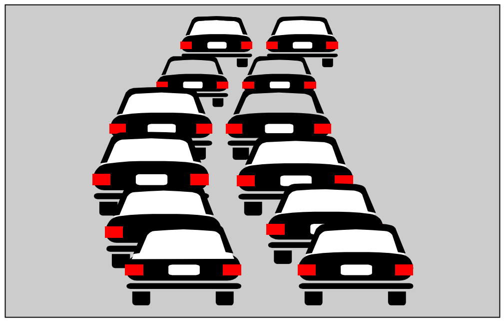
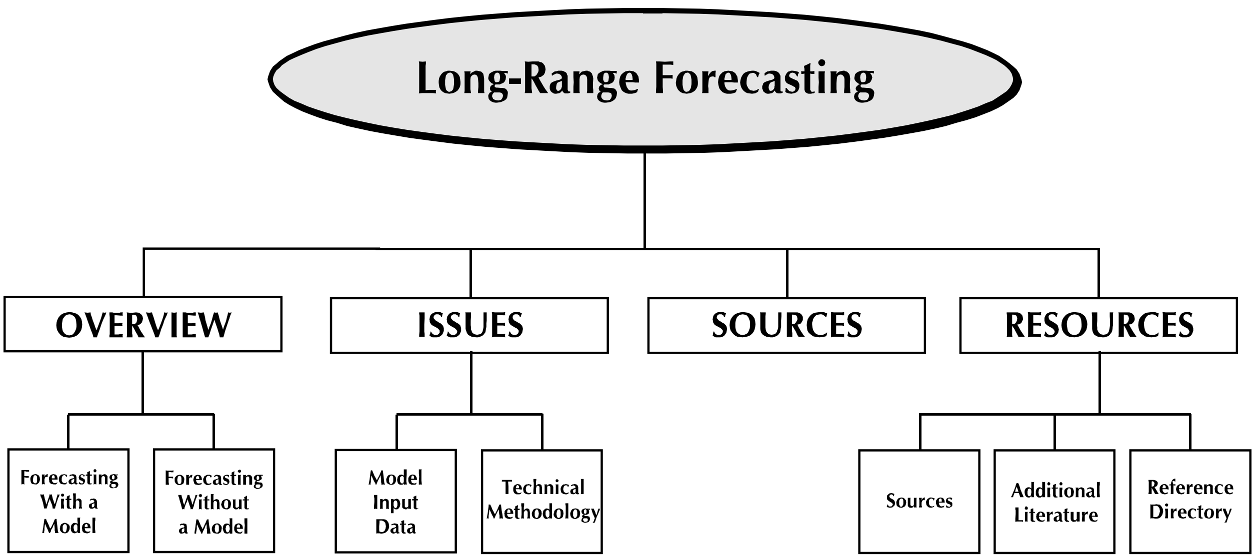
Long-Range Forecasting

For Small and Medium MPOs





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INTRODUCTION

A. LONG-RANGE FORECASTING

Federal regulations (23 CFR § 450.322) require MPOs to develop long-range transportation plans which identify the projected transportation demand of persons and goods in the metropolitan planning area over the period of the plan. Congestion management strategies that are adopted by the MPO must demonstrate a systematic approach in addressing current and future transportation demand. In addition, MPOs have been required (23 CFR § 450.316) to develop transportation plans and programs that are consistent with projections of potential transportation demand. This demand is based on the interrelated levels of activity in the areas of economic, demographic, environmental protection, growth management, and land use activities in accordance with metropolitan and local/center city development goals.

Long-range forecasts of transportation demand are used by MPOs for a number of purposes. Martin and McGuckin (1998: pp. 4 - 5) identify some of these:

- Long-range transportation plan development;
- Project-level studies requiring hourly traffic volumes;
- Subarea traffic circulation studies requiring peak hour turning movements;
- Feasibility analysis for transit capital improvements;
- Evaluation of the impacts of transportation investments on land use and development;
- Air quality analyses;
- Analysis of travel reduction programs, travel demand management strategies, and congestion management systems.

There are four steps in the traditional travel demand forecasting process:

- **Trip Generation**: forecasts the number of trips generated from a traffic analysis zone based on zonal demographics or other descriptive geo-coded population data. Data describing characteristics of individuals or groups composing an area's population are often predictive of behavioral patterns, such as trip rates (that can be derived from travel surveys).

- **Trip Distribution**: develops an origin-destination table that distributes forecast generated trips based on the attractiveness/impedance between zones (resulting from zonal land uses and the transportation network).

- **Mode Split**: predicts how trips are divided among available transportation modes; and

- **Assignment**: predicts route choice, or the number of trips using highway links and transit links or lines.

Preparation of a travel demand forecast using either manual techniques or software follows the general four-step process. The use of a computer-based travel demand forecast requires extensive effort to input the necessary transportation network and data. It is, thus, time and resource consuming. In some areas, less sophisticated tools for developing travel demand estimates may be more appropriate. Smaller MPOs may choose to develop long-range forecasts of transportation demand with or with out a network model.

If a model is used to forecast travel demand, a calibrated base year scenario is validated to demonstrate that the model is capable of reasonably replicating observations from the existing transportation network. The model is then used to forecast future-year travel demand based on future-years' projected numbers of persons, households, incomes, auto-ownership rates, and employment, as well as changes to the transportation network (U.S. Department of Transportation, 1998).

B. APPROACH AND ORGANIZATION

This section is designed to act as a primer/anthology about long-range forecasting that links the user with available resources. It is composed of four parts:

- **Overview of Long-Range Forecasting**

  This part presents an overview of developing long-range forecasts with or without a model. This section is not designed to be a prescriptive guidance manual. The user should not expect to execute the process from this brief introduction alone. Rather, it explores the technical methodologies necessary for a general understanding of long-range forecasting. As the process (though somewhat complex) is relatively sequential and well defined, this extended primer will establish the basics of long-range forecasting before the user delves into the remainder of this section.

- **Issues Outline**

  This part serves as an index which links the major issues related to long-range forecasting with various sources of guidance and information. These issues include model input data types, collection methods, and technical methodologies for developing a long-range forecast.

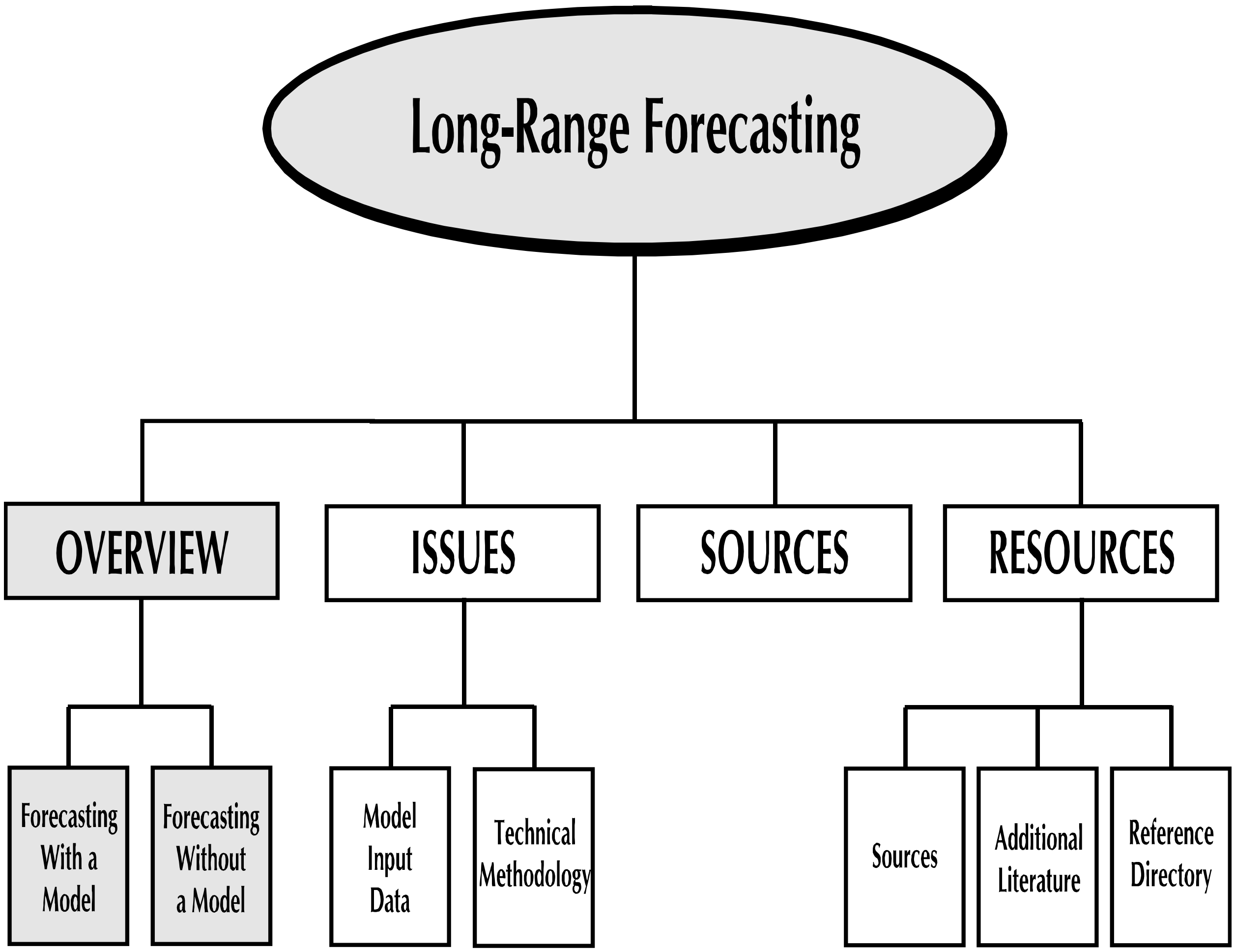
- **Sources Outline**

  This part provides excerpts and highlights from 29 sources of guidance on developing a long-range forecast. The table of contents and the issues outline direct the reader to each of these sources.

- **Resources**

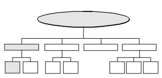
  This part includes a sources bibliography, a list of additional forecasting-related literature, and a reference directory. The sources segment provides bibliographic information plus information on how to obtain copies of source material. The additional literature segment lists documents related to long-range forecasting which, while not essential for a basic understanding of relevant concepts, may be of value for further exploration of specific topics. The reference directory provides a listing of national and regional agencies that have additional information that should assist MPOs in better understanding the long-range forecasting process.

Overview of Long-Range Forecasting



OVERVIEW OF LONG-RANGE FORECASTING

This part presents an overview of developing long-range forecasts with or without a model. This section is not designed to be a prescriptive guidance manual. **The user should not expect to execute the process from this brief introduction alone.** Rather, it explores the technical methodologies necessary for a general understanding of long-range forecasting. As the process (though somewhat complex) is relatively sequential and well defined, this extended primer will establish the basics of long-range forecasting before the user delves into the remainder of this section.



A. FORECASTING WITH A MODEL

Three major issues relative to developing long-range forecasts were identified by MPOs in small and medium sized areas in a survey conducted for this study. These include: 1) developing the general inputs of population, households, income, and employment for the base year and planning year; 2) allocation of future growth to the traffic analysis zone level; and, 3) development of trip rates. The techniques to develop model inputs, methods of zonal allocation, and trip rates are discussed in this segment.

Most MPOs located in areas with less than 500,000 population use one of the commercially developed travel demand software packages such as TRANPLAN, TRANSCAD, QRSII, MINUTP, or EMME2 to prepare the areawide long-range forecast. Although each of these software packages uses the traditional four-step process to prepare estimates of future travel, the setup, data format, and operation varies. Assistance on running each of these models is available from the vendor. The information provided in this segment does not address the operation of the travel demand model, but it does provide an overview of the data required to run a travel demand model.

1. Data Sources and Data Collection

Transportation demand forecasting requires a range of data on population, households, household income, auto ownership, employment, and travel behavior, as well as traffic counts and other various data needed to describe the network and establish travel time between zones. Some data, such as traffic counts and roadway network data, must be collected locally (primary data). Other data can be obtained from secondary sources.

Locally collected data include:

- Traffic counts for use in model validation;
- Roadway network speed and capacity data for each link;
- Other descriptive roadway network data (including number of lanes, directional flow (one-way or two-way), type of traffic control for each link); and
- Appropriate data for each identified special generator.

A wide variety of secondary data is readily available and easily accessible through various media. Use of data obtained from a secondary source requires a thorough understanding of the data — how the data were collected, the geographic boundaries for the data, how the data were expanded, and any other data limitations.

Some secondary sources of data required for developing population, household, employment, income, and auto ownership are provided in the reference directory (found in the resources part of this section). These references can provide historic, current, or projected socioeconomic data needed as model inputs. There are many other sources of data, particularly local data, that may better suit the individual needs of an MPO.

A recent research project, Multimodal Transportation Planning Data (NCHRP Project 8-32(5)), produced a series of reports that outline a data program (with primary and secondary data collection activities) needed to support current transportation planning requirements. One of the reports produced under this research project, *Compendium of Data Collection Practices and Sources* (Jack Faucet Associates, et. al, 1997), provides an excellent guide to data collection methods as well as data available through secondary sources.

The State Data Center Program was initiated in 1978 to provide training and technical assistance in accessing and using census data for research, planning, and administration. These state data centers develop estimates and projections of population for areas within their state on a regular basis. Each state has a designated state data center which can be identified through the U.S. Census Bureau website.

The Bureau of Economic Analysis, in the U.S. Department of Commerce, produces projections of employment and income for the States and to Metropolitan Statistical Areas within each state. Federal Reserve Economic Data provide historic U.S. economic and financial data, including consumer price index information. These data are available at http://www.stls.frb.org/fred. Some regional data are also available.

State workforce or employment commissions are good sources of employment data. In many cases, monthly and annual average employment data by major industry groups are available. Some states have made arrangements to provide MPOs with county and or local data in a format which gives the names, addresses, and numbers of employees of businesses by Standard Industrial Classification codes. The state agency with fiscal responsibility (e.g., state comptroller's office or department of finance) can also be an excellent source of current economic activity and economic projections.

2. Overview of Trip Generation

Individuals make trips for many different purposes (such as work, shopping, school, social/recreational, or personal business). Generally, trip purposes are classified as home-based work (trips beginning at home and ending at work), home-based non-work (trips beginning at home and ending a destination other than work), and non-home based (trips beginning and ending at points other than home). In some areas, the home-based non-work trips may be separated into additional categories such as home-based school, home-based shopping, home-base social, etc. Other trip purposes which are used in travel forecasting include truck/taxi trips and external trips (trips which have one or more of their trip ends outside the planning area).

A production is a trip originating from a given zone, while an attraction is a trip with a destination in a given zone. There are two types of models used in trip generation: those which estimate trip productions and those which estimate trip attractions. Thus, each trip purpose has a trip production model and a trip attraction model (showing separately modeled trip origins and destinations).

In trip generation, trips may be estimated as person trips or vehicle trips. Person trips must be used if mode split is to be performed or if different improvements which may affect the mode of travel or the vehicle occupancy are to be considered in the analysis. If these conditions do not apply, then an estimate of vehicle trips may be satisfactory.

Person or vehicle trip rates for trip production models are developed from data collected in home travel surveys. Trip rates for each trip purpose will be established based on the number of persons in the household and either the household income or number of autos owned.

Person or vehicle trip attraction rates for trip attraction models are developed from data collected in workplace and home travel surveys. Trip attraction rates are established based on the number of employees by type of employment (usually classified as basic, service, and retail employment). Employment may also be described in terms of an area type, usually defined by population and employment density. In some areas, some measure of employee income is also used.

Trip production rates for non-home based trucks and/or truck/taxis trips are developed from the data collected in commercial vehicle surveys. Usually, trip production rates for commercial vehicle trips are calculated such that a total number of truck trips within the area can be developed. Truck/taxi commercial vehicle attraction rates are developed from data collected in the workplace survey. Attraction rates are based on employment and area types.
Surveys conducted at external stations on the planning area boundary are the bases of the data used for external trips. External trips may be classified as external-external (trips which begin and end outside the planning area), external-internal (trips which begin outside the area and end at a point inside the area), or internal-external (trips which begin inside the planning area and end outside the area). Based on data collected in the survey, the percentage of external-external, external-internal, and internal-external trips at each external station are calculated for the planning area. Attraction rates for external-internal trips are developed from data collected in the external survey.

Trip production and attraction rates developed from survey data are used in conjunction with estimates and projections of households, household size, and household income or auto ownership to develop an estimate of the number of trips produced in a traffic analysis zone and the number of trips attracted to a traffic analysis zone.

3. Techniques to Develop Trip Generation Input Data

The trip generation models used in travel demand models forecast future travel on the basis of socioeconomic variables (such as population, number of households, employment, income, auto ownership, and household size). The variables used depend on the trip generation model used, although most current models use the number of households by household size cross-classified by either income or number of autos owned. Generally, the socioeconomic variable must be produced for two time periods: the base year (against which the model will be validated) and the planning year (the year for which future travel will be estimated).

Most urban areas develop model inputs in three steps: 1) preparing base year estimates for the area and individual traffic analysis zone; 2) developing areawide projections of the variables for the future planning year; and, 3) allocating the projections and/or developing the necessary data for traffic analysis zones. This section discusses methods of developing areawide projections. The methods for developing households (classified by household size and income or auto ownership) may also be used to develop that data at the traffic analysis zone level.

Previous research has shown that travel demand model output is sensitive to the projected change in demographic inputs and to the zonal allocation of population, households, employment, and income estimates. Of particular importance is the number of households because trips are "produced" at the household level. Household size is also important because people, not households, make trips. Household size is also needed in the analysis of income and/or auto ownership. Since the projection of households is based on population, care should be taken to ensure a reasonable control total for future population. Furthermore, even if the projections of the demographic variables are free of error, poor allocation of those variables to the zonal level will result in poor travel demand estimates (Hamburg, Lathrop, and Kaiser, 1983).

There are a number of ways to estimate current and project future population, households, income, household size, and employment for an MPO planning area. The decision of which technique to use must be based on the individual MPO staff level of expertise and time available. This topic is discussed further in document CC of the sources outline.

4. Techniques to Develop Model Inputs at the Zonal Level

a. Methods to Allocate Population and Employment

The output of travel demand models, in terms of traffic predicted on specific facilities, is sensitive to the allocation of population and employment. Errors in the future allocation of population and employment can result in over or under design of transportation facilities.

Previous research conducted to evaluate the sensitivity of models to allocation errors has shown that:

1. The magnitude of the error varies according to the magnitude in the allocation error, but is not the same for all types of roadway facilities. Arterial road facilities, both major and minor, are the most sensitive, followed by local roads and then freeways/expressways;

2. Errors in district forecasts more strongly affect arterial facilities and freeways, while errors at the zone level influence traffic more on local

roads. However, very large errors in zonal allocation will impact traffic across all types of facilities; and

3. Trip table expansion (using a regional trip table to develop trip interchanges for smaller geographic areas) introduces large errors into traffic forecasts.

Once projections of population, households, average household size, employment and income have been made for a planning area, the future growth must be allocated to the traffic analysis zone level. Typically, the process of developing the socioeconomic inputs is performed in two steps; first, from the region or planning area to the district level, and then from the district to the zone level. However, in some areas, allocation is made directly from the region to the zonal level. Additionally, once the basic population and employment has been allocated, the household characteristics of the population in terms of distribution of households by household size, household income and/or auto ownership must be developed.

Methods used to allocate future population and employment to small geographic areas include land-use based socioeconomic models such as EMPIRIC, spatial interaction models such as PLUM, POLIS, DRAM and EMPAL, the Delphi technique, and analytical methods such as ratio method and carrying capacity method. Additionally, non-modeling or judgmental approaches are also used in some areas. A thorough review of the above listed techniques was accomplished in NCHRP Report 328, *Forecasting the Basic Inputs to Transportation Planning at the Zonal Level* (Bajpai, 1990). This research effort found that the sophisticated models such as POLIS and DRAM and EMPAL performed “best” in terms of allocating growth in consideration of the various interactions which occur over time between transportation, economy, and site suitability. However, these models require large volumes of data, and their operation and calibration require well-trained analyst familiar with modeling and programming. Both of these requirements (data and trained computer analysts/programmers) are contrary to the usual staffing limitations of small MPOS. Small MPOs should consider using the Delphi technique, ratio trend analysis, and shift-share techniques.

b. Allocation Using the Delphi Technique

Delphi inquiry techniques were developed during the 1960s by the RAND Corporation with the objective to design a method by which the opinions of a group of individuals could be solicited, collated, and ultimately, brought to the most reliable consensus possible. The basic characteristics of the Delphi technique is anonymity of responses by the group, statistical review of the responses given by the group, and controlled feedback to the group. This process is completed in iterations which permits and encourages the reassessment of previous responses by the group.

The first four steps are in preparation of conducting the meetings and include: selecting panel members, aggregating traffic analysis zones, preparing the information packets and scheduling meeting times and locations.

The growth allocation process consists of an introductory meeting, four to eight meetings to complete questionnaires and exchange information, and an evaluation meeting. Beginning after the first round of questionnaires feedback regarding the responses and results should be provided to members of the panel. Once a general consensus is reached at each allocation level the process advances to the next level.

Due to the large number of traffic analysis zones within even small urban areas, the allocation of growth to the zone level using the Delphi process might prove to be too lengthy and many panel members may not wish to dedicate the time required. As a result, consideration should be given to having the MPO staff perform the allocation from the area level to the zone level.

c. Allocation Using Ratio Methods

Allocation of future growth using a ratio method is based on the same concept as the ratio methods used to project population or employment. A ratio is often used to apportion projected growth for the planning area to smaller geographic areas. Two such methods are the constant share and the shift-share ratio methods. The constant share method assumes that an individual traffic analysis zone would share the growth projected within a district at the same rate it has in the past. The shift-share ratio method accounts for differences between traffic analysis zones and districts in that it affords the identification of variables affecting recent growth trends within the area, and allows changes to these variables to be considered in the apportionment of future growth.

Ratio methods may be accomplished in a single (regional growth total to traffic analysis zone) or multiple step down (regional growth to district to traffic analysis zone) process. Although these methods lack a firm theoretical basis and are biased toward continuation of past trends, they are relatively simple to use. They may be used alone or in combination with other techniques such as the Delphi method or carrying capacity method.

d. Carrying Capacity Method

As the name implies, this method is based on identification and analysis of the population and employment capacity, sometimes called holding capacity, of a defined geographic area. Some techniques classified as carrying capacity methods actually use density models to allocate population. In these techniques, the densities and the percentage of area population of concentric rings (comprised of traffic analysis zones) are calculated for past years for which data is available. These densities and population percentages are extrapolated to the planning year, then adjusted based on the holding capacity of the geographic area. The adjusted percentages are then used to allocate future population to the area.

In some cases, carrying capacity methods can be used in conjunction with other techniques, such as ratio or Delphi. For example, traffic analysis zones could be grouped to form districts and future population apportioned to the districts using a ratio. Once the control population for a district is determined, the population could be allocated to individual zones based on carrying capacity. Likewise, ratio and carrying capacity analyses may be incorporated into an allocation process following the Delphi process.

As with the methods used to make area projections of population or employment, these allocation methods are all based on some set of assumptions about future land use, policies, zoning, and housing preferences. A database of information on past growth and development with documentation of the assumptions is essential.

e. Developing Household Size, Income, and Auto Ownership

The same procedures used to estimate a regional distribution of households by household size and household income or auto ownership can be used to develop the same data for households at the zonal level.

5. Developing Trip Production and Attraction Rates

Small MPOs often cite the need for current trip production and trip attraction rates. Travel demand models are ideally calibrated and validated with locally developed travel data, including trip production rates, trip attraction rates, external travel and commercial truck/taxi rates. Such data are obtained by conducting home, workplace, external and truck/taxi travel surveys. However, many areas do not have current travel survey information. Conducting home and workplace travel surveys is expensive and time consuming. As a result, many small areas must use trip rates developed by others for forecasting local travel demand.

a. Using Borrowed Trip Rates

Using trip rates from other areas can produce questionable results due to differences among areas' local socioeconomic conditions, transportation facilities, employment types, and urban structure. Additionally, trip rates are generally developed by the local area according to the locally developed model (and thus may or may not be available in the same cross-classification format needed locally). For example:

- Household trip production rates may have been developed for households classified by household size and income or for households classified by household size and auto ownership;
- The number and range of household income groups or number of autos owned used in this classification may not match those used locally;
- Trips rates may be developed as person trip rates or auto-driver trip rates;
- The number of trip purposes used (home-based work, home-based non-work, non-home based, truck/taxi, etc.) may vary;
- Trip attraction rates may also vary according to the specific area type definition used; and
- Trip attraction rates vary according to the employment definitions used to forecast travel (service, basic, and retail, etc.)

Published trip rates are available from a variety of sources. One of the more recent sources containing trip generation rates for use in travel demand modeling is NCHRP Report 365, *Travel Estimation Techniques for Urban Planning* (Martin, et. Al, 1998). This report provides travel parameters for areas that do not have fully developed local travel demand models (models calibrated and validated to local travel behavior data). Within this report, household trip generation rates are provided for urban areas in four population ranges. Methods for estimating trip attractions for home-based work, home-based non-work (or home-based other), and non-home based trips in zones classified as CBD and non-CBD are also provided.

Trip rates developed for other areas may also be used. The use of non-locally developed trip rates is less than ideal, but should produce reasonable results. An analysis conducted using travel survey results from four small (under 200,000 population) and one large (over 1,000,000 population) urban areas showed that the use of trip rates from the other areas would produce estimates just as accurate as those developed locally (Pearson, Gamble, and Salami, 1996). This analysis was expanded to include two medium urban areas (200,000 - 500,000 population) and a second large urban area. Again, the trips rates from other areas were found to produce estimates just as accurate as those developed locally.

Factors which should be considered in selecting trip generation rates from another area include:

1. Rates from urban areas within the same state or region;

2. Rates from areas of similar population;

3. Rates from an areas with similar socioeconomic characteristics (methods of determining similarity include a comparisons of households by household size; households by household income or auto ownership; employment in basic, service, and retail industry groups; median or mean household income; labor force characteristics; population by age cohort; and other special population characteristics); and

4. Rates from areas with similar urban form characteristics (such as similar central business districts, density patterns, and distribution of housing types).

Trip production rates stratified by household size and income or auto ownership are more easily transferable than trip attraction rates. Trip attraction rates, even when stratified by area types, generally have much greater variation. This variation appears to exist because area types (defined generally using a measure of population and employment density) do not account for all the differences between the number of trips attracted to like establishments. Other factors (such as income of the surrounding zones, lifestyle variables, or access and location) appear to influence attractions.

External trips can vary widely among urban areas. This variation may be due to local conditions, the location of the planning area or cordon line. As a result, local data should be used for estimating external trip rates. If time and funding preclude a full external survey, other methods may be considered to obtain the required data (including a postcard or license plate surveys). Additionally, a method using two perpendicular screenlines instead of a cordon line may be considered. As an alternative, data from a previous external survey may be expanded if: 1) through traffic is not considerable; 2) major through highways have not been constructed since the last survey; 3) the cordon line for the last survey remains outside the urban area; and 4) major new generators of regional travel have not been constructed within the urban area since the last survey (Sosslau and Reed, 1980b).

b. Updating Trip Rates From Previous Survey Data

Analyses of current and previous trip rates, conducted for several urban areas in Texas, suggest trip rates within categories of income and household size (in terms of trips per person) have not changed greatly over the past 30 years. This observation is not true across trip purposes, nor is it true for average distance traveled per trip. The distribution of households by household size and income has, however, changed significantly.

Most urban areas have conducted travel surveys, many of which were performed in the 1960s and 1970s and have not been updated. If an area desires to have trip rates based on local data, it may be possible for a very small sample travel survey (in the range of 500 households) to be performed and used to update the previous trip rates. The steps for determining the trip rates are described in *Trip Generation Analysis* (Federal Highway Administration, 1975).

B. FORECASTING WITHOUT A MODEL

It has long been recognized that the transportation planning efforts of each urban area should be based on the needs of that area, not a specified set of requirements or tools. There are no set procedures, forecasts, or models that must be adhered to by every urban area. Consideration should be given to the area's local goals, demographic and economic characteristics, transportation system facilities, the range of viable transportation solutions, existing planning process and the available staff and financial resources. This means that the methods used may vary from area to area.

Most MPOs in urban areas of 50,000 population currently use one of the widely available travel demand forecasting computer software programs to conduct area-wide travel forecasts. However, newly designated Metropolitan Planning Organization areas may not yet have fully developed computer travel demand programs. Some small urban areas (under 200,000 population) that consistently experience slow, stable growth (generally 1 to 1.5% a year) may not need to develop and use a computer travel demand model each time they conduct a transportation plan update (Fleet, Kane, and Schoener, 1978; DeCorla-Souza, 1994). As in ISTEA, TEA-21 provides small MPO areas the option to develop and use simplified procedures.

Use of computerized travel demand forecasting requires extensive effort to prepare the necessary base year and planning year data for input into the models, and thus, is costly and time consuming. In certain areas, other more direct and less sophisticated tools for developing travel demand estimates may be more appropriate. Additionally, in many small urban areas the monitoring phase of the transportation system planning process should be given more emphasis.

A number of transportation system travel demand analysis options available to small MPOs (and, in some cases, medium-sized MPOs) can be used by these areas to meet the planning requirements. General approaches for estimating travel demand on an area-wide basis without a computerized model and approaches to monitor travel and activities are discussed in this section along with a description of how and where these methods may be most appropriate.

1. The Manual Four-Step Process for Long-Range Travel Forecasting

Although manual techniques for travel demand estimation are best suited to corridor, subarea, or site specific analyses, such techniques can be used for area-wide analysis in small urban areas. The data requirements for conducting a manual four-step travel demand estimation are similar to those required for computer methods. Additionally, the computational requirements can be significant, depending on the number of zones and number of links required for area-wide analysis. Therefore, unless financial considerations preclude the purchase and use of a travel demand computer software package, it is not recommended that the manual four-step techniques be employed for area-wide travel demand estimation. Generally, area-wide travel demand estimation using a manual four-step process is appropriate for:

- Small urban areas where the number of traffic analysis zones is approximately 40 and the number of roadway links is less than 200 (a greater number of zones and links can be accommodated, but the process will become much more time consuming);

- When the goal is to identify future problems on the existing network (if the goal is to analyze alternatives, either land use or roadway alternatives, a computer program is recommended); or

- In areas where slow to moderate growth is anticipated and no major changes in land development patterns or major new facilities are being planned (Sosslau and Reed, 1980b).

a. Data Requirements

Information required to estimate current and future travel demand with manual techniques is similar to that required in computer packages. Data will be needed on the physical transportation system and system operations, local area socioeconomic and employment characteristics, and travel behavior.

(1) Transportation System Inventory

The transportation system inventory should include both roadway and public transit (if available), and relates to various data on the physical characteristics of the system. Physical characteristics of the roadway network and/or public transportation system are required in determining capacity of a facility/ service. Capacity is used to determine current level of service and to analyze future facility adequacy. Much of this data should be available from local cities, counties and/or state departments of transportation. Where the data is not readily available, the information can be obtained by conducting a “drive out” of the proposed roadway network. Data for each link is noted on a map through actual observation (Sosslau and Reed, 1980b; Gruen Associates, 1974; Sosslau and Reed, 1980d).

The major roadways to be included in the travel demand analysis should be functionally classified. Functional classification of roadways is based on a graduation of traffic flow from the movement function to the access function. General functional categories and the theoretical figures for spacing and volume ranges are given in Table 1. For the purpose of manually estimating travel demand for an entire urban area, it is suggested that only roadways classified as major arterials and freeways/expressways be included in the transportation network (Sosslau and Reed, 1980b; Gruen Associates, 1974).

TABLE 1
General Functional Categories and Descriptive Characteristics

Facility	Facility Spacing (miles)	Operating Volume Range (vehicles/day)	Access Spacing (miles)
Freeway	4	60,000 +	1
Arterial	1	10,000 - 30,000	1/4
Collector	1/4	2,000 - 5,000	1/20
Local/Access	1/20	less than 500	1/80
Source: Gruen Associates, 1974			

Other data that should be collected as part of the transportation system inventory include:

- Pavement width, condition, and surface type
- Number of lanes
- Type and location of traffic control devices
- Parking regulations
- Existence of designated bicycle lanes
- Pedestrian movement control

The inventory of the local public transit system should generally include a map of the transit routes, the round trip route miles for each route, number of stops, number of vehicles operated, and passenger capacity of vehicles.

(2) Transportation System Operating Characteristics

Various operating characteristics for the roadway and public transit system need to be obtained in order to determine the existing operations and levels of service. Data needed for the roadway system include traffic counts, travel times and speeds, and roadway capacity. Traffic counts, when related to capacity, serve as an indication of current problems. They are useful in the review of the results and analysis when using a manual four-step travel demand estimation technique. Since obtaining average daily traffic counts for the entire system may be beyond the planning resources of an area, sampling methods may be used to obtain traffic counts. Travel time data is required for the manual trip distribution step. Travel time may be obtained by conducting travel time studies on a particular roadway or network. Alternately, travel time may be estimated through a process using airline miles.

(3) Area Socioeconomic Characteristics

The transportation system serves to link people with activities (shopping, school, work, recreation, etc.), and thus must respond to changes in the location and intensity of such activities. Trip generation is based on the characteristics of the household in terms of number, size, household income and/or auto ownership. It is also based on the characteristics of the activity to which the trip is attracted in terms of activity type, number of employees or employees per area. Existing and estimated future data on households and activity will be required for each traffic analysis zone.

(4) Travel Behavior

The amount and type of information needed to understand travel behavior should depend on the anticipated growth of an area and the type of transportation problems. Many small areas do not have current household or work place travel surveys. These areas may also lack the funding to conduct such surveys. However, default values are available for use (and in fact, have recently been subject to reevaluation), and data from other areas of similar size, income, and employment characteristics may be used.

