EVALUATING AND COMMUNICATING MODEL RESULTS: GUIDEBOOK FOR PLANNERS

Requested by:

American Association of State Highway
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Standing Committee on Planning

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1.0 Introduction

1.1 Purpose of this Guidebook

Planners are engaged in increasingly complex decision-making analyses relying on the output of ever-more sophisticated modeling tools, yet they often possess only a cursory understanding of travel demand forecasting (TDF) models and their inherent assumptions, biases, and limitations. It is not uncommon to find a division of labor whereby TDF model development and direct use are relegated to technical experts, while the use of TDF model output for policy and plan development is in the hands of planners and policy makers. This can lead to unintended consequences in the decision-making arena. As noted by the Committee for Determination of the State of the Practice in Metropolitan Area Travel Forecasting (2007) "there are many sources of error and uncertainty in travel demand forecasting, but end users of most travel forecasts would not be aware of these limitations."[1] This heightens the risk that the modeling process or its output will be unintentionally misrepresented or misapplied, with unfortunate consequences for resulting decisions and investments.

Transportation planners do not need to be able to develop a TDF model or conduct a traffic forecast, but they do need a solid understanding of key modeling fundamentals that go beyond recitation of the basic process. This is true whether the model is developed in-house by agency staff or is contracted to a consultant or outside agency. Planners often act as the liaison between policy makers, the public, and modelers. A stronger foundation in the appropriate applications of forecasting models and the ability to effectively communicate this will strengthen that planning role.

The goal of this guidebook is to make the modeling process more understandable to planning practitioners in order to minimize the potential for misinterpretation, misrepresentation, and misapplication of TDF models in the planning process. Transportation planners should be able to 1) ask and answer critical questions about their agencies' models and model development processes; 2) understand how robust or sensitive the outputs are, why that matters; and 3) incorporate that knowledge into planning and programming decision-making processes.

[1] Transportation Research Board, "Metropolitan Travel Forecasting, Current Practice and Future Direction," *Special Report 288*, Washington, D.C. (2007).

1.2 Audience of this Guidebook

This guidebook is targeted at planners and other stakeholders who are not modelers. It assumes a basic understanding of transportation planning. The guidebook describes assumptions, applications, and limitations of conventional and advanced TDF models.

1.3 Organization of this Guidebook

Information in this guidebook is intended to be practical and relevant to the planning process. The guidebook takes a serial approach to explaining TDF models, but each section also can stand alone. Section 2.0 of the guidebook address the role of TDF models in the transportation planning process and provides a context for application of the models. It addresses the uses and limitations of the general model framework.

Section 3.0 focuses on the process and defines the current state-of-practice and where future development is headed. Section 4.0 dissects the sequential TDF model and details the inputs and outputs of each step in the modeling process in terms that are relevant for reader. Section 5.0 addresses model applications starting with historical applications and how those applications have impacted model development. It reviews the current types of applications and then finally evolving applications.

Sections 6.0 and 7.0 deal with results and reasonableness. These sections of the guidebook address interpreting results, communicating results, understanding model sensitivity, and checking for model reasonableness.

Appendix A includes the results of a literature review looking at other available guidebooks and teaching tools on TDF models. Appendix B provides a glossary of TDF model-related terms.

The underlying theme of the guidebook is that TDF models are simply a tool for supporting decision-making. Understanding this tool and its applications, limitations, and qualifications can enhance the ability of planners to use this tool effectively.

2.0 Role of TDF Models in Transportation Planning

This section introduces the role of travel demand forecasting models in the larger transportation planning process and covers the following topics:

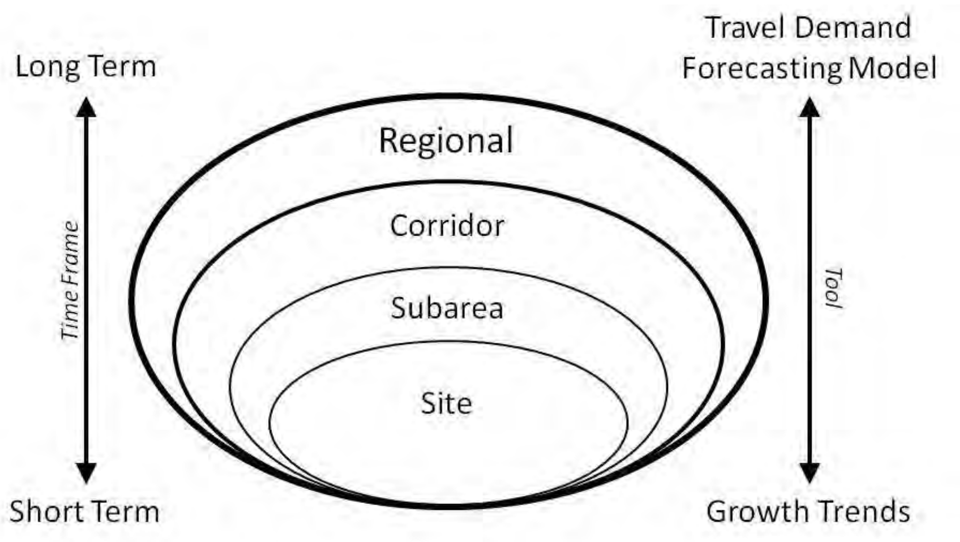
- Definition of TDF models;
- Model uses;
- Model classification by mode, scale, and timeframe;
- Model limitations; and
- Basic terminology.

