the link traverses; (e.g., CBD, fringe, suburban);
- Link Group -- a reported group of connected links that may be used to describe screen lines, cut lines, etc.;
- Link Location -- a group of links aggregated by area for reporting purposes (e.g., super districts);
- Node Coordinators -- the X, Y coordinates of each node which are required if the network is to be plotted; and
- Other information depending on intended usage and computer programs to be used.

Coding the Data

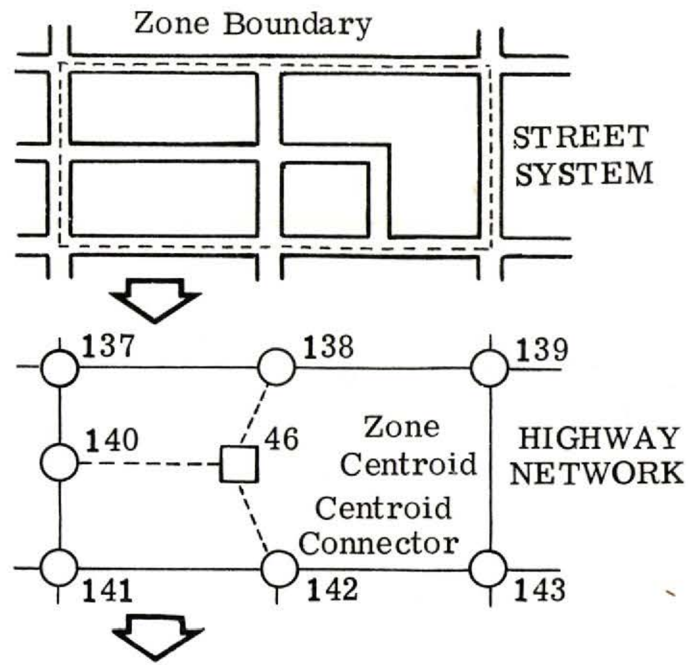
The information describing the network must be coded in a manner that can be processed by the computer. Standard format and forms are available to aid in this tedious but important process. Information for each link in the system is coded onto these forms in the prescribed format.

The figures at right summarize the highway network file development process to this point by showing how a very small portion of a highway network file might be coded. Study this for a few minutes and review the sample highway network shown in the figure on page 2-10.

Evaluating the Network File

Editing the Network File

Once the network file is coded, it can be processed on the computer. The initial processing involves testing for and correcting errors made in the coding process. Computer programs are available to check for many different types of errors. Among the errors that often result are: miscoded data items, such as speed and distance; missing links; one-way links coded as two-way; links that connect the wrong nodes; and inconsistent coding such as 50 mph speeds on CBD arterials. Many errors can be uncovered if the network file is plotted by computer procedures then compared to the hand-plotted network file used for coding. Testing a certain number of paths by tracing them through the network file to see if they are logical can also uncover errors.



Node A	Node B	Distance (Miles)	Speed (mph)
137	138	0.5	20
137	140	0.25	15
138	46	0.20	10
138	139	0.5	20
137	143	0.7	25
•	•	•	•
•	•	•	•
•	•	•	•
•	•	•	•

COMPUTER DESCRIPTION

Calibrating the Network File

After coding errors are corrected, tests are made to see if the network file abstraction of the actual highway system is a reasonable representation. This test can be made by assigning the observed trip table, which is assumed to be correct, to the coded network file and evaluating the results.

Once the observed trips are assigned to the network, the evaluation takes place at several different levels. As one check, the urban area is broken into large grids and observation of traffic across the grid is compared to traffic assigned by computer programs. If these comparisons appear reasonable, the network evaluation passes the test; if not, adjustments to the coding and network description might be required. Another check involves comparing the observed vehicle miles of travel (VMT) by function classification (freeway, arterial, etc.) on major areas with the VMT calculated by the computer program. This comparison might reveal additional problems that can be corrected by changes in the network description. The above checks will be a good indication of whether the zone system and network description are compatible. The observed volume of traffic in corridors can also be compared to that assigned by the computer programs; this comparison will provide checks to assure that the assignment is generally realistic for the major travel corridors in the area.

Future Additions to Network File

Changes to the highway system are coded and edited in the same manner described for the existing system. Since observed ground counts are not available for future additions to calibrate the network file, the planner must code future links in a manner that is consistent with the existing calibrated network file. The level of detail of the network file and its relation to the zone system must be the same for future additions as it is in the base year to maintain zone network compatabiity.

This completes our discussion of network file development. Once the network file is determined to be a realistic representation of the highway system, several options are available on how the trips will be assigned. These options are the subject of the next section.

QUIZ

The zone ________________ represents the center of activity for a zone.

The highway network file should include the level of detail necessary for the analysis being undertaken. True or false? ______________

Intersections in the network are represented by ______________.

Comparing observed traffic volumes across grid lines to volumes assigned in the trip assignment process is helpful in __________________ the network file.

centroid

True

nodes

calibrating

HIGHWAY TRIP ASSIGNMENT PROCEDURES

Several techniques are available in highway trip assignment to determine which paths through the network are to be assigned trips between zones. In this section, we will discuss three:

1. minimum path,
2. minimum path with capacity restraint, and
3. multiroute probabilistic assignment.

Several functions in trip assignment are common to all methods; we'll discuss them briefly.