In areas where external travel (travel with origins or destinations outside the urban area) is high, an external survey may be necessary. Alternate approaches to updating data on external travel are available. One approach is based on building a trip table from surveys conducted at two perpendicular screenlines from one edge of the urban area to the other. In areas where through traffic is not significant, bypasses have not been built, major new regional generators have not been developed inside the urban area, and the cordon for the last survey is still valid (not inside the urban area), a previous external travel survey may be expanded or updated using current traffic counts (Sosslau and Reed, 1980b; Sosslau, Hassam, Carter, and Wickstrom, 1978).

(5) Traffic Analysis Zones and Network Considerations

Traffic analysis zones will be required for the manual four-step process. When determining the zone boundaries, consideration should be given to the following census geographic boundaries (tracts, block groups and/or blocks), natural barriers (such as rivers, lakes, railroads), the roadway network (zones should not be split by a road included in the network), and the type and intensity of development.

The roadway network should include major facilities such as freeways or expressways and major arterial roads. Centroids and centroid connectors are not used in the manual four-step estimation techniques; thus the number of links will be less than those for computer analysis. There should be approximately two to three physical roadway links per zone. As a general guide, Table 2 provides the number of zones and links appropriate for manual area-wide analysis according to population.

TABLE 2
Number of Analysis Zones and Links For Areawide Analysis

Area Population	Number of Traffic Analysis Zones	Number of Roadway Links
25,000	10-15	20-45
50,000	20-30	40-90
75,000	30-50	60-150
100,000	35-60	70-180
125,000	45-75	90-225
150,000	55-90	110-270
175,000	65-100	130-300
200,000	75-125	150-375

Source: Sosslau and Reed, 1980b

b. Trip Generation

The purpose of trip generation, the first step in estimating travel, is to determine the number of person or vehicle trips produced from and attracted to activities within an area. The factors influencing travel include automobile ownership, income, household size, availability of public transportation, density of development, and the quality of the transportation system. Estimates of trip generation can be made for an entire urban area, a specific transportation corridor, or an individual site. Estimates of the number of trips produced in an area can be calculated from the area's land use and socioeconomic characteristics of the population. Trip attractions are described in terms of land use characteristics (intensity and location of activities) and employment characteristics (number of employees per type of employment).

Manual trip generation will require data on the number of households, household income and/or auto ownership in order to estimate the number of trips produced within an area. Data required for estimation of attractions includes the type of employment, number of employees, or number of employees per unit of building area. Productions and attractions are generally made by three trip purposes: home-base work, home-based non-work, and non-home based trips. When available, local travel survey data should be used as the basis for determining the trip rates. If current local survey data is not available, default data or survey data from an area of similar size, median household income, and employment types may be used.

c. Trip Distribution

Manual trip distribution uses a calculator with accumulating memory to perform a gravity model procedure. This includes:

- A short cut calculation of area-to-area impedances,
- Friction factors for urban areas of two population sizes and three trip purposes (home-based work, home-base non-work, and non-home based), and
- Simplified worksheets for entering the required information and calculating the trip interchanges.

In small communities where growth is expected to be relatively slow and concentrated in certain small areas, a one-purpose trip distribution gravity model may provide the detail and accuracy necessary. In general, a one-purpose trip distribution model might be used in areas between 25,000 and 150,000 population where growth is expected to be less that 1% to 1.5% annually.

The data required for trip distribution includes a map of the traffic analysis zones and roadway network including boundary limits of the CBD, and central city and suburban regions. It also includes information on the physical and operational characteristics of the roadway network, production and attraction trip ends for each zone, and a travel time/distribution factor matrix.

d. Mode Split

For most small urban areas, the number of trips made by transit is quite small relative to the overall number of trips made in the urban area. Therefore, many small areas do not perform mode-split analysis.

For areas that do have a significant number of "choice" public transit riders, a three-purpose trip distribution and single purpose trip distribution manual technique is available. This method is used to determine change in the level of travel by mode caused by varying the transit and auto system operating characteristics. Only fixed route transit is considered by this mode choice analysis. The methodology is similar to the gravity model. However, attractions for all modes (auto and transit) are summed, and an impedance value based on in-vehicle time, excess time, trip cost, and income is used in place of travel time.

The data required to compute the mode-split analysis include:

- Highway-airline distance
- Transit route-airline distance
- Transit fare
- Auto operating costs
- Attraction-end parking cost
- Average speed
- Impedance
- Median income
- Access time
- Person trip table
- Transit network

e. Assignment

Assignment is the process for simulating current and forecasted traffic on the roadway and/or transit network. A traditional manual traffic assignment technique (in which trips are assigned to each segment of the roadway) is used in an area-wide travel forecast. The basic methodology involves determining a logical path for each trip and then accumulating the number of trips on each roadway segment along the path. The logical path is usually selected based on travel time. The input requirements for a traditional traffic assignment include a matrix of trips between origins and destinations as provided from trip distribution. The requirements include a roadway network and an estimate of the travel time between traffic analysis zones via alternative routes.

2. Forecasting Using Trend Analysis

Prior to the development of travel demand modeling, forecasting travel was accomplished using trend analysis. This approach may still be used today to manually estimate travel on a limited number of roadway facilities within an area.

This technique uses historic traffic facility data and extrapolates that traffic to a future year. Limitations of this method include the lack of considering roadway capacity and the lack of anticipating growth and development patterns. One way to improve on this technique is to analyze the past trends of growth and decline in traffic volumes and growth and decline in development in the areas surrounding roadway facilities. Once this analysis is completed, an estimate of future growth and development could be used to revise the past growth rate prior to extrapolating traffic into the future.

Perhaps the best application of this procedure would be to update a previous travel forecast to see how the growth in traffic is tracking the previously estimated travel demand from the forecast.

3. Resources For a Manual Four-Step Travel Forecast

The most comprehensive set of manual techniques to estimate travel demand using a general four-step process are documented in the NCHRP Report 187, *Quick-Response Urban Travel Estimation Techniques and Transferable Parameters* (Sosslau, Hassam, Carter, and Wickstrom, 1978). The material provided in this report consists of tables, graphs, nomographs, simplified methods, sample work sheets and other aids for analysis procedures. This report was recently updated by NCHRP Report 365, *Travel Estimation Techniques for Urban Planning* (Martin and McGuckin, 1998) in which the trip rates and other parameters were reviewed and revised based on the most recent travel survey data available. Although the focus of the more recent report is on development of parameters for use in computer travel demand models, there was a difference in the revised trip rates for smaller urban areas. It is recommended these be reviewed.

Further information and helpful hints in using the techniques outlined in the NCHRP 187 Report are found in *Transportation Planning For your Community: System Planning* (Sosslau and Reed, 1980b) and *the System Planning Appendix* (1980c).

A simplified method for very small urban areas, areas in the range of 10,000 to 15,000 has been developed and used by the North Carolina Department of Transportation. This procedure is documented in *Technical Report #11, Allocation Type Approach to Estimation of Travel For Small Urban Areas* (North Carolina Department of Transportation, 1989).

Alternative transit demand analysis procedures are available for areas that do not require a mode choice analysis. These procedures are documented in *Transportation Planning for Your Community: Transit Planning* (Sosslau and Reed, 1980d) and *Analyzing Transit Options For Small Urban Communities: Transit Service Objectives and Options* (Peat, Marwick, Mitchell and Company and D.H. James, 1978).

For information on traffic data collection methods, the reader should refer to the Institute of Transportation Engineers *Traffic Engineering Handbook* (Institute of Transportation Engineers, 1992) or *Manual of Transportation Engineering Studies* (Institute of Transportation Engineers, 1994). Methods to determine the capacity of a roadway are detailed in the *Highway Capacity Manual* (Transportation Research Board, 1994).

One of the best discussions found on functional classification of roads was *Traffic Circulation Planning for Communities* (Gruen and Associates, 1974). Functional classification related to travel demand analysis is also found in *Transportation Planning For your Community: System Planning* (Sosslau and Reed, 1980b).

4. Monitoring Program

In small urban areas which have been experiencing slow, stable growth, it may not be necessary to conduct a full long-range travel demand forecast for updates of the transportation plan. Rather, development of a program to monitor transportation related characteristics could provide the information needed to assess previous forecasts and establish whether the current plan is adequate for anticipated growth or to identify needed changes to the planned improvements. In general, monitoring is applicable to small urban areas under 200,000 population that have experienced slow, stable growth in the range of 1% to 2% per year, and have not experienced any major shifts in development and/or employment patterns.

A monitoring program requires the development of a baseline inventory and continuous update of transportation related data and characteristics. Information that should be included in the inventory and monitoring program includes:

- Population
- Number of Households
- Employment by Type
- Traffic Volumes
- Transit Ridership
- Changes to the Transportation System

Inventories should be accomplished and updated at the traffic analysis zone level, and should include many of the same data required for conducting a long-range travel demand forecast. Data items that should be included are:

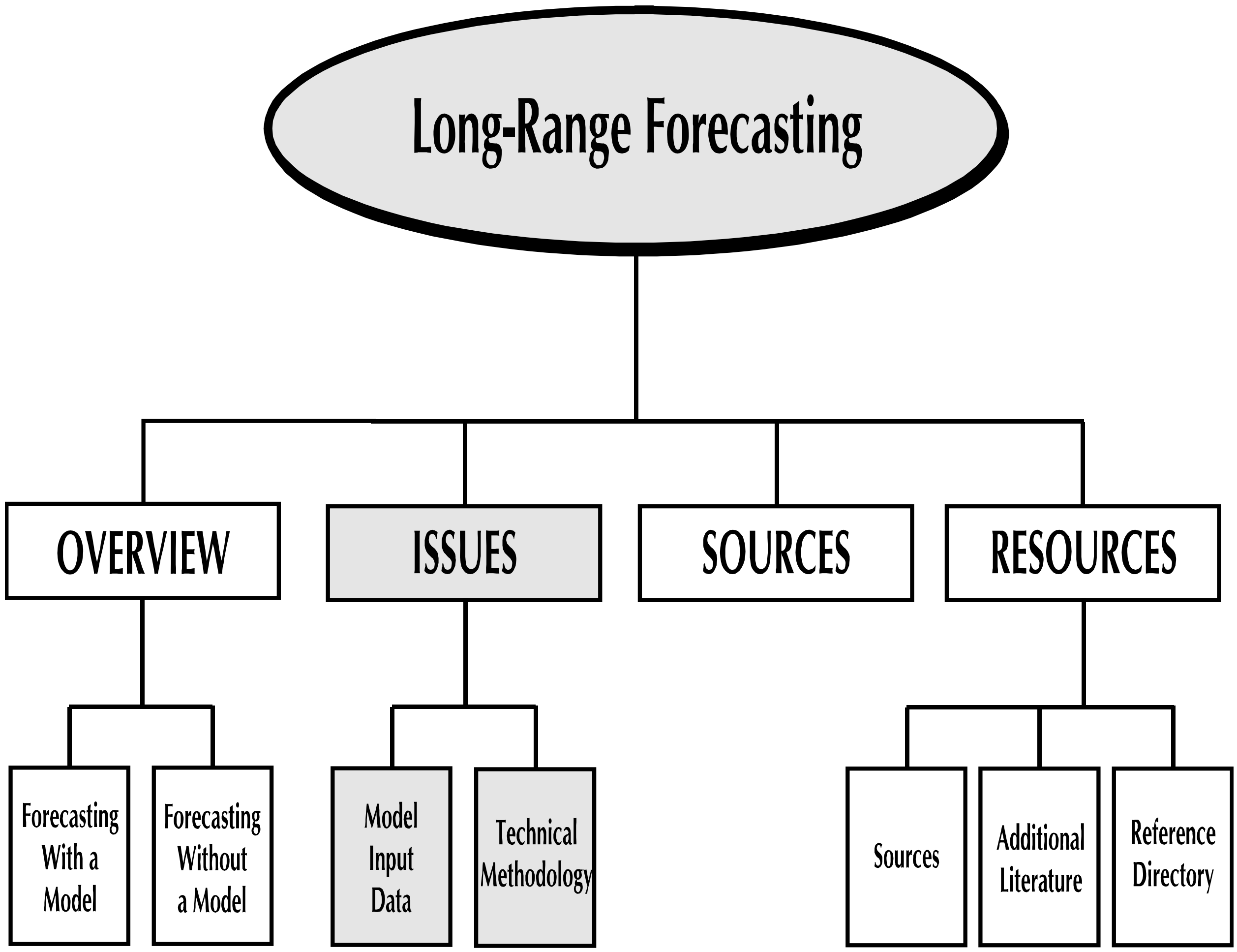
- Roadway system mileage (by functional classification)
- Roadway physical and operating characteristics
- Traffic Counts
- External Travel
- Fixed Transit Routes
- Service Areas/Operations for Special Transit Service
- Public Transit Vehicle Characteristics
- Population and Number of Households
- Employment by Type
- Median Household Income

The basic steps in a monitoring and assessment program involve regular collection of the data items and comparing the current trends to those forecast for the development of the long-range plan. If changes indicate travel demand or development is not following that forecast, then analysis of the changes should be accomplished and the transportation plan reviewed/updated to be consistent with changes to identified needs.

5. Resources for Developing a Monitoring Program

The most comprehensive discussion for a transportation planning monitoring program is found in *Transportation and Your Community: Monitoring and Forecasting* (Sosslau and Reed, 1980a).

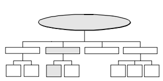
Issues Outline



ISSUES OUTLINE

This section serves as an index that links the major issues related to long-range forecasting with various sources of guidance and information. The major issues associated with long-range forecasting are presented below in outline form, with links to locations in the sources outline. For each issue, links are listed in order of the sources outline. This issues outline will direct the reader to:

- Information about the types of data needed for long-range forecasting (local traffic counts, trip rates, and zonal demographics and land uses);
- Information describing how MPOs collect and manipulate data for travel models used in long-range forecasting (travel surveys and other primary data collection methods, secondary data sources, and techniques for forecasting future-year model inputs);
- Information about the technical methodology used by MPOs to develop and use travel demand models. This includes developing the transportation network for use in the model, the four step modeling process (trip generation, trip distribution, mode split, and assignment), model calibration, and model validation.



A. MODEL INPUT DATA

1. Data Types

a. Local Traffic Counts

(1) A 3.c.
(2) A 9.a.(4)
(3) X
(4) Y
(5) Z
(6) BB 4.c.

b. Trip Rates

(1) A 2.
(2) P
(3) Q 3.d.

c. Zonal Demographics and Land Uses

(1) A 3.
(2) Q 3.
(3) BB 4.c.

2. Data Collection

a. Surveys and Other Primary Data Collection Methods

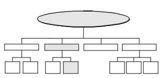
(1) A 2.
(2) D
(3) BB 4.c.

b. Secondary Data Sources

(1) A 2.e.
(2) I
(3) Q 3.e.

c. Forecasting Techniques

(1) A 3.e.
(2) A 8.e.
(3) B 1.
(4) D
(5) F
(6) N
(7) Q 3.f.
(8) CC



B. TECHNICAL METHODOLOGY

1. Network Development

(1) A 4.
(2) J
(3) K

2. Four Step Process

a. Trip Generation

(1) A 5.
(2) B 2.
(3) C
(4) E
(5) O
(6) P
(7) Q
(8) CC

b. Trip Distribution

(1) A 6.
(2) B 3.
(3) C
(4) E
(5) R
(6) S
(7) T

c. Mode Split

(1)	A	7.
(2)	B	4.
(3)	C	
(4)	E	
(5)	U	

d. Assignment

(1)	A	8.
(2)	B	5.
(3)	C	
(4)	E	
(5)	L	
(6)	M	
(7)	V	
(8)	W	
(9)	X	
(10)	Y	

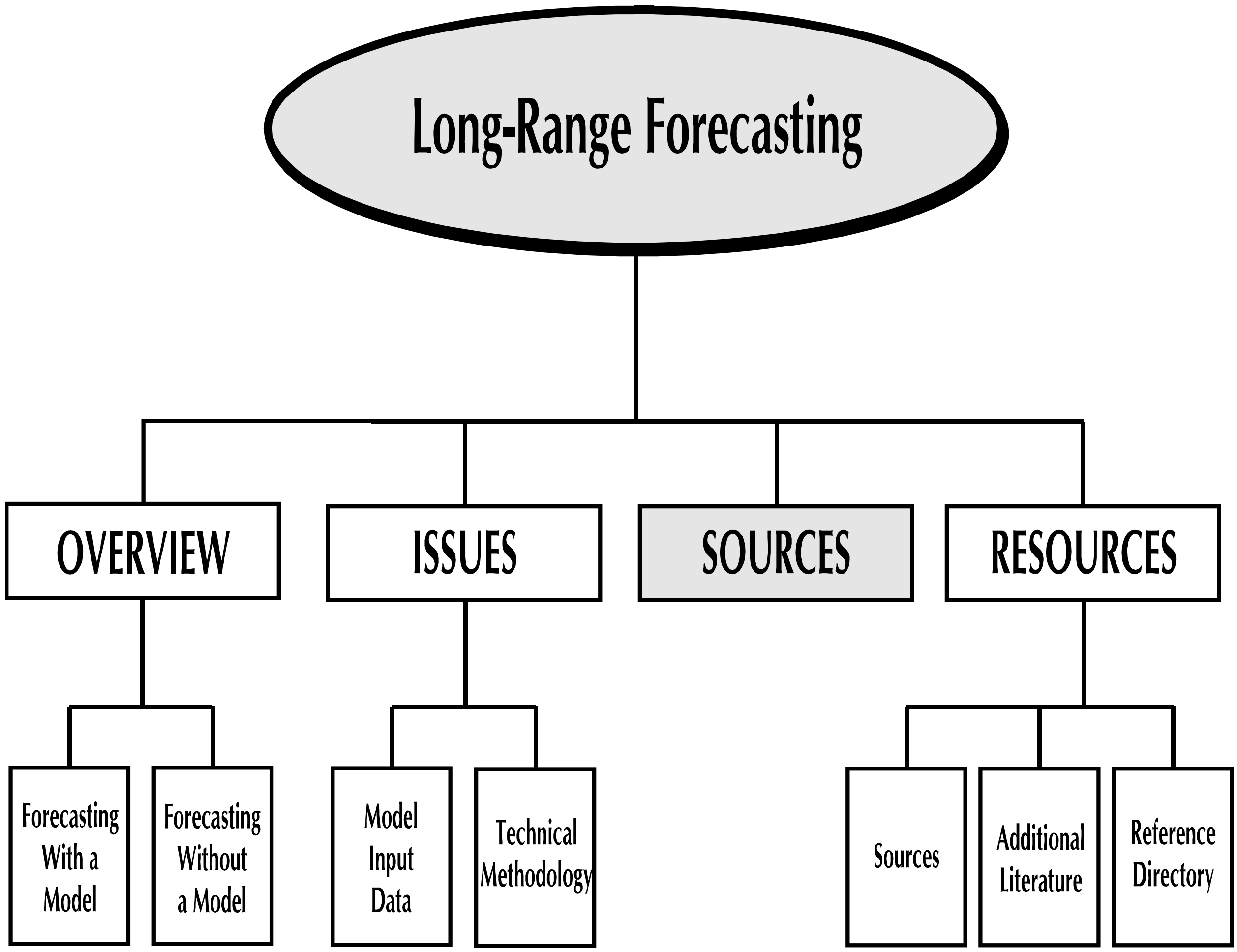
3. Model Calibration

(1)	A	9.a.
(2)	I	
(3)	Z	
(4)	AA	

4. Model Validation

(1)	A	9.b.
(2)	Z	
(3)	BB	

Sources Outline



SOURCES OUTLINE

A. INTRODUCTION TO URBAN TRAVEL DEMAND FORECASTING: PARTICIPANT'S NOTEBOOK
(U.S. Department of Transportation, 1998)

1. Introduction: The Four-Step Process

"There are four basic phases in this traditional TDF process.

- **Trip Generation**: forecasts the number of trips that will be made based on decisions as to the choice of trip frequency.
- **Trip Distribution**: determines the destination choice of the trips.
- **Mode Choice**: predicts how the trips will be divided among the available modes of travel (car, transit, car pool, etc.).
- **Trip Assignment**: predicts route choice, or the number of trips using highway links and transit links or lines.

"Trip Forecasting is the process of using a calibrated travel model to forecast travel for a future year. This is performed by first calibrating a base year model and demonstrating through validation that the model is capable of replicating existing travel reasonablely well. The model is then used to forecast travel for a future year given the forecasted changes in the number of persons, households, employment, and changes to the transportation system. Typically, the travel model is used to evaluate how well the existing transportation system will perform given the forecasted growth for the urban area. The model is then used to test or evaluate how well alternative proposed improvements to the transportation system would perform if they were implemented. This evaluation is used to guide the selection of the preferred alternative(s) included in the adopted metropolitan transportation plan (MTP)."

2. Travel Surveys and Other Data

a. Basic Sampling Theory

"The basic data collection units for transportation planning are normally individual households or single-vehicle movements. It is not economically feasible to develop a database consisting of data pertaining to all households or vehicle movements within a study area. Statistical sampling techniques are available for developing reliable inferences about the characteristics of a population, based on the characteristics of a sample (1).

"Since the purpose of sampling is to collect information about the nature, or distribution, of elements in a particular population, one must make assumptions about the form of the underlying distribution of these elements. One common assumption is that the population is normally distributed. The normal probability distribution is a smooth bell-shaped curve and is symmetrical about the mean.

"Another important decision concerns the acceptable error for the sample. This is usually determined by specifying that a sample mean for a data item should be within some value α of the true mean for a specified percentage of samples. The percentage of samples falling within the desired limit of error is called the level of confidence. The level of confidence is denoted as 100(1-α), where α is the fraction of the area under the normal distribution falling outside the confidence limits.

"Once an assumption is made about the population distribution and the desired precision is selected, the required sample size can be determined. Use the following formula to determine the required sample size:

$$n=[(Z_{\alpha/2}\sigma)/d]^2$$

Where,

- n = required sample
- d = tolerable margin of error of the mean
- σ = standard deviation of the population distribution
- α = fraction of area under normal curve representing events not within the Confidence level (thus 1-α is the desired level of confidence)
- $Z_{\alpha/2}$ = standard normal statistic corresponding to the 1-α confidence level (found in tables of any statistic book)"

b. Travel Survey Types

(1) Household Surveys

"The travel diary technique is normally used to obtain information about the following three categories:

- *Personal Characteristics*. Characteristics that include, relation to the head of the household, gender, age, possession of some drivers license, education level, and activity.
- *Trip Data*. Data that includes aspects such as origin and destination, trip purpose, start and trip end times, mode, and walking distances.

- *Household Characteristics*. These are aspects such as vehicle availability, household size, and household income."

(2) Workplace Surveys

"Workplace surveys are similar to household surveys, except that the subject is contacted at the workplace. The emphasis of the survey questions are more related to the attraction end of the trip."

(3) External Station Surveys

"External station surveys involve asking a sample of drivers and passengers crossing an external station a limited number of questions. External stations are locations where major roadways cross the study area boundary. These interviews are useful in obtaining information about trips not sampled as part of the household or workplace surveys. The surveys provide information on external-external, and internal-external trips. The questions seek information on the trip origin and trip destination, trip purpose, time, number of passengers, etc."

(4) Cordon Line Surveys

"Cordon line surveys typically are taken at the boundary of the central business district (CBC). These surveys are used to assist in the calibration of mode split models. In urban areas where the public transit system is oriented to the CBC, it is critical that the mode split between public transit and auto be accurately calibrated for CBC trips."

(5) Special Generator Surveys

"Special generator surveys are conducted to estimate trip attraction rates for activities that generate above or below the average number of trips per employee. Activities that attract above average number of trips per employee are regional shopping malls, commercial service airports, and regional medical centers. Activities that attract below average number of trips per employee are military bases and warehouse complexes."

(6) Truck Surveys

"Commercial truck surveys are conducted to better estimate the number of trips, the average trip length, and the trip length frequency of trucks used in commercial operations. This type of survey is critical for an urban area that has an above average number of truck trips or truck VMT. These could include areas with a high amount of industrial or manufacturing activity, or an area with a major seaport."

c. Travel Survey Outputs

"Travel surveys provide information used in the trip generation, trip distribution, and mode split steps in the modeling process. Trip production rates by trip purpose, trip attraction rates by trip purpose, average trip length by trip purpose, and trip length frequency distributions by trip purpose are the more important estimates developed from the household and workplace surveys."

(1) Development of Trip Production Rates

"The data from the household travel survey is used to calibrate a trip production model. In a trip production model, the trip rates are the dependent variables and household characteristics are the independent variables. The rates are developed by trip purpose. An example of a trip production model is a cross classification table where the trip rate by purpose is a function of the household size and the household income."

(2) Development of Trip Attraction Rates

"The data from the workplace travel survey is used to calibrate a trip attraction model. In a trip attraction model, the trip rates are the dependent variables and the workplace characteristics are the independent variables. The rates are developed by trip purpose. An example of a trip attraction model is a regression equation where the trip rate by purpose, the dependent variable, is a function of the number of employees by type in a zone and the area type of the zone, the independent variables."

(3) Average Trip Length and Trip Length Frequency Distribution

"The data from the household travel survey is used to estimate the average trip length and the trip length frequency distribution (TLFD) for each trip purpose. A TLFD shows the percentage of trips for a particular trip purpose that are one-minute long, two-minutes long, three-minutes long, up to the length of the longest trip. The average trip length and the TLFD by purpose are used to calibrate the gravity model used in the trip distribution step."

d. Data Needs for Travel Demand Forecasting

(1) Highway Inventory

“The highway network requires data on the functional classification, the number of lanes, distance between intersections, parking or no parking, the presence of medians, signal density, speed limits, etc., in order to build a digital representation of the highway system.”

(2) Transit Inventory

“The transit network requires data on transit routes and headways, the location of transit stops, the location of park and ride facilities, any operational features that provide preferential treatment to transit vehicles, exclusive use lanes, and data on walk access and auto access to transit.”

(3) Highway Count Inventory

“Extensive highway counts are taken during the base year. These counts are typically made on weekdays during the school year. Most models are calibrated to represent weekday school year traffic. Traffic counts are taken on all the highway functional classifications that are included in the highway network. The counts are used for model validation.”

(4) Demographic Inventory

“The demographic inventory by zone is used in conjunction with the trip production rates developed from the travel surveys to estimate the number of trip ends in each zone during the base year.”

(5) Employment Inventory

“The employment inventory by zone is used in conjunction with the trip attraction rates developed from the travel surveys to estimate the number of trip ends in each zone during the base year.”

e. Data Sources

(1) Mapping

- *Digitized Census Map Files.* The Census Bureau compiles digital data for all 1990 census map features such as roads, railroads, and rivers. Other information contained in digital format includes census tracts, political areas, address ranges, and zip codes for streets. Users can order a single-county file, a group of county files that make up a Metropolitan Statistical Area, or all files for the state.

- *Census TIGER Files.* These are comprehensive sources of data. They can be used to produce area maps such as census blocks or county boundaries, as well as street system networks. The TIGER files are available on CD-ROM from the Census Bureau.

- *Commercial Digitized Map Files.* Commercial digitized map files are available from many vendors.
- *Scaled Maps.* These maps enable the user to digitize the base data required to construct a computerized highway network file (location of links and nodes).

(2) Demographics

- *Latest U.S. Census.* This data is available at block level and can be aggregated to traffic zone levels. The census is the best source for population statistics but cannot be used to compile employment data for small geographic areas.

- *Census Transportation Planning Package (CTPP).* The 1990 CTPP is a specialized, computerized collection of data tables developed from responses to the 1990 Census providing information for the transportation planning community. The CTPP contains detailed information on worker and commuting characteristics by place of residence, by place of work, and worker flows among small areas.

- *State Employment Commission.* The State Employment Commission generally documents all employees for tax purposes. Each employer is identified by a federal identification number, total number of employees, and an address.

- *Market Research Listings.* Numerous market research firms offer commercial listings of all (or major) employers and number of employees by county and city. The listings show businesses locations by street address and/or post office box.

- *Local Area Population and Employment Data.* Many areas collect and record some type of population data. Chambers of Commerce often publish lists of member businesses.

- *Telephone Directory.* The telephone directory is a rich database that lists residential units and businesses by street address. The rate of unlisted residential numbers is rising and may influence the accuracy of this data source.

- *Polk Directory.* The Polk Directory is a comprehensive list of household and employment data sorted by name and address. Household information can include occupation and employer data.

Business information can include the type of business and possibly any associated business operations.

- *Aerial and Satellite Images.* Aerial and satellite images can be used to determine housing units, and, to a certain extent, employment opportunities in a selected area.

- *State Department of Finance.* Some State Departments of Finance prepare population forecasts for the state in five-year intervals out to 20 years.

- *Local Planning Departments.* Local planning departments may have information regarding various socioeconomic aspects. The departments may have forecasts for future year planning.

3. Estimation and Forecasts of Zonal Demographics

a. Definition of Zonal Demographics

“Data on population, households, and employment at a small geographic area level.

- Additional information on the population/households and employment that is relevant to the transportation demand forecast process (e.g. household income, auto availability, and employment by type).

- Zonal demographics are required for the base year and for each future analysis year.”

b. Use of Zonal Demographics

“Zonal demographics are used as inputs to the first 3 steps of the four-step travel demand forecasting process

1. Trip Generation- forecasts the number of trips generated in each zone based on:

   - households by household size, and income or auto ownership, and
   - employment by type (basic, services, retail) and number of households.

2. Trip Distribution- determines where the produced trips will be attracted based on the:

   - spatial distribution of households and employment.

3. Mode split- determines the mode of travel primarily based on time and cost differences between highway and transit usage, the characteristics of the trip maker and the characteristics of the trip. The characteristics of the trip maker are based on the trip maker's household size, household income, and auto availability."

c. Key Concepts

(1) Base Year

"The model base year is the year chosen for model calibration. Needed for the base year are estimates at the zonal level of the number of households typically by household size, and household income or auto availability and amount of employment broken down by basic, service, and retail employment. These base year and zonal estimates must be developed with great care. If not, a proper model calibration cannot be performed.

"Also, to be accomplished during the base year are the execution of the travel surveys that are performed to support model calibration and the conduct of an extensive traffic volume counting program. The traffic counts are used to support model validation.

"If the Zonal estimates, travel surveys, and traffic volume count programs are not all conducted during the same time frame, then adjustments must be performed to get them to the same time frame. Careful advanced planning must therefore be accomplished in advance of the model base year."

(2) Forecast Year

"For each future year for which the model is to be used to forecast highway and transit volumes, zonal household and employment estimates must be prepared. Naturally, there cannot be any travel surveys or traffic counts performed for a future year. The estimation of the future year zonal households and employment is probably the most difficult step in the urban travel demand forecasting process. Therefore, considerable time and resources must be made available to perform this task. Because of the importance of these zonal estimates, it is essential that qualified and experiences staff be available to guide the work.

“Many states have a state agency with the responsibility for developing regional forecasts of urban area population and households. Estimates of forecasted median household income may also be prepared. The local planning agency or MPO task is to allocate the forecasted changes in population and households to those zones where the changes are expected to occur. Several different methodologies are available for accomplishing this work; some are quantitative and some are qualitative. Also, almost always there will be political considerations.”

d. Base Year Estimates

(1) Population/Households

Five basic steps:

1. Obtain base year or most recent population estimate.

2. Adjust population estimate to base year (if base year is not available)
   - Determine average annual growth rate
   - Assess growth rate for reasonableness
   - Apply growth rate to recent estimate

3. Check against data from past years and alternative sources.

4. Allocate estimate to Traffic Analysis Zones (TAZ) if original data are not at that level. Use data collected on building permits, demolitions, of aerial photography to identify areas of population/household growth and decline.

5. Household size, income, or other factors are used in the trip generation step to determine trip rates. The population and households in each zone must be classified by the factors required in the trip generation step. For the small time period generally occurring between the base year and the most recent population estimate, it is generally sufficient to use regional trends

(2) Employment

Four basic steps:

1. Obtain most recent employment data for county, urban area, or TAZ.

2. Adjust the most recent estimate to the base year, if necessary.

3. Allocate changes to TAZ if data from Step 1 are not at TAZ level, generally a simple “straightline” or trend technique is fine for this small time period.

4. Identify special generators (e.g. military base, hospital, university campus, jail) and their employment data if these uses exist in the estimated area

e. Forecasting Techniques

Transportation planners typically use current population, employment, and a regional control total to generate future land use scenarios at the TAZ level. To accomplish this, both quantitative and qualitative methods are used.

- **Qualitative Methods**

  - Delphi: systematic way to use expert opinion.
  - Policy and Technical Committees: used to endorse and review inputs, assumption, and forecasts.
  - Comprehensive Plans: forecasts are based on supply side of vacant land; zones within vacant land are assumed to be equally attractive to development.

- **Quantitative Methods**

  - Regression Models: statistical method used to fit relationship between one variable and one or more other variables.
  - Logit Models (MetroSim, UrbanSim): advanced statistical method for modeling choices where probability of each choice is predicted.
  - Linear Programming (Polis, Topaz): advanced quantitative method for models that require optimization such as traffic assignment.
  - Micro-simulation (Master, Dortmund): most detailed and disaggregate form of modeling.
  - Input Output Models (Implan, Rims-II): accounting system showing economic transactions between businesses, households, and governments.
  - Gravity Models (Dram/Empal): formal land use models.

- **Others**

  - Allocation Procedures/Methodologies: methods used to determine the locations of population and employment growth.
  - Sketch Plans: quick analysis to demonstrate the result of a certain public policy.

The “best” technique will depend on local data (many techniques are *very* data intensive), local development trends, and staff experience

4. Network Development and Zone Definition

a. Defining a Zone System

“Traffic zones are a geographically defined area used to aggregate households and employees for use in travel demand forecasting models. This aggregation is required because of the lack of data at the household or business level and the historically limited computational power. Techniques and hardware, being developed to overcome these obstacles, is discussed in the final section of the chapter. Current TDF software packages rely on some level of aggregation, however, the number of zones that can be accommodated by software and hardware is increasing rapidly.