Transportation planning studies are usually conducted to determine the best course of action for transportation facility or service changes given anticipated changes in the surrounding land use, transportation system, or demographics. This often involves analyzing the effects that certain projects or policies will have on a surrounding area. As part of the transportation planning process, it is therefore necessary to understand the conditions that will be in effect in the future and the impacts that are likely to be caused by the development of a specific project or the implementation of a specific policy.

TDF tools with differing levels of complexity and depth are used in the transportation planning process, based on the level and need of the study. For example, while for one study it may be such that it is sufficient to only know the expected number of vehicles on a specific facility, for another study it may be required that broader information be developed, such as estimates of usage of different modes of travel. Inputs to the study are usually data about land use or demographics in the study area, in addition to information about the transportation system. Ultimately, travel demand forecasts often play a key role in the analysis of potential projects because they outline the potential travel conditions that will result from the project.

For purposes of illustration, transportation planning studies can be categorized into four focus levels based on the impacted geographic area and the timeframe: Regional, Corridor, Subarea, and Site. Figure 2.1 shows these different focus levels and how they relate to each other. Differences in the focus and therefore timeframe for study can help guide selection of the appropriate tool for developing the associated travel demand forecasts.

Figure 2.1 Levels of Transportation Planning Studies



In the center of Figure 2.1, the different focus levels of planning studies are illustrated, from very localized (Site Level) to the least localized (Regional Level). The left side of Figure 2.1 illustrates that for a very localized study (Site Level), the forecast time frame is usually short term, e.g., only a few years out, while for the least localized study (Regional Level), the actions taken and policy decisions are usually long-term actions, and therefore the forecast time frame is usually long term, e.g., over a period of 25 years or more.

The right side of Figure 2.1 illustrates the type of TDF tool which would therefore be used, i.e., it is a function of the time frame and the focus level of the study. If the study is very localized (Site Level), the analysis is usually based on growth trends, i.e., how many vehicles did a similar site produce, which direction did those vehicles come from, and other such trends. As the focus level of the planning study expands, both in terms of geography and time frame, a more robust model is required that considers the changes in transportation demand based on a broader array of inputs, including land use changes, demographic changes, and changes in the overall transportation system. The following subsections discuss tools at each of the four focus levels.

Site Level – Site Level studies generally evaluate proposed land use changes on a specific parcel or group of parcels. An example Site Level study might be a site impact analysis for a new shopping center, an office complex, or a housing development. Because of the small size of a single site, its impact on the transportation network is generally limited in both geographic area and scale. The analysis therefore typically only focuses on the surrounding roadways over a short-term timeframe, typically only five to 10 years because such sites can change quickly. In this type of study, the forecast is usually at the vehicle level with simple regression models used to determine the number of trips entering and leaving the site based on trends from similar types of developments and/or historical growth rates. A source for these regression models, commonly referred to as trip rates, is *Trip Generation* from the Institute of Transportation Engineers (ITE)[2]. The basic application of trip rates is to estimate traffic for a given time period and allocate it to the roads immediately surrounding the site. This type of approach is best for forecasting changes in level of service for the surrounding roadways in a short-term timeframe.

Subarea Level – Subarea Level studies are concerned with a larger geographic area and generally a greater diversity of land uses than Site Level studies. A Subarea Level study may cover an area of several blocks, such as a Central Business District (CBD), a special shopping district, an entertainment district, or a large cohesive area that includes a mix of uses, including residential. An example of a Subarea Level study is a Sector Plan. A Subarea Level study typically looks at more than just impacts on the roadways immediately in or surrounding the study area because travel to and from the subarea is likely to have a larger footprint than an individual parcel. Modes other than automobiles, such as transit or bicycles also may play an increased role in the analysis of a subarea. Because the size and scope of a subarea study is greater than a site-specific study, the investment in planning needs to be greater as well. Since entire subareas do not change or redevelop as quickly as individual sites, the timeframe of interest is usually longer for a Subarea Level study, typically forecasting a minimum of 10 to 15 years into the future. Depending on the complexity of the area being studied, a range of different tools might be applied to develop traffic forecasts and calculate different measures on the impact of potential changes. At this level of study, the analysis starts to become too complex for a spreadsheet framework. The appropriate tool may be a combination of simpler models, a regional TDF model, or, potentially, a pairing of a regional TDF model with a detailed subarea model.