Given a network, it must be analyzed to find the "paths" or routes that trips will likely take; this is known as "path finding."

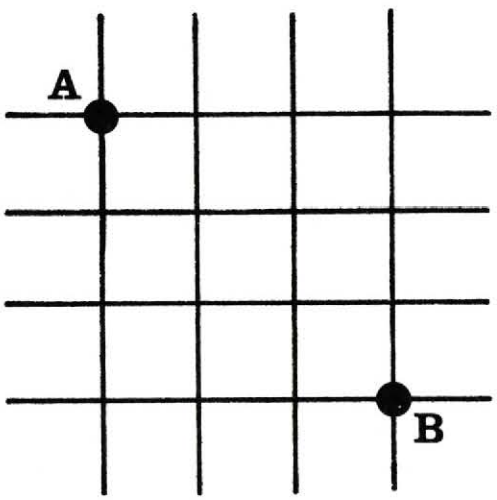
Once paths through the network are found, we can calculate the total time, cost, distance or impedance it takes to go between two points by adding the individual link values along the path. This process is known as "path skimming," since the values are skimmed from those network segments on the minimum path. These skimmed paths are used in the trip distribution and mode usage phases of the travel demand forecasting process.

With knowledge of paths, the trip assignment techniques can be used to "load" trips onto the network by assigning them to specific paths. This results in the estimates of travel on each link. Some common assignment techniques will be briefly discussed in the pages that follow.

Minimum Path Techniques

Minimum path techniques are based on the assumption that travelers want to use the minimum impedance route between two points.

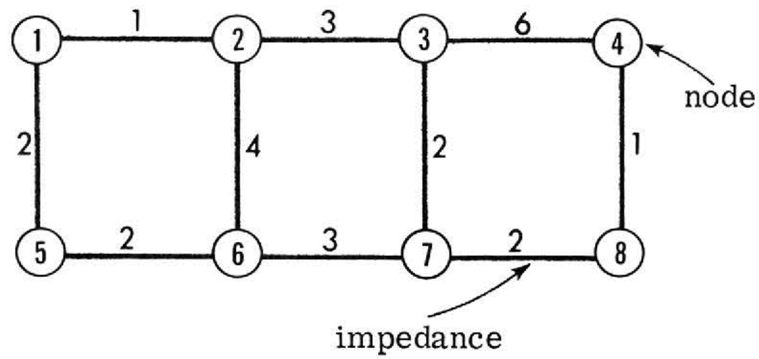
Efficient methods of determining minimum paths had to be developed, since -- as you can imagine -- manual determinations would be nearly impossible. In the diagram at right, 40 different paths must be tested in order to determine the minimum path between A and B. You can see what the problem would be in an area with thousands of links.



Work that was undertaken to determine the minimum paths for long-distance telephone calls provided the help that planners needed. Rather than simply testing each path, these new "algorithms" allowed planners to find minimum paths to complete networks.

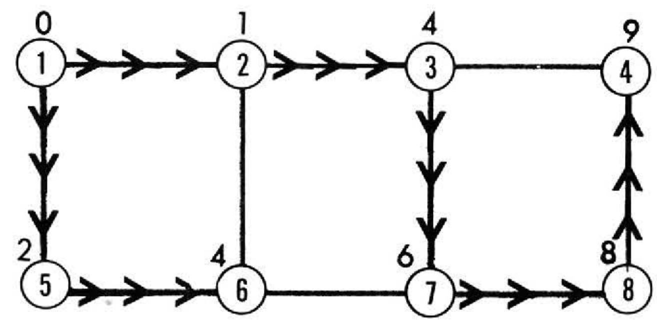
With the most widely used algorithm it is not necessary to investigate each possible route between an origin and a destination in order to find the shortest route.

In using the algorithm, minimum paths are developed by fanning out from the origin to all other nodes. Determining the minimum paths from Node One to each of the other nodes results in a "tree" from Node One.



Here's an example of how the algorithm is used to build trees. Since going from node 1 to node 6 via node 2 takes five minutes of impedance, and it takes only four minutes by way of node 5, link 2-6 is eliminated from the tree. The algorithm also eliminates links 3-4 and 6-7 in a similar fashion, resulting in the tree in the lower diagram. This tree shows the minimum path from node 1 to all other nodes in the diagram.

The tree is built successively using the terminal node nearest the origin of the tree as the next branching node. All links connected to the branching node are added to the tree, and their terminal nodes become branching nodes.