“Size of the zones should vary with the model application and can be as small as a block or more than 10 square miles. Consistency in zone boundaries aids in computing historic trends error checking, etc. Many regions use a hierarchical zone structure that permits the aggregation of very small zones to districts or super districts depending on the analysis goals and the area of interest.

“During the process of defining zones there are four items that should be kept in mind:

- <u>Location of Census boundaries</u> - Census tract groups and block boundaries should not be split. If blocks are split during zone definition, census data will also have to be split and/or allocated.

- <u>Transportation Network</u> - Arterials and freeways should not split zones. Arterials are often used as zone boundaries, because they are frequently the census boundaries and linking centroid connectors into arterials results in better distribution of traffic on the TDF network.
- <u>Natural and manmade barriers</u> - Natural barriers, such as rivers or mountains, and manmade barriers, such as railway tracks and freeways, restrict access and therefore are logical TAZ boundaries.

- Land-use Characteristics - TAZs should include homogenous land uses where possible. For example, a major office park should be placed in a different zone than a neighboring residential development."

b. Transportation Networks

"A network is a representation of the existing transportation system. The two most common types of networks are highway and transit. These networks are used to represent many modes, including non-motorized, automobiles, high occupancy vehicle lanes, bus routes, high speed rail, etc. In most TDF models, non-motorized travel is not specifically assigned with the exception of the assignment on access links to transit systems.

"Highway and transit networks are used in the final three steps of the four-step process - trip distribution, mode choice, and assignment. They play a critical role in each of these steps."

(1) Trip Distribution

"Networks are used to produce tables of impedance for each zonal interchange. The term impedance, in TDF, is a function of the time and cost to travel from one zone to another. Impedance is based on 'congested speeds' rather than 'freeflow' speeds to more accurately reflect travel conditions. In most areas the impedance used in trip distribution is only composed of highway travel time and costs, assuming that a highway network impedance would not be sufficiently different from a composite transit and highway network impedance to significantly impact the resulting trip table."

(2) Mode Choice

"In very simple terms, mode choice is based on a comparison of the time and cost of an auto trip to the time and cost of a transit trip. The actual application of mode choice models also includes person, household, and trip characteristics, but the network characteristics are a critical component of this procedure."

(3) Assignment

"Highway and transit trips for each zone interchange are assigned to the highway and transit networks. Network characteristics are used to choose the optimum path, on either the highway or transit system. Information on the number of trips assigned to each link is then stored in output or 'loaded' network files."

"Each of the steps described above will be covered further in later sections. However, it is important to realize that the development of networks is a very critical step that has implications for the remainder of the TDF process.

"TDF modeling efforts require a number of different networks. The networks, described below, are an example of the types of networks used to analyze transportation alternatives in a congested corridor."

(4) Base Year Network

"A base year network is used to validate and calibrate the model. A base year TDF model, using trip tables and networks from a past year, is created and the highway and transit assignment volumes from the model are compared to observed highway and transit volumes for that same year. The model calibration (adjusting coefficients and parameters) continues until a 'satisfactory fit' is achieved."

(5) Future Year No-Build Network

"Once the base year model has been validated and calibrated, the model may be applied to future networks. The future year no-build network includes only existing facilities and those programmed for construction. Programed transportation improvements are obtained from Transportation Improvement Plans (TIPs) and State Transportation Improvement Plans (STIPs) for which a funding commitment has been made by the implementing agency. Environmental clearance, political concerns, financial limitations, construction schedules, and other circumstances can influence the completion date for transportation improvements. This uncertainty makes developing a reasonable no-build network a very difficult task. When developing a no-build transportation network, decisions concerning which committed projects to include must be explicitly stated"

(6) Future Year Alternative Networks

"Future year networks which represent the alternatives under study are developed by adding or editing the links representing a specific alternative to the highway no-build network and making changes to the transit system. The accurate development of future year networks, each representing a different alternative, is critical to the evaluation process."

Corridor Study Networks

Base Year (1995)
Year 2010 - Light Rail
Year 2010 - New Freeway
Year 2015 - No New Major Investment (No-Build)
Year 2015 - Park-n-Ride and Improved Bus Service

(7) Time-of-Day vs. 24 Hour Networks

"In addition to networks representing different years and transportation alternatives, networks can be developed for different times of the day. The accurate representation of time-of-day is particularly critical when transit, high occupancy vehicle (HOV) facilities, or tolls are being investigated. For example, transit schedules vary greatly during the day. In the peak hour, the number of buses in operation might be three times greater than the number in operation in the off-peak. HOV lanes may operate in different directions during the morning and afternoon peaks. This variation of the transportation system by the time-of-day emphasizes the importance of carefully considering whether the time-of-day is critical for the analysis to be conducted."

c. Highway Network Files

(1)Nodes

"Nodes generally represent either intersections or the centroids of zones (described later). Shape nodes are used to improve the legibility and recognition of node maps by creating curves or other street patterns. Node information must include 'x' and 'y' coordinates. Intersection nodes can contain information about turn penalties or prohibitions depending on the TDF software being used."

(2) Link Attributes

"Links represent roadway segments or centroid connectors. The information associated with links describes the roadway segment and can include a wide range of information depending on both the software being used and the application. Link data generally includes the following:

Required Link Attributes

A-Node: Number assigned to the node at one end of the link
B-Node: Number assigned to the node at the other end of the link
Direction: One-way or two-way travel on the link
Length: Length of the link in hundredths of miles, for example 0.17 miles
Lanes: The number of lanes for both directions of travel
Area Type: Varies by model, but can contain CBD, CBD fringe, urban, suburban, etc.
Facility Type: Varies by model, but can contain freeway, expressway, principal arterial, minor arterial, frontage road, etc.
Capacity: More typically provided in a look up table based on number of lands, area type and facility type
Speed: More typically provided in a look up table based on number of lands, area type and facility type

Optional Link Attributes

Volume: Counted vehicle volume for the base year, used for model validation or other volume depending on application
Zone: Number of the zone associated with the link
Penalties: Turn penalties or turn prohibitions associated with the a-node or b-node
Route #: Number assigned to the route profile
Intercept #: Number assigned to the corridor intercept or screenline the link crosses
Comment: The comment field may be used to annotate information about the link."

d. Centroids and Centroid Connections

"Centroids represent the activity center of a zone. The activity center can be located anywhere in a zone, the goal is to locate the centroid to best represent the average trip time in and out of the zone. Therefore, if development is evenly dispersed over a zone, the centroid should be placed in the center. If all the zonal development is located on the western edge of the zone, the centroid should be placed in this location.

"Centroid connectors represent the path from a centroid to the highway or transit network. The connectors represent local streets that carry traffic out of or into the TAZ. Connectors should generally be connected to links representing collectors, minor arterial, or frontage road facilities. Centroids should not be linked across natural or manmade barriers or to limited access facilities. An example of a barrier would be a zone that is bounded by river with no bridge within or adjacent to the zone. In this case, no centroid connector should be coded across the river. The location of centroid connectors will affect the route selection and assignment of traffic to and from the zone and should therefore be carefully coded."

c. Transit Networks

"Transit networks are, as was the case with highway networks, representations of the transit transportation system. In a bus system, the most common transit service, the representation emphasizes service levels, such as the bus headways, stops, transfers conditions, etc."

(1) Application of Transit Networks

"Transit systems are analyzed to answer a wide variety of questions and the most appropriate type of analysis can vary greatly. Creating transit networks and developing complete mode split models is a very time consuming and expensive process and should only be undertaken when the questions to be answered require that level of detail. The alternatives to detailed transit analysis will be discussed in the mode choice session of this course. Students should remember that generally only the largest metropolitan areas in the U.S. need to develop full transit networks."

(2) Time-of-Day and Other Consideration

"Many decisions must be made before the first transit line is coded. The techniques used depend on the software being used, the type of transit system being represented, the questions being answered, the types of data available (both travel data and network information), and other factors, such as:

- Time-of-day (AM Peak, PM Peak, Off-peak) to be coded.
- How much of the branching, turn-backs etc. will be coded?
- How will bus operating speeds be included?
- How will access to the transit system be coded?
- How will fares be represented?"

(3) Actual Routes or Best Representation

"During transit network development there are many smaller questions that arise. The most important factor to consider when making these decisions, is which coding convention will best represent the time/cost/impedance of using the transit system. For example, if a bus line runs along a roadway that is not included in the highway network, the analyst must decide whether to add that roadway (resulting in additional links and time), or which alternative road to use to best represent the actual bus route. With a large transit system, this type of decision will be made hundreds of times. Consistency and documentation of the decisions is critical."

(4) On-Top-of Highway Networks

"Transit networks are generally built 'on top of' highway networks. Along bus routes, for example, the path of the bus is traced on the highway network and the nodes that the bus would pass over are listed. This is not possible with a busway or grade-separated rail line. These new facilities are added to the highway network when necessary. The accompanying illustration shows the process for coding a transit network and the resulting transit line file."

f. Transit Access Coding

"Transit access links are important for several reasons, the most obvious is the need to accurately represent the travel impedance of transit trips. A less obvious reason for the great attention paid to access coding, is in the design of transit station areas to accommodate the pedestrians, autos, and buses entering the station area."

(1) Software Dependent

"Transit access coding is so dependent on software design, the data available to develop the model, mode choice algorithm structure, and the type of analysis that coding schemes are difficult to describe. Most software packages now have procedures to automatically generate the basic transit access links. Several types of transit access, that can be included in a transit network, are described in the following paragraphs. The most sophisticated transit networks and access schemes are generally used only in the analysis of high cost and fixed guideway transit projects. The high cost of data collection and coding limits the use of these more sophisticated schemes."

(2) Central Business Districts

"CBD present a particular problem in access coding because of the large number of transit stops within walking distance of every zone and the large number of potential transfers. Often two-way walk networks are coded in the CBD to link all zones and transit stops."

(3) Walk Access Links

"Walk links between zone centroids and transit stops are generally limited in distance. Half a mile is the frequently used limit. In larger zones, the zone is often partitioned to indicate the percent of the population within the maximum walk distance. The process of partitioning zones illustrates the magnitude of data required for transit coding. Population is rarely evenly distributed across a zone, so more effort is required when estimating the population in the zone area that is within a half a mile of a transit stop. This effort requires a large amount of land use information. Walk access links are required at both ends of the transit trip."

(4) Auto Access Links

"There are two types of auto access to transit, kiss-n-ride (traveler is an auto passenger) and park-n-ride (traveler is the auto driver.) Auto access links are only coded at the origin end of the transit trip because travelers rarely leave autos at the destination end of the trip. Auto access links are generally only created to either official park-n-ride lots or stations with a large amount of parking available. The catchment areas for park-n-ride lots are very difficult to determine. They depend on the many factors a traveler considers, such as parking cost at the destination end of the trip, the comparison of the transit and auto travel time from the park-n-ride lot to the destination, transit and auto level of service, etc."

(5) Transfer Links Between Transit Routes

"Transfer links are generally required only when the routes do not intersect (pass through a common node.) Transfer links can often be created by the TDF software."

g. Speed/Capacity Table

- **Look-Up Table**

"The speed and capacity on highway links can be coded in two different ways. The most common technique is to classify the links by their facility type and the type of area where they are located. The facility type and area types are then used to find the speed and capacity in "look up" tables. The other procedure is to code the capacity and speed on each link. During calibration, link speeds and capacities are adjusted to improve the distribution of traffic. If speed and capacities are coded in the link data, these adjustments must be made manually for every link impacted. For this reason, most models use look-up tables.

“Facility type (also referred to as functional classification) describes how the roadway segment operates. The particular classification scheme varies between regions, but the most critical characteristics are access control, speed limit, and intersection spacing.”

- **Freeway**

“A facility with full control of access, giving preference to through traffic (e.g., interstates and turnpikes.)”

- **Principal Arterial**

“A facility with a painted area wide enough to protect a left-turning vehicle or with barrier/median separating opposing traffic flows. This facility carries most of the long trips made within an urban area and emphasizes traffic movement rather than land access.”

- **Minor Arterial**

“A facility similar to a divided arterial, except no painted area or physical barrier separates opposing traffic flows. Generally, this facility has more signals per mile and fewer frontage roads.”

- **Collectors**

“Streets that collect traffic from local streets in neighborhoods, and channels flow into the arterial system. A small amount of through traffic may be carried on collector streets, but the system primarily provides abutting land, carrying local traffic to roads with more capacity.”

- **Centroid**

“Local streets within a zone are represented by centroid connectors. Area types modify the speed and capacity on the facility types by providing an indication of the level of congestion, type of traffic movements, and type of activities that will affect travel. Again the classification schemes vary between regions.”

- **Central Business District (CBD)**

"Usually the downtown retail area of a city. High land values and traffic flows are typical."

- **CBD Fringe Area**

"Outskirts of a city and city periphery."

- **Mixed Urban Area**

"Contains a mix of urban land uses, including commercial retail and office, residential, other employment, and public facilities."

- **Non-CBD Business District**

"Primarily commercial and employment areas, usually along principle arterial. This type of district may have the intense activity characteristics of the central area (e.g., edge cities.)"

- **Suburban/Residential Areas**

"An area of predominately residential development, but some neighborhood retail may be included."

- **Rural**

"A sparsely developed area, with agriculture and scattered residential uses."

h. Network Building

"The network building process is accomplished somewhat differently in software packages, however, the general procedure is to create a network file from a link file and a node coordinate file. This binary network can be viewed and edited (in most software packages) on the screen. Completion of the network building process and visually checking the output network on the screen is the first opportunity to check for errors. A more complete discussion of error checking for both networks and zone structure will follow, but it is important to emphasize that creating the first built network is in no way the end of the network development process. Extensive network error checking should occur before the calibration phase begins."

Path Building and Skims

“Path building procedures find the minimum path between every zone interchange. The path can be the minimum time, distance, or a calculated impedance. Impedance is a function of time (including wait time, transfer time, in-vehicle time, etc.), distances, and cost. The impedance function is defined by the user and can vary between link types and mode. Path building is the basis for the assignment step of TDF models, but it also plays an important role in error checking and validation of networks, trip distribution, and mode choice. In trip distribution, the interzonal impedances are used as an input to the gravity model. The difference between transit impedance and auto impedance for each zone interchange is one component used to predict mode choice.

“Path building, in most software packages, will generate matrices showing the time, distance, and impedance for all zone interchanges. Skims are an accumulation of other network values, such as tolls, wait time, and transfer time. Trees are the graphic display of the chosen paths and they can either be viewed on the screen or plotted.

“Trees are a graphic display showing the minimum impedance paths through a network from one zone to all other zones. Trees are particularly useful for checking that the minimum impedance paths for a network are reasonable paths.

“Skims or travel time matrices contain information about the minimum impedance paths between all zone pairs in a network. Also referred to as the skim tree matrix or travel time matrix, these matrices are used in trip distribution, mode share, and traffic assignment steps. The matrices can contain:

travel time - minimum travel time between all zone pairs
travel distance - minimum distance between all zone pairs
travel impedances -
minimum impedance path which is a function of time, distance, and tolls.”

5. Trip Generation

a. Trip Types

“It has been found in practice that better trip generation models are obtained if trips by different purposes are identified and modeled separately. The most common trip types are:

- Home based-work
- Home based-other
- Non-home based

In transportation modeling the concept of trip productions and attractions are used instead of origins and destinations. Where a production is the home end of a home-based trip and the origin of a non home-based trip, the attraction is the non home end of a home-based trim end the destination of a non home based trip."

b. Trip Generation Process

(1) Information Needs for Trip Productions

"Socioeconomic disaggregate data is required to calibrate trip production models. Typical socioeconomic data elements include: income, car availability, household size, and number of workers. Other less commonly used socioeconomic data elements are: race, gender, age, value of land, residential density, and accessibility. A household travel survey may be used as a secondary source for verifying the distributions since it is not as coarse as the Census data.**"**

(2) Information Needs for Trip Attractions

"It is difficult to obtain adequate information to calibrate trip attraction models. For trip attractions, the most important data element is employment. Employment is broken down into three categories namely basic employment, retail employment, and service employment. Accessibility is rarely used in the U.S., but is commonly used in overseas countries. The following sources are often used to obtain trip attraction rate information: work place survey, household survey, cordon survey, and screen-line survey."

(3) Special Generator Information Needs

"To obtain trip rates for special generation specific information relating to the land use type needs to be obtained. For example in the case of a hospital the number of beds is important and for a large shopping mall the gross leasable area needs to be obtained."

(4) Trip Rates From Travel Surveys

"Travel surveys include the following types of surveys: household and work place surveys,, roadside interviews, cordon surveys, and screen-line surveys. These surveys are covered in Session 2, Travel Surveys and

Other Data. The data obtained from travel surveys are used to develop trip production and trip attraction rate models. In addition to the basic trip generation information needs, specific detail regarding the frequency, mode, length and purpose of trips are also obtained through travel surveys."

c. Production Cross-classification Submodel

"A cross-classification model is often used to determine trip productions. This model is based on estimating the response (e.g. the number of trip productions per household for a given purpose) as a function of household attributes. This model assumes that trip generation rates are relatively stable over time for certain household stratifications. The method determines these trip rates empirically and a large amount of data is required. Cross classification is based on grouping the households in different strata, for example, a specific cell is based on household size and car ownership. The trip generation rate for that specific cell is then the total number of trips in that cell divided by the number of households in that cell. This relationship can be stated as follows:

$$t^p(h) = T^p(h) / H(h)$$

where,

h =

$t^p(h)$ = Trip rate for purpose p made by members of households of type h;

$T^p(h)$ = The total number of trips by purpose made by households in cell h.

$H(h)$ = Number of households in cell h.

The following are some advantages of the cross classification method:

- Cross-classification groupings are independent of the zone system of the study area.
- No prior assumptions of the shape of the relationship are required and can easily accommodate non-linear relationships.
- Can also be employed for mode split.
- The procedure is simple to use and understand.

The following are some disadvantages of the cross classification method:

- The model does not permit extrapolation beyond its calibration strata.
- There are no statistical goodness-of-fit measures for the model.
- Large sample sizes are required, otherwise cell values will vary in reliability."

d. Attraction Submodels

"Home based trip attraction models are usually aggregate models for predicting trip ends that are associated with the non-home end of the trip. A lack of data is a major problem with trip attraction models. Household surveys provide excellent data for production models, while much less information is available for attraction models. The same trip purposes used for the trip production models are used for the trip attraction models.

"Trip attraction submodels have received considerably less attention than has production submodels. The techniques used to predict these trips are also less sophisticated. Typically, simple cross-classification models are used although regression techniques that relate trip making to the various land use types to which they are attracted are also used.

"In cross-classification the most commonly used classification is employment type which is divided into basic employment, retail employment, and service employment. There is also a category for attractions per household. The rates are typically derived from data aggregated over the entire zone, although in a number of cases the area is divided in CBD, urban fringe, urban residential, suburban, and rural.

"With regression equations very simple linear regression equations are developed with only one are two variables. There are also applications where regression analysis and cross-classification techniques are combined."

e. Special Generator Submodels

"Special attention should be given to the location and possible impact of major trip generators. These special generators typically include CBD's, shopping malls, hospitals, government installation, airports, colleges, and universities. They result in trip generation ratio that are not compatible with results from standard trip production or attraction models.

"Trips produced by these kinds of activity centers can be predicted by using local surveys, such as traffic impact studies, or the Institute of Transportation Engineers (ITE) published trip generation rates [3]. For modeling purposes, these trips need to be converted to person trips by using average auto occupancy rates."

f. Balancing Attractions and Productions

"The final step in trip generation modeling is balancing productions and attractions. The estimated number of trips produced at the household level should be equal to the number of trips attracted at the activity centers. Each trip must have a production and an attraction end. In reality, the estimation of productions and attractions will not be equal. As a rule of thumb the ratio of productions to attractions should not differ by more than 10 percent prior to balancing.

"Trip production totals are normally used as control totals, and attractions are scaled to productions, because there is a greater degree of confidence in the production models than in the attraction models."

g. Balancing Non-home Based Trips

"NHB trip productions were generated in the 'home' zone, but by definition, NHB trips should not begin nor end in the 'home'zone. Therefore, we throw out the NHB productions generated in the 'home' zone and substitute them with the NHB attraction for that zone assuming that people going to that zone will have to leave the zone. This is because NHB trip ends represent true beginnings and endings. The point of departure in a NHB trip is a beginning, and the point of arrival is an ending. In contrast, for home-based trips the home is the beginning or production, whether you depart from or arrive at home.

"This means that NHB trips must balance by zone -- if zone 1 has 100 NHB attractions it must also have 100 NBH productions."

6. Trip Distribution

"Trip distribution is the stem of the TDF process where the planner determines *where* the trips will go. Session 5 focused on how the trip generation step provides frequency of travel, or *how many* trips will be produced or attracted to/from a zone. This session will focus on distributing those trips produced in one zone to all other zones based on zone attractiveness. This step is calibrated to reflect current travel patterns, and then applied to forecast future travel patterns.

"For example, the trip generation step Zone 3 has 602 productions, trip distribution assists in determining how many of those 602 trips will go to each zone.

"The purpose of this session is to illustrate and explain how a trips' destination choice is determined using the Gravity Model Equation, that will be discussed in detail later in this session."

a. Gravity Model

"The Gravity Model was adapted from Newton's Law of Gravitation, which determined the amount of gravitational force between masses as a function of the mass of the bodies and distance between them.

"Again, the focus is to apply the Gravity Model to determine where trips go. The gravitational force in the Gravity Model will now become the amount of travel between zones. This application is possible if the calculations using the Gravity Model are based on the *relative attractiveness* of the zones. To apply the Gravity Model to travel, some modifications are needed. To convert the Gravity Model equation to represent the amount of travel or number of trips as opposed to gravitational force, two modifications must be made:

- accessibility is used instead of distance, and
- number of attractions is used instead of mass."

(1) Equation

$$\text{Trips}_{ij} = \text{Productions}_i \times \frac{\text{Attractions}_j \times FF_{ij} \times K_{ij}}{\Sigma\ \text{Attractions}_j \times FF_{ij} \times K_{ij}}$$

Where:

Trips_{ij} = Trips between zones i and j

Productions_i = Productions from zone i

Attractions_j = Attractions from zone j

Friction Factor (FF_{ij}) = Friction Factor for zones i and j

Socioeconomic Factor (K_{ij}) = Socioeconomic Factor for zones i and j

i = production zone

j = attraction zone

"The Gravity Model Equation determines the number of trips being exchanged between two zones. This calculation must be performed for all zonal interchanges in the regions. For example, if a region had 500 zones, then 500 X 500 or 250,000 calculations are necessary. The variable sin the equation are discussed below.

"The right side of the Gravity Model Equation represents the relative attractiveness of a zone. The greater the friction factor (FF_{ij}) and the number of attractions ($Attractions_j$) compared to the other zones, the greater the relative attractiveness of a zone. This is discussed in detail later.

"Socioeconomic factors, or k-factors, consider defined social or economic linkages that affect travel behavior that is not other wise considered in trip distribution. An example of this is blue-collar workers living near white-collar jobs. The Gravity Model will distribute a large amount of workers to the white-collar jobs since they are close and there is a large amount of employment there. Therefore, trips may be overestimated. If necessary, K-factors must be quantitatively related to socioeconomic characteristics to the particular Ones to which they apply. This is important since these factors will be used in a forecast where the socioeconomic data will change."

(2) K-Factors

"K-factors are applied to the Gravity Model Equation as a fraction. If there is a deficiency of trips between zones, and the condition cannot be corrected with the use of calibrated friction factors, a k-factor greater than 1 would be applied, making the zone more attractive. If the zonal interchange had too many trips, a k-factor less than 1 would be applied. To prohibit trips, a zero is used.

"The subjective nature of these factors in application tend to reduce the credibility of the forecasts since they decrease the sensitivity of the model to variables that may change over time, such as changes in the blue-collar neighborhood. Some k-factors are justified, but in general, they should be used sparingly and with caution. These factors will not be used in the class workshops or examples."

(3) Friction Factors

"Friction factors are used in the Gravity Model Equation to express the effect of spatial separation or accessibility (travel time or impedance) on travel patterns.

"Friction factors must be calibrated so that the number and lengths of trips from trip distribution are correct. The calibration process is illustrated later. Once calibrated, friction factors are stable over time and are assumed not to change for the forecast year.

“The figure shows that friction factors are higher as travel time decreases. A review of the Gravity Model Equation helps explain this result. Top calculate the relative attractiveness of a zone, multiply the friction factory by the number of attractions. The greater the friction factor and the number of attractions, the greater the relative attractiveness of a zone. This fact become clearer after completing the trip distribution example.

“Friction factor curves also differ by trip purpose because of differences in travel preferences. The average traveler will make decisions based on trip importance and the traveler’s willingness to travel. Travelers are likely to spend more time making home-based work (HBW) trips than trips for other purposes. Home-based non-work (HBNW) trips are usually quite short; hence the higher friction factors on short trips. In other words, travelers are more likely to travel further to get to jobs, but a HBNW trip (grocery store, cleaners, and gas station) is more convenience-driven. Non-home based (NHB) trips (lunch, errands, from work trips) typically have friction factors between HBW and HBNW.

“When the TDF models were being developed, friction factors were used to represent the probability of travel between zones. They have evolved into a number of relevant importance, representing a weighting factor for calculating the attractiveness of a zone.”

b. Inputs and Outputs

“The trip distribution process uses data produced in the trip generation and path skimming steps of the TDF process. Travel times, or impedances, are used to measure the accessibility of a zone.

“Travel times are in the form of a matrix; each cell representing the time it takes to travel from one zone to another. These numbers are derived form path skimming, which uses the transportation network to identify the shortest path to travel between each zonal interchange.

“Productions and attractions reflect the frequency of travel or number of trips produced from or attracted to a zone.

“Productions and attractions are an output of trip generation. They indicate how many trips will be produced from and attracted to each zone. The example in this session represents HBW productions and attractions, but HBNW, NHB, and other trip purposes will also be calculated. It is important to note that these are ‘balanced,’ indicating that there is agreement between the total number of productions and attractions by trip purpose. For each trip produced, there is a related attraction. This was discussed earlier in Trip Generation (Session 5), and becomes important later is this session.

“The output of the trip distribution model is a trip table. Each cell in the matrix represents the number of trips between each zonal interchange.”

7. Mode Split and Transit Estimation

a. Factors Affecting Mode Split

“Split is determined by the relative cost/time for making the trip by each mode and the person/trip/land use characteristics, including those listed below. Not all of these factors are used in every mode split models. In some cases, although from a behavioral perspective the characteristics logically influence travel decisions, the available data or the model structure precludes the use of the characteristics.”

Person/Household Characteristics

Auto ownership/Auto availability
Income
Household Size

Trip Characteristics

Trip Purpose
Trip Chaining
Time of Departure
Origin & Destination
Trip Length

Land Use Characteristics

Sidewalk or Pedestrian Facilities
Mixture of Uses at Both Ends of Trip
Distance to Transit
Parking availability and cost at both ends of the trip

Service Characteristics

Facility Design (HOV lanes, bike facilities)
Frequency
Congestion
Cost (Parking, tolls, fares, out-of-pocket costs)
Stop spacing

Policy Actions

Steps to affect the factors described above to change mode split to achieve other goals, such as reducing congestion, air quality, welfare to work etc.

b. Mode Split Model Applications

“The type of analysis conducted should be driven by the types of question the analyst need to answer. The following are the major types of analysis in which mode split plays a critical role.”

(1) Route or Service Changes

“Planning for changes in cost, frequency, transfer system, extension or cutbacks of routes, or adding new routes is rarely done with complete four-step process. A full four-step model application is too expensive and not accurate enough in this setting. Instead, analog or elasticity methods are generally used.”

(2) Major Investment Studies (MIS)

“Determining the costs/benefits of various alternative transportation investments is one of the most important uses of a four-step process with sophisticated mode split technique. For example, a MIS would use the results of a TDF model to analyze the affect of HOV lanes in a corridor versus additional general travel lanes or additional bus service.”

(3) New Rail or Other Capital Investment Project Design

“The ridership or link volumes from TDF models are used in the design of rail system, (including station design, train selection, etc.), and the design of roadway facilities (number of lanes, ramp design, etc.) Extensive engineering and operational models are used to produce final design volume, with TDF models providing traffic volumes or passenger loads.”

(4) Policy Changes

“There is an increasing effort push to use TDF models and, the mode split step, in particular, to evaluate policy actions. Examples of the policy actions under consideration are parking costs, urban growth boundaries, congestion pricing, etc. These types of analysis push the capabilities of the models and the basic research into the connection between these policy actions and travelers corresponding travel decisions.”

c. Mode Split Techniques

(1) Analog

"Analog methods are sketch planning-tools for predicting transit ridership on a new route or to answer similar questions. They assume that an existing route (or routes) can be identified, and it is similar enough to the proposed new route that it can serve as the basis for computing the ridership for the new route. This very straightforward approach is often used in the business world. Consider, for example, how you would estimate the sales for a proposed new convenience store. If a store already existed in the metropolitan area, with a similar customer base and similar products, you could use the existing store's sales as a reasonable estimate for the sales at the proposed site. In the same way, there are two dimensions to identifying a similar existing transit route. The first is that the route serves an area with similar demographics to that proposed (the customer base in the convenience store example). The second dimension is that the transit service and transportation environment are similar (the product line cited above).

"To account for the inevitable differences in demographics and service characteristics between the existing and proposed routes, adjustments may be necessary. For example, if an existing route is twice as long as a proposed route, the number of riders on the existing route may have to be halved to obtain a reasonable estimate for the new route."

(2) Elasticities

"Transportation elasticities are the ratio of change in travel demand in response to a change in the transportation system. The concept is derived from the classical economist measure of 'price elasticity.' Transportation elasticities, when used properly, provide a technique to quickly prepare a first-cut, aggregate response estimates for transportation system changes such as transit service, transit frequencies, transit fares, parking charges, and gasoline costs. Elasticities are also a valuable 'reasonableness check' for results from other techniques such as disaggregate choice models.

"Proper use of elasticities requires similar consideration as described in the analog session. Communities, transit service, and other characteristics should be similar or the elasticities used may produce unrealistic results. For example, a region with very high parking costs or limited parking available in a Central Business District (CBD) would much less elastic transit trips oriented to the CBD in response to transit fares because the alternatives to paying the higher fare are still quite expensive. Also, elasticities can only be used when the transit service of interest is already in place. For example, use of a HOV facility could not be estimated with elasticities in a region with only bus service.

"If a one percent change in a service characteristic cause more than a one percent change in demand, the demand is elastic. If a one percent change in service results in less than a one percent change in demand, the demand is inelastic. The figure to the left shows elasticity demand curves for a community with a fare elasticity of -0.30. A doubling of the fare would result in a reduction in ridership between 20% and 30% depending on the calculation techniques.

"There are several equations that are used to calculate elasticities, the most common is a shrinkage ratio. The various equations yield the same results when the fare or other changes are small, but the choice of the equation should be made very carefully when the changes are large. A document published in 1981, *Traveler Response to Transportation System Changes*, contains a good summary of elasticity measures and their use along with a good (but dated) compendium of studies of transportation elasticities.

"Where service levels have remained constant the following fare elasticities were reported in 1981.

Atlanta	- 0.15 to - 0.20
Cincinnati	- 0.38
San Diego	- 0.51
St. Louis	- 0.20"

(3) Off-line Procedures

"Small and medium regions with limited transit use will generally not require detailed or complex procedures to estimate transit use. If transit riders generally fall into very specific population groups such as zero-car household, students, and elderly and there are no indications that transit rider characteristics will change simplified off-line procedures can be used to identify transit trips.

"These off-line procedures generally begin with estimates of the district-to-district or TAZ-to-TAZ transit share. This information is based on census data, transit provider information, or other external estimate. These transit shares will probably only be available for all trip purposes, however, if information that is more specific is available it should certainly be used. The transit share is subtracted from the person trip table(s).

"This technique can be used for other non-auto modes, including bicycle, pedestrian, or HOV trips."

(4) Disaggregate Mode Split Models

"Disaggregate mode split (DMS) model approach is much more sophisticated than the three approaches previously discussed. It predicts mode choice based on transit and auto travel times and costs, as well as information about the household of the traveler. This analysis is usually performed by trip purpose. The approach produces transit and auto shares for each production-attraction cell in a person travel matrix for each purpose. These shares are then multiplied by the trip table to obtain transit and auto trips by purpose.

"The probability of selecting a mode is determined from utility equations, which use the concept of impedance. A mode impedance is a combination of the mode's cost, travel time, and other factors which reflect the difficulty of using the mode. The higher the cost and time associated with the mode the lower the modes utility, and the lower the probability of selecting that mode.

"The discussion of these models will begin with a description of utility equations, then describe logit models which are based on the utility equations, examine binomial logit models, and will close with a description of multinomial logit models."

d. Utility Functions

"The building blocks of DMS models are utility equations. Utility equations rank the desirability of the potential travel modes. These equations incorporate characteristics of the alternatives and the traveler that are believed to influence the choice between alternatives. An analyst studying the relative utilities of alternatives could then predict which alternative would be chosen. Utility equations are deterministic—meaning they assume travelers presented with a set of relative utility for a choice of alternatives would always chose the alternative with the highest utility or lowest disutility. This, of course, violates what we know about travel choice processes. The limits to utility equations, and how those limits are overcome will be discussed later.

"Utility equations are estimated using a travel survey (the census or a home interview survey) and travel time and cost data for the transportation alternative. The travel cost and time information generally comes from the travel demand model networks. Using the individual's characteristics, the alternative characteristics and the chosen alternative equations are developed to predict the mode choice. The figure to the left shows a utility equation and the results of applying the equation for two individuals for different incomes. The higher income ($40,000) individual would chose to use an SOV for this particular trip. The lower income ($10,000) individual would chose to carpool, mainly because of the lower cost. This equation is very simple compared to those actually used by metropolitan areas, which could contain 10 or more factors. The coefficients reflect the relative value of each factor.