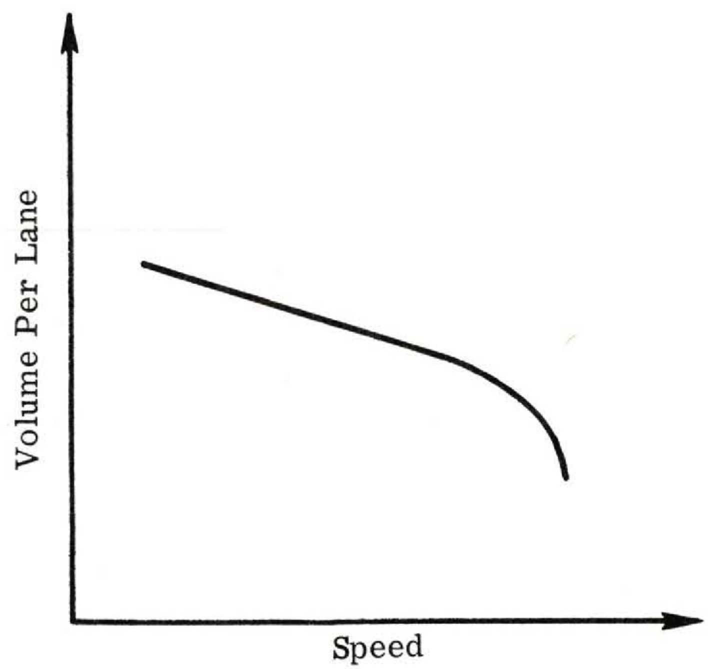


TREE FROM NODE ONE

Once the minimum paths are found, the trips between zones are loaded onto the links making up the minimum path. This technique is sometimes referred to as "all-or-nothing," since all trips between a given origin and destination are loaded on the links comprising the minimum path and nothing is loaded on the other links. After all possible interchanges are considered, the result is an estimate of volume on each link in the network. This method can cause some links to be assigned more travel volume than the link has capacity at the original assumed speed. This volume/capacity problem led to the development of trip assignment procedures to be discussed in the following pages.

Minimum Path with Capacity Restraints

Capacity restraint techniques are based on the finding that as the volume of traffic increases, the speed of traffic decreases. There is a relationship between speed and volume of all types of highways. This relationship is shown graphically at right.



The trip assignment process assigns trips according to the impedances coded on the links of the network. The result of this process is the traffic volume on each link of the network.

Since there is a direct relationship between travel time (or speed) on a link and the volume on the link, a process was developed to allow for consideration of this relationship. This process is called capacity restraint. Capacity restraint attempts to balance the assigned volume, the capacity of a facility, and the related speed.

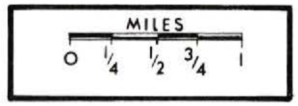
There are several methods of utilizing capacity restraint in a trip assignment. The most common method is simply to load the network and adjust assumed link speeds after each loading to reflect volume/capacity restraints. These loadings and adjustments are done incremently until a balance is obtained between speed, volume, and capacity. Experience has shown that a reasonable balance can be obtained after 3 or 4 loadings.