“The utility equation is not generally used due to several factors. Travelers rarely know the entire set of alternative transportation modes, rarely know exactly the relative merits of that choice set and travel decisions are based on personal variables that cannot be or are not measured. The analyst cannot include every factor influencing our decision, encounters measurement errors in trying to characterize the alternatives and travelers, and is forced to use proxy variables that may not capture exactly the effect they were intended. And finally people make different choices based on non-recurring circumstances ‘ I usually ride the bus but today I have a doctors appointment, so I will pay the extra cost to drive to work.’”

e. Probability Equations

“The predictive powers of utility equations are limited due to the following:

- omission of relevant variables;
- measurement error;
- proxy variables;
- differences between individuals, and
- day-to-day variation in choice.

“Due to the above, it is now standard practice to use utility equations in a probabilistic equations. By making the decision probabilistic a set of individuals faced with an identical set of utilities will make a variety of decisions. This range of choices is intended to overcome the limitations described above.

“Logit equations are the most common form of probability equations used today. The equation shown to the left is a binomial logit equation. It predicts the probability of choosing one of two possible alternatives. The graphic below shows the change in probability with varying utilities of the bus and auto. Note that where the difference between the utilities is zero (they are equal) the probability of choosing each both the bus and auto are also equal.”

8. Traffic Assignment

“Traffic assignment is the process of allocating a given set of trip interchanges to a specific road network. Traffic assignment accomplishes this by:

- Identifying a set of routes which might be considered attractive to drivers. The driver wants to minimize impedance which is a function of distance, free-flow speed, and capacity. These routes are stored in a particular data structure called a tree. This is often referred to as the tree-building stage.

- Assigning suitable proportions of the trip matrix to these routes or trees. This results in flows on the network.

- Searching for convergence. Most assignment techniques have different iteration strategies.

"Although manual traffic assignment techniques are possible for very small networks, traffic assignment requires the use of digital computers. These computerized approaches are based on the assumption that the underlying principle for route selection is *user equilibrium*. In a network where user equilibrium is reached, no user can improve travel time (cost) by unilaterally changing routes. Traffic assignment methods include the following:

- all-or-nothing (minimum path) assignment;
- equilibrium assignment;
- stochastic assignment;
- capacity-restraint or interactive assignment;
- incremental assignment; and
- public transport assignment.

"The equilibrium method is becoming the state of the practice. For clarity purposes this session will further outline this method along with the all-or-nothing assignment technique. The other three methods will not be covered in this session.

"Apart from the private transport-related techniques mentioned above, certain techniques are available to assign passengers using public transport. A discussion of these techniques will follow later in this session."

a. Traffic Assignment Methods

(1) All-or-nothing Assignment

"In this approach, we compute minimum impedance routes for each origin-destination (O-D) pair. All flows between these pairs are loaded on these routes. A given route receives all or nothing of a given O-D pair's flow, thus ignoring capacity.

"This is a simple and inexpensive approach. It depicts the routes most travelers would use in the absence of capacity and/or congestion effects. Results of this approach are each to understand and interpret. The major disadvantage of this approach is that it clearly generates unrealistic flow patterns in situations where capacity constraints and congestion effects exist.

"The all-or-nothing assignment technique is a quick and inexpensive way to determine whether the network has been coded correctly. It also provides a picture of the true desired route of travel.

"To perform the all-or-nothing assignment, you will need a trip matrix to be assigned and link information so that the uncongested travel time (impedance) between the different O-M pairs can be computed. Then perform the following steps:

Step 1: Compute the minimum travel time paths for each O-D pair. (This is based on uncongested travel times or travel costs.)

Step 2: Assign all trips from each origin to each destination to the minimum paths. If more than one shortest path exists for a particular trip, a first-link-selected (tie-breaker) link is loaded."

(2) Equilibrium Assignment

"Equilibrium assignment techniques recognize that transportation link impedance generally depend on link flow levels. Therefore, these techniques search for a user equilibrium solution in which link flows and impedance are simultaneously solved. Under equilibrium conditions, traffic arranges itself in congested networks so that no individual trip maker can reduce path impedance by switching routes.

"Solving the equilibrium assignment for a matrix of trips is not as easy as using the all-or-nothing assignment. Some improved user equilibrium algorithms are now available. The basis for theses algorithms is mathematical programming formulations of the problem that guarantee convergence to a user equilibrium solution.

"Given a network with congestion functions for each link, a trip matrix to be assigned and a current solution for the link loading (V_a). Then performed the following steps:

Step 1: Compute travel time on each link $S_a(V_a)$ that corresponds to the flow V_a in the current solution.

Step 2: Trace minimum path trees from each origin to all destinations by using the travel times from step 1.

Step 3: Assign trips from each origin to each destination to the minimum path (all-or-nothing assignment). Label this link loading (W_a).

Step 4: Combine the current solution (V_a) and then new assignment (W_a) to obtain a new current solution ($V_a{}^1$) by using a value B selected as to minimize the objective function.

Step 5: If the objective function sufficiently minimized, stop, otherwise return to step 1.

"The objective function is stated as follows

$$\sum \int_0^{V_a^1} S_a(X)\,dx$$

"and $V^1_a = (1\text{-}B)V_a + W_a$

"Initially a current solution can be obtained by performing an all-or-nothing assignment based on free-flow times. This initial assignment is then used to compute revised travel times and perform another all-or-noting assignment as per steps 1-3 above. The two assignments are then combined by using a weight B selected so as to give a new solution that minimizes the objective function of the nonlinear programming problem.

"The Change in the value of the objective function provides a measure of the convergence of the algorithm. As the change approaches 0, the value of B also approaches 0, which means that V^1_a becomes equal to V_a and the objective function is minimized."

(3) Transit Assignment

"Transit assignment is different and more complex that private transport assignment because:

- The network of transit services is different from that of private cars. Links in this network include sections of the bus or rail service running between two stops or stations. Many of the public transport services share road links with private cars. This results in an assignment to a more complex network.

- The transit assignment involves the movement of passengers, not vehicles. The travel time has an in-vehicle component as well as out-of-vehicle time such as waiting at stops and walking to and from stops. Passengers may also transfer between two routes, and even drive part of the way to board a public transport service.

- In private car networks the monetary cost is directly associated to fuel consumption, tolls and parking. In transit services, the different fare structures determine the monetary cost associated with a trip. There is also transfer cost and parking if an auto is used to get to the transit station.

- For some O-D pairs there are sections in the path where more than one parallel service is offered. This allows passengers to select a preferred service. This choice can be complex and require a more detailed modeling treatment.

"Transit assignment is divides into the following stages:

- Input:
  - Demand inputs such as the O-D trip matrix and the transit mode share form the mode split model.
  - Network inputs such as routes, headway, transfer structure, fare structure and transfer stations.
  - Travel times like access and egress times at the origins and destinations.

- Assignment:
  - Each person trip is assigned to the network from the origin to the destination. The fare system forms the major criteria in assigning the person trips.

- Output:
  - Passenger volumes per mode on each link.
  - Transit travel time from origin to destination.

- Assignment Includes capacity Restraint on busses, trains, or stations."

b. Speed, Volume, and Density

"The traffic state of any roadway can be described by three basic measures namely flow rate, speed, and density. Whereas traffic volumes provide a method of quantifying capacity values, speed is an important measure of the quality of traffic service provided to the motorist.

"When there is only one vehicle on the roadway, the vehicle can move at what is called *free-flow speed.* Nothing prevents the driver from operating the vehicle at a preferred speed. In traffic assignment, however, we add vehicles to that link, representing the trips made by travelers between zone pairs. When more vehicles are added to that link, the speed, volume, and density relationship makes the interaction between the vehicles more evident.

"The relationship between these measures is:

$S= v/D$

Where:

S = average travel speed (mph)

v = rate of flow (v/hour), number of vehicles which can pass by a given point on the roadway.

D = density (v/mile), the number of vehicles that occupy a segment of the roadway"

c. Speed, Flow, and Density

When the are no vehicles on the roadway, density is zero and the rate of flow is also zero. A vehicle traveling under these conditions could move at free flow speed.

As density increases, the rate of flow also increases until D_o (optimum density) at which point flow begins to drop. While flow increases, speed is beginning to decrease. This decline is almost negligible at low and medium densities, but as the flow increases toward capacity (V_m), speed begins to decrease significant.

When density increases to a point where all vehicles stop, the speed and rate of flow become zero.

A maximum situation is reached when the product of density and speed results in a maximum rate of flow. This condition is shown as *optimum* speed S_o, *optimum density* D_o, and *maximum flow* V_m.

d. Speed, Flow, and Level of Service

Average travel speed decreases with increased flow on the network. "Therefore, the average travel time should increase as the volume to capacity ratio on a specific link increases. The bureau of Public Roads (BPR) formula shows this relationship:

$$T= To [1 + .15 (v/c)^4]$$

where:

T = Actual travel time
T_0 = Free flow travel time, and
v/c = Volume to capacity ratio

“In the application of the BPR formula a specific LOS must be assumed. Generally LOS C, or in some instance D, is assumed. By applying this formula, a V/C ratio is selected that will yield the actual travel time.”

e. Forecasting Future Year Assignment

“During the trip distribution phase, a trip matrix for a chosen forecast year is established. Trip assignment is performed for both the base year and forecast year scenarios. The base year traffic assignment is performed by using factors such as distance, free-flow speed, capacity, and speed flow relationships. Use the same factors, adjusted for the extended network and higher predicted traffic volumes, to perform the forecast year traffic assignment.”

9. Model Calibration and Validation

a. Calibration

“Model calibration is the process of developing mathematical functions to explain travel behavior and the process of developing the associated coefficients or parameters for these functions. For example, the Bureau of Public Roads (BPR) formula used in the traffic assignment step is an example of a mathematical function. The exponent in the BPR formula is an example of a parameter value. The BPR formula is a mathematical function that predicts changes in the travel time on a roadway segment represented by a link in a coded network as a function of changes in a link’s volume to capacity ration. Calibration is performed individually for each of the four steps in the modeling process and for the entire model.

“The model calibration/validation/application process describes a sequential approach to developing travel models, validating travel models by comparing model output with observed results, and then using the model to forecast future travel.

- **Travel Surveys:** A variety of travel surveys are used to assist in the development of a travel model. These surveys may include household, workplace, special generator, external station, truck, and travel time surveys. The household survey data is used to develop a mathematical relationship or function which relates observed travel behavior to variables that can be more easily forecast directly.

- **Mathematical Relationships:** A trip production function in the form of a cross classification table is an example of a mathematical relationship where the cell values represent 24-hour trip rates for a particular trip purpose for households of a particular size and income range. The assumption is made that households in the future will have the same trip rates as those households included in the sample data. Therefore, future trips can be forecast provided the analyst has an independent forecast of the future number of households of the same household size and income range. The speed and capacity look-up table used for estimating link speeds and capacity as a function of the area type, number of lanes, and facility type is an example of a mathematical relationship. Travel time studies are used to assist in the calibration of the look-up table. The assumption is made that future drivers will travel at similar speeds given the same area type, number of lanes, and facility type. Applying the models in travel forecasting infers an extrapolation of these mathematical relationships into the future.

- **Code Formulation Into Software:** Once developed, the mathematical relationships are coded into computer software for efficiency of use. Several commercial travel demand forecasting software packages are available. These packages have many of the mathematical functions typically used already coded. Most packages provide some flexibility for the analyst to modify these functions to meet the needs of a particular urban area.

- **Compare Models with Observations:** Comparing models with observations refers to the process of making judgements about how well a particular mathematical function and its associated coefficients predict travel behavior. Comparisons are made for each step in the modeling process and for the model as a whole."

(1) Trip Generation

"Trip generation calibration involves three components, evaluation of the base year zonal socioeconomic estimates, development and application of a trip production model, and the development and application of a trip attraction model. In the trip generation step, the trip production rates or model is applied using the zonal socioeconomic estimates to produce zonal trip production, that is, zonal trip ends. Similarly, the trip attraction rates or model is applied using zonal socioeconomic estimates to produce zonal trip attractions, that is, zonal trip ends.

- **Zonal Estimates, Production Models, Attraction Models, Production and Attraction Balance:** The analyst is concerned with the reasonableness of the base year zonal socioeconomic estimates, the appropriate functions or mathematical expressions used for the trip production and trip attraction models, and the parameters associated with these models. Finally, the analyst is concerned with the trip production trip attraction balance.
- **Zonal Socioeconomic Estimates:** The Census Transportation Planning Package (CTPP) provides a breakdown of households by zone by household size, by auto ownership, and by income group. These 1990 household and auto ownership data and the 1989 income data can be used to verify the reasonableness of the base year zonal estimates. A comparison of observed (CTPP data) and estimated (base year zonal estimates) households by size subgroup will help identify serious bias in the base year zonal estimates.

- **Trip Production Models:** Household travel surveys are used to estimate trip rates. Surveys doe not provide direct estimates of zonal trip ends. Therefore, there are no observed number of trip ends to compare with model estimated trip ends. What the analyst can do is compare summary statistics such as vehicle trips per household, person trips per household by trip purpose, and the percentage of person trips by trip purpose for the study area with values for similar study areas.
- **Trip Attractions:** Home interview surveys do not provide sufficient

data to develop zonal trip attraction rates. As a result, attraction models are typically developed with regression equations using data aggregated to large districts. Relationships such as HBW person trip attractions per total employment and HBNW trips per retail employment can be calculated and compared with other areas.

- **Trip Production and Attraction Balance:** A comparison of the productions and attractions by trip purpose provides an excellent check on the trip generation step. A productions to attractions ration of 0.90 to 1.10 is considered good.

(2) Trip Distribution

“Calibration of trip distribution model results is performed using two methods:

- Regional trip length frequency distributions (TLFDs) and mean trip lengths by trip purpose, and

- Area-to-area flows of trips.

“Household travel survey data is used to estimate trip length frequency distributions and mean trip lengths in miles and in minutes for each trip purpose. A sample as small as 500 households will provide a stable estimate of the TLFDs and mean trip lengths for the three internal trip purposes. These observed TLFDs and mean trip lengths from the travel survey are compared with the TLFDs and mean trip lengths from the application of the gravity model.

“The Census Journey-to-Work data can also be used to develop an observed TLFD for the HBW trip purpose. There are differences in the definition of trips between travel surveys and Journey-to-Work data that the analyst must consider.

“Observed patters of area-to-area flows of trips cannot be derived from small-scale household travel surveys. Large-scale metropolitan area surveys involving 5,000 plus households, or reported commuter flows from the Census Journey-to-Work tables, that are based on a 17% sample, are required to obtain reliable estimates of small area-to-area flows of trips. Nevertheless, comparison of area-to-area flows for the HBW trip purpose from the Journey-to-Work data with the output of the gravity model will provide an excellent check on the performance of the gravity model. And, since the HBW trip purpose is so critical to the estimation of public transit trips, the analyst must make this comparison if there is a significant number of public transit trips.

"Calibration of the gravity model continues by adjusting the friction factor values until a satisfactory agreement is achieved between the modeled and observed mean trip lengths an TLFDs for each trip purpose."

(3) Mode Choice

"Calibration of an initial mode choice model for an urban area generally requires the assistance of an experienced planning consultant. Questions concerning the form of the logit model, the variables to be included in the utility functions for each mode for each trip purpose, the calibration of the coefficients for each utility function for each trip purpose, testing for independent irrelevant alternative properties, and the analysis of household and on-board transit surveys all require experience and expertise. Discussion of these calibration steps are beyond the scope of an introductory course.

"However, evaluation of the performance of a calibrated mode share model can be undertaken by most analysts. Evaluation of the performance of the mode choice model focuses on the proportional shares of total trips estimated by the model to be highway or transit, as well as the absolute numbers of transit trips made on an average weekday.

"The absolute number of transit trips predicted by the mode choice model can be compared with transit ridership totals reported by the transit operator. If an on-board transit survey was conducted, mode choice model trip estimates can be compared with observed estimates for each trip purpose. Further, the transit operator can provide ridership estimates by route that can be compared with ridership estimates by route predicted by the mode choice model.

"For urban areas where transit service is focused on the central business district (CBD), observed mode choice estimates can be obtained through a comprehensive program to monitor traffic volumes, auto occupancies, and transit system usage on the approaches to and from the CBD. These observed highway and transit shares observed at the CBD cordon can be compared to the shares predicted by the mode choice model."

(4) Trip Assignment

“Calibration of the trip assignment step builds upon the successful calibration of each of the previous steps. If significant errors persist in these earlier steps, calibration of trip assignment will be meaningless. Only after the analyst is satisfied that the base year zonal demographics are reasonable, that the trip by purpose trip production and trip attraction estimates produced by the trip generation models are reasonable and in balance, that the gravity model is distributing the trips appropriately and the resulting mean trip lengths and TLFDs by trip purpose are agreeing with observed values, that the mode choice model is providing a reasonable share of trips to each mode by trip purpose, should the analyst proceed to a comparison of assigned link volumes with counted link volumes.

“The comparison of observed and counted link volumes is accomplished beginning with aggregate measures and proceeding to the comparison of individual link volumes as follows:

Screen line volume comparisons	Cut line volume comparisons
Corridor volume comparisons	Volume group percent RMSE comparisons
Facility type percent RMSE comparisons	Individual link volume comparisons

“Typically, travel models are calibrated to estimate average daily weekday (Monday-Friday) school year traffic volumes. In support of the model calibration effort, base year traffic volume counts are made on as many roadway segments of the network as resources permit, but generally on about one-third of the roadway segments that are to be included in the coded network. All of the roadway segments that form screen lines or cut lines are counted.

“Screen line evaluations are made by comparing the total counted screen lines with the total modeled screen line volumes. An urban area may have four to six screen lines. Screen line volumes should agree within about 5%. Cutline evaluation s are made for each individual cutline. Two to six roadway segments may constitute a cutline. The counted and modeled volumes for each cutline are totaled and compared. An urban area may have 10 to 30 cutlines. Cutline volumes should agree within about 10%. Corridors are roadways that carry traffic in the same direction. Counted and modeled volumes are totaled for corridor segments and compared.

“Volume group and facility type percent root mean square error (RMSE) are calculated for all links with counts. The percent RMSE values typically are 30% or less.

$$\frac{((\Sigma(\text{Modeled Volume - Counted Volume})2 / (\text{Number of Counts}))0.5 \text{ X } 100}{(\Sigma\text{Counted Volumes / Number of Counts})}$$

“Similarly, transit ridership counts by route are made to assist with the calibration of the transit assignment.

“For both highway and transit counts, the analyst must recognize the day-to-day inherent variability in traffic volumes and transit ridership.”

b. Validation

“Model validation is the process of comparing model output with observed data and making judgements about the performance of the model. If the analyst finds that the model output and the observed data are in acceptable agreement, the model can be said to be validated. Validation is an iterative process. The analyst may go back to the calibration step a number of times before an acceptable validation is achieved. There are two types of validation checks, reasonableness checks and sensitivity checks. Reasonableness checks include the comparisons of the model output with observed data and the comparison of model parameters with parameters for similar urban areas. Sensitivity checks determine how the model output changes in response to changes in input data. Currently, research is being conducted through FHWA’s Travel Model Improvement Program (TMIP) to increase the sensitivity of travel models to transportation policy issues.

“Before models are used to forecast travel, they are applied to the complete model chain sequence using base year inputs. This results in an estimate of base year travel that is compared with observed travel. The model chain is applied in its entirety in the same manner as it would be in the forecast year. Model validation, therefore, involves assessing the ability of the model to replicate observed travel.

“If the comparisons of the base year model output with observed travel is judged to be unacceptable, the analyst will return to model calibration. The performance of the model in the validation effort provides important insight regarding the ability of the model to forecast travel.

“A new model calibration may not always be necessary when updating a model. The transportation conformity guidelines require that the travel model used to prepare the conformity analysis have a validation that is not more than 10 years old. A model may be validated by simply comparing the model output for a new base year with observed travel (network traffic volume counts) for the same year. If a reasonable comparison between the modeled output link volumes and the counted link volumes is achieved, it can be assumed that the various functions and parameters developed in the original model calibration are still performing well.

"Once validated, the model is available to forecast travel, given forecast zonal activity and future transportation system alternatives."

B. AN INTRODUCTION TO URBAN TRAVEL DEMAND FORECASTING: A SELF INSTRUCTIONAL TEXT

(U.S. Department of Transportation, 1977)

"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."

"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 not 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.”

1. 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 UPTOWN. 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.”

2. 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 UPTOWN survey data show that Zone I 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.”

3. 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 I 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 I'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.”

4. 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 trip maker,
- the characteristics of the trip, and
- the characteristics of the transportation system.

“The planner looks at how these characteristics interact to affect the trip maker'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.

5. 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 travel time 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.”

C. ADVANCED TRAVEL DEMAND FORECASTING: PARTICIPANT’S NOTEBOOK

(U.S. Department of Transportation, 1997)

“The Advanced Travel Demand Forecasting Course is designed for experienced travel demand modelers, generally those who have been practicing travel demand modeling for several years at metropolitan planning organizations, state Departments of Transportation, in consulting or academia, and in other environments. While it is recognized that auto travel dominates in many urban areas in the U.S., many of the procedures discussed in the course deal with non-auto modes such as transit or walking or with mode choice issues. However, there is substantial information in the course that can be applied in any U.S. urban area or state.

“This course is offered as the transportation modeling field is in a state of fairly rapid advances in procedures. These advances have resulted from a renewed interest as all levels of government in travel modeling, which stems in part from recent federal legislation (ISTEA and the Clean Air Act Amendments), recent research into travel demand forecasting procedures, and advances in computing technology, which enable more detailed travel demand analysis. The course attempts to communicate to travel modeling professionals some of the procedures developed by their colleagues around the U.S. and abroad, most of which have been implemented as part of an existing travel demand modeling system.

"The structure of the course generally follows the traditional four-step travel modeling process. While this process is in a state of flux and may eventually be replaced, it still forms the basis for nearly all U.S. urban area and statewide travel models. Procedures which are not commonly part of or have only recently become more common in the travel modeling process - such as land use modeling, trip generation input modeling, time-of-day modeling procedures, ITS modeling, and tour-based modeling - are described at the point where they would fit into the traditional process."

The participant's notebook for this course contains the following chapters:

- **Introduction to Logit Modeling:** utility theory, the random utility model, the binary logit choice model, estimation of the logit model, the multinomial logit model, the art of model building, and prediction with disaggregate models;

- **Modeling of Trip Generation Inputs:** motivation, commonly available data and problems in forecasting, auto ownership modeling, and modeling other household characteristics;

- **Trip Generation**

- **Trip Distribution:** weakness of traditional approaches, measures of composite impedance, home-work linkages/market segmentation, a behavioral approach to trip distribution, and singly versus doubly constrained models;

- **Mode Choice Modeling:** nested logit modeling, market segmentation, other types (non-motorized travel modeling, HOV modeling, transit transfers, toll roads, and model transferability);

- **Trip Assignment:** multi-class assignment, transit assignment considerations, use of alternative volume-delay functions;

- **Time-of-Day Modeling:** need for time-of-day analysis, review of existing practice, peak spreading approaches, and future research;

- **Integration of Individual Model Components:** type of model relationships, variables used in model relationships, feedback strategies, examples of integrated model structures, examples of feedback strategies, and conclusions;
- **Modeling for Intelligent Transportation Systems**; and
- **Model Validation:** overview, reasonableness checking, validation of each model component, sensitivity checks, and error propagation.

D. NORTH CAROLINA PROCEDURE FOR SYNTHESIZING TRAVEL MOVEMENTS

(Poole and Newnam, 1987)

"This paper describes procedures developed by the planning staff of the North Carolina Department of Transportation for synthesizing travel movements in small and medium size urban areas. Included is a brief history of the evolution of the synthesis procedure whose development began in the 1961 - 1963 period.

"Four methods are used depending upon the extent of travel surveys which may be done as part of the transportation study. Method 1 uses data from an external cordon origin and destination (O-D) survey and small sample internal O-D survey. Method 2 procedures are followed if only an external cordon O-D survey is done. Method 3 requires only travel data from an internal O-D survey. Method 4 is followed if no origin and destination surveys are done. All four methods require comprehensive traffic volume counts, and comprehensive inventories of employment, commercial vehicles, and dwelling units.

"The North Carolina Procedure has greatly reduced the time and cost required for the travel modeling phase of transportation studies and enabled more time and effort to be devoted to travel forecasting and transportation plan development and evaluation."

E. TRAVEL ESTIMATION TECHNIQUES FOR URBAN PLANNING

(Martin and McGuckin, 1998)

"This report updates NCHRP Report 187, 'Quick-Response Urban Travel Estimation Techniques and Transferrable Parameters,' published by the Transportation Research Board in 1978. Like that guide, this report is organized to follow the traditional travel-demand forecasting steps of trip generation, trip distribution, mode choice, and traffic assignment. Unlike the earlier report, this report does not give manual techniques for applying the travel procedures significant attention. The parameters presented are organized in a format that allows for application in many of the widely available travel-demand forecasting programs that run on microcomputers.

"The report provides transferable parameters for use when area-specific data are not available or need to be checked for reasonableness. The material focuses primarily on the needs of smaller urban areas, but some material will be useful to other areas. In general, more complex procedures will be needed for large urban areas, growing medium-sized urban areas, and severe air quality nonattainment areas. Area-specific parameters will almost always be preferable to transferred parameters, though it may not be cost-effective to develop them for smaller urban areas.

"In addition to the chapters devoted to the steps in travel demand forecasting, a chapter is presented that identifies data requirements and sources of data for building the travel-demand database. The data requirements and data sources include both the transportation supply system (highway and transit networks) and socioeconomic data. The remaining chapters of this report are as follows:

- Chapter 2, Building a Transportation Database;
- Chapter 3, Trip Generation;
- Chapter 4, Trip Distribution
- Chapter 5, External Travel Estimation;
- Chapter 6, Mode-Choice Analysis;
- Chapter 7, Automobile-Occupancy Characteristics;
- Chapter 8, Time-of-Day Characteristics;
- Chapter 9, Traffic Assignment Procedures;
- Chapter 10, Capacity Analysis;
- Chapter 11, Development Density/Highway Spacing Relationships; and
- Chapter 12, Case Study Application of Default Parameters. . . .

"A chapter has been included that discusses the database required to build a travel demand model. These include supply-side data (e.g., highway and transit networks) and demand-side data (e.g., zonal socioeconomic data on population and employment). A description of the data requirements is presented along with sources for building the database. Also in this chapter is a brief discussion of the use of geographic information systems (GIS) and the opportunities for using GIS in the building of the travel demand database and in model application. The survey of MPOs and state DOTs revealed that more that one-half of the agencies have GIS available.

"For trip generation analysis, two sets of parameters are presented. The first set represents vehicle trips generated by specific site activities. The data for these rates were extracted from the Institute of Traffic Engineers' *Trip Generation Manual*, 5th Edition. The second set of rates are typical for trip production and attraction models. These rates represent average daily person trips and were arrived at by using both the data from the recent National Personal Transportation Survey and several home interview surveys taken since 1985. An interesting finding in this study is that, although the trip rates are divided by urban areas with different populations, the variation between small and large urban areas was not as great as presented in the *NCHRP Report 187*. The rates are more closely grouped around an average of 9.0 daily person trips per household. Different rates are presented for the population ranges of 50,000 to 200,000; 200,000 to 500,000; 500,000 to 1,000,000; and greater than 1,000,000.

"The trip distribution section presents the standard gravity model formulation. The report assumes that the user will be developing zone-to-zone travel times from a network-based travel demand package and the default data required are the travel impedance friction factors. The friction factors are presented as both a gamma function and a lookup table. Presented in this section is a discussion of how the gravity model can be calibrated to match observed trip length distributions. Unlike the trip generation section, the default friction factors are not grouped by urban area size. The trip distribution within an urban area depends heavily on both the local highway (and transit networks for areas with significant transit shares) network and the geographic location of the households and employment.

"External travel estimation has been the least documented component of the travel demand models. A chapter has been included that presents a procedure for estimating through, internal-external, and external-internal trips for small urban areas. The research concluded that, although the procedure works adequately for small urban areas, it is not applicable for larger areas. Research into external travel revealed that very little has been done in the advancement of external travel estimation, yet for many areas, external travel is not easily transferrable between urban areas — particularly through-trip estimation, which depends heavily on the urban area location (in relation to other urban areas) and size. It is recommended that local external travel data be collected to the extent possible and that further research is needed into the collection and estimation of external travel.

"Mode choice is a step in the modeling process that has been largely ignored in small to medium-sized urban areas. These sizes of areas have transit systems that carry a small percentage of total person trips and the data have not been collected from which a locally calibrated model can be derived. Advances in mode choice modeling have largely been tied to the analysis of major investments in fixed-guideway transit systems such as light rail starts. The chapter on mode choice presents a discussion of the logit formulation of the mode choice model as well as a presentation of the incremental logit model structure that can be used for the analysis of transit and HOV alternatives in corridors and subareas. It is in these analysis areas that mode choice analysis using transferrable parameters is most applicable.

"Auto occupancy and time-of-day parameters are presented in separate chapters. The research resulted in a conclusion contradictory to the *NCHRP Report 187* assumption that auto occupancy would increase. During the last decade, auto occupancy has actually been declining. This is reflected in an average occupancy rate for home-based work trips of about 1.11 versus the *NCHRP Report 187* rate of about 1.35. The time-of-day factors can be used to construct trip tables for peak and off-peak periods. Also included in the time-of-day chapter is a discussion of procedures for converting production-attraction formatted tables to origin-destination tables.

"The traffic assignment chapter presents refinements to the standard BPR formulation for travel times as a function of volume and capacity. As with the trip distribution procedure, the assumption is made that the traffic assignment is done by a travel demand package and that the default parameters required are the relationship of travel time to volume and capacity. Different functions are presented for different facility types, including freeways and multilane arterials. The corridor diversion and screen-line smoothing techniques presented in *NCHRP Report 187* are presented in this report.

"Capacity analysis is presented from two views — the analysis of intersection level of service and the development of link capacities that can be used as input to the building of the highway network in the modeling process. The revised *1985 Highway Capacity Manual* was the source for the intersection procedures and the user is referred to that document as the primary source for applications.

"A case study has been developed in order to illustrate the application of the parameters and techniques described in this report. The data included in this case study were provided by the State of North Carolina for the City of Ashville, North Carolina. The applications of the study parameters and techniques to this case study are presented at the conclusions of Chapters 1 through 9. This case study allows the user to follow the development and application of the travel forecasting model beginning with the data collection phase, where the highway networks and the socioeconomic data are presented. Subsequent chapters follow the model development through trip generation, where standardized trip generation rates are applied, and trip distribution, where standardized friction factors are applied. Ultimately, the final traffic assignment is presented, along with screenline comparisons of the existing traffic counts to the model results.

"The final chapter of this report presents the case study in its entirety, from data collection through traffic assignment. As can be seen in this report, the results of this demonstration are quite reasonable when compared with the observed traffic volumes."

F. TRANSPORTATION MODELING IN SMALL & MEDIUM-SIZED AREAS

(Chatterjee and Weggmann, 1994)

"Comprehensive long-range transportation planning for urban areas, based on complex land use and travel forecasting models, began to evolve in the mid-1950s. Travel forecasting models for these studies were based on comprehensive origin-destination survey data and mathematical formulations that evolved gradually over the 1950s and 1960s. Computer programs were developed for the complex modeling analyses, and the use of such software packages as PLANPAC and UTPS became standardized. These early software packages ran on mainframe computers, and their users were primarily consulting companies, state departments of transportation (DOTs), and a few large metropolitan areas. The use of these travel forecasting software packages was beyond the resources available to many small and medium sized areas.

"During the 1980s the rapid technological advancement in microcomputers provided new opportunities to local agencies. Travel forecasting software such as MIMIUTP, TRANPLAN, QRSii, Tmodel, and EMME/2 were designed to run on microcomputers, giving local governments or Metropolitan Planning Organizations (MPOs) the option to develop transportation models in-house instead of relying entirely on state DOTs or consultants. Likewise, state DOTs had the option of continuing their role in conducting the travel modeling for the MPOs or delegating the task to the local agencies. Different areas/states have used different approaches, and new issues and opportunities are being encountered. Now after more than a decade of microcomputer use, it is timely to investigate the balance between the technical sophistication provided by the microcomputers and the planning needs and resources available in small and medium-sized areas. For the purpose of this paper, the experiences in North Carolina and Tennessee are presented as case studies. . . .

"North Carolina historically has maintained a strong state focus towards transportation planning and provides traffic modeling capabilities within NCDOT on behalf of the local areas. In Tennessee, due to funding and personnel limitations, TDOT, with the support of local MPOs, has used a decentralized approach and encouraged and helped MPOs undertake traffic modeling at the local level."

G. DEVELOPMENT OF INEXPENSIVE RURAL TRAVEL DEMAND MODELS

(Crevo and Bromage, 1997)

The document includes slides from the session's presentation, a section on demonstration software (FastNet, FastZone, and TripGen), and a section discussing travel demand model concepts. It is "intended to provide background and reference material for attendees of the inexpensive Rural Travel Demand Models session of the 50th Annual North Atlantic Transportation Planning Officials meeting. The content focuses on the traditional four-step process and the activities associated with the development of travel demand models."

H. TOWARDS CONSISTENT TRAVEL DEMAND ESTIMATION

(Miller, 1997)

"A travel demand analysis consists of assessing four components of the travel pattern for a study area: i) *trip generation* (TG) or where trips are coming from; ii) *trip distribution* (TD) or where trips are going to; iii) *modal split* (MS) or the shares among available modes for the flow between origin-destination (O-D) pairs; and, iv) *network assignment* (NA) or the route choice within each mode. The standard "state-of-the-practice" in travel demand modeling is the sequential or *four-step approach*. This modeling strategy estimates the four travel demand components sequentially and feeds the results from one component to the next component in the sequence. Unfortunately, the four-step approach is flawed. A particularly severe problem is potential inconsistency among the travel demand component estimates. Another problem is that prediction errors from any component are compounded in each subsequent stage, potentially leading to substantial errors in latter stages.