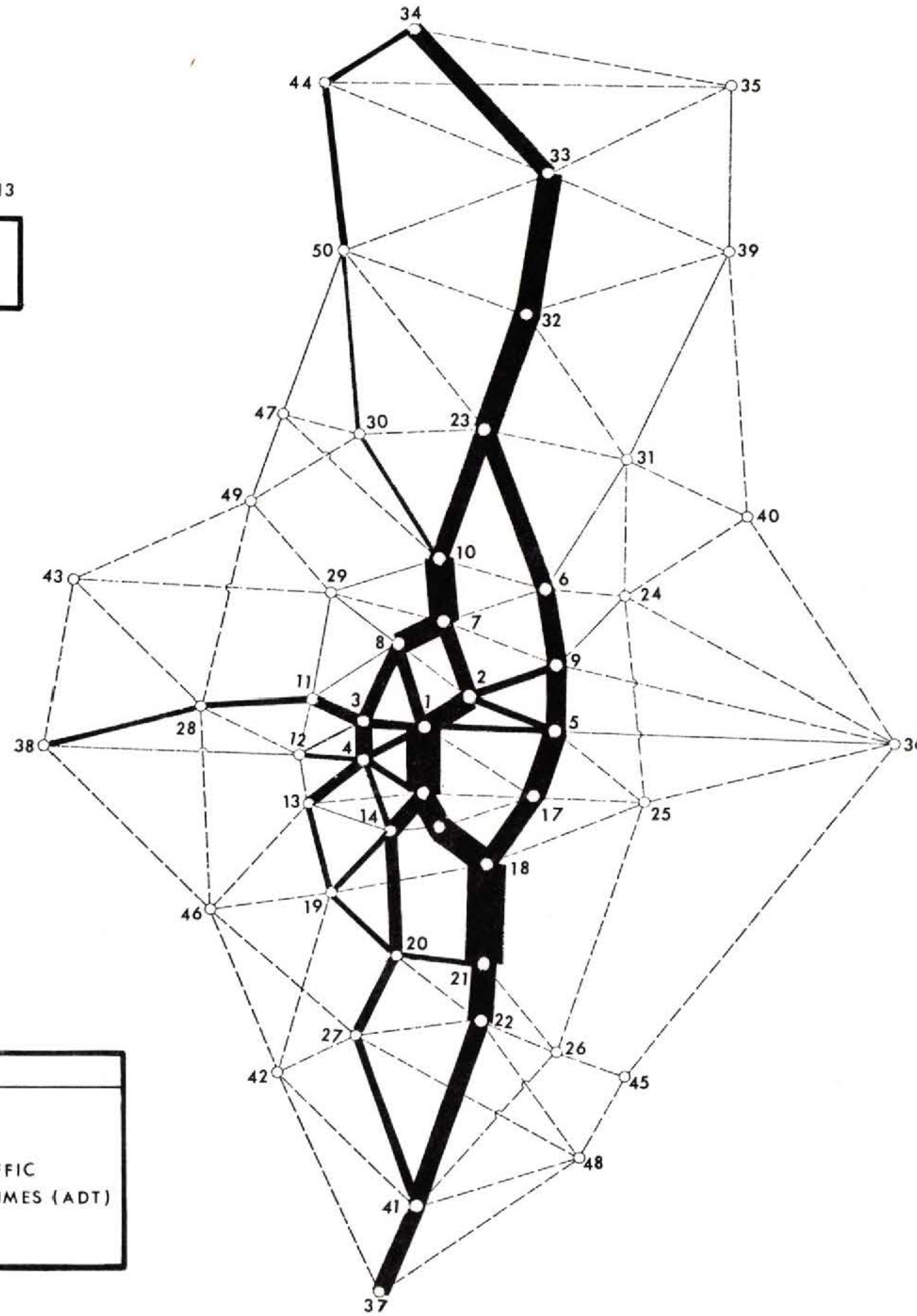
Multiroute Probabilistic Assignment

This technique recognizes that several routes between two points might have nearly equal impedances -- and, therefore, equal use -- and that there is some probability that even longer routes will be taken by some travelers.

Using this approach, trips are assigned to reasonable paths between zones as a function of the path's relative impedance. Therefore, paths of equal impedance would receive equal traffic and longer paths less traffic. The probabilistic assignment technique considers a path between zones only if every link in it has its initial node closer to the origin than its final node.

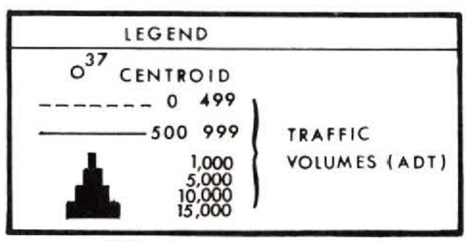
TRIP ASSIGNMENT NO. 13





This assignment should result in a more realistic representation of traffic on the network and is now in fairly widespread use.

Regardless of the technique used, the highway trip assignment procedure results in estimates of the volume of traffic on each link in the network. The figure at right shows a graphical representation of a loaded network.



QUIZ

A specific route through a network is known as a ____________.

Calculating the time it takes to traverse a path is known as __________________.

Capacity restraint procedures attempt to bring ________________, __________________ and ____________ on each link into balance.

path

skimming

volume, capacity, speed

TRANSIT TRIP ASSIGNMENT PROCEDURES

The transit network file development involves essentially the same steps as development of the highway network file. Naturally there are overlaps in information requirements for the two networks and one should not undertake the development of transit networks without a thorough review of what's been done for highways.

Defining the Network

Review of Existing Transit Data

Transit route maps can usually be obtained from the transit companies, along with time schedules and, possibly, passenger counts. These data can provide much of the necessary information for preparing transit networks, such as (1) origins, destinations and paths of existing transit lines; (2) headways (average time between transit vehicles); (3) distance between stops; (4) time or speed between stops; and (5) maximum passenger load points.

Establishing Zones and Centroids

The zones and their centroids will likely be the same as those used for highway assignments. If for some reason a zone system has not been developed for the highway system, the same principles can be applied to develop one for transit.

Describing the Network

A transit system is described for computer analysis by defining the zones, the transit routes that are operated (lines), the types of transport operations (modes), the facilities over which the system operates (links), and the intersections of links (nodes). The transit network differs from that used for highway analysis in that, for transit network simulation, it is necessary to represent both the travel facilities (links) and the ordered sequences of links (lines) on which services are offered.

Thus, the network representation is a two-tiered structure. A system of links is established defining the guideway as segments of travel facilities between points of transfer, including travel time or speed, and distance. The second-level network of lines overlays the links and defines fixed routes.

One feature of the two-tiered structure is that there need not be lines on all links. When many similar systems are to be considered, it is possible to code all feasible links and simply change line descriptions to change the network.

Connecting the Centroids

Access to the transit system can be provided in one of two ways. Walk links are used to represent connections to the transit system when the distances are short enough that walking will be the primary access mode. These links represent the average walking access time for a zone. Auto connector links are used to represent access by private vehicle when a connection to a zone is beyond a reasonable walking distance and the planner feels that people may drive to the transit stop. Unlike the highway network, not all centroids must be connected to the transit network.

Locating, Defining and Numbering the Nodes

Nodes are points in the transit network where transfers are made from one line or mode to another line or mode, but not all intersections, transit stops, and stations are nodes in the system. Nodes are limited to legitimate transfer points only, which means that a bus stop that does not permit transfer to another transit mode or line, or is not joined to a centroid by a walk or auto link, need not be a node. Thus all lines, walk links or auto links entering a node are considered transfer possibilities. A node is not, therefore, just a transit stop but should always imply that a transfer to another line or mode of transit (includes walk and auto links) is possible.

The zone centroids should be numbered one-two-three until all zones are assigned a number. A group of numbers should be set aside for future centroids and then the network nodes numbered. At the present time the transit nodes are numbered separately from highway nodes due to computer software requirements. Work now under way will allow for the coding of a single unified network.

Coding the Network

Defining Link Parameters

For each link in the network, information is associated with it to provide data on its characteristics. The following information is necessary:

- Node A -- number designating one end of link;
- Node B -- number designating other end of link;
- Modes -- code identifying the modes operating on that link (these can be transit-type modes, such as bus or subway, or non-transit modes, such as walk or auto);
- Distance -- length of link in miles;
- Speed or Time -- the time it takes to traverse a link or the average speed on the link (this can be provided for two peak periods and off peak); and
- Fare -- a fare indication on links where the fare changes.