"While the inherent flaws in the four-step approach are recognized widely, an existing, viable alternative is not widely known. The *equilibrium travel demand modeling* approach embeds the travel demand components in the four-step approach within a *market equilibrium* framework. This generates consistent answers among the four travel demand components. *Achieving this consistency in general does not require substantial increases in computational resources nor data inputs*.

"This research report addresses the gap between the state-of-the-art and the state-of-the-practice in travel demand modeling. This report is an *accessible* review of the theory and practice of equilibrium travel demand modeling. This review is intended for practitioners and beginning students in transportation analysis, modeling and planning. Key features of this review include: i) a focus on *practical* travel demand models, i.e., models that can be implemented at the urban or regional-scale; ii) a focus on the behavioral assumptions, data requirements, parameter estimation procedures and solution procedures that are key to model application; iii) placement of mathematical formulae are in appendices, allowing the less mathematically-incline reader to skip the formulae but still receive an intuitive understanding of the models' structures. These features should render this review accessible to its intended audience, transportation analysts and planners.

"This report first reviews the theoretical conditions for network flow equilibrium (i.e., the NA phase of the four-step approach) and the overall market equilibrium for the remaining travel demand components (MS, TD, TG) based on the assumed network equilibrium. The available network equilibrium principles include:

- *User optimal-strict* (UO-S): At network equilibrium, no traveler can reduce his or her travel costs by unilaterally changing routes (i.e., changing routes independently without other users' route changes);

- *User optimal-general* (UO-G): Travelers change routes *in the next time* period in a manner that reduces total cost *based on the current route costs*;

- *Dynamic user optimal* (DUO): At network equilibrium, no traveler *who departed during the same time interval* can reduce his or her travel costs by unilaterally changing routes;

- *Stochastic user optimal* (SUO): At network equilibrium, no traveler can reduce his or her *perceived* travel costs by unilaterally changing routes.

These network equilibrium principles can be linked in a theoretically consistent manner to equilibrium conditions for the higher-level travel demands. Models that do not enforce this simultaneous equilibrium are misspecified and consequently flawed. Empirical evidence going as far back as the 1970's suggests that the four-step approach suffers from misspecification, nonconvergence and error." . . .

"The equilibrium travel demand models discussed generally follow an equivalent optimization approach. This strategy first specifies a combined travel demand model then derives an equivalent optimization problem whose solution corresponds to a market equilibrium of the specified travel demand components in the initial model. Typically, this problem contains a [sic] objective function to be minimized and constraints that represent flow and aggregate demand feasibility requirements. In the interest of brevity and due to the pragmatic orientation of this report, this section only discusses the equivalent optimization problems. The report discusses the models from the perspective of: i) *basic assumptions*; ii) *model structure*; iii) *data requirements and parameter estimation*; and iv) *solution procedure*.

"After discussing the basic characteristics of each model, this report compares the travel demand methods based on several criteria. The comparison provides guidance for the travel selection and use, although it does not provide a definitive answer. Comparison of the travel demand models uses the following criteria: i) *basic theory* or the major strengths and weaknesses of the model's theoretical base; ii) *mathematical elegance* or the parsimony and flexibility of the model's formalism; iii) *computational requirements and performance*, including the basic procedural needs of each model's algorithm as well as performance efficiency; and, iv) *data requirements and parameter estimation*.

"Although this report's objective is an accessible review of equilibrium travel demand models rather than the research frontiers, this review nevertheless suggests three major research and development issues. This includes: i) *specification and development of a computational toolkit for equilibrium travel demand modeling*; ii) *development of a travel demand model testbed*; and iii) *development of a combined statistical distribution theory and simultaneous parameter estimation procedures*. The first issue concerns the specification and development of a toolkit that can support *several* of the equilibrium travel demand models within the same computational platform. Instead of forcing a travel demand analysis into the model available within a given GIS software, this would allow the practitioner to access the model or models most appropriate for the research question at hand. The second issue, closely related to the first, concerns support for extensive testing of equilibrium travel demand models as well as other competing approaches.

"The third research and development issue addresses a weakness of equilibrium travel demand models, specifically, a lack of statistical distribution theory for the combined travel demand components within each equilibrium model. This weakness is shared with the 4-step approach: a consistent combines statistical distribution theory does not exist for the sequential travel demand estimation procedure. However, this weakness is not as apparent in the 4-step approach since it artificially separates the travel demand modeling components. When these components are embedded in an equilibrium framework, this weakness becomes more obvious. Some discussion of these combined estimation issues does exist in literature. However, no existing model has a combined statistical distribution theory and an efficient and unbiased simultaneous estimation procedure for all parameters. Continued research along this line is required for effective application of equilibrium travel demand models."

I. CONVERSION FACTORS FOR THE USE OF CENSUS DATA
(COMSIS Corporation, 1996)

"The goal of this handbook is to assist the transportation planner in using the 1990 Census to develop and calibrate local travel demand models. Often, collecting new data to complete the development of a local model is not an option. Therefore, planners must rely on existing data and previously completed models with little else to assist in model calibration. Regardless of what local data are available, the 1990 Census provides another source of information to assist in model development.

"Potential users of the Census and the conversion factors and procedures proposed in this report need to be aware that there would appear to be a substantial variance between results obtained from the Census journey-to-work files and locally developed home interview surveys. A quick comparison was made of models as they are currently being applied across the country and the results obtained by applying the Census conversion factors suggested herein to Census journey-to-work files for those same areas.

"There was a substantial difference between the results in many areas. While a few of the models developed from local home interview surveys apparently produced significantly fewer trips than would be suggested by the Census data, many others appeared to have more trips than the Census files produced. Several areas showed differences of 10 to 15 percent in total trips. Without careful comparisons of the files by individuals familiar with the models as they were developed, it is difficult to be certain that the differences are real or simply an 'accounting difference.' In attempting to compare data files there were several pitfalls that were encountered. For example:

- Differences in the definition of the area covered by local models - often only parts of counties are included in the model definition and unless detailed attention is taken to make certain that the geographic coverage is identical, apparent differences can be imputed where they do not exist.

- Differences as to whether external trips were included or not and what types of externals were included.

- Differences as to whether vehicle trips or person trips were being reported.

- Differences in the definition of a home-based-work trip. Some metropolitan areas use a definition of a home-based-work trip that may ignore intermediate stops at a store, day care center or gasoline service station, thereby substantially raising the number of home-based-work trips that would be reported locally as compared to the more restrictive definition of a home-based-work trip as used in this report.

“These differences were surprisingly difficult to resolve without extensive effort. It is for this reason that the metropolitan Atlanta area was selected for a comparison of local survey results with the Census. A complete home interview survey was conducted in 1990 in Atlanta and the areal and trip type definitions were well documented and understood. In Atlanta the comparisons between the Census derived trip tables and those derived from the home interview surveys were virtually identical

“Without further research, however, it can only be concluded that the planner using the Census adjustment factors suggested in this report should do so with caution. Where there is current, reliable home interview survey data available, it is recommended that this data be used as the source of first choice for local model development. Where such quality data is not available the Census factors developed in this report may be viewed as a useful means of developing a model set.

“As a data source to develop a consistent set of Census conversion factors, the 1990 Nationwide Personal Transportation Survey (NPTS) was used. The first NPTS was conducted in 1969 by the U.S. Department of Transportation (DOT) to address data needs related to personal travel. The survey was conducted again in 1977, 1983, and 1990. The objective of the survey was to collect trip-based data on the nature and characteristics of personal travel on a typical travel day. The NPTS incorporates typical surveying procedures. The survey considers all persons 5 years of age and older. Those that are 14 years of age and older are surveyed directly. Those that are between 5 and 13 years are surveyed by proxy. The NPTS is conducted in all 50 states including the District of Columbia. The data is stratified by three categories: (1) the nine U.S. Bureau of Census divisions, (2) presence or absence of a fixed-guideway public transportation system, and (3) three metropolitan size categories. The number of usable households interviewed in the 1990 NPTS is 21,869.

"The particular utility of the NPTS as a source of Census conversion factors is the fact that travel-to-work data is collected by the NPTS both in the format that Census data is collected and in the format employed by the home interview travel survey. This is critical to the development of the conversion factors. This allows a direct comparison of each worker's response for usual travel last week, and actual travel on the survey day. Thus an internally consistent set of conversion factors can be derived from the NPTS alone." . .
"This document is divided into chapters that outline the procedures for using the 1990 Census data for travel demand forecasting, followed by a case study example of converting Census work trips to local survey data. Development of the factors relies upon the 1990 NPTS. Chapter 2 details the limitations in the Census that are related to travel demand models. These limitations are related to the way in which the Census questions are worded. This wording makes the data from the Census different from typical local survey data. Appendix A provides the questions that are at issue in the 1990 Census as well as those in the 1990 NPTS used to develop adjustment factors. It discusses some of the inherent problems I using Census data directly and related issues that are addressed in Chapter 3.

"Chapter 3 outlines the adjustment factors developed using the 1990 NPTS data. It includes four steps in the development of a composite conversion factor to adjust Census journey-to-work data. The chapter concludes with a sample calculation of a composite adjustment factor that can be used to estimate total work trips and work trips broken down by travel mode. This estimation is specific to metropolitan area size.

"Chapter 4 provides a comparison of the NPTS adjustment factor to local factors developed for a case study developed in Atlanta, Georgia. Where possible, conversion factors developed from the recently completed local survey are compared to the NPTS results."

J. UTPS HIGHWAY NETWORK DEVELOPMENT GUIDE
(U.S. Department of Transportation, 1983a)

“The Urban Transportation Planning System (UTPS) Highway Network Development Guide is both a user's manual to UTPS software and an overview of current network development planning and analysis techniques. Three audiences will profit from reading this material:

- Transportation analysts who previously have used UTPS software: These individuals will learn the differences between current highway network analysis programs and earlier programs, including added program capabilities, new coding conventions, and increased planning and analysis flexibility.

- Transportation analysts who are familiar with PLANPAC software: These individuals will discover bow the latest UTPS programs utilize PLANPAC datasets to increase their network analysis planning capabilities and application.

- Transportation planners new to network analysis: These individuals will find a step-by-step explanation of network analysis as a planning tool; how to use networks to solve a variety of transportation planning problems; how to scale a network to the problem at hand; and how to code, debug, and use the results of the individual programs which make up the Urban Transportation Planning System.

“The present chapter reviews the contents of the five other chapters, which progress from a description of network uses and traffic assignment methods to the actual development, calibration, and evaluation of a transportation network.

“Chapter II describes how UTPS highway network data may be applied to short-term or long-term travel forecasting, traffic assignment, and related highway system evaluation. Two key concepts are introduced: the scale of the problem always determines the level of analysis, and successful analysis depends upon a clear understanding of the relationship between traffic zones and the entire highway network.

“Chapter III examines specific assignment methods: all-or-nothing, probabilistic multipath, and capacity restrained. A discussion of impedance then follows with comments on speed/capacity options, toll links, and turn penalties. The Integrated Transit Network program (INET), which is now part of the UTPS package, also is discussed. Finally, micro assignment methods are presented in the context of their various applications.

“Chapter IV features a discussion of UTPS highway network data components and attributes. A general review of basic network components leads to a discussion of key UTPS network attributes and coding conventions, and then to a discussion of the new data base structures. Additionally, methods for converting PLANPAC and UTPS historical record network formats to the UTPS highway network data base are presented. The chapter concludes with a discussion of network checking and debugging procedures.

“Chapter V contains an extensive discussion of network calibration. More specifically, it discusses in detail calibration measures and their proper application during network development and analysis.

“The final chapter, Chapter VI, addresses the issue of network evaluation procedures. UROAD reports, UMATRIX capabilities, network plotting, and selected link assignment methods are examined separately in order to help the UTPS user to check on the validity and completeness of his program results.

“This Urban Transportation Planning System Highway Network Development Guide offers detailed and fairly complete information on one aspect of network planning and analysis. However, other manuals and program descriptions should be consulted for a thorough grasp of the concepts and techniques discussed here. Recommended to the reader are the following materials:

- HNET Program Documentation
- UROAD Program Documentation
- NAG Program Documentation
- UMATRIX Program Documentation
- ‘Transit Network Analysis - INET,’ UMTA, 1980
- ‘Computer Programs for Urban Transportation Planning - PLANPAC/BACKPAC General Information,’ FHWA, April, 1977
- ‘Traffic Assignment - Methods, Applications, Products,’ FHWA, August, 1973.”

K. TRANSPORTATION NETWORK ANALYSIS TECHNIQUES FOR DETAILED TRAVEL FORECASTS

(Chang and Kurth, 1994)

"The city of Chicago is in the preliminary engineering final environmental impact statement phase of planning for a central area circulator system. Because of the wealth of existing bus and transit service and the amount of activity taking place in the central area, detailed modeling of transit options was required. Described here are enhancements to the transportation network coding and analysis made to travel demand forecasting models necessary to properly model the various transit options. These enhancements include determination of travel speeds on the basis of intersection control and signal timings, explicit coding of transit stops, and detailed multipath transit assignments. Finally the reasonability of applying the detailed network processing techniques in typical regional model applications is discussed."

L. NETWORK EQUILIBRATION WITH ELASTIC DEMANDS

(Garner, 1980)

"Elastic-demand equilibration (assignment) is an analytical model for travel forecasting in homogeneous and multimodal transportation networks in which the demand for travel between each origin-destination (O-D) pair is an elastic function of the service level offered by the network. The problem was formulated as a mathematical optimization program in 1956 and, since that time, a variety of iterative schemes have been proposed for its solution. In this paper, the mathematical-programming formulation of the network-assignment problem (NAP) with elastic demands is examined, an economic rationale for its optimization objective is derived, and an efficient method for its solution is presented. The method is based on modeling the NAP as an equivalent-assignment problem in an expanded network. The variable-demand NAP is thus transformed into a fixed-demand NAP that has a trip table that consists of the potential O-D travel demands and can therefore be solved by any fixed-demand assignment procedure available."

M. TIME-OF-DAY MODELING PROCEDURES: STATE-OF-THE-PRACTICE, STATE-OF-THE-ART, FINAL REPORT: EXECUTIVE SUMMARY

(Cambridge Systematics, 1994)

"In recent years, there has been increasing interest in the ability of travel demand models to estimate travel not only for the average weekday, but for different periods within the day. Travel demand models are increasingly required to be analysis tools for a broad range of issues on transportation policy and project alternatives. These issues often require detailed analysis, not only spatially, but temporally as well. This report provides documentation on methods used in U.S. urban areas to handle the issue of time of day in their travel demand models. Commonly used practices are described, the most innovative methods used by metropolitan planning organizations and states are documented, and emerging approaches are described as well."

1. Standard Approaches

"Trips occur at different rates at different times of the day. Typically, there are one or more peaks in daily travel. The dominant weekday peak periods are in the morning (AM peak period) and in the late afternoon (PM peak period). A peak period can be characterized by its maximum trip rate (in trips per unit time). The peak hour is the hour during which the maximum traffic occurs. The portions of the peak before and after the peak hour are called the "shoulders of the peak". The time at which travel occurs and, more specifically travel peaking intensity and duration are critical to the estimation of a number of important travel performance measures, including speeds, congestion, and emissions. Yet peaking and time of travel are included in the traditional travel model in highly approximate ways, typically by developing peaking or time-of-day factors from observed data and assuming the same patterns will persist in the future.

"A time-of-day factor (TODF) is the ratio of vehicle trips made in a peak period (or peak hour) to vehicle trips in some given base period, usually a day. Time-of-day factors are most commonly specified as exogenous values that are fixed and independent of congestion levels. If applied prior to trip assignment these time-of-day factors are usually determined from household activity/travel survey data and from on-board transit and intercept auto surveys, with a separate TODF for each trip purpose. If applied after assignment, the peaks' timing and duration are generally estimated from traffic data (e.g., 24-hour machine counts on streets and highways, transit counts, or truck counts), perhaps interpreted and adjusted based on data from special studies (e.g., travel surveys of workplaces and customer-serving businesses in a particular area or driveway counts at major activity centers). Occasionally, time-of-day factors are borrowed from other areas and adjusted during the model calibration process.

"There are several commonly employed methods for accounting for time of day of travel in the four-step travel modeling process. To proceed from the initial daily trip generation estimates to the volume estimates by time period, average daily travel estimates must be converted to trips by time period. This time-of-day assignment can happen at four places in the modeling process:

- After trip assignment;
- Between mode choice and trip assignment;
- Between trip distribution and mode choice; and
- Between trip generation and trip distribution.

“These four time-of-day assignment approaches are described in the following paragraphs. Table ES.1 summarizes their applicability, level of effort and data required, and their limitations and advantages.

2. Time-of-Day Assignment after Trip Assignment

“In this method, the assigned daily link volumes are factored to produce volume estimates by time of day. This method is the simplest and probably the most commonly used. The post-assignment static technique uses a daily traffic assignment as a basis. In its simplest form, peak hour factors (usually in the range of 8 to 12 percent) are used to reflect peak period link-level travel demand. In this approach, the daily assigned volumes are multiplied by the peak period factor to estimate peak period demands. The technique can be refined to reflect different peak hour percentages. A directional split percentage (e.g., 60 percent), derived from observed traffic conditions, is applied to obtain link-level peak volumes.

“This procedure yields only a rough approximation of link- or corridor-level peaking though it may suffice for smaller MPOs where the duration and intensity of congestion are limited. In general, there is little reason to expect specific facilities to exhibit the same peaking patterns or characteristics as ‘regional averages,’ and application of a fixed TODF may be a significant source of error.”

3. Time-of-Day Assignment between Mode Choice and Trip Assignment

“This widely used procedure factors the purpose- and mode-specific, daily trip tables produced by the mode choice model. These trip tables are then used as inputs to time period-specific trip assignments. For example, three time periods may be used: morning peak, afternoon peak, and off-peak. Peak hours, rather than peak periods, are modeled in some regions. Daily traffic volumes are produced by adding up the results of the morning, afternoon, and off-peak period traffic assignments.

TABLE ES.1 Time of Day Assignments			
Method	Applicability	Level of Effort and Data Required	Limitations and Advantages
TOD Assignment after Trip Assignment	• Method may be sufficient for smaller MPOs where the duration and intensity of congestion are limited • Most commonly used and simplest method	• Simplest method • Minimal labor and data required • Data required include peak hour factors that reflect peak period link-level travel demand • Directional split factors are also required	• Does not consider peak travel times in assignments • Trip distribution and mode split being done without accounting for congested times • Does not account for localized effects of changes in demand
TOD Assignment between Mode Choice and Trip Assignment	• Method may be applicable in the least congested areas • Widely used method	• Data required include factors representing the percentages of the trips (by purpose and by mode) during each hour and for each direction, production-to-attraction or attraction-to- production • Directional split factors are also required	• Trip distribution and mode split being done without accounting for congested times • Lack of sensitivity to general policy changes, increasing congestion levels, and corridor or subarea-specific changes
TOD Assignment between Trip Distribution and Mode Choice	• Method may be applicable in the least congested areas • Limited use	• Data required include factors representing the percentages of the trips (by purpose) during each hour and for each direction, production-to- attraction or attraction-to- production; • Directional split factors are also required	• The effects of time of day characteristics such as congestion or transit levels of service are ignored in the way trips are allocated to time periods • Trip distribution and mode split being done without accounting for congested times
TOD Assignment between Trip Generation and Trip Distribution	• Method may be applicable in the least congested areas • Limited use	• Data required include factors representing the percentages of the trips (by purpose and by mode) during each hour and for each direction, production-to-attraction or attraction-to- production; • Directional split factors are also required This approach can significantly increase model application time	• An advantage of this method is that differences in travel characteristics by time of day can be considered in trip distribution and mode choice • Procedure is not sensitive to increasing levels of congestion, nor is it sensitive to policy changes or congestion-management actions

"The process for preparing peak hour directional trip tables requires the factoring of the person or vehicle production-attraction formatted trip tables to peak hour (or period) origin-destination formatted vehicle trip tables. The data required include an hourly distribution of trips across the day. These should be by trip purpose, usually grouped into home-based work, home-based non-work, and non-home-based. From this diurnal distribution of trips, factors are developed which represent the percentages of the trips (by purpose) during each hour and for each direction, production-to- attraction or attraction-to-production. The hourly distribution is developed from local travel survey data. The production-attraction formatted trip tables are multiplied by the appropriate factors and transposed where necessary to produce balanced origin-destination trip tables."

4. Time-of-Day Assignment between Trip Distribution and Mode Choice

"In this method, the total daily person trip tables by purpose are divided into total person trip tables by purpose for each time period. These estimates are then used as inputs to time period specific mode choice models. Directional splits (e.g., home to work vs. work to home) must be determined as part of this process. If peak period to peak hour conversions are also done at this point, a second set of factors is used."

5. Time-of-Day Assignment between Trip Generation and Trip Distribution

"This process factors the daily trip productions and attractions by purpose and zone to produce trip end estimates by purpose and zone for each time period. These estimates are then used as inputs to time period specific trip distribution and mode choice models. Directional splits (e.g., home to work vs. work to home) must be determined as part of this process. If peak period to peak hour conversions are also done at this point, a second set of factors is used."

6. Innovative Approaches

"There are several innovative methods used by MPOs or state agencies that go beyond the relatively simple factoring methods described in the previous section. These 'Peak Spreading' methodologies work within the confines of the current 'four-step' modeling process. The peak spreading process addresses the problem that projected demand exceeds capacity in certain corridors during the peak period and that failing to account for the excess demand results in a flawed assessment of travel conditions in the future. Three approaches to improving the time-of-day modeling process are presented in this report:

- Link-based peak spreading
- Trip-based peak spreading
- System-wide peak spreading

“These three peak spreading approaches are described in the following paragraphs. Table ES.2 summarizes their applicability, data required, and their limitations and advantages.

7. Link-Based Peak Spreading

“This approach accounts for congestion at the link level and diverts trips to the "shoulder" hours on either side of the peak. One of the most well known examples of this method was developed for Phoenix, Arizona. The result was a set of significantly more realistic estimates of future traffic volumes and speeds on congested highways, as well as more realistic estimates of regional travel performance measures.

“The Phoenix study was based on data collected from 49 corridors in Arizona, California, and Texas. These data provided relationships between peak hour and peak period volume as a function of facility type and volume/capacity ratio in the peak period. The peak spreading procedure was applied as part of a peak period (typically three hours) equilibrium assignment. As each link is considered, in turn, during the equilibrium assignment's travel time updating, peaking factors representing the ratio of peak hour volume to peak period volume are computed using a decreasing function of the link three-hour volume-to-capacity ratio. The peaking factor function was estimated with time series and/or cross-sectional vehicle count data. The peak hour volume corresponding to this peaking function was used to estimate revised travel times during each iteration of the equilibrium assignment procedure.”

8. Trip-Based Peak Spreading

“An alternative to the link-based peak spreading approach is a trip-based approach that spreads the number of trips for an origin-destination interchange that occur in the peak period or peak hour. Trip-based peak spreading approaches recognize the overall constraint of future highway network system capacity (by time of day) by limiting the assignment of trips to that network based on the overall capacity of the future network at selected congested links. This approach was applied in the Tri-Valley model in Contra Costa County, CA and in the Central Artery model in Boston, MA.

TABLE ES.2
Peak Spreading Approaches

Method	Applicability	Data Required	Limitations and Advantages
Link-based Peak Spreading	• Accounts for congestion at the link level and diverts trips to the "shoulder" hours on either side of the peak • Limited use (Phoenix, AZ)	• Data required include peaking factor functions (by facility type) representing the ratio of peak hour volume to peak period volume; these are decreasing functions of the link three-hour volume-to-capacity ratio	• This method does not guarantee continuity of link flow in the peak hour prediction • Does not reflect spreading of the peak outside of a three-hour period • Provides more realistic estimates of regional travel performance measures
Trip-based Peak Spreading	• Spreads the number of trips for an origin-destination interchange that occur in the peak period or peak hour • Limited use (Tri-Valley, CA, Boston, MA, Washington, DC)	• Data required include interchange-specific peak hour factors that are applied to daily trip tables; these factors may also be specific to trip purpose	• No explicit treatment of the trips being reduced outside the peak period • Does not account for changes in traveler behavior due to congestion
System-wide Peak Spreading	• Considers the system-wide excess travel demand and delay and dis-tributes excess travel demand between the individual travel hours that comprise the peak period • Limited use (VNTSC)	• Data required include TOD factors that describe the distribution of trips in each of the three analysis hours that comprise the peak period • Also a set of v/c limits (by facility type) that differentiates between temporal and spatial diversion	• Not sensitive to different trip purposes • Not sensitive to traffic congestion on specific links or specific origin-destination flows

“A variation of this approach was applied in the Washington, D.C. model. This peak spreading model was calibrated using household survey data and used a stratification of data by trip purpose. The prevailing assumption is that the non-work trip purposes would have flatter peaking than the work and university trip purposes. This procedure estimates the percentage of peak period travel at the vehicle trip interchange level that occurs during the peak hour as a function of two variables including congested travel time minus free-flow travel time; and trip distance.”

9. System-Wide Peak Spreading

"This method includes a system-wide peak spreading approach that has been implemented by the Volpe National Transportation System Center (VNTSC) within a modeling framework applied in evaluating Intelligent Transportation Systems (ITS). This peak spreading approach considers the system-wide excess travel demand and delay and distributes excess travel demand between the individual travel hours that comprise the peak period. This approach is neither link-specific nor trip-specific; because it was designed to model the travel impacts of ITS deployment, it assumes that a significant amount of travel information is available to travelers and thus the traveler's temporal response to congestion can be modeled on a system-wide basis rather than on a trip-specific or link-specific basis."

10. Emerging Approaches

"The peak spreading approaches described in the previous section do not fully address travel response to system changes and, thus, cannot be used to fully analyze policy changes or effects of travel demand management actions. Emerging approaches intend to model traveler response to congestion in much the same way that mode choice is modeled. While there are no working models at present, there is potential for implementation of this procedure within the traditional four-step modeling process.

"Several MPOs, including MTC (San Francisco Bay Area), Metro (Portland, Oregon), and SACOG (Sacramento) have proposed explicit time choice components for proposed travel demand model system updates. These proposals include the following:

"A model of time of day choice that predicts the period of travel as a function of variables such as free flow and congested travel times, transit level of service, trip purpose, and area type variables. This can be a logit model that could be applied after mode choice.

"A model of whether peak period trips occur in the peak hour or not. This can also be implemented as a logit model as part of a 'variable demand' multiple vehicle class assignment. Use of a variable demand assignment guarantees that the results of the peak hour models are in accord with the congestion resulting from the assignment. Off peak vehicle trips would still be assigned using a traditional static demand assignment.

"A model based on a combination of traditional TOD factors and a binary time-of-day choice model. The choice model will be based on congestion represented by peak/off-peak travel times, delays, etc. The underlying hypothesis is that relatively higher congestion during peak time results in a higher likelihood of off-peak choice."

N. GROWTH ALLOCATION BY THE DELPHI PROCESS
(Gamble, Pearson, and Dresser, 1993)

As part of a project funded by the Texas Department of Transportation (TxDOT) to examine methods of improving transportation planning techniques, the need to decrease the burden on the planning staff in smaller urban areas (populations less than 200,000) was addressed. In many cases, these smaller areas may not have the financial or personnel resources to determine growth using the traditional models or methods. An existing technique (the Delphi process) was modified to establish a procedure for allocating projected growth at the zone level. A qualitative measure of each zone's growth potential relative to the other zones in the area was established and used to allocate the projections of population and employment. The Delphi process can provide good results in a short time frame which provides the benefit of accelerating the overall planning process. The Delphi process is based on an iterative process. A panel of local experts and involved citizens participates in the process to reach a consensus.

A pilot project was conducted in Longview, Texas, in the summer of 1992 to examine the ability of the Delphi process to allocate future growth. The pilot project employed a three-tiered process in allocating the area's projected population and employment growth (for the year 2015) to 219 traffic analysis zones. Benefits of the Delphi process include reduced costs to the MPO in both time and money; social, political, and legal advantages of basing the allocations on a panel consensus; and the advantages of involving members of local agencies and committees during the allocation process. Support software and a user's manual are currently under development for TxDOT.

O. TRAVEL MODEL DEVELOPMENT AND REFINEMENT — TRIP GENERATION — FINAL REPORT: EXECUTIVE SUMMARY
(DKS Associates, 1997)

"The Puget Sound Regional Council has undertaken an effort to enhance and refine its travel demand modeling capabilities. This project, which is part of the Regional Council's long-range plan for model development, focusses on the trip generation component of the modeling chain. The intent of the trip generation model development effort is to redefine the structure of the current model and meet the requirements of the Intermodal Surface Transportation Efficiency Act (ISTEA) and federal legislation as described in the 1991 Clean Air Act Amendments (CAAA).

The project will include examination of the current practices in trip generation modeling, data needs for model development, redevelopment of model structure, and the implications for further model development."

1. Literature Review and Model Strategy

"A literature review was conducted on the latest efforts in trip generation modeling throughout the U.S. and overseas. Based on this review, and an analysis of the Regional Council's current model and data availability, a general model strategy was developed.

"Any model improvement strategy should focus both on making immediate adjustments to enhance model validity and credibility and on ensuring a smooth path to more extensive but longer-range and more fundamental changes. Any strategy that uses carefully checked data from the recent household travel diary surveys to produce new trip generation estimates should improve the travel models performance. Other key considerations for the new trip generation models are:

- It includes travel by all modes including non-motorized modes.
- It uses cross-classification as its basic methodology.
- ANOVA methods should be used to measure and compare model fit.
- The partitioning of trips into purposes should preserve as much information about the activity pattern as possible.
- Predictions for new trip purposes may be combined to match the trip purposes in the remainder of the current model system.
- The model development should explore a basic core of household variables including household size, number of workers, income, auto availability and the age of household members.
- Additional variables relate to life-cycle status should be considered.

2. Trip Production Analysis

"The trip production analysis involved developing and testing a number of alternative cross classification schemes for each trip purpose. The 1985-1988 Puget Sound cross-sectional survey was the primary source for the household trip production analysis. A number of 'filters' were applied to eliminate households associated with missing, invalid, or inconsistent household and/or travel data. These filters excluded 24 percent of the surveyed households. Compared to other travel surveys, this rejection rate is actually quite low and is evidence of a good level of integrity of the survey data. The remaining 3507 households were still quite adequate for the trip generation analysis. The Regional Council may do well to review and correct some of the excluded observations in preparation for its future work on a mode choice model, due to mode choice models' sensitivity to and dependence on ‘unusual’ observations (i.e. ‘outliers’).

“The significance of various household characteristics, alone and in combinations, in explaining home-based trip productions in certain trip purposes was analyzed, using the 'filtered' 1985-88 Puget Sound cross-sectional survey. The household characteristics studied were:

- Number of persons in household,
- Number of employed persons in household,
- Household income,
- Number of vehicles available to household members,
- Persons in various age groups, applicable to the trip purpose, in household.

“Trips included all modes including walk and bicycle. The trip purposes analyzed were:

- Home-based work
- Home-based shop
- Home-based school
- Home-based college
- Home-based other

“Major conclusions found in the trip production analyses include:

- Most of the household variables have statistically significant relationships to each trip purpose, apparently due to multiple colinearities between a household's numbers of persons, workers, vehicles, and income.

- In general, the strongest single predictor of trips in a given purpose is the number of persons eligible or most expected to make such trips. For work trips, this is the number of employed persons; for school trips, it is the number of school-age children; for college trips, it is the number of persons in a college age group. (The college trip analysis checked persons age 18 to 24. Measures of proximity to a college were unavailable.) For shop and other trips, this is simply the number of persons counted as trip makers, in this case, persons age 5 and older.

- Other household variables can be used as less-direct predictors. Counts of persons approximating the most direct measures also yield strong models (such as total persons in lieu of persons age 5 and up). Other measures, such as income and vehicles, give statistically significant but less strong models, because they are only indirectly related to numbers of particular groups of persons. (Some such variables should be more strongly related to mode choice than to trip generation.)

- Several two-variable models demonstrated statistical significance over the respective one variable models, but the greatest part of variance is still explained by the strongest one variable model. In particular, Persons x Workers models show home-based shop and home-based other trips tend to be made more by non-workers, and offer a strong substitute for school-age children in predicting home-based school travel (should direct predictions of school-age children be unavailable). Some of the other two-way models may be used to predict secondary effects (say, of income) in conjunction with principal predictor variables, should this be deemed necessary.

“Implementation of the strongest model in each trip purpose requires development of both current and future year dataset of household in a cross-classified form. The future year household forecasts could initially be based on the current year stratification of households. A true forecast of household cross-classified by workers and persons will require a land use model that can predict changes in household demographics.

“The Regional Council would need to develop the following data for each traffic zone to implement the recommended trip generation model:

- Number of households in 16 cross-classified categories using persons (1, 2, 3, 4+) x workers (0, 1, 2, 3, 3+)

- Persons 5-17 in household (with households in a zone classified into 0, 1, 2, 3+)

- Persons 18-24 in household (with households in a zone classified into 0, 1, 2+)

“The above classification schemes could be developed using the 1990 Census Public Use Microdata Sample (PUMS) and techniques developed by other MPO's (i.e., Portland and Sacramento). Due to the level of effort needed to prepare this 1990 dataset, and anticipating the eventual need to update the mode choice model, it was recommended that the Regional Council also include income as a cross-classified variable.

“Trip rates were estimated for both total person trips (with walk and bike modes) and for motorized person trips, both using the recommended cross-classification schemes. The use of motorized trip rates is equivalent to using percentages for each household classification as a ‘pre-mode choice’ model. A better estimate of walk and bike mode choice could be made but only as part of an overall mode choice model update that includes key variables that are important to the walk and bike mode choice (variables not used in the Regional Council's current model structure). Until the mode choice model is updated, the motorized trip rates for the new cross-classified household schemes should be used.”

3. Trip Attraction Analysis

“Non-residential trip generation has received considerably less attention than home-based trip generation, and the techniques that have been used are generally less sophisticated. The Regional Council currently uses a two-way cross-classification scheme using 6 employment categories and 3 activity density categories.

“Attempts were made to estimate ‘relative attraction rates for each employment category using both regression analysis and ‘aggregate maximum likelihood' techniques. These methods were not successful in developing reasonable attraction rates. Therefore, the analysis focussed on comparisons between the Regional Councils current attraction rates and those from a number of other MPO'S. This analysis resulted in some minor adjustment to the Regional Council's attraction rates. These rates may be adjusted further in a re-calibration of the regional model using the new trip production rates.”

4. Commercial Vehicle Trips

“Commercial vehicle trips presented a special difficulty in the trip generation study because these trips are not reported in the household surveys. Their estimation would require separate surveys of commercial vehicle owners or other special data. For these same reasons, few regional travel models have estimated separate trip rates for commercial vehicles. Many modelers use the approach taken by the Regional Council; they estimate commercial vehicles as a percentage of the estimated person or vehicle trip attractions for some or all trip purposes. The Regional Council currently estimates commercial vehicle trips based on the number of non-home-based trips produced and attracted in a zone.

"No recent data is available on commercial vehicle trips in the Puget Sound region. Therefore, improving the estimation of commercial vehicle trips requires either special surveys of commercial vehicle owners, or transferring trip generation rates (and possibly other model parameters) from other regional models where special surveys were conducted. Although strategies used to survey and estimate commercial vehicle trips are well documented and straight forward to apply, the costs of doing the data collection is significant. For this trip generation analysis, the transferability of commercial vehicle trip generation rates was explored."

"Commercial vehicle trip generation data from Phoenix, Chicago, Florida and the San Francisco Bay Area was reviewed. It was decided that the Phoenix commercial vehicle trip rates were the most appropriate to transfer to the Regional Council's model since they:

- included all commercial vehicle trips not accounted for in the household surveys.
- provide employee-based trip rates for most of the non-residential categories used by the Regional Council.
- were based on the most recent surveys of commercial vehicle owners in the U.S."

5. Special Generators

"Discussions with the staff of the Regional Council indicated that they are comfortable with the trip generation for the major generators in their current model. DKS Associates and Rao Associates, however, have identified the following additional categories that should be considered as special generators in the revised model:

- Resident Colleges, including the University of Washington, have significant percent of students living on or near these campuses.
- Community Colleges which are purely 'commuter' colleges.
- Major military bases which have a large number of employees but may also have a large number of on-base military housing.

"Trip rates for these additional special generators have been recommended."

6. Next Steps

“This trip generation project is only a first step in updating the Regional Council's full model chain based on data from the recent household surveys, and to fully incorporate walk and bike trips into the model. Some important next steps that will lead to the eventual full model update include the following:

- recalibration of the current model structure using ‘motorized’ trip rates developed in this project

- developing some basic strategies for the updates of the model choice and distribution models

- developing the data needed for the mode choice and distribution models

“A recalibration of the Regional Council's current model structure using the motorized person trip rates outlined in this report will be more limited in scope than a ‘full’ recalibration effort involving updates to the mode choice and distribution models and other structural changes. Given that other elements of the model will remain relatively unchanged, the recalibration effort will principally focus on comparing traffic assignments to traffic count data using a regional and systematic approach.

“The Regional Council has a large number of ‘screenlines’ that it uses for both model calibration/validation and for analysis. It is likely that initial 1990 model assignments using the new trip production rates will generally be lower than 1990 traffic count data when all screenlines are viewed in aggregate. This will likely be due to some under-reporting of trips in the household survey data.

“It is generally believed that work and school trips are not subject to significant under-reporting in a household survey since these are regular trips known by all household members (except in cases where a person has a very irregular work schedule). It is also generally believed that short distance non-work trips are most affected by under-reporting. A trip made across town for any purpose is seldom not reported while a quick trip to the store may not be reported.

“If the model assignments indicate that short distance are a bigger problem than longer distance trips then the trip distribution should also be changed to truly reflect the impact of missing short distance trips in the survey data.

“The screening process of the household survey data eliminated about 24 percent of the households due to missing or invalid data. The screened database of 3,507 households provides an adequate survey size for development of the trip generation model. Estimation of a sophisticated mode choice model, however, would benefit from a larger sample size. Therefore, he Regional Council should have trained analysts systematically reviewing the rejected observations, and attempt to correct as many as possible, using the original data sheets and judgement.

“Other key data issues for the mode choice and destination model updates involve development of variables that are important to walk and bike travel. These include the following:

- Development of ‘pedestrian environment factors’ - A variety of factors have been used in other models including ones in Maryland, Portland and Sacramento. These factors have included the availability of sidewalks, continuity of streets, topography and other barriers to walking. A GIS system could help provide these factors, but a careful review of maps and aerials and consistent judgement is an adequate method.

- Estimation of household auto ownership (or auto availability). This will likely require a new submodel, but its estimation is important to walk, bike, transit and HOV modes.

- Improving the walk distance measurements in the network that do not merely rely on auto centroid connectors and auto related distance.

- Development of accessibility measures for walking, such as the number of total jobs and retail jobs within one mile of the household.”

P. DEVELOPMENT AND APPLICATION OF TRIP GENERATION RATES - FINAL REPORT: INTRODUCTION

(U.S. Department of Transportation, 1985)

“Local agencies are continually facing the need to address the physical condition and service capabilities of the streets and highways in their jurisdictions. Recently this concern has turned to the rapidly developing suburbs of metropolitan areas and the access needs of new development. Related to this are the issues of zoning variances and joint public/private funding for highway improvements to support these developments. Regional planning agencies are being called on more frequently to provide technical assistance and service to sub-regional areas and local jurisdictions. Local cities and counties face the need for accurate technical procedures to analyze the potential impacts of new development.

“This publication and its companion document, the ‘Site Impact Traffic Evaluation (S.I.T.E.) Handbook’ provides guidance on site access analysis procedures. This report presents updated 'trip generation rates along with factors for adjusting trip rates due to variations in residential characteristics The use of trip rates is also described. The S.I.T.E. Handbook presents a seven phased site access study process including a trip generation rate development procedure (50). Four case studies are presented that demonstrate the use of trip generation rates and also analyze the sensitivity of site-related traffic to trip rates, trip distribution patterns and other key variables. Additional and related publications include:

- The ITE trip rates publication: ‘Trip Generation - An Informational Report’, Third Edition, 1982 (45)
- ‘Using the ITE Trip Generation Report’ prepared by Carl Buttke for ITE, July 1984 (5)
- NCHRP Report 187 ‘Quick Response Urban Travel Estimation Techniques and Transferable Parameters: User's Guide’ 1978. (83)

“These publications should be collectively used for guidance and not relied upon' as the sole source of information for trip rate information in site access analyses. Where local data and procedures are available, they should be used if the analyst considers them to be more accurate.

“There are many methods for collecting trip generation rates, ranging from driveway (ground) vehicular counts to regional home interview surveys. Driveway vehicular counts of traffic entering and leaving development sites have been collected for many land uses. Manual counts or automatic traffic recorders are used to collect traffic data on driveways during peak hours of adjacent streettraffic and/or the generator and sometimes over a twenty-four hour period. The traffic data for the cordoned site along with the background information on each site (such as dwelling units, gross floor area, number of employees and acres of land) are utilized to estimate vehicle trip rates per dwelling unit (or other independent variable). Most of these ground count based rates are compiled in such documents as the Institute of Transportation Engineers (ITE) ‘Trip Generation - An Informational Report’ (45) and numerous locally developed documents. These rates, when applied to future land uses, result in an estimate of future daily and peak hour trips. Regional home interview surveys are not covered in this report. They provide information at the individual household level and are generally used to model trip generation relationships with various socioeconomic factors and land use characteristics. These trip generation relationships are generally used for long-range comprehensive planning.

“Several concerns have been raised regarding existing trip generation rate data:

- Variability among trip generation rate sources and geographic locations as well as differences between these rates and other national data sources, such as the 1977 Nationwide Personal Transportation Survey (NPTS).
- Effects of older data (collected in the 1960's) included in the more current trip generation rates.
- Lack of detailed guidelines on the use of existing trip generation rate data.

“This publication provides guidance on the use of trip generation rates in light of these concerns. In addition three related issues are also addressed:

- The effect of socioeconomic variables on residential trip generation rates.
- Reduced external trips generated by multi-use centers (i.e. a percentage of the trips generated by a multi-use center are internal and remain on site).
- Capture rates for ‘pass-by’ traffic (i.e. trips attracted to the development from traffic normally passing-by the site).

“This technical concern for trip rate accuracy has emerged coincidentally with increased emphasis on site access studies. To illustrate this emerging issue, the FHWA has completed a study to: 1) investigate the existing uses of private funds for highway improvements 2) evaluate the mechanisms-used to obtain private funding and, 3) to recommend improvements for which private funding may be used (52).

“A key issue in the technical process is trip generation rates and their subsequent role in the estimation of traffic impact and needed road improvements. Since trip rates are so important to local zoning regulations it is essential-for the success of this new concept of private/public cost sharing to have accurate trip rate information. In most areas the ITE Trip Generation Report is considered the reference manual on trip generation. Accurate trip rates will enhance the application and accuracy of the quick response techniques and significantly aid site access analyses in the United States -- and also facilitate equitable cost sharing negotiations between public and private interests.

"The findings of this study have implications for the public and private sectors in achieving cost effective roadway improvements. The trip rates and their adjustment factors developed in this study can be used to:

- conduct site access studies including the estimation of traffic generated by either a single use, multi-use or planned unit development.
- forecast daily and peak hour traffic volumes for the geometric design of traffic circulation and access plans.
- evaluate on-site alternative land use development conditions to optimize or minimize the traffic impact on the adjacent highway network.
- aid in the determination of the private developer's share in local transportation improvements.
- estimate daily and peak hour trip rates and traffic flows for transportation corridor and sub-area analyses.

"The S.I.T.E. Handbook presents details on the uses of trip generation rates."

Q. TRIP GENERATION ANALYSIS: CHAPTER 1
(U.S. Department of Transportation, 1975)

"The purpose of this document is to provide a step-by-step approach to trip generation analysis which should be pertinent in many current urban studies. The approach is straightforward, is based upon logic and common sense, is more easily monitored and can be updated with more efficient use of survey and secondary source data, is easily understood by the administrator and the public and allows application to the various areal units required for regional, corridor and small area study. The approach is based upon cross classification for residential trip generation and upon rates for non-residential generation."

Topics discussed in this report include 1) a recommended approach to trip generation, 2) an evaluation of trip generation results, 3) additional considerations, 4) monitoring and surveillance for trip generation, 5) forecasting income, 6) household trip generation rates and income/auto ownership relationships, 7) travel forecasting, and 8) flow charts of practical applications of trip generation.

1. Definition and General Description

"Trip generation provides the linkage between land use and travel. Trip generation may be separated into two phases. In the first, an understanding and quantification of the travel-land use linkage is developed. In the second phase, the results of the quantification are applied to forecasted land use characteristics to develop future travel estimates.

“For trip generation purposes travel is considered in terms of trip ends. That is, the number of trips. It does not consider their other characteristics such as direction, length or duration. The trips considered are usually those generated for an average weekday but they may also be for weekend travel, for a particular trip purpose, by mode of travel or other stratification required for a specific analysis or forecasting purpose. Trip ends may be in terms of origins and destinations or in terms of productions and attractions dependent upon the purpose of the forecast and the subsequent models to be used for trip distribution and modal choice.

“Land use for trip generation purposes is usually described in terms of land use intensity, character of' the land use activities, and location within the urban environment. These measures, described in greater detail. later in this chapter, are input to trip generation. Initially the land use and travel are linked for some measured current period utilizing techniques such as cross classification, trip rates or regression analysis. These relationships are then utilized and applied to forecasts of land use to develop future travel.

“Early travel forecasts utilized the results of origin/destination studies to describe existing travel patterns in the form of tables of trip origin and destination and by ‘desire lines’ to indicate the major trip movements. This data was often extended into the future by some form of extrapolation. In the early 1950's analytical techniques were developed to quantify urban trip volumes in terms of measurable land use and socio - economic characteristics of the people making trips. Trip generation rates were developed from the O-D surveys and land use data and applied to a land use plan for the forecast year. In the late 1950's and early 1960's regression techniques which developed equations relating trips to land use and socioeconomic character- istics found favor and were widely applied. The relative ease with which many variables could be considered often resulted in equations that could not be easily understood, that were often misinterpreted, that could not easily be monitored and updated and that required forecasts of characteristics which could not be forecasted with acceptable degrees of confidence. However, much was accomplished through regression analysis in gaining basic insight into travel and providing background to further development.

“In the last few years a shift in emphasis from aggregated zonal analysis utilizing regression procedures to a disaggregated household cross classification approach also often termed category analysis has occurred. This latter work has the advantages of:

- making efficient use of survey information
- being valid in forecasting as well as in the base year
- being easily monitored and updated
- being straightforward and understandable

“Sufficient work has already been accomplished in trip generation analysis to allow the presentation of a step-by-step approach for consideration in urban study applications. While this publication suggests a simplified approach, alternative methods of trip generation analysis were treated equally in ‘Guidelines for Trip Generation Analysis’ (13).”

2. Trip Generation in the Transportation Planning Process

a. Regional Study

“Trip generation plays a role in many phases of transportation planning and traffic engineering related activities. The continuing urban transportation planning process depicted in Figure 1 generally is based on a comprehensive study of an urbanized area. The overall technical process includes the major phases of (1) formulation of goals and objectives; (2) organization for the process and the assembling of data; (3) analysis of current conditions including the calibration of models; (4) areawide forecasts of future conditions; (5) the analysis of future alternative systems; (6) the continuing elements of surveillance, reappraisal, procedural development, service and annual report. The models developed and applied usually include those for land use, trip generation, trip distribution, modal split and traffic assignment. Population and economic studies are used to develop input to land use models in terms of the magnitude of population, employment and other economic characteristics. Land use models are used to determine where the activities will be located throughout the region and provide input to trip generation models which are used to predict the number of trips the activities will generate. Trip distribution models take the output of trips to and from the land use activities produced by the trip generation model and determine their spatial orientation-or where the trips will go. These trip interchanges are usually input to a modal choice model which determines how much of each trip interchange will be by each of the modes considered. The assignment process then determines the loading of the highway and mass transportation facility segments resulting from the trip interchange desires.'

“For regional study, the broad range of land use and related social-economic characteristics must be considered in the base year trip generation analysis and in application of the trip generation relationships to forecasted activities. Trip generation analysis usually is stratified into two components:

- trip generation at the household level
- trip generation at the non-residential level

“At the household level, characteristics usually considered, for trip-generation include car ownership, income, density of development and household size. The household generation results generally are used as a ‘control’ on the total of non-residential generation which usually considers characteristics such as employment, type of land use (retail, office, etc.), and type of area (CBD, suburban, shopping center, etc.). ‘Special generators’ such as the airports and stadiums are usually separately handled from the rest of-the analysis because of their unique travel generating characteristics.

“Of necessity, regional trip generation analysis is broad in nature considering the full range of travel and land use activities. The trips analyzed are usually for an average weekday with statistics developed on a zonal level for input to subsequent models.

“The continuing transportation planning process requires adequate monitoring and updating of trip generation relationships when sufficient change warrants. Since trip generation provides the linkage between land use and travel, it is important that the relationships established be evaluated periodically for stability and applicability. Likewise, changes in land use and socio-- economic characteristics must be monitored on a continuing basis to evaluate changes in trip generation from the most current forecasts. To accomplish this, selected land use and social-economic data must be maintained through an on-going surveillance program to assure the ability to evaluate, and if necessary, update previous forecasts through a routine review process.”

b. Corridor and Small Area Study

“The transportation planning process has seen a shift in emphasis from long-range plan development to short range planning and the evaluation of specific corridor needs, special detailed area study and other service functions. There has been a demonstrated need for the incorporation of policy sensitive factors in the estimation process with the corresponding need to increase the sensitivity of the modeling process to 'current' problems. Examples of these more current problems are:

- Evaluation of transportation demand resulting from redevelopment or rezoning an area within a city.
- Determining the impact of a new office building complex on the surrounding system.
- Detailed evaluation of alternate highway configurations, ramp spacing locations, etc.
- Evaluation of alternate modes for a heavy demand corridor.

"There has been considerable study of sub-areas and corridors in the past, generally based upon regional level analysis. As the shift to shorter range detailed area study progresses there will, of necessity, be requirements for trip generation at a more detailed level of application. Much of the increased interest in small area detailed study appears to be from counties, cities and towns within regional transportation study boundaries.

"There is much interest at this level of government to study in detail the transportation implication of the regional systems being developed in their areas. Many regional studies have already geared up to support these local applications through providing data, computer support, and technical know-how.

"Trip generation analysis for corridor planning must be accomplished at a finer level of detail than generally used for regional study. This is based upon the requirement for traffic assignments to be made to more detailed networks utilizing smaller zones. The choice of technique used for trip generation on the regionwide basis has an impact in corridor and sub-area study. Generation analysis at a zonal level for the residential analysis will usually result in problems in application to zone sizes different from the zone sizes used for relationship development, especially when regression techniques are used. Disaggregate analysis such as that accomplished with cross-classification at the household level will produce results which can be applied at any level for which land use and related characteristics can be developed. Likewise, at the non-residential end, sufficient disaggregation is desirable to allow a detailed accounting for the specialized land uses in the area of study. Usually, a rate approach with specialized handling of major generators can provide the required level of detail. It has been found that a high proportion of trips in an area are attracted to a small portion of the land. The following sections discuss special generators and new development evaluation."

c. Special Generators

“Regionwide trip generation analysis must of necessity be somewhat general in the treatment of the wide diversity of land uses in an urbanized area. There are specific generators which are of sufficient size and perhaps unique in their trip generation characteristics to warrant special consideration in the trip generation analysis and forecasts Such generators might include airports, sports stadiums, hospitals, army bases, and large regional shopping centers. These land uses are generally handled separately from the regionwide analysis, and the results merged together prior to trip distribution in the forecasting process. In addition to the development of trip generation rates for specific sites for merging into regional forecasts of travel, site analysis is of considerable use in the assessment of impacts of-new developments on the current transportation system and in the determination of improvements to the highway and mass transit system to serve new developments on a short range basis. This use is further discussed in the next section.

“Most trip generation analysis for regionwide application has relied on trip information collected in a home interview survey with the land use and non-residential socioeconomic characteristics obtained from field surveys and secondary sources. For example, work trip generation at the work place is usually based upon employment, with the trips accumulated at the work place from a sample survey collected at the home. There have been studies which have supported this approach and others which have recommended that site collected trip data is more appropriate for such analysis. For regionwide analysis aimed at total systems planning, the home interview survey data should be sufficient for analysis at the non-home end. Where appropriate, special sites should be evaluated through trip data collected at the site. For impact analysis, corridor and small area studies, site analysis and the other phases of the continuing planning process, better information on the generation of travel can be obtained by collecting both trip and land use information at the site rather than relying on home interview data. Such an approach can be established as a continuous monitoring process possibly eliminating the need for additional home interview data.

“Major generators are relatively few in number in most urbanized areas. Concentrating data collection and analysis on the few major generators, should provide more accurate estimates than using the same resources to thinly cover all areas. It is recommended that the base trip data used for trip generation (usually home interview data) be supplemented with more specific information for the few sites requiring more detailed data and analysis. In base year model development site analysis is useful to improve the accuracy of nonresidential trip generation estimates. In the continuing phases of regionwide study collection of travel information at selected sites can supply much of the necessary update information. Such data with perhaps very small home interview sample updates can provide the framework for the continuing trip generation analysis. Consideration should also be given to 'borrowing' the needed rates. See the next section for references."

d. New Development Evaluation

"Trip generation is important to the traffic engineer in considering the impact of a new office complex, shopping center or residential development. Of interest at this level is the amount of traffic a new development will generate, the necessary upgrading or improvement to existing facilities, traffic control requirements and any new connecting facilities required. For these purposes trip generation is obviously most pertinent relative to traffic at a specific land use activity. The range of specific activities might include:

- Shopping centers
  - Regional Shopping Centers
  - Community Shopping Centers
  - Neighborhood Shopping Centers
  - Free Standing Discount Stores
  - Strip Commercial Areas

- Residential developments
  - Subdivisions
  - Apartments
  - Mobile home parks
  - High rise apartments
  - Retirement communities

- Industrial developments
  - Industrial parks
  - Warehousing
  - General Industry
  - Office Buildings
  - Doctors Clinics
  - Trucks and Rail Terminals
  - Hospitals
  - Colleges
  - High Schools
  - Elementary Schools
  - Civic Centers
  - Libraries

- Airports
- Theaters
- Hotels
- Parks

“Data for this type of trip generation analysis is also more specific than required for regionwide transportation forecasting. Sites are chosen for study which are expected to be representative of the proposed development. Traffic counts are made at all entrances to and exits from the sites chosen for analysis. These are usually made over perhaps a week. In addition to counts, background information on the site is compiled in order to develop the required traffic generation rates. This background data might include dwelling units, aircraft off and on passenger loadings, number of employees, residing doctors, etc. Two rather complete documents containing trip generation rates by specific site types for regions of the United States are:Volume XV Travel Generation prepared by the National Association of County Engineers and Trip Generation by Land Use Part I, A Summary of Studies Conducted prepared b the Maricopa Association of Governments (1,2). An Institute of Traffic Engineers Technical Committee is currently Compiling and analyzing rates from studies around the country in an on going study and results should be available mid 1975 (16). Rates from sources such as these can be very useful in providing a ready reference to estimating the probable impact of a pro-posed activity.”

3. Basic Trip Generation Considerations

“The goal of trip generation model development is to establish a functional relationship between travel and the land use and socioeconomic characteristics of the units to and from which the travel is made. A causal relationship is desired in which the following types of questions are answered:

- What is the difference in trip making between a family living in a high rise apartment close to the central business district and a similar family living in a single family home in the suburbs?
- What is the difference in trips to a 50 store shopping center serving a suburban area as compared to 50 stores of a similar size and nature located in a central business area?

“Questions of the above nature can be considered in terms of intensity of land use, the character of the land use and its location within the urban environment.”

a. Intensity of Land Use

"Intensity of land use is the amount of activity to be found in a given areal unit (i.e. zone) and is usually stated in terms of a density measure such as employees per square foot of floor area or acre of some specific land use category, or dwelling units per acre. As an example, the number of trips per dwelling unit generally decreases as the number of dwelling units per residential acre increases. High rise apartments (dense) and other dense residential developments are usually within walking distance of many services, thus alleviating the need for a vehicular trip. When residential density is low (perhaps less than 10 dwelling units per acre) trip rates are high since almost all trips must be made by vehicle."

b. Character of Land Use

"Land use intensity measures are usually not sufficient in themselves for trip generation relationship development. There is additional variation in travel that is accounted for by variables that may be termed the 'character' of land use. On a household level, character is expressed in socioeconomic terms such-as family income and car ownership. With all other conditions the same, families with higher incomes generally own more automobiles and make more trips. Low income families often own no cars, rely on public transportation and walking and thus exhibit low vehicular trip making potential. The higher trip making families usually show increases in shopping and social-recreational trips with trips for work remaining relatively stable.

"For non-residential land uses character is usually reflected in the type of activity (e.g., manufacturing, retail, commercial)."

c. Location of Land Use Activity

"This factor relates to the spatial distribution of land uses and land use activities within a study area. The location of residential land is important as may be shown by the higher trip rates of a high rise complex in the suburbs versus rates for a similar complex in the CBD. Likewise, a department store in the CBD with the same floor space, number of customers, same merchandise, etc, as one in the suburbs would have a lower 'trip' generation rate since many customers walk to the store.

"It is difficult to separate the individual effects of intensity, character, and location. Each type of variable explains some of the variation in trip making. These types of variables are used in trip generation model development regardless of the type of analysis used-cross-classification, regression analysis or rate development."

d. Procedures for Trip Generation

"Cross-classification is a technique in which the change in one variable (trips) can be measured when the changes in two or more other variables (land use-socioeconomic) are accounted for. Cross classification is not heavily dependent upon assumed distributions of the underlying data and, as such, is some times referred to as a 'nonparametric' or distribution free technique. Basically, the technique stratifies 'In' independent variables into two or more appropriate groups, creating an n-dimensional matrix. Observations on the dependent variable are then allocated to the cells of the matrix, based on values of the several independent variables and then averaged.

"The land activity rate approach is based upon the development of rates in which trips are related to land use characteristics reflecting the character. location and intensity of land use. The method may also be considered a type of cross-classification analysis.

"Non-residential trip generation is usually based upon an initial stratification of trip data by trip purpose and attraction variables considered most pertinent. For example, work trip rates may be based upon total employment, school trips on school enrollment and shop trips on retail sales. The rates should further be stratified by land use density or categories within an activity type (e.g., regional shopping center, CBD or strip commercial). The rates developed are strictly ratios between trips and the variable chosen such as trips/employee or trips/student. The data used is usually aggregate data summarized to some multizonal system.

"Details of regression analysis can be found in 'Guidelines for Trip Generation Analysis' (13). In summary, the regression process consists of developing equations in which trips or a trip rate (i.e., trips/household) is related to independent variables which explain the variation in the dependent variable (trips or trip rate). The equations are usually developed by trip purpose and generally are based on data aggregated to the zone level as observations. Although regression is a linear technique fitting straight lines through data, transformations of variables into log functions, taking reciprocals etc., can be made resulting in curvilinear representations.

"The important statistics used in evaluating the equations developed include: the multiple correlation coefficient which indicates the degree of association between the independent and dependent variables in the equation: and the standard error of estimate which indicates the degree of variation on the data about the regression line established. A statistics text should be referred to if further detail on regression and correlation analysis is required (3).

“Regression analysis has been an important tool in trip generation analysis. A wealth of understanding of travel has resulted from application of the technique and most transportation studies undertaken in the 1960's relied on the technique. The procedure has good applicability to some current planning problems which will be discussed later in this document. However., based upon the regression analysis of the past and current work using cross- classification and rate analysis, it appears that more efficient and straightforward trip generation procedures can now be recommended.”

e. Data Sources

“The basic data source for trip generation analysis has been the home interview survey. Within this one survey most, if not all, of both the travel and land use-socioeconomic factors can be obtained for relationship development at the residential end. It is at the residential end that the home interview survey is most useful since it is here that the sample is selected, data collected and the survey is most accurate. Non-residential trips may be accumulated from the home interview survey and related to non-residential land use characteristics. The trips to this land from the home interview are less stable since the accumulation at the non-home end is a rare attribute with respect to each dwelling unit within a study area. It is expected, however, that for general land uses such as office buildings, the accumulations from a home-interview survey are suitable.

“Other sources should, however, be considered and used where desirable. For example, special surveys of transit travel, i.e. on board surveys, should be considered to supplement the dwelling unit survey when samples of transit trips are scarce. Special generators should be studied utilizing on the ground surveys where actual counts are made of trips to the generator.”

f. Forecasting Land Use-Socioeconomic Characteristics

“It must be kept in mind that the purpose of the trip generation estimating procedure is to forecast future travel based upon forecasts of land use and socioeconomic characteristics. The trip generation estimating procedure is therefore, only as good as the quality of the future estimates of land use and socioeconomic characteristics. The analyst should be sure not to become so involved in the analytical techniques used for developing the trip generation relationships that the goal of meaningful forecasts is lost. Great care must be exercised in the selection of characteristics to include in the relationships developed, keeping in mind the two important factors of: a) ability to forecast; b) the contribution provided in the trip generation relationship. These are sometimes at odds and a careful evaluation is required.

“Some other factors to be considered are: an evaluation of the trip growth rates as expressed by application of future land use and socioeconomic characteristics for reasonableness; the development of control totals on an area wide basis for trip production and attraction to allow evaluation of possible changes in trip generation characteristics or further analysis of land use.

“The land use and socioeconomic characteristics to be included in the relationships developed should reflect changing conditions. For example, dwelling units per acre or total dwelling units for the analysis unit might be chosen rather than net residential acreage in order to reflect changing intensity.

“Land use and social-economic forecasting for transportation planning is usually a two step process in which total study area or regional forecasts are first made for the entire area for characteristics such as population, employment, income and car ownership, and the areawide forecasts are then allocated to small areas (i.e., zones) within the area. Common methods for population forecasts for an entire area include trend based methods, ratio methods (based on relationships of population growth in one area to that of other areas) and component methods (based on analyses of net migration and natural population increase). Economic activities projections have been based on trend line projection, input-output models, sector analysis, etc.

“In allocating regional forecasts to sub-areas a number of models have been developed. Most areas have used and still use judgement or trend analysis. Of the land use models currently in use, residential models are the most advanced.

“A discussion of the several models finding application in land use forecasting is contained in the Federal Highway administration report An Introduction to Urban Development Models and Their Use in Urban Transportation Planning (4).”

4. Future Directions in Travel Demand Forecasting

a. Behavioral Disaggregate Approach

"A considerable amount of research and application of techniques has been undertaken over the last decade in travel demand forecasting. The current research and direction in demand forecasting should result in considerable improvement in forecasting. This section will describe some of the current thinking in the area of improved travel demand forecasting techniques.

"The basic difference between aggregate and disaggregate estimation generally is in data efficiency. An aggregate model is usually based upon home interview origin destination data that have been aggregated into units (e.g., zones) and average values developed as parameters for model development. Disaggregate modelling relies on samples over a range of household types and travel behavior and uses these observations directly (without aggregation) for model calibration.

"The advantages of behavioral disaggregate models include:

- savings in data required to calibrate models
- transferability to different situations such as regional analysis and detailed corridor analysis
- transferability between cities ability to express non-linear relationships which are often lost in the case of aggregate analysis
- ability of more rapid data evaluation and analysis and development of relationships in a more timely fashion
- more easily understood
- more efficient monitoring and updating

"In a behavioral disaggregate model approach to trip generation, observations of the behavior of individuals (households) are used directly for estimation. This is in contrast to the aggregate approach which has generally been used (zonal estimates) where observations for households are combined and then used for estimation. Behavioral models are formulations in which estimation 'is directed at capturing elements of travel makers' decision processes and forecasting becomes an application of the derived parameters to new sets of information about the independent variables.'

"In the regression approach to trip generation widely used in the past, hypotheses about the association between socioeconomic variables and trip making are compared with regression results to indicate the validity of the developed model. Statistical goodness-of-fit measures are used to

measure goodness of fit in an effort to provide a close replication of base year data.
Behavioral models attempt to replicate portions of the traveller's decision making process. These decisions may either have a significant impact on travel choice or may be relevant to some specific issue(s) which must be addressed by the model forecasts."

b. Travel Demand Models

"Current transportation planning models usually consist of a sequential set of steps from trip generation through trip distribution, modal split and traffic assignment. The formulation of models is associative in that for trip generation as an example, hypotheses concerning association between travel and land use and socio-economic variables are generally compared through regression. Goodness-of-fit statistics are used in trying to provide a replication of base year data under the assumption that similar fits are obtained in future year application. The current models are usually somewhat choice abstract in that attributes of the transportation system are handled independently of a given mode's attributes. The analysis is usually of an aggregate nature in that model development is based upon zonal averages of travel and land use characteristics. The models currently used are generally deterministic in that they output 'single value' predictions rather than predicting each individual's probability of choosing a destination, mode, etc. (probabilistic) (5).

"Within the last few years there has been increasing activity in the developing of overall demand models incorporating trip generation, trip distribution and modal split into a single estimation process. It appears that much future research and development will be aimed at total-demand models. These direct demand models tend to be behavioral in that the model includes traveler decision processes which have a significant impact on travel choices and/or are relevant to specific issues which must be addressed by the model forecasts. These next generation models may be sequential or simultaneous in nature considering a number of decisions such as whether or not a trip is to be made, which destination to travel to, which mode to select and what path to take. The models will tend to be disaggregate in nature and will tend toward probabilistic structures in which each individuals probability of taking a trip, selecting a mode, selecting a destination, etc., will be considered. The models will also tend toward choice specific representations in which specific attributes of the transportation mode(s) being considered are represented.

"A conference conducted jointly by the Highway Research Board and the U.S. Department of Transportation at Williamsburg, Virginia in December

1972, addressed the entire area of urban travel demand forecasting. The findings of the conference were (6):

- travel forecasts are required for informed transportation decision-making
- improvements are needed
- information is now available that can be used to achieve immediate improvements in operational capabilities (approximately in a 1-3 year time frame)
- a repertory of improved methods should be developed
- substantial improvements in forecasting capabilities can be achieved in the future (perhaps in a 5-10 year time frame)
- improved information dissemination and training are needed

"There is no question that improvements in demand forecasting will be continuously made. Much of the change is probably far enough off in the future to discourage serious consideration in practical application over the next few years. The sequential application of trip generation, trip distribution, mode choice and traffic assignment will still provide the needed tools for some years to come. However, newer improved methods which can be implemented within this modelling framework deserve strong consideration. Disaggregate trip generation techniques using cross classification analysis can be applied with today's methodology and provide significant advantages over aggregate methods. For this reason, use of the approach deserves serious consideration by the transportation planner.

"The purpose of this chapter is to provide a summary of the current state of the art in trip generation as well as probable future direction. The next chapter will provide the details of a simplified approach to trip generation analysis."

R. DISAGGREGATE TRIP DISTRIBUTION MODELS: ABSTRACT
(Ben-Akiva, Gunn, and Silman, 1984)

"The principal method used in transportation studies to forecast matrices of person trips between origins and destinations is usually an aggregate gravity model. This paper presents the theory and methods for the application of disaggregate estimation of probabilistic choice models to trip distribution. The most important practical differences between the aggregate and the disaggregate models are in the model estimation stage. Disaggregate models can be estimated with smaller traveler surveys and place an emphasis on the specification of utility functions with a larger set of explanatory variables. The paper deals with the issue of aggregation of actual destinations into traffic zones, also addressed by aggregate trip distribution models. However, it presents an aggregation of alternatives theory that was developed for disaggregate logit models based on the concept of random utility. Destination choice models are presented that were estimated in two recent studies in Paris, France, and in Maceio, Brazil, using the methods described."