Defining Line Parameters

As mentioned earlier, the transit network is a two-tiered system with lines operating over links. The transit lines represent the actual paths that the transit vehicles take through the network and require the following information:

- Transit Company -- an indicator so that separate companies or divisions may be identified;

- Mode -- the type of transit service provided, such as subway, express bus, local bus;

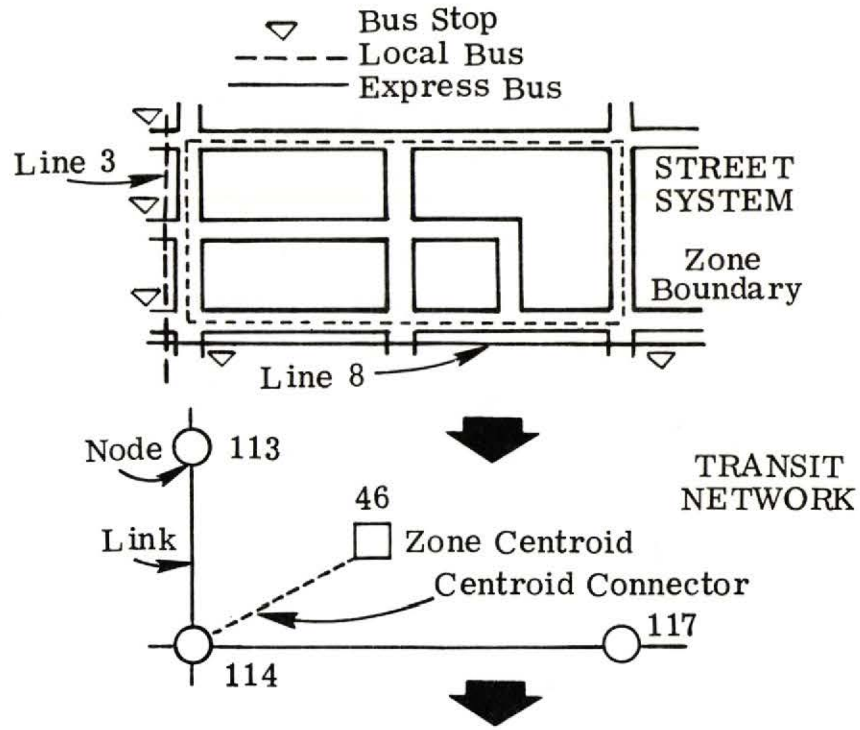
- Headway -- the average time between buses for various periods during the day; and

- Route description -- a sequential list of node numbers over which the line operates.

Coding the Data

The information for the transit network links and lines is transferred to coding sheets, then keypunched for computer processing.

The figures at right summarize the transit network file development process for a very small segment of a transit network file. After observing these figures you might review the figure on page 2-10 which showed a similar example of a highway network file.



Link Cards

A Node	B Node	Modes	Distance (mi.)	Time (min.)	Etc.
46	114	1		3.0	
113	114	4	0.7	4.2	
114	117	5	1.0	6.0	

Line Cards

Mode	Line	Headway (min.)	Etc.
4	3	10.0	
5	8	15.0	

COMPUTER DESCRIPTION

Evaluating the Network File

Editing the Network File

After the link and line data have been coded, computer programs can be run that produce reports to enable the planner to identify and correct coding mistakes. These programs identify logic mistakes, card sequencing, link and line compatability, and, if required, information appears. The mistakes are corrected and the network file updated to reflect these corrections.

Automated plotting routines can aid greatly in the network editing process as well as checking selected paths for logic.

Calibrating the Network File

Once the network file is edited for mistakes in coding, an observed transit trip table can be assigned to it and checks can be made to see if the network reasonably represents the existing transit system. Several checks can be made, including comparisons of passenger loadings, route mileage, vehicles miles and hours of service, vehicle requirements, and other items. If major differences are encountered, alterations to the network file description may be required, such as adjustments in the headways, link times, or speeds.

In transit assignment, trips between two zones are assigned to a path through the network. The path is approximated by the "minimum weighted time path," where the times to traverse various types of links are weighted to reflect differences in the values that transit passengers place on time spent walking, waiting, and riding by various modes.

The basic assumptions of the algorithm are:

- the time to traverse a link is constant; and
- the time spent waiting to transfer is satisfactorily estimated by one-half the inverse of the headway of the line the passenger is transferring to, or not more than a specified maximum.

Passengers are assigned to the transit network based on these minimum time calculations, weighted by each category of time (walking, waiting, riding).

Output from the procedure includes:

- volumes on walk and auto connector links;
- a summary of mode-to-mode transfers;
- total trips assigned;
- loads, by line, between stops;
- passengers off and on at each stop; and
- summaries of passenger-miles, passenger-hours, and peak loads.

These outputs canbe used to calibrate the existing network file or to evaluate the effectiveness of proposed new services.

QUIZ

In transit trip assignment, the network file is represented as a two-tiered structure where ______________ represent facilities and ______________ represent the fixed routes.

All bus stops must be coded onto the network file to assure adequate representation. True or false? ____________

links, lines

False

Comparison of estimated and observed passenger loadings is helpful in ____________ ____________ ______________.

network file calibration

For additional information about trip assignments, consult the following documents:

"UTPS Network Development Manual" (on UTPS tape). Covers transit network coding for use in UTPS programs.

Traffic Assignment, FHWA, August 1973. Available from FHWA, HHP-20, Washington, D.C. 20590. Covers aspects of traffic assignment and some network coding issues.

"Computer Programs for Transportation Planning - PLANPAC/BACKPAC General Information Manual," FHWA, April 1977. Has a chapter on network file development.

Chapter Seven

REVIEW QUIZ

You've completed the course; now, to evaluate your comprehension of the subject matter, take the quiz that begins on the next page.

If you answer 85% of the questions correctly, you've done well; if not, you should review the sections that gave you trouble and take the quiz again. To help you find those sections, we've added the textbook page that each question comes from.

The quiz isn't meant to test your memory -- so don't spend too much time on any one question; but think about each, and try to reason them out.

Urban transportation planning leads to decisions on transportation policies and programs. Travel demand forecasting predicts the impacts on ________________ that these policies and programs will have.

TSM means ________________ ________________ ________________, with the emphasis being on ________________.

Installing reversible lanes to accommodate rush-hour traffic is one way to "ensure that existing road space is used efficiently." True or false? ________________

The long-range element of the transportation plan is primarily concerned with capital-intensive improvements. True or false?

____

travel (page 1-1)

Transportation Systems management, management (page 1-2)

True (page 1-7)

True (page 1-10)

Travel demand forecasting provides important inputs to the TSM element, to the __________ element, in plan refinement, and in the ________________ process.

Urban activity forecasts are a major input to the ______________ ______________ phase.

Mode usage analyzes the characteristics of the traveler, the trip and the ________________ ______________.

Trip distribution forecasts the ________________ of the trip productions.

The study area boundary is known as the ___________ ________.

long-range, continuing (page 1-17)

trip generation (page 1-23)

transportation system page 1-29)

destinations (page 1-27)

cordon line (page 2-2)

The study area is divided into small analysis units known as ______________.

Once zones have been established, information about the character and intensity of _________ is gathered.

Numbering the nodes on the network provides definitions of ______________ between the nodes.

____________________ is a combination of time and cost used to describe the difficulty in using any link.

Travel information allows the planner to ____________________ the necessary travel nodes.

zones (page 2-3)

activities (page 2-6)

links (page 2-9)

impedance (page 2-12)

calibrate (page 2-14)

Extensive home interviews are now required to obtain travel data. True or false? ________

Measures of ______________ and ___________________ of urban activities are input to trip generation.

Special generators represent large or unusual concentrations of trip ends. True or false?

____

The recommended approach to trip generation analysis is called

__________-____________________.

Trip ends that have one end outside the cordon line are known as

___________-_____________trips.

False (page 2-14)

amount, character (page 3-2)

True (page 3-4)

cross-classification (page 3-6)

internal-external (page 3-9)

Trip production and attraction rates can be developed from travel surveys or borrowed from similar areas. True or false? ______________

The gravity model distributes trips from the ________________ zone to the ________________ zone.

Home-based trips are always produced at the ______________ end and attracted to the ________________ end.

True (page 3-16)

production, attraction (page 4-6)

The most often used measure of the separation of zones is ____________________.

home, non-home (page 4-6)

traveltime (page 4-7)

A more general term, which also represents the separation of zones, is ___________________.

impedance (page 4-8)

K factors balance the effect that unique ____________________ conditions have on trip interchange.

The most commonly used characteristics of the tripmaker are ____________ and ____________ ____________________.

The approach to developing direct generation mode usage models is similar to trip generation and is known as ______________ ____________________ ________________.

Trip interchange mode usage models are used during the trip generation phase. True or false? ____________

The zone ______________ represents the center of activity for a zone.

socioeconomic (page 4-8)

income, auto availability (page 5-3)

cross-classification analysis (page 5-12)

False (page 5-15)

centroid (page 6-5)

In transit trip assignment, the network file is represented as a two-tiered structure where ____________ represent facilities and ____________ represent the fixed routes.

links, lines
(page 6-21)

GLOSSARY

Activity System

All nontransportation aspects, including land use and socioeconomic variables, of an area that affect the demand and nonuser impacts of the available transportation alternatives.

Aggregate Demand Model

Model obtained by combining travel observations for individuals into geographic zones. These combined observations are used to estimate new flows when service attributes or zone sizes change. (See also disaggregate demand model.)

All-or-Nothing Assignment

The process of allocating the total number of trips between each pair of zones to the path or route with the minimum traveltime.

Alternative

For travel demand modeling purposes, a unique combination of number or frequency of trips, time of travel, mode of travel, trip destination and travel route. Relevant alternatives for a given potential traveler are those combinations that have some positive probability of being chosen.

Analysis Area

Any geographic area such as a zone or group of zones combined for the purpose of making an analysis.

Annual Element

A list of transportation improvement projects proposed for implementation during the first program year.

Appropriate Local Officials

(a) In urban areas under 50,000 population, the principal elected officials of general purpose local governments. (b) In urbanized areas, the principal elected officials of general purpose local governments acting through the Metropolitan Planning Organization.

Assignment

Process by which trips described by mode, origin, destination, and time of day are distributed among the various available paths or routes in a network according to one of a number of flow distribution rules.

Attraction

The pull or attracting power of a zone. For non-home based trips, attractions in a zone can be considered synonymous with trip destinations in that zone.