S. TRIP DISTRIBUTION USING COMPOSITE IMPEDANCE: ABSTRACT

(Allen, 1983)

"In this paper the theory and results of a trip-distribution model that uses a multimodal composite definition of impedance as its measure of separation, instead of highway time, are presented. The distribution model is part of a complete travel-demand model chain developed for the New Orleans region. This model chain is briefly described, and its special features of income stratification and connectivity among programs are emphasized. The disutility functions of a three-mode logit modal-choice model are used to develop modal impedance values. The structure and coefficients of these equations are discussed. Two alternative methods for combining these modal impedances are presented: harmonic mean and log sum. A special technique for calibrating the F factor curves was developed to circumvent shortcomings in the urban transportation planning system (UTPS) software. The results of the calibration are presented. These results indicated that the log sum formula produced better results than the harmonic mean formula, based on various observed and estimated comparisons. In addition, the log sum composite impedance-based model proved suitable only for home-based work trips. Unsatisfactory results for the other trip purposes led to the use of off-peak highway time for those purposes. Results for home-based other and non-home-based models are also presented. The conclusions of this analysis are that a distribution model can be successfully calibrated by using composite impedance; that, at least in this case, the log sum formula worked better than harmonic mean; and that a successful alternative to the standard AGM gravity model calibration process can be developed."

T. ANALYTIC MODELS OF TRIP LENGTH DISTRIBUTIONS: ABSTRACT

(Ben-Akiva and Litinas, 1982)

"This paper develops analytic models of trip length distributions. The models are derived from a destination choice model for a range of assumptions about the distributions of transportation level-of-service attributes and opportunities over the urban space. These models include all previously reported analytic trip length distributions. Their derivation from an explicit model of individual choice behavior illuminates their underlying assumptions about the urban space. It is shown how the parameters of the derived trip length distributions can be interpreted and estimated from available data that include estimated parameters of travel demand models and other readily available statistics on average speeds and fuel consumption. This makes these models useful for simplified analyses of various urban transportation policies, especially areawide pricing and travel time changes."

U. A SELF-INSTRUCTING COURSE IN DISAGGREGATE MODE CHOICE MODELING: INTRODUCTION

(Horowitz, Koppelman, and Lerman, 1986)

1. The Motivation for This Course

"Many practical transportation policy issues are concerned with mode choice. For example, the gain or loss in transit revenues caused by a fare increase depends on how travelers' mode choices are affected by the increase. If few current transit riders switch to other modes because of the fare increase, transit revenues will increase proportionally to the increase in fare. But if many riders switch to other modes, revenues will increase less than proportionally to the fare increase and may decrease. Similarly, the effects of changes in transit routes and schedules on ridership, revenues, and traffic congestion all depend on how the changes affect individual travelers' mode choices. The effectiveness of programs to encourage ridesharing -- for example, preferential parking or preferential access to freeways for carpools -- also depends on how the programs affect mode choice. In most situations, planners must choose among a variety of fare schedules and service designs. An understanding of the separate and combined effects of these decisions on travel mode choice is essential to selection of the best plan to meet specific transportation objectives.

"The importance of mode choice in transportation policy analysis and decision making has lead to a variety of methods for predicting the effects of policy measures on travelers' mode choices. Two well-known and frequently used prediction methods are the method of elasticities and aggregate mode split modeling. Both of these methods have serious defects that greatly restrict their practical usefulness. For example, the method of elasticities cannot predict accurately the effects of making several changes in transit service simultaneously (e.g., of increasing both the fare and the schedule frequency or of adding a new route to the system). Aggregate mode split models can be exceedingly costly and cumbersome to develop. Moreover, they are subject to serious biases and prediction errors owing to their reliance on aggregate travel data rather than records of individual trips. The range of policy questions that can be treated with aggregate models is quite limited. For example, it usually is not possible to carry out multimodal analyses with these models (e.g., analyses-in which it is necessary to predict the use of several different modes such as bus transit, rail transit, carpool, and single-occupant automobile).

"This course is concerned with a third class of mode choice models, called disaggregate models, that have substantial practical advantages over both elasticity methods and aggregate mode split models. Disaggregate models achieve a higher degree of policy sensitivity than either elasticity or aggregate mode split models. Disaggregate models can represent a wider range of policy variables than can either elasticity or aggregate models, and they can treat multimodal problems without difficulty. Moreover, disaggregate models avoid the biases inherent in aggregate models, and they are much more efficient than aggregate models in terms of data and computational requirements. Disaggregate models can be developed using data from only 1000-3000 households -- less than one tenth the number required by aggregate models -- and they can be implemented on microcomputers. In fact, as the examples given later in this course will show, many useful applications of disaggregate models can be made by hand with the aid of a desk calculator.

"Disaggregate mode choice models have been available for use in transportation planning and policy analysis for nearly 15 years. Many transportation agencies now use these models for practical policy analysis. This makes it important for transportation professionals to understand the principles underlying the development and use of disaggregate models, since failure to understand these principles can lead to the development of seriously erroneous models and to serious prediction errors.

"Unfortunately, materials that explain how to use disaggregate models are not readily available. Most descriptions of disaggregate modeling techniques are written for members of the research community or for graduate students. People in both groups have extensive backgrounds in mathematics and statistics, and graduate students may be able to spend several months learning to use the techniques. Consequently, the available descriptions emphasize the mathematical and statistical details of the techniques and, thereby, convey the impression that the techniques are useful mainly to researchers and can be used only by people with considerable mathematical training. This is a false impression. The main concepts and methods of disaggregate mode choice modeling can be understood and applied by, anybody who has mastered high-school algebra. The purpose of this course is to explain what disaggregate mode choice models are, how they work, and how they can be applied to practical problems, and to do this with a minimum of mathematics and jargon."

2. Description of the Course

"This is a complete, self-instructing course in disaggregate mode choice modeling. It includes a text, worked examples, problems for readers to solve, and solutions to the problems. The course is designed for readers who are familiar with urban transportation planning issues and methods and have knowledge of mathematics at the level of high school algebra. No prior familiarity with statistics or computer programming is needed. The only equipment required, apart from pencil and paper, is a desk calculator. A supplement to the course provides problems to be worked on a microcomputer. This supplement may be skipped by readers without access to an IBMcompatible microcomputer. The course is divided into self- contained modules of 1-2 hours duration. It is expected that most individuals will be able to complete the entire course in 15-20 hours of work.

"The purpose of the course is to familiarize readers with the basic concepts and methods of disaggregate mode choice modeling and to do so with a minimum of mathematics and technical jargon. It is designed to help readers understand how disaggregate models work and why they are useful so that readers can become informed users of these models and their outputs. The course will not make experts out of its readers. No short, selfinstructing, non-mathematical course could do this. However, this course will enable readers to understand what the experts are doing (or should be doing) and how the results can be used. It also will enable readers to do some of the things that, they previously may have thought require the services of an expert. Readers who wish to achieve a more detailed understanding of disaggregate models or a higher level of expertise than this course provides should consider taking a college course in travel demand modeling or reading one or more of the references listed at the end of this module.

"The course consists of 7 modules, including this introduction. Modules 2-4 describe the conceptual foundations of disaggregate mode choice modeling. These modules explain the assumptions about travel behavior that underlie disaggregate mode choice models and show how these assumptions are represented in models suitable for use in practical analysis. Numerical examples are given that illustrate the usefulness of the behavioral assumptions and the plausibility of mode choice models based on these assumptions.

“Modules 5-7 are concerned with the practical development and implementation of mode choice models. Module 5 discusses the explanatory variables that typically are used in disaggregate mode choice models, the choices that analysts face in selecting variables, and the practical consequences of alternative choices. Module 6 explains how disaggregate mode choice models are estimated or calibrated. This module also describes the data requirements of these models and discusses how the models can be tested empirically. Particular emphasis is placed on practical procedures for determining whether the correct explanatory variables have been used in a model and on comparing different versions of the same model to determine which provides the best explanation of the available data. Module 7 explains how aggregate travel demand can be predicted using disaggregate mode choice models.

“The modules build on one another. Each uses material from its predecessors, and none can be understood without first understanding its predecessors. Therefore, readers are strongly advised to work through the modules in sequence without skipping any. Each module contains numerical examples that illustrate the material being presented, and each includes problems for the reader to solve. Readers are urged to work through the numerical examples and to understand them fully. Readers are also urged to solve the problems. It is possible to gain a complete understanding of the ideas presented here only by working with them. The problems provide an opportunity to do such work. Solutions to the problems are given following Module 7.

“The time required to work through a module will vary greatly among both modules and readers. It is likely that most readers will be able to work through the text and examples of most modules in 1-2 hours, although some modules and readers may require more or less time. Working the problems at the end of a module may require an additional hour.”

V. DEVELOPMENT, TESTING, AND EVALUATION OF A NODAL RESTRAINT PROCEDURE

(Yuan-Wang, Benson, and Dresser, 1992)

This research proposes a traffic assignment procedure in which capacity restraints are applied to nodes instead of links. The development is based on the concept that the capacity of an urban street system is constrained by nodes instead of links. The nodal restraint assignment procedure was developed by utilizing the concept of the intersection sum of critical lane volumes in the *Highway Capacity Manual 1985*. A nodal impedance adjustment subroutine was incorporated in the assignment process to account for intersection delays where link impedances were held constant and nodal impedances were updated from iteration to iteration. The

impedance for each turning movement at a node is determined by the association of all movements encountered at the node.

The proposed procedure was applied to a test network (Preston Road in North Dallas). In the application, various assignment procedures and different impedance adjustment function parameters were used to test the procedure's robustness.

The results from the nodal restraint assignment procedure were compared to the selected "best" of the available conventional capacity restraint assignments based on traffic counts at major intersections on Preston Road. The evaluation was based on micro-level analyses including mean difference, root mean square errors, turning movements as a percentage of approach volumes, and a series of paired-t tests. The analyses show that the nodal restraint assignment generally produced better turning movement replications than the available capacity restraint assignment.

W. MULTIPATH TRAFFIC ASSIGNMENT: A REVIEW OF THE LITERATURE

(Wang, Stover, and Dresser, 1990)

Most multipath assignment techniques are generated based on either path enumeration or path diversion. Path enumeration models primarily reiterate the assignment procedure with variable link impedance inputs. Burrell's algorithm is a typical path enumeration model in which the link impedances are assumed to be randomly distributed to account for errors in the driver's perception in link travel time. Path diversion models assign trips to alternate paths without repeating the assignment procedure. The most noted path diversion model is Dial's algorithm. Dial's technique originated from logit discrete choice theory in that each "reasonable" path between a particular O-D pair is assigned a portion of the trips according to a route-choice probability.

The literature review indicates that these multiple path algorithms can be incorporated into the capacity-restraint process, either iterative or incremental. Burrell's algorithm can be implemented either in a single-pass procedure or with the capacity-restraint procedure. Paths are enumerated by repeating simulations of link impedances for each origin zone (or a number of origin zones) in a single-pass procedure; paths are enumerated by repeating simulations of link impedances for each assignment stage when combined with the capacity-restraint procedure. In theory, Dial's algorithm can be implemented with the capacity-restraint procedure although his algorithm is a single-pass procedure.

X. COMPARISON OF TRAFFIC ASSIGNMENT TECHNIQUES

(Chang and Dresser, 1990)

This report compares and evaluates the traffic assignment results from five assignment techniques: all-or-nothing, stochastic multipath, iterative, incremental, and equilibrium. The results of the assigned volumes from the five techniques are compared to ground counts. Various statistical measures are used to evaluate the results. Five different assignments of the existing Tyler, Texas, network were compared to ground counts to determine if there were differences among the results. Measures of the assignment's ability to reproduce traffic counts were divided into two groups: macro-level measurements (screenlines, cutlines, and VMT) which are network-wide analyses and micro-level measures which are link-by-link comparisons.

No significant difference was found among the five assignment techniques when using the macro-level measures. The values for the incremental assignment had the best results compared to ground counts when using micro-level measures.

Some of the statistical measures were affected by the introduction of capacity restraint. Otherwise, it was concluded that the incremental and the equilibrium assignments represented a slight improvement from the all-or-nothing and the stochastic multipath assignments. However, the difference in results was not significant enough when using capacity restraint to warrant the extra cost such as link capacity data and computer run time involved in the capacity-restraint assignments. This implies that much of the precision in the assignment procedure using the different techniques may be sacrificed and still produce acceptable assignment results.

Y. DEVELOPMENT OF A PEAK PERIOD TRAFFIC ASSIGNMENT CAPABILITY

(Benson, Bell, and Stover, 1988)

The basic objective of this study was to develop and incorporate into the Texas Travel Demand a peak hour or peak period travel demand modeling capability. Peak hour and peak period travel demand modeling techniques vary considerably in their level of sophistication. These techniques can generally be categorized into three basic approaches: factoring of 24-hour trip tables; factoring of 24-hour trip ends; and direct generation.

Two sets of data analyses were performed: (1) analyses of traffic count data from 254 locations in Houston, and (2) analyses of peak period data from the recent Houston travel survey. Based on the results of these analyses and some basic conceptual concerns, the use of three-hour peak periods instead of a single peak hour for travel demand modeling applications is strongly encouraged.

Perhaps the most important product of this study is the software. Three new routines were developed, tested and implemented in the Texas Travel Demand Package to provide for peak period modeling applications.

Z. CALIBRATING AND ADJUSTMENT OF SYSTEM PLANNING MODELS: INTRODUCTION

(U.S. Department of Transportation 1990)

This report discusses calibration and adjustment of networks, trip generation, auto occupancy, trip distribution, traffic assignment, transit ridership effects on highway volumes, external stations, system changes versus local changes, expected and required accuracy, and trouble shooting.

“The four-step transportation modeling process, as applied at the regional level, has traditionally been dependent upon an extensive and reliable origin-destination (O-D) data base. In the early years of such models, this data base was developed largely through household surveys, a time-consuming and expensive undertaking. Such surveys were instrumental in developing the transportation models that have been used during the past 30 years. Since 1980, over 30 urban areas have conducted new home interview surveys to update their data base and ensure the validity of their modeling process. However, given limited resources, many planning agencies have had to rely on other means to validate their system models.

“This manual describes quick and simple procedures for calibrating and adjusting systemwide transportation models so as to replicate existing ground counts and thus be used with some validity for forecasting. The four-step modeling process will not be described in detail. More detailed information on this process can be found in the documents listed in the reference section, or from documentation of various software packages. For this manual to be useful, the reader should have some basic knowledge of transportation planning. In addition, this manual is not intended to replace the need for good O-D data. Clearly, model calibration and validation is best undertaken with such data. In its absence, however, there are several approaches that can be adopted. This manual discusses the appropriate manner of their use. It is oriented to the smaller urban areas but many of the techniques are applicable to larger areas as well.”

“Calibration in the traditional four-step modeling process was accomplished by modifying model parameters until the models replicated the travel patterns exhibited by the O-D survey. After the models were calibrated, a validation effort was undertaken. Validation consisted of running the calibrated models with current socioeconomic data and comparing the simulated link volumes with ground counts. Over the years, however, the use of large scale O-D surveys for this purpose has generally declined due to their expense. Rather, default values for trip generation and trip distribution models developed from past surveys have been used. Sometimes, very limited small sample surveys have been conducted to update the model parameters. Also, the Census Journey-to-Work data are available every 10 years to calibrate a work trip generation and distribution model. As a result, the practical application and meaning of calibration and validation have changed over the years.

“With the decline of large scale O-D surveys, calibration and validation have merged into one process. Initial default parameters are used in the models. The models are then used to simulate link volumes, which are compared with ground counts. If this comparison shows significant differences, key model parameters are modified until the model replicates ground counts with an acceptable degree of accuracy. When modifying the model parameters, it is important to keep the values reasonable and not have the end justify the means. If the only way the model will replicate ground counts is by using unusual parameters, then the entire process should be checked, including the validity of the ground counts and the socioeconomic data.

“Before any calibration or validation process is initiated it is extremely important that the transportation planner verify the accuracy of the socioeconomic and network system data. If the socioeconomic and network system data are accurate, the level of effort needed to calibrate or validate the transportation planning models will be greatly reduced. Usually, inaccuracies in data and networks are the most common cause of error in travel demand forecasting models. It is necessary that the accuracy of the traffic counts used in comparison with the simulated volumes be checked as well.

“The following steps summarize the overall model calibration and adjustment process.

Step 1. Run the region-wide transportation system models using default values for model parameters. If old model parameters are available from previous studies or O-D surveys, they are used in the initial runs. More recent data, such as that from small sample surveys, are used to update these parameters.

Step 2. From the initial results of the model runs, develop region-wide values such as trips/person and VMT/person.

Step 3. Compare the region-wide values developed under Step 2 with typical values shown in appendix A.

Step 4. Develop screenlines and cutlines for your area. An example of screenlines and cutlines is shown in Figure 1. Screenlines should be established to intercept major traffic flows through the region and should be located so that ‘double' crossings of the screenlines are minimized. A screenline located along a physical barrier such as a river or railroad track is desirable since the number of crossings is minimized. More than one screenline may be used to intercept a variety of major flows such as between a major suburban area and the downtown area and between the suburban area and an outlying commercial and industrial area. It is sometimes useful to establish such a line to intercept all travel into and out of the central area. A series of traffic counts must be taken at each roadway location crossed by a screenline or cutline. These counts must be factored to one time period such as 1990 peak traffic season or 1990 ADT.

Step 5. Having evaluated the results from the above steps, determine whether systemlevel, local or a combination of problems have occurred in the application of the model. Modifications to the model can be made by adjusting various equations, parameters or variables as described in the following sections of the manual. In some cases, adjustments to more than one item may be necessary to obtain appropriate results. Simulated volumes from the traffic model can be raised or lowered to match ground counts by examining and modifying, either individually or in combination, the following:

- Network.Characteristics
  - Centroid Connectors
  - Roadway Speeds and Capacities
  - Intersection Penalties
  - Intrazonal Times
  - Coding Errors

- Trip Generation Rates
  - Socioeconomic Data
  - Household Income
  - Production and Attraction Rates

  - Special Generators
  - Trip Balancing Factors

- Auto Occupancy

- Trip Distribution
  - Mean Trip Length
  - Estimating Trip Length
  - Employment Distribution
  - Non-work Trip Purposes
- Traffic Assignment
  - All-or-Nothing
  - Capacity Restraint
  - Equilibrium

"The remainder of this manual is organized to discuss each one of these model variables or steps."

AA. CALIBRATING & TESTING A GRAVITY MODEL FOR ANY SIZE URBAN AREA

(U.S. Department of Transportation, 1983b)

This manual describes the history, present use, calibrating, and testing of the gravity model.

"Trip distribution is an important and complex phase of the transportation planning process. It provides the planner with a systematic procedure capable of estimating zonal trip interchanges for alternate plans of both land use and transportation facilities. These zonal interchanges constitute a basic part of the travel information necessary for transportation planning.

"This manual documents in detail the process of trip distribution utilizing the gravity model as it is now defined. Since automated trip distribution techniques have only become available in the last decade, the details involved in the various steps are still being improved. However, every attempt has been made to include in this manual the most up-to-date information available.

"A companion manual. the Traffic Assignment Manual (1) 1 was published by the Bureau of Public Roads in June 1964. Together, these manuals document two of the basic steps necessary for transportation analysis and forecasting.

"The techniques described in these manuals have functioned satisfactorily when used by the Bureau of Public Roads and several urban transportation studies. The programs and procedures have proven to be quite efficient in handling large as well as small urban systems.”

1. Gravity Model Theory

“To date, the most widely used trip distribution model has been the so-called ‘gravity model.’ As the name implies, this model adapts the gravitational concept, as advanced by Newton in 1686, to the problem of distributing traffic throughout an urban area (5). The gravity model has been the most widely used formula mainly because it is simple in concept and because it has been well documented.

“In essence, the gravity model says that trip interchange between zones is directly proportional to the relative attraction of each of the zones and inversely proportional to some function of the spatial separation between zones. This function of spatial separation adjusts the relative attraction of each zone for the ability, desire, or necessity of the trip maker to overcome the spatial separation involved. Mathematically, the gravity model is stated as follows:

$$T_{ij} = (P_i) \frac{\frac{A_j}{d_{ij}^b}}{\frac{A_1}{d_{i1}^b} + \frac{A_2}{d_{i2}^b} + \frac{A_n}{d_{in}^b}}$$

Where:

- T_{ij} = trips produced in zone i and attracted to zone j
- P_i = trips produced by zone i
- A_j = trips attracted by zone j
- d_{ij} = spatial separation between zones i and j. This is generally expressed as total traveltime (t_{ij}) between zones i and j.
- b = an empirically determined exponent which expresses the average areawide effect of spatial separation between zones on trip interchange.

2. Gravity Model Application

“In applying a gravity model trip distribution formula to urban studies, it is necessary to develop the parameters in the gravity model formula for each urban area under study. Furthermore, these parameters are developed for each of several different categories of trips. These categories take into account the basic purpose for making trips and are generally referred to as trip purpose categories. Past experience has demonstrated that the exponent of traveltime is not constant for all intervals of time. Thus it is necessary to work with a gravity model formula which differs from that shown previously. This revised formula is expressed as follows:

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

Where:

F_{ij} = empirically derived traveltime factor which expresses the average areawide effect of spatial separation on trip interchange between zones which are t_{ij} apart. This factor approximates $1/t_n$ where n would vary according to the value of t, and where t is the traveltime between zones.

K_{ij} = a specific zone-to-zone adjustment factor to allow for the incorporation of the effect on travel patterns of defined social or economic linkages not otherwise accounted for in the gravity model formulation.

And where: T_{ij}, P_i, and A_j are the same as previously described.

“The use of a set of traveltine factors to express-the effect of spatial separation on zonal trip interchange, rather than the traditional inverse exponential function of time, simplifies the computational requirements of the model. It also takes account of the fact that the effect of the spatial separation on trip making generally increases in a more complex manner than can be represented by the single exponent.”

BB. MODEL VALIDATION AND REASONABLENESS CHECKING MANUAL: INTRODUCTION

(Barton-Aschman Associates and Cambridge Systematics, 1997)

“A major shortcoming of many travel demand models is the lack of attention and effort placed on the validation phase of model development. Validation involves testing the model's predictive capabilities. Travel models need to be able to replicate observed conditions within reason before being used to produce future-year forecasts. As metropolitan areas continue to refine and improve the travel demand forecasting process, the credibility of the process with decision makers will depend largely on the ability of analysts to properly validate procedures and models used.

“The travel modeling process has undergone many changes in the past few years in order to evaluate more complex policy actions resulting from legislation such as ISTEA and the Clean Air Act. As travel models have become more complex, so have the procedures needed to validate them. Often there is a tradeoff between increasing confidence in the level of accuracy of the models and the cost of data collection and effort required to validate models. Tests or checks used to evaluate the reliability of models can range from a simple assessment of the reasonableness of model outputs to sophisticated statistical techniques."

1. Purpose of Manual

"This manual builds upon the 1990 Federal Highway Administration publication Calibration and Adjustment of System Planning Models (FHWA-ED-90-015). That manual provided a set of simple procedures for calibrating travel models that reflected the limited number of regions with current household travel survey data available.

"Since 1990, many regions have conducted, or are planning to conduct, new household travel surveys and other data collection efforts to improve their ability to develop and validate more detailed and rigorous models. In addition, the Travel Model Improvement Program has provided technical assistance, aiding planning organizations in implementing state-of-the-art modeling practices. This validation manual provides guidance on how to perform reasonableness checks on the latest generation of models commonly included in the four-step modeling process. While it is impossible to specify exact checks for every possible model, this manual will describe families of checks and provide concrete examples of validation checks. The manual also provides tips for regions with limited resources for model validation.

"The manual should serve as a set of guidelines for best practice, not as a list of required steps. The process used to validate a travel model is dependent on the purpose of the model, available data resources, model structure, and desired level of accuracy. Improving the performance of travel models depends not only on the proper calibration of parameters, but also on careful review of exogenous inputs. Typical inputs include (1) zonal socioeconomic inputs such as population, households, employment, income or auto ownership, and school enrollment; and (2) transportation system characteristics such as highway and transit network definition and attributes. Therefore, this manual prescribes a number of reasonableness tests for model inputs, model parameters, and model outputs.

"One difficulty in prescribing a set of procedures for validating models is that the concepts of model validation, calibration, and estimation have taken on different meanings and sometimes overlap in their objectives. In practice, travel model development usually involves all three steps, as well as model application, as shown in Figure 1-1. In this manual, the following definitions are used:

- **Model Estimation**: Statistical estimation procedures are used to find the values of the model parameters (esp. coefficients) which maximize the likelihood of fitting observed travel data, such as a household travel survey or on-board transit survey. The focus is on correctly specifying the form of the model and determining the statistical significance of the variables. For example, the initial cross-classification of a trip production model or the logit estimation of level-of-service coefficients in a mode choice model are developed in the estimation phase. If local data are not available, then this initial step is often skipped and the coefficients are borrowed from another urban area.
- **Model Calibration**: After the model parameters have been estimated, calibration is used to adjust parameter values until predicted travel matches observed travel demand levels in the region. For example, calibration of the mode-specific constants in a mode choice model ensures that the estimated shares match the observed shares by mode (and often by mode of access).
- **Model Validation**: In order to test the ability of the model to predict future behavior, validation requires comparing the model predictions with information other than that used in estimating the model. This step is typically an iterative process linked to model calibration. It involves checking the model results against observed data and adjusting parameters until model results fall within an acceptable range of error. If the only way that a model will replicate observed data is through the use of unusual parameters and procedures or localized ‘quick-fixes’, then it is unlikely that the model can reliably forecast future conditions.
- **Model Application**: Although the model may replicate base year conditions, the application of the model to future year conditions and policy options requires checking the reasonableness of projections, so there is a link between application and validation as well. The sensitivity of the models in response to system or policy changes is often the main issue in model application.

"The focus of this manual is on the iterative process shaded in the figure which links validation with calibration. It is not a manual on travel model development. While the estimation phase of model development does have a link to validation, this manual assumes that the final model structure, especially the inclusion of relevant variables and specification of initial parameters, has already been determined.

2. Target Audience

"The model validation manual should prove to be a useful reference for the following persons:

- Travel Forecasters
  - responsible for model calibration and/or validation
  - responsible for model application
  - employees of metropolitan planning organizations (MPOs), states, municipalities and counties, and consultants;

- Transportation Planners
  - responsible for evaluation of plans
  - responsible for designing alternatives
  - employees of metropolitan planning organizations (MPOs), states, municipalities and counties, and consultants;

- Decision-makers
  - at overview level to know the questions to ask
  - employees of metropolitan planning organizations (MPOs), states, municipalities and counties;

- Members of the public with an interest in travel forecasting.

3. Overview of the Model Validation Process

"Typically the calibration and validation processes focus only on the overall results of the travel model, especially highway volumes at screenline crossings. The models are run to obtain the necessary output such as mode shares, overall transit ridership, transit boardings for a specific line, or traffic volumes, without detailed checking of results from individual model components. This 'all-too-common' approach to model validation might be used under the justification that traffic counts or transit boardings are the only historical data available or because time constraints preclude detailed checking of interim model steps.

"The approach advocated in this Validation Manual is to apply reasonableness checks during the processes of calibrating each individual model component. After each component has been validated, the overall set of models is validated to ensure that each is properly interfaced and that modeling error is not propagated by chaining the models together. Figure 1-2 presents an overview of the validation process contrasting the desired approach with the ‘all-too-common’ approach.

“Individual model validations are used as part of calibration to show that each component reasonably reproduces observed travel characteristics. For example, trip generation models should be checked to ensure that trip productions and attractions estimated on a district and regional basis are reasonably similar to the observed number of trips; trip distribution models are checked to ensure that they reasonably reproduce the observed average trip lengths by trip purpose; etc.

“Validation of the overall set of models tests the effects of compounding errors. For example, suppose that the trip production model produced too few trips from a zone that was relatively close to a large attractor of trips. If these trip generation results are input to the trip distribution model, they would have a tendency to increase trip lengths because of the error in trip production modeling. Overall measures of model performance, such as regional VMT and screenline volumes, should be reviewed with the possibility of error propagation in mind.

“The following steps summarize the recommended overall model calibration and validation process:

1. Estimate model parameters and test the specification of the model structure using household travel survey data set.
2. Calibrate model parameters to reproduce desired regional control totals.
3. Validate each model component to ensure that reasonable results are produced, and that observed conditions are replicated. When available, use independent data sets to validate individual model components.
4. Apply travel model chain using initial calibrated parameters. Check overall aggregate measures (such as VMT by facility type and speed ranges, and screenline/cutline volumes). Compare modeled volumes with observed traffic counts.
5. Evaluate results from the steps above to determine whether systemwide and/or localized problems have occurred in the model application.

4. Validation Issues

"Before presenting the validation checks in the following chapters, it is useful to consider a number of issues regarding the types of checks which are used, the level of aggregation, data sources, accuracy requirements, and sources of error."

a. Types of Validation Checks

"As noted earlier in the Introduction, the approach used to validate travel models can vary a great deal depending on a variety of factors such as the types of policy options being tested and the availability of historical data. This Validation Manual provides a range of validation measures for both base year calibration and future year application of models.

"Two major categories of validation checks are used in this report:

- Reasonableness Checks: These include comparison of rates and parameters, total regional values, subregional values, logic tests, etc. Parameters should be checked against observed values, parameters estimated in other regions, or secondary data sources for consistency. The models should be evaluated in terms of acceptable levels of error, their ability to perform according to theoretical and logical expectations, and the consistency of model results with the assumptions used to generate them.

- Sensitivity Tests: These include response to transportation system, socioeconomic, or policy changes. Sensitivity is often expressed as the elasticity of a variable. For example, one might examine the impact on travel demand if parking costs were to double or if bus headways were reduced dramatically. Sensitivity analysis should be used for all components of the modeling process, prior to application of the model for forecasting. It is important because projected policies (e.g. tolls) or conditions (e.g. high congestion levels) might not exist in the base year.

"Throughout this manual, a number of validation tests will be described which compare observed and estimated values for a given model output (e.g. trips produced, daily link volumes) over a number of observations (e.g. TAZs, links with traffic counts).

"There are four common approaches to evaluating how well the model estimates match the observed data:

1. Absolute difference: Calculated as the actual difference, i.e. Estimated

- Observed. The sign (positive or negative) may be an important indicator of performance.

2. Relative difference: Values are normalized to remove scaling effects. Can be expressed as a percentage difference (e.g. acceptable range might be ±10%) or as a ratio (e.g. 0.9 to 1.1) and are calculated as follows:

$$\text{Percentage difference} = \frac{(\text{Estimated - Observed})}{\text{Observed}} * 100$$

$$\text{Ratio} = \frac{\text{Estimated}}{\text{Observed}}$$

3. Correlation: In regression analysis, an equation is estimated which relates a dependent (or unknown) variable to one or more independent variables. Correlation analysis determines the degree to which the variables are related, i.e. how well the estimating equation actually describes the relationship. In the case of model validation, we determine the degree to which observed and estimated values are related. The most commonly use measure of correlation is the coefficient of determination R2, which describes the amount of variation in the dependent variable which is explained by the regression equation. R2 can range from 0 to 1, with a value of 0 for no correlation and 1 for perfect correlation. Acceptable values of R2 can vary depending on the type of comparison being made, but it would ideally explain more than half of the variation (R2 > 0.5). Note that as aggregation increases, the amount of correlation will increase.
4. Variance: Statistical measures can be calculated which measure the variance between observed and estimated values. The most common measure for validation purposes is the Percent Root Mean Square Error (RMSE) which is described in section 7.1.3 Highway Assignment.

“These validation tests can be easily calculated with a spreadsheet, database, or statistical package. For example, to estimate a regression line, most spreadsheet packages simply require that the observed and estimated values be placed in columns - the regression equation and R2 are calculated using a simple command. For additional information, you may want to consult an introductory statistics textbook.”

b. Level of Aggregation

“Some researchers differentiate between the calibration procedures used for aggregate or first-generation models, such as zone-based regression models, and the disaggregate or second-generation models, such as individual-based choice models. With the first-generation models, calibration may involve trial-and-error adjustment of parameters which improve the overall goodness of fit between the model results and the observed data. With the second-generation models, much more attention is placed on the statistical properties of the parameters and the confidence limits of the estimated values.

“Similar to calibration procedures, validation checks also vary by the level of aggregation. There is a continuum of checks ranging from validation using disaggregate data at the household level to aggregate results at the regional level. In the middle would be validation checks using the models applied to zonal data. For state-of-the-art disaggregate models, the entire range of checks is needed to ensure that the models can reproduce not only the travel behavior of individual households, but also the resulting performance of the transportation system when all of the individual trips are aggregated over the entire metropolitan area. The two ends of the continuum are defined below:

- **Disaggregate Validation** provides a means of exploring how well a candidate model fits the observed data at the household or individual level. It involves defining subgroups of observations, based, for example, on household size and income or auto ownership levels. Model predictions are compared with observed data to reveal systematic biases. Note that disaggregate validation plays more of a role in the estimation phase of model development

- **Aggregate Validation** provides a general overview of model performance through regional travel characteristics such as average trip rates, average trip lengths, average mode shares, and regional vehicle-miles of travel (VMT). Reasonable ranges for model parameter values have been included in the manual for comparative purposes. Travel models are applied to aggregate data at the regional, county, district, or zonal level. Traffic assignment results are validated at a regional level, using screenline volumes, and then at a local level, using cutline and individual link volumes.”

c. Validation Data Sources

“In order to sufficiently prove a model has been validated, the model should match observed data from an independent data source. Each chapter of this manual will discuss necessary validation data sources in detail.

“While not an independent source, the calibration data set (typically from a household travel survey) is used in validation. Other travel surveys may be available for validation such as workplace/establishment, on-board transit, roadside origin-destination, and external cordon surveys. The Census Public Use Microdata Sample (PUMS) provides socioeconomic and travel behavior data at the household level.

“For disaggregate models, particularly choice models with a large enough sample, a validation sample can be created by splitting the observed data set into two random groups. One sample is used for calibration, and the calibrated models are used to predict the second group's demand. A similar approach identifies stratification biases within the population by applying the models to a segment of the calibration data set. While this process does provide an independent set of observations, it lacks temporal variation.

“The best estimate of socioeconomic data should be available locally, although these inputs should still be reviewed for reasonableness, particularly changes over time. Transportation system data can be compiled from other public agencies, such as the local highway administration or transit operator. Typical validation data includes daily and peak hour traffic volumes at screenlines, cutlines, critical links, and transit boardings by route.

“A number of national data summaries provide comparative data including:

- FHWA's Highway Performance Monitoring System
- Census Transportation Planning Package
- Nationwide Personal Transportation Survey

“Comparisons can also be made with observed data from other similar metropolitan areas. NCHRP Report 187 has recently been updated in the forthcoming report 365, Travel Estimation Techniques for Urban Planning. The transferable parameters contained in this report are useful for validation purposes.

“Zonal socioeconomic input data and transportation system performance data should be collected for the same base year. Since virtually all transportation models have been based on cross-sectional survey data, there has been a tendency to view validation exclusively in terms of the ability of the model to match observed traffic volumes for a single base year. However, individual model components and the overall set of models should also be tested by predicting demand for a different historical time period than was used for calibration. When the models are applied to historical data, this is often referred to as backcasting. Unfortunately, consistent historical data for more than one time period are rarely available.”

d. Sources of Error

"Even when models reasonably reproduce their portions of regional travel, they are not without error. Error is inherent in all models since they are abstractions of real travel behavior; simplifications of reality are unavoidable in order to make the models usable and practical. Sources of error resulting from development and calibration of travel models include:

- **Measurement Errors** inherent in the process of measuring data in the base year, such as survey questions, network coding and digitizing errors, etc. resulting from poor data quality control.
- **Sampling Errors** such as bias introduced in the process of selecting the set of observations from the population.
- **Computational Errors** due to arithmetic mistakes, which are typically small for computer-based calculations
- **Specification Errors** due to improper structure of the model, such as omission of relevant variable.
- **Transfer Errors** when a model or parameters developed for one context or region is applied in a different one.
- **Aggregation Errors** arising from the need to forecast for groups of individuals (or households) while modeling needs to be done at the level of the individual.

"A major concern for validation of travel models is error inherent in the collection of input data or historical data used for validation. Problems with input data or validation data can lead to erroneous corrections to models that, ultimately, will damage model performance, credibility, and results. For example, if daily traffic counts collected at screenlines are low due to incorrect collection methods, the analyst may attempt to increase auto occupancy rates or lower trip rates in order to match the screenlines. This suggests that a course of action for responding to models that do not validate is to check for errors first, then consider adjustments to parameters. Throughout the planning process, it is important to periodically perform a peer review of networks, socioeconomic inputs, and modeling procedures. Involving more than one person in the review process will often improve results and force the modeler to re-examine steps taken.

"Figure 1-3 shows the possible effect of compounding error in model validation. Each step in the modeling process increases the overall error. While there is a potential for the errors to offset each other, there is no guarantee that they will."

e. Accuracy Requirements

“There are no absolute measures or thresholds that can be achieved to declare a travel model or its components ‘validated.’ The level of accuracy expected of a model is somewhat subjective, and ultimately depends on the time and resources available, and on the intended application of the model. For example:

- Emissions estimates for air quality analysis require accurate summaries of VMT by speed range.
- Individual link volumes are not as critical in a long-range regional sketch plan as in a sub-area traffic impact study.
- Consideration of significant land-use changes introduces additional uncertainties and interactions into future year alternatives analysis.
- Transit contributions can vary considerably among metropolitan areas, as do the level of analysis and the complexity of representation of transit in various models.

“Table 1-1 shows the estimated accuracy of some parameters in the travel modeling process. Accuracy tends to be greatest on higher volume links and screenlines. The confidence limits also show that, due to error propagation, assignment results tend to contain more error than earlier steps in the process such as trip distribution.

“The reliability of a model validation effort is always constrained by the quality and quantity of validation data available. There is some error inherent in even the best data. Traffic counts alone can vary by 10 percent or more due to daily and seasonal variation (FHWA Guide to Urban Traffic Volume Counting, 1980). Other sources of count error include improper count location, variation in the portion of multi-axle vehicles, special events, accidents, mechanical count failure, and personnel mistakes.

“Sources of significant uncertainty or potential error should be identified early in an effective validation process. Thorough knowledge of a model's design, inputs, and applications is needed to recognize if a point-of-diminishing-returns has been reached. It is important to recognize that uncertainty is inevitable, and to avoid confusing precision with accuracy.”

Table 1-1 Estimated Accuracy of Some Parameters in the Travel Modeling Process		
Parameter	Typical Magnitude	95 Percent Confidence Limit
Zonal Generation	2,000 person trips	± 50%
Interzonal Movement	Small	Extremely Inaccurate
Major Trip Interchange	40,000 person trips	± 10%
Minor Trip Interchange	15,000 person trips	± 16%
Highway Link Loading:		
Minor Link	5,000 vehicles	± 55%
Average Link	20,000 vehicles	± 27%
Major Link	50,000 vehicles	± 17%
Public Transit Loading:		
Average Urban Link	5,000 passengers	> ± 46%
Major urban link	20,000 passengers	> ± 23%
Source: J. Robbins, 'Mathematical Models - the Error of Our Ways,' Traffic Engineering + Control, Vol. 18, No. 1, January 1978, p.33.		

5. Organization of Manual

"The remainder of the Validation Manual is divided into the following chapters:

"Chapter 2 discusses reasonableness checks for input data, including zonal socioeconomic data and network inputs. While these checks are not actually model validation checks, a tremendous amount of time can be wasted testing and adjusting models when the problem is with input data. Thus, a separate chapter has been devoted to this subject.

"Chapters 3 through 7 discuss validation techniques and reasonableness checks for model parameters and outputs for each of the following travel model elements:

- Trip Generation
  - Socioeconomic Disaggregation
  - Trip Production
  - Trip Attraction
  - External Travel
- Trip Distribution
  - Estimating Travel Impedances
  - Gravity Model
- Mode Choice
  - Nested Logit Model
  - Auto Occupancy
- Time-of-Day/Direction Split Factors
- Traffic Assignment
  - Highway Assignment
  - Transit Assignment

"Chapters 3 through 7 focus on standard four-step models. However, concepts presented in these chapters should lead the reader to reasonable validation checks for non-traditional modeling processes. Each chapter discusses strategies for systematic troubleshooting of validation problems. The highway assignment section also includes examples of validation targets used to validate the overall modeling process after the initial calibration of each component.

"Appendices are included at the end of the manual which provide specific examples of parameters and travel characteristics for a number of metropolitan areas."

CC. TECHNIQUES TO DEVELOP TRIP GENERATION DATA

(Ellis, 1999)

1. Population Estimates and Projections

"Population estimates refer to approximations of population for time periods in which population counts are not, but could have been available — generally, estimates are made for years between census counts. Population projections refer to approximations of population for future time periods. Both estimates and projections are made on the basis of specific assumptions about past, current, and future trends.

"Estimates and projections of population are often not done well due to a lack of overall understanding of demographics, and to a certain extent, a lack of understanding of the limitations of the various techniques. Some general principles underlying estimates and projections are as follows (Murdock, 1981):

- Any estimate or projection is only as accurate as the assumptions on which it is based and only correct if the assumptions are correct.

- No specific methodology guarantees accuracy. But, accuracy will usually be greater for estimates or projections that are made:
  - For an entire nation or large geographic region rather than for a small component area or subregion;
  - For total populations rather than for population subgroups;
  - With methods using data directly related to population change (births, deaths, and migration data) rather than using data that provide indirect or symptomatic indicators of populations change (auto registration, housing counts, school enrollment, etc.);
  - For shorter rather than longer periods of time;
  - For areas in which past trends are more likely to continue rather than new patterns to arise; and
  - For areas undergoing slow rather than rapid change."

a. Population Estimates for the Base Year

"Population estimates are required for the base year in travel demand forecasting. The most common techniques used to estimate population include mathematical techniques, symptomatic techniques, and component techniques."

(1) Mathematical Techniques

"Mathematical techniques are those which refer to curve fitting (e.g. Gompertz, logistic, and others) and trend extrapolation. In general, these techniques are best suited to very short time estimation periods. One example, is the assumed rate of growth method in which the assumption is that recent growth trends have continued. This may be accomplished using recent exponential growth rates or compound average annual rates of growth."

(2) Symptomatic Techniques

"Symptomatic Techniques are methods in which factors believed to be indicative of population change (e.g. school enrollment, auto registrations, utility connections, etc.) are used to estimate population. Two consistently used symptomatic techniques include the ratio method and the correlation method. In the ratio method, the ratio of a selected symptomatic indicator (such as school enrollment) to the total population for the most recent census year is developed. This ratio is assumed to continue to the year of estimation, so that current counts of the symptomatic indicator could be multiplied by the ratio from the census year to approximate the current population. The correlation method uses linear regression, either simple or multiple regression, to estimate population on the basis of one or more symptomatic indicators."

(3) Component Techniques

"Component techniques are those which use components of populations change (births, deaths, and migration) to estimate population. The best known component techniques used to estimate population are cohort component, and the component method I and II which were developed by the U. S. Census Bureau. In component techniques, current birth and death rates are used along with estimates of migration. Estimates of migration can be developed a number of ways. One that has been used by the U.S. Census Bureau to make current estimates of population for places and counties is the Administrative Records method. As the name implies, the method uses records obtained for other administrative purposes to estimate migration. In the case of the U.S. Census Bureau, income tax returns from the IRS are used. The Bureau compared tax returns filed for adjacent years, and migrants are identified as those persons who file in two different areas in adjacent years.

"Another method used to estimate migration is the component method II. This method uses school enrollment data to estimate the migration rates for school aged children, and these migration rates are then used to estimate the rates of the general population. The strength of this method is that it is relatively straightforward and has been widely tested. The weakness is that it is based on the assumption that the relationship between the migration of school aged children and the general population is stable.

"Any of these methods, used judiciously and with sound assumptions, should provide reasonable estimates of population for the base year. As an option to making local area base year estimates, consideration should be given to using estimates prepared by the U.S. Census Bureau or individual State Data Centers. MPOs are encouraged to review these estimates and the methodology used to prepare them, before use."

b. Population Projections

"Population projections are required for developing future estimates of travel. The three most widely used techniques for projecting population include cohort component (or, cohort survival), ratio or step-down, and trend analysis."

(1) Cohort Component

“This technique is the most reliable method for projecting population to a future date. The formula uses births, deaths, and net migration by age cohorts (generally in 5 year increments such as age 0-4 years, 5-10 years, etc.) to project a future population. The equation is:

“Future Population = Current Population + Births - Deaths + Net Migration (can be positive or negative).

“The birth rate and death rate for specific ethnic groups by age cohorts are monitored and updated on a regular basis. Birth rates and death rates change slowly over time. The most difficult component to predict, and the one that changes most rapidly, is migration. Migration rates are determined subsequent to each decennial census. It is calculated for each age cohort by taking the population at the first census and aging, applying birth rates and death rates to each cohort for 10 years to obtain a population estimate without migration. When the most recent census is tallied, the difference between the recent population count and the projected population without migration are compared. That difference (either negative or positive) is the net migration.

“Quite often population projections are made for several different migration scenarios. For example, the scenarios might represent: zero net migration (any increase or decrease in the population is due to births and deaths), migration equal to that of the previous decade, one-half of the net migration of the previous decade, and, in some cases, a net migration rate estimated for the period since the previous census (i.e. an estimate of the migration between 1990 and 1997).

“Despite it’s relative mathematical simplicity and the availability of computer software to perform the calculations, the inexperienced user of the cohort component technique should be aware of certain special circumstances regarding it’s use.

- Race specific fertility rates (births per 1000 women between the ages of 10 and 49) and survival rates (deaths per 1000 population by age cohort) should be used because of differences between the races. This means that an understanding of the current and anticipated future ethnic make-up of an area is required.

- There are certain special populations that may exist within a planning area that will need to be handled separately. For example, populations of universities or colleges and/or prisons, both of which are included in census counts for an area, will need to be separated from the general population because they do not follow the same pattern of birth rates or migration rates as the general population (i.e., women in college, although in prime child bearing years, do not have children at the same rate as the general non-college population within the same age cohorts).

- One of the assumptions in the cohort component techniques is that the migration rate will remain the same. Yet, migration rates can be very volatile. People choose to move for a wide variety of reasons such as a change in the economic conditions of an area, job relocation, a change in lifestyle (such as retirement, marriage, or having a child), a change in climate, etc. The reasons behind migration are as varied as the population.

- It is unlikely that migration rates for an area will stay constant during the 20 to 25 year forecast period. Yet, a future population projection will likely be based on one specific set of migration rates. A way to assist in selecting a reasonable migration rate to use is to graphically plot historic population change over 25 to 30 years along with the current estimate of population. Then, develop population projections using different migration scenarios (e.g. zero net migration, one-half the most recent migration rate, estimates of the current migration rate, etc.) Plot the results of the different projection scenarios on the same graph as the historic and current estimates. Then determine which scenario ‘best fits’ the historic/current population trend line.

“The cohort component procedure is probably the most developed technique available. The major advantages to its use are that 1) it allows the basic demographic processes (births, deaths, and migration) to be simulated, and, 2) age, sex and other detail are provided in the output. This type of detail can be useful in making reasonable projections for other needed variables such as employment, income and auto ownership. Using cohort component method to project population is time and data intensive and requires a certain level of expertise and knowledge of local demographics in order to make reasonable assumptions."

(2) Ratio or Step-Down

"This is a relatively simple method for projecting population. It involves developing a ratio between the planning area and a larger area such as the county or state and the country. The forecast for the planning area is then projected by multiplying a recent population projection for the larger area by the ratio. This process can be applied in a single step (such as state to planning area) or in multiple steps (nation to state, state to county, county to planning area). Use of the ratio technique is not limited to total population. Ratios can be developed and applied for age, sex, and/or ethnic specific components of the population.

"When applying this technique, a clear understanding of how the ratio might change in the future is needed. Changes in the ratios could occur due to changes in planning area boundaries, major shifts in economic conditions specific to a certain region or planning area, major changes in the ethnic make-up of an area which would affect birth rates, as well as other factors. As a guide for future possible changes in the ratio, the historic ratios should be determined and analyzed. Additionally, when using a projection for a larger area (such as the nation, state or county), an understanding of how that projection was made is needed in order to make the required professional judgements in developing and using the ratios."

(3) Trend Analysis

"Trend analysis is based on projecting population using only data on past total population size. In these techniques, population is always a function of time, and the underlying assumption is that time is the variable that accounts for the many factors that influence population. There are a variety of trend or mathematical methods that can be used to make a population projection. The most common of these include linear arithmetic change, geometric or exponential change, Gompertz model or curve, logistic model and the polynomial model. Each of these methods uses the historic association between population and time, but they do vary in the presumed relationship between time and population.

"Use of trend analysis methods is best suited to areas which have historic and anticipated future slow, stable growth (averaging 1 to 1.5 percent per year). Areas which are experiencing a more rapid growth pattern or significant changes in migration (either in migration or out migration), particularly migration of an ethnic group(s) different from historic population percentages, should exercise care and judgement when applying trend analysis. Also, areas with special types of growth patterns, should use caution when applying trend analysis. As with ratio techniques, considerable knowledge of the area coupled with professional judgement is required to apply trend analysis in a reasonable fashion.

"Any of these techniques, when used appropriately and with sufficient knowledge of the limitations and special circumstances, and understanding of how to check the results for reasonableness, are adequate for use in projecting the population for travel demand modeling. The cohort component methods are best for use in long-range projections, but also require the most data, time, and technical expertise. The selection of a forecast technique should be based on:

- MPO staff technical expertise and time available. The cohort component methods are better for long-range forecasts, but require more time to complete and a thorough understanding of the technique.

- An assessment of the area's rate and type of growth (stable or high fluctuations). Areas with a history and expected continuation of slow, stable growth may use ratio or trend methods.

- An assessment of the rate and type of demographic changes occurring in the area. Areas which have experienced significant changes since the last census in 1) the demographic characteristics of the population (such as change in the ethnic make-up of the community), 2) a major economic change such as the loss of a major employer or closing of a military base, or 3) another type of major change within the community that has significantly changed the type or rate of growth should consider using one of the cohort component techniques."

c. Using Estimates and Projections Made by Others

"There are many agencies, public and private, which today make population projections for specific geographic areas which may be used if the technique and assumptions are valid. Many of these projections may be quite reasonable while others may be very optimistic or pessimistic. The decision to use a projection made by another entity should be made only after 1) researching the methodology and assumptions used to prepare the estimate (Is the methodology acceptable? Are the assumptions reasonable?); 2) completing a historic analysis of population trends; 3) researching current and anticipated future population trends. In other words, some analysis and research will need to be accomplished by the MPO in order to make a reasonable judgement regarding the projections made by others."

2. Estimating and Projecting Households

“A household is defined as persons, related or unrelated, living in a single dwelling unit and representing a single economic unit with regard to housing. Thus, a household is different from a dwelling unit in that only occupied dwelling units may be households. A household also differs from a family, in that a family is a household consisting of related individuals only, while a household may consist of either related or unrelated individuals.

“Most travel demand models require a base year estimate and future year projection of the number of households by household size (i.e., number of one person, two person, three person households, etc.). Thus, a projection of the average household size for an area will be required. To make a reasonable estimate of average household size for an area, past trends in average household size should be reviewed. For most areas of the country, the average household size has decreased in the past 20 years. This decrease is the result of a number of demographic trends including a decrease in the birth rate, an increase in the divorce rate, an increase in the average age at which individuals marry, as well as changes in lifestyles. In general, most of these trends seem to have leveled to the extent that while household size may continue to decrease, it will do so at a slower rate. And, in some areas, average household size is estimated to have increased since 1990 due to significant increases in certain ethnic populations which tend to have higher fertility rates, a lower age at marriage, and cultural differences with regard to including extended family in the household.

“Once the average household size for an area has been developed, it can be used with area population to estimate the number of households. This is accomplished by dividing the area population by the average household size.

a. Trend Analysis Techniques

“Trend analysis is the most common method used to analyze, estimate and then project future average household size. Each area will need to study past and current trends with regard to changes in local demographics. Factors which influence the size of households include the age at which persons marry and have children, the fertility rates of the various ethnic groups, changes in the percentage of the local population which are made up by the various ethnic groups, divorce rates, co-habitation rates, as well as the general economic conditions. Thus, anticipated trends in these factors should be reviewed in the preparation of projections of the average household size. Additionally, keep in mind that changes in the various factors mentioned above occur very slowly.

"A comparative trend analysis can also be used to estimate base year and to project future average household size for an urban area. This method employs a comparative trend analysis of historic data on average household size for the nation, the state, the county and the urban area to determine how the urban area tracks with national and/or state trends. Based on the results of that analysis, estimates or projections of average household size developed for the nation and/or state can be used to estimate the average household size for the urban area."

b. Ratio Technique

"A ratio technique can also be employed to estimate future household size for a planning area. As with ratio techniques used in population, historic data on average household size for the planning area and a selected larger area such as the nation or state is collected and a ratio of the average household size for the two areas is prepared. Based on the analysis of past and current ratios, assumptions as to how this ratio might change in the future must be made.

"A great deal of professional judgement is needed when estimating future household size. However, there are some general guides that can provide assistance. Changes in average household size for an entire planning area will normally occur relatively slowly, although the average household size in individual traffic analysis zones can change by a large amount more quickly. While average household size is expected to continue to decrease, it is unlikely that any planning area as a whole would achieve a future average household size of less than 2.2, although it would be possible for individual traffic analysis zones to have an average household size of less than that. Areas which are experiencing a significant increase in ethnic populations which have a higher birth rate and culturally tend to have larger families may actually see an increase in the average household size for a number of years."

c. Distribution of Households by Household Size

"Estimates of future average household size for an area can be used in conjunction with historic data on the number of households by household size (available in census publications) to estimate the base year and future distribution of households by household size.

"Perhaps the easiest method to accomplish this is with disaggregation curves. This methodology is based on the assumption that there is a correlation between the distribution of households by household size and the average household size of a given area. This method can be used to develop distribution of household by household size at the urban level, census tract level and/or traffic analysis zone level. It has been used successfully in large, medium and small urban areas.

"The basic steps include:

1. Plot a relationship between average household size and the distribution of households by household size. One plot is accomplished for each household size category.
2. Hand fit the curves found in the data plotted for each household size category. Regression techniques or other mathematical relationships may be used to develop the curves, if desired.
3. Use the average household size for either the urban area (when determining distribution for the urban area) or traffic analysis zone (when determining the distribution of households for at the zone level) in conjunction with the appropriate curves to determine the percentage of households by household size."

3. Estimating and Projecting Employment

"Current estimates of employment, both total and by major industrial group, for development of base year data are readily available. State, county and/or local area employment estimates should be available in most states from the state employment commission or state workforce commission.

"As noted in the data sources section, local data may be available for use in a format which gives the name, address and number of employees by Standard Industrial Classification (SIC) codes. Although this information is considered confidential, agreements ensuring confidentiality of the data have allowed MPOs to have access to this data. This data, if it can be obtained, is very useful in estimating base year employment by type for each traffic analysis zone because it provides the location of the business. If using this type of data, it should be noted that:

- Some addresses may not be local. The address may be for a company headquartered in another area. The local phone book should provide the local address.
- State workforce commission data does not generally include persons

who are self-employed.

“Projections of employment require estimates of future economic conditions, changes in technology, consumer preferences, changes in labor force participation, inflation, personal saving habits, and other factors which are beyond the normal area of expertise for most staff involved in transportation planning. In making projections of employment and income, remember that there is no ‘crystal ball’ to give the future economic conditions. There are many things that cannot be foreseen even by experienced economists.

“There are a number of possible methods that may be used to forecast employment. Techniques, such as economic base analysis, multiplier analysis and econometric models do not actually produce an estimates of employment. Rather, they project economic activity which must in then be converted into estimates of employment and income. There are available computer software programs designed to forecast employment. However, most of these require sufficient knowledge and understanding to enable the user to construct models based on time series data and then interpret the results. These approaches have been used successfully by planners for some time. There are, however, some simpler methods that will provide reasonable estimates of future employment. The two most common methods include trend analysis and ratio or step-down.”

a. Trend Extrapolation For Estimating Employment

“Trend analysis may be used to estimate future employment just as it is used to estimate population. The use of trend extrapolation may be applied to project total employment as well as employment by industry groups, labor force participation and unemployment. Comparative trend analysis, where the historic employment trends by industry group in the planning area are compared with historic employment trends of the state and the nation can be used to forecast future employment by the different industries or industrial groups of basic, service and retail. This type of comparison can be extremely helpful in that economic forecasts and forecasts of employment are generally available for individual states and the nation. A simple trend/comparative trend analysis process for estimating future employment by the major industrial classifications of basic, retail and service employment is described in *Simplified Procedures For Estimating Inputs for Trip Generation*. This procedure uses trend analysis of labor force and unemployment in conjunction with population projections by age cohort to project total employment. A comparative trend analysis for employment in the basic, service, and retail industries in used to estimate the total employment by industry group. As with any technique, considerable judgement and local knowledge must be used to determine if the results are reasonable estimates. Additionally, since this method uses estimates of future labor force, considerable care should be made in projecting the population and such projections will need to provide age specific data for the future year.

“There are benefits and limitations inherent in this method of forecasting employment. On the one hand, it ties future employment to the future population within the planning area. Thus, the estimate of employment will be reasonable relative to the future population and labor force. At the same time, it does not account for people that may live outside the planning area, but be employed within the planning area. This may be a large concern in some areas, and not important in others. Professional judgement and local area knowledge will need to be used to evaluate if estimates of employment will need to be adjusted.”

b. Ratio Methods for Projecting Employment

“There are two types of ratio methods that may be used to project employment. Both of these methods use a step-down process, but one accomplishes this using an apportionment technique and the other uses a direct step-down.”

c. Apportionment and Direct/Indirect Ratio Procedures

“These procedures use a ratio or step-down process similar to that used in population projections. In this approach forecasts of employment for the nation, region of the nation, the state, and/or a state region are allocated to a local area by apportionment procedures. The process of apportionment consists of determining how the local area has historically ‘shared’ in the growth of employment occurring in the nation, the state or region. Then, the future employment for the local area is determined using the apportionment process and available projections of employment for the larger areas (i.e. nation, state, region). This process uses either ratios or correlation procedures, and can be accomplished for total employment and employment by major industrial sectors.

“The difference between the two processes is that the direct/indirect ratio process does not reflect important shifts in competitive advantages that may occur between regions or states. That is, as different areas develop or decline in their position relative to changes in economic activity, the area’s share in employment in various sectors may shift in the future. The second part of the apportionment technique uses a trend analysis of supply and demand factors relative to commodity (basic employment industrial sectors) and non-commodity (retail and service industrial sectors). National trends with regard to changes in supply and demand factors in the basic industrial sectors and an analysis of how competitive a region or state is with regard to skilled labor, access to raw materials and transportation and other factors, are used to determine possible future shifts in employment.

“These simple methods of projecting employment should work sufficiently well in small urban areas. Use of any of the methods, however, requires that the employment projection be compared to the projected population by estimating the future labor force. If the projected employment significantly exceeds that of the labor force projection, then the revisions will need to be made.”

d. Privately Developed Employment Projections

“There are a number of well known companies which develop estimates of employment for states, counties and urban areas. Some MPOs may wish to purchase and use these estimates. Before purchasing employment data, MPOs should carefully examine:

- The methodology used to develop employment projections.
- The population estimates upon which the employment projections were based. If the population estimate is significantly higher or lower than that developed by the local area for input into the model, the employment estimates will not be reasonable.
- The future percentage of employment in major industries relative to historic and current data. If there are significant changes, are they reasonable?”

4. Estimating and Projecting Income

“Estimates of median household income and mean household income since the last census are available from the U.S. Census Bureau. These estimates are made for the nation, for regions of the country, and for individual states. This data may be used in conjunction with a comparative trend analysis of historic income data to make estimates of base year income.

“As with employment, trend extrapolation and/or trend comparative analysis can be used to estimate current and project future household income, either mean or median household income. To understand how the various measures of income have changed, and are likely to change in the future, requires an understanding in the changes that have occurred in the structure of the household. According to the U.S. Bureau of Census publication, ‘Changes in Median Household Income: 1969 to 1996', median household income has increased by only 6.3 percent in constant dollars while per capita income during the same period rose by 51 percent. The difference between these two vastly different increases can be explained by the change in household structure. Mean, or average household income, has increased by approximately 26.3 percent during the period of 1975 to 1997. As with median income, there are differences in the amount of increase in income due to changes in household structure.

“Do these differences mean each MPO area needs to forecast households by household structure for the planning year in order make a reasonable estimate of household income? No. Projecting future changes to household structure is beyond the expertise of most MPO staff, and is not needed to make reasonable projections. What is needed is general information on anticipated future changes in household structure. Such information is provided for the nation by the U.S. Census Bureau for three different scenarios. This information can be used in conjunction with historic census data on household structure for the local area to determine if there is a need to account for future changes in household structure in the projection of household income.

“For most small urban areas, particular if relatively slow, stable growth is anticipated, there is not likely to be a great enough change in household structure to warrant consideration in the projection of income. But, each area must make that judgement based on local conditions.

The following provides some guidelines for using trend analysis to project income.

- Income, whether it is median household income or mean household income, must be converted into constant dollars for a certain year. To do this use the Consumer Price Index.
- Future estimates of income are made in constant dollars. That is, do not inflate income estimates. As an example, the median household income in the U.S. in real dollars (dollars which represent inflation) in 1975 was $11,800 and in real dollars in 1997 was $37,005. In constant 1997 dollars (dollars without inflation) the median household income in 1975 was $33,699 and in 1997 was 37,005. In real dollars income for that period grew 213 percent. In constant dollars the growth was only 9.8 percent.
- Always use the same measure of income. That is, if the model input is to be median household income, always use median household income in the trend analysis. Do not use trend analysis of average (mean) household income or per capita income to project median household income.
- Collect historic and recent trend data on income for the U.S., the state, the county and the urban area. Graph the historic data to see how the urban area compares to the larger areas. If income tracks the U.S.

and/or the state in terms of changes to income, use local area knowledge and professional judgement to determine if it will continue to do so. If it does not track the income of the larger areas, try to determine how the area differs and if this is likely to stay the same."

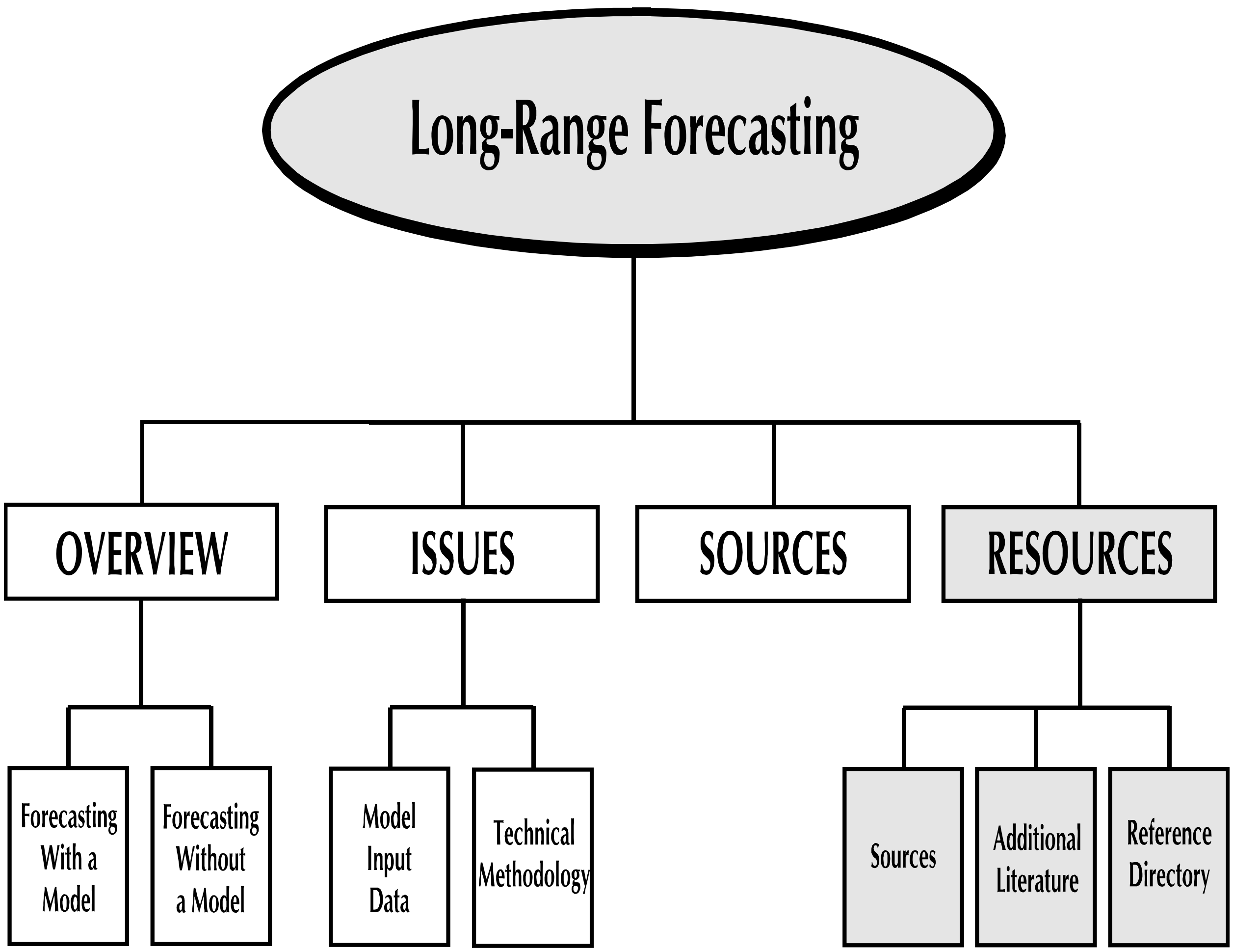
5. **Projecting Auto Ownership**

"Research has shown that auto ownership is related to household size, household income, number of persons employed in the household, residential and workplace locations, transportation (highway and transit) service levels, and overall urban density and structure.
Several methods for projecting auto ownership are available. These methods can generally be classified as: 1) Trend extrapolation of observed auto ownership rates for households based on income or historic data; 2) Trend extrapolation of total motor vehicle registrations using curve fitting; and, 3) Use of a multinomial logit model to dissagregate data.

"Trend extrapolation of total motor vehicle registrations can be used to project total number of autos. This method, however, does not provide information from which to make an estimate of the number of autos owned relative to household size and income. Trend extrapolation that uses curves which relate the percent of households at different income levels to auto ownership is a method that has been in use for some time. Such curves can be developed from census data for several time periods and compared to determine if trends in auto ownership by income group are continuing. Professional judgement will be needed to determine if the current trend in auto ownership relative to household income will continue in the future or will change in some way.

"Numerous large MPOs have developed models for making projections of auto ownership. A number of these models have been in use for some time and are relatively simple to use. An excellent source to review some of these models is 'Vehicle Availability Modeling", Volume 1 Final Report.'"

Resources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NOTE: Over 50 full text travel demand forecasting documents and approximately 1,000 abstracts are available from the TMIP Clearinghouse. These are classified into model input documents, documents relating to the basic modeling steps, specific applications of models, and other related documents.

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