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 two-lane or three-lane highway) during 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. The capacity would not normally be exceeded without changing one or more of the conditons that prevail. In expressing capacity, it is essential to state the prevailing roadway and traffic conditions under which the capacity is applicable.

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.

Census Tract

Small areas into which large cities and adjacent areas are divided for the purpose of providing comparable small area population and housing census tabulations.

Central Business District (CBD)

Usually the downtown retail trade area of a city, or generally an area of very high land valuation, traffic flow, and concentration of retail business offices, theaters, hotels, and service businesses.

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 of zonal area.

Comprehensive Planning

A planning process which requires inclusion of land use, transportation, water and sewer, education, health, and other elements.

Cordon Line

An imaginary line enclosing a study area, along which external interviews are conducted.

Demand

Used in an economic sense and based on the theory and methodology of consumer demand, a schedule of the quantities of travel consumed at various levels of price or levels of service offered by the transportation system. Demand is not a fixed amount of travel, but a function of level of service. Nearly all urban travel forecasting methods are based on the concepts of travel demand and transportation facility supply interacting in a transportation network as the market to produce an equilibrium flow pattern.

Destination

Location to which trips are made, variously identified as a zone of specified area (in aggregate travel forecasting) or a location with a specified "attraction power," measured by things such as employees (for work trips) or square feet of sales area (for shopping trips).

Deterministic Model

Model that provides the "best" estimate of a predicted event; e.g., in demand modeling the best estimate of number of travelers (in aggregate models) or alternatively selected (in disaggregate models). (See also probabilistic model.)

Direct Demand Model

Model that simultaneously (in a single equation) predicts all travel choices for aggregate groups of individuals.

Disaggregate Demand Model

Model that is obtained by using the observations of the travel choice behavior of individuals directly for model calibration and that is usually probabilistic. (See also aggregate demand model.)

Distribution

Process by which trips defined by origin are distributed among the various available destinations. Common trip distribution models are the gravity model and the opportunity model.

District

A grouping of contiguous zones that are aggregated to larger areas.

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.

Forecast Zone

A subdivision of the study area used for purposes of forecasting trip ends and perhaps for trip distribution.

Forecasting

The process of determining the future values of land use, socioeconomic, and trip making variables within the study area.

Fratar Distribution

A method of distributing trip ends based on the growth factor of the origin and destination and on the given trip interchanges. Named for Mr. Thomas J. Fratar.

Friction Factors

Represent the effect that various levels of traveltime will have on travel between zones.

Generation

Step in the sequential, aggregate forecasting process in which trips defined by origin or destination (but not both) are predicted based on the characteristics of the activity system and, in some applications, some measure of transportation service to or from the zone. The output of generation is a one-dimensional array of trips into or out of a zone for input to trip distribution models.

Gravity Model

A mathematical model of trip distribution based on the premise that trips produced in any given area will distribute themselves in accordance with the accessibility of other areas and the opportunities they offer.

Highway System

The network of streets which carry the automotive vehicles through local, arterial, ramp and freeway type facilities.

Home-Based Trip

A trip with one end at the residence.

Impedance

More general than Friction Factors, impedance shows the effect that various levels of time and cost will have on travel between zones. Impedance can include various types of time (walking, waiting, riding, etc.) and cost (fares, operating costs, tolls, parking costs, etc.). Other factors, such as comfort, convenience, personal safety, etc., may also be included.

Input

Information (instructions or data) to be transferred from external storage (such as tape or cards) to the internal storage of the machine.

Interzonal Traveltime

The total traveltime 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 Traveltime

The average traveltime 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.

K Factor

Normally, an adjustment factor applied to a gravity model.

Land Use

The purpose for which land or the structure on the land is being used.

Level of Service

Multidimensional characteristics of the transportation service provided that are usually identified specifically by the location of the origin and destination of trip and that are divided into those that are quantifiable (travel time, travel cost, number of transfers) and those that are difficult to quantify (comfort, mode image).

Link

In traffic assignment, a section of the highway network defined by a node at each end. A link may be one-way or two-way.

Logit Model

Analytical form for demand modeling that is suited to modeling of multiple travel choice situations.

Long-Range Transportation Plan

A map showing transportation facilities that are projected for the next 20 years.

Long-Run Demand

Forecast of how transportation system changes affect the redistribution of the location of urban activity. (See also short-run demand.)

Low-Capital Alternatives

Transportation alternatives that can be implemented relatively rapidly at low initial or capital costs; e.g., changes in operating policies (fares, frequencies, traffic signal systems, and bus routes) and changes in regulations (automobile-exclusion areas, parking time limits, reserved bus lanes). Low-capital alternatives have often been neglected in the past in favor of alternatives involving investments in major new fixed facilities (expressways and rapid transit lines).

Minimum Path

That route of travel between two points which has the least accumulation of time, distance or other parameter to traverse.

Mode Usage

Process of forecasting how many travelers will use each of the available or proposed transportation modes. Normally, models are either pre- or post-distributional models, depending on whether they are applied to total trips from an origin or total trips between an origin and destination.

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; e.g., land use, economic, socioeconomic, and travel characteristics.

Multiple Regression

Sometimes used interchangeably with multiple correlation, but normally the term is used with reference to the regression equation resulting from correlation analysis.

Network

Set of nodes and connecting links that represent transportation facilities in an area. Normally associated with links are modal names, distances, levels of service, capacities, and level-of-service and volume requirements.

Network Description

The record which describes the highway system in terms of distance and time and includes turn indications and turn prohibitors.

New Options

Transportation alternatives that involve the use of new technology (tracked air-cushion vehicles, automated guideways), new operating policies (time-of-day fare differentials on transit), new regulations (vehicle exclusion zones, bus priority lanes), or new institutional arrangements (incorporation of taxi service into public transit authorities).

Origin

The location of the beginning of a trip or the zone in which a trip begins.

Output

Information transferred from the internal storage of a computer to output devices or external storage.

Parameter

An item of information which is usually furnished by the user to make a general routine workable for particular operation or condition.

Peak Hours

That one-hour period during which the maximum amount of travel occurs. Generally, there is a morning peak and an afternoon peak and traffic assignments may be made for each period, if desired.

Probabilistic Model

Model that provides the probability of a predicted event; e.g., in disaggregate demand models, the probability of the selection of an alternative. (See also deterministic models).

Productions

The number of home-based trip ends in the zone of residence. For all non-home based trips, productions are synonymous with origins.

Program

A precise sequence of machine coded instructions for a digital computer to use to solve a problem.

Prospectus

A document which outlines the scope of the planning program, procedures to be used in carrying out the elements of the planning process, a breakdown of the functional responsibilities of all participating agencies, and a list of products expected to be delivered by the end of the program year in terms of major milestones.

Rings

Districts in circumferential groups.

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 river or railroad tracks, splitting the study area into 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.

Sectors

Groups of districts that radiate from the central business district.

Service Attributes

Aspects of a transportation alternative that affect travel decisions concerning the use of the alternative. The set of all relevant service attributes for a given alternative is termed the level-of-service vector for the alternative.

Share Model

Any travel demand forecasting model that divides a trip-making total (such as total trips from an origin) into its various components (such as trips from the origin to each of the destinations). Share models can be used in both the aggregate and disaggregate modeling of each step of the forecasting process (generation -- frequency, time-of-day choice; distribution -- destination choice; mode usage; assignment -- path choice).

Short-Range Transportation Program

A staged multimodal program of capital and operational projects consistent with the long-range transportation plan, and leading to achievement of the short-range transportation objectives of a metropolitan area.

Short-Run Demand

Forecasting that assumes a fixed set of locations of urban activities on which (conditional) travel forecasts are based. (See also long-run demand.)

Simulation

To reproduce synthetically; e.g., to simulate a trip distribution.

Simultaneous Model

Demand forecasting model based on the assumption that travelers choose a level of trip frequency, time of day, destination, mode, and path as a single "joint" choice and consider in making that choice the alternatives for each of these choices simultaneously.

Sketch Planning

Transportation analysis procedures that are simpler, faster, and cheaper than using forecasting systems in their entirety and that typically require less input detail and provide fewer output measures with more variability.

Skimmed Trees

A series of binary records containing the traveltimes between each pair of zones.

Special Generators

Concentrations of activities of such size or unusual nature to warrant special consideration in trip generation analysis.

Station

A location at the external cordon line where driver interviews are conducted.

Study Area Boundary

The area that is expected to take on urban characteristics in the next 20 to 30 years by the end of the planning period.

Subarea, Subregion

Normally, an analysis area that is significantly smaller than the usual metropolitan region and is important because many alternatives influence only subareas.

Terminal Time

The traveltime required to unpark or to park and the additional walking time required to begin or complete a trip.

Transportation Improvement Program (TIP)

A staged multiyear program of transportation improvement projects including an annual element.

Transportation System

All aspects of the available or proposed transportation alternatives that affect the demand, profitability, and nonuser impacts of these services and that can be classified as technology, network, link, and operating policy variables.

Traveltime

The time required to travel between two points, including the terminal time at both ends of the trip.

Traveltime Factor

An empirically determined set of factors, each factor expressing the effect of one particular traveltime increment on trip interchanges between zones.

Tree

A record showing the shortest routes from a given zone to all nodes in the highway network.

Trip

A one-direction movement which begins at the origin at the start time, ends at the destination at the arrival time, and is conducted for a specific purpose.

Trip Assignment

The process of determining route or routes of travel and allocating the zone-to-zone trips to these routes.

Trip Distribution

The process by which the movement of trips between zones is estimated. The data for each distribution may be measured or be estimated by a growth factor process, or by synthetic model.

Trip End

Either a trip origin or a trip destination.

Trip Generation

A general term describing the analysis and application of the relationships which exist between the tripmakers, the urban area, and the trip making. It relates to the number of trip ends in any part of the urban area.

Trip Length Frequency Distribution

The array which relates the trips or the percentage of trips made at intervals or various trip distances.

Trip Purpose

The reason for making a trip, normally one of ten possible purposes. Each trip may have a purpose at each end; e.g., 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.

Unified Planning Work Program

A document covering all work activities of the state and local agencies involved with the continuing transportation planning process.

Urbanized Area

An urbanized area contains a city (or twin cities) of 50,000 or more (central city) plus the surrounding closely settled incorporated area which meet certain criteria of population size or density.

Zone

A portion of the study area, delineated as such for particular land use and travel analysis purposes. There may be two types of zones used in the trip assignment process:

1. Survey Zone -- A subdivision of the study area which is used during the data collection phase of the study;
2. Trip Assignment Zone -- A subdivision of the study area.

SUBJECT INDEX