Corridor Level – A Corridor Level study typically focuses on a specific major transportation corridor of regional significance and the area immediately surrounding it. Corridors involve diverse land uses and may focus on multiple parallel roadway facilities or a transit facility. Examples could include a major arterial of regional importance, an interstate, or an area with a high concentration of a specific type of development, such as a high-tech or biotech business corridor. These types of major corridors impact travel patterns in a wide area; a Corridor Level study area typically extends across multiple jurisdictions. Like other levels of transportation planning studies, a Corridor Level study is centered on determining necessary actions to improve mobility in the corridor in the future, such as determining the required number of lanes for a new freeway, planning a new bridge, studying an extension of an existing transit line, or

[2] Institute of Transportation Engineers, *Trip Generation*, 8th Edition, An Informational Report of the Institute of Transportation Engineers, Washington, D.C. (2008).

improving mobility for an area that is experiencing high levels of growth and development. Corridor studies focus on the longer-term interactions between proposed land use and transportation scenarios and are concerned with what conditions might evolve over time. Given the scope, the type of changes being analyzed, and the impacts of the results of corridor studies, the timeframe for such forecasts is generally on the scale of 20 to 30 years. In order to develop this type of long-term travel forecast and understand the impacts of such large-scale corridor projects, the use of a TDF model is required.

Regional Level – A Regional Level study typically focuses on a large geographic area such as a metropolitan urban area. Regional Level studies focus on long-term transportation issues such as transit system planning, testing of alternative land use scenarios, air quality conformity analysis, greenhouse gas emissions, as well as freight planning. These types of complex issues are addressed on long-time horizons with the goal of setting public policy and statutes. The need for regional studies to answer many long-term transportation questions encompassing multiple modes, mobility, and economic impacts makes TDF models the ideal tool for this type of study. Statewide planning studies may also use TDF decision support tools; one resource on this topic is the Federal Highway Administration's *Guidebook on Statewide Travel Forecasting*[3].

2.1 WHAT IS A TDF MODEL?

A TDF model is a series of mathematical relationships linked together in a sequential process that calculates expected travel patterns based on a given land use and transportation system scenario. Changes to land use patterns or the transportation system are reflected in the travel patterns forecasted by the TDF model. The basic steps in the modeling process answer the following questions:

- Trip Generation: How much travel occurs (and why)?;
- Trip Distribution: Where does travel occur?;
- Mode Choice: What modes will be used? (e.g., automobile, transit, etc.); and
- Trip Assignment: Which path or route is used?

These questions form a serial process that outlines the general structure of the TDF model. Though they apply to all four levels of transportation planning studies, the application and simplicity of how these elements are determined vary by level of study. Determining how much and where travel occurs is basic to all transportation planning studies. Mode choice addresses the important question of what transportation mode people use, although many lower-level

[3] Center for Urban Transportation Studies, University of Wisconsin-Milwaukee. *Guidebook on Statewide Travel Forecasting*. Federal Highway Administration (March 1999).

transportation planning studies focus solely on automobiles. The final question of determining the path taken for each trip is important at all levels of the transportation planning process, whether the whole path is traced across a region or a shorter path is traced from exiting a parking lot to the first major signalized intersection.

By answering all of these questions, TDF models are able to estimate traffic levels on roadways and transit systems in the study area. In every level of transportation planning study, the impacts are quantified using some type of measure of effectiveness (MOE). The MOEs used will depend on the type and scale of the study, the desired outcomes of the proposed strategies or projects, and the computational capabilities of the selected TDF tool. MOEs are typically used to compare the forecasts associated with different projects or scenarios to determine which will have the best effect on future travel conditions. Common MOEs are volume to capacity ratios on roadways, vehicle miles traveled by facility, mode share, and similar types of measures.

2.2 USES OF TDF MODELS

TDF models are used to evaluate transportation conditions at a time point in the future (i.e., horizon year) and test different scenarios or alternatives to determine which option results in the best future mobility. Inputs to TDF models include land use, demographic data, and a transportation system which can include highway, transit, and nonmotorized networks. Any of these elements can be altered to test potential changes to a specific land use or transportation system alternative, or to evaluate socioeconomic policies that affect transportation, such as accessibility to jobs and travel pricing. By comparing the MOE output from the TDF model for different scenarios or project alternatives, a TDF model can be used to describe the relative impacts of a specific project or development.

The goals and needs of each specific study will help determine which MOEs are calculated and how the results are specifically used. Historically, TDF models have been used to evaluate the impacts of construction and development projects, determine highway design requirements, analyze the economic viability of toll roads, analyze the user cost of traveling by automobile, and to quantify environmental impacts of traffic for air quality and noise analyses.

The current design of TDF models are significantly influenced by Federal regulations. Since 1990, many Metropolitan Planning Organizations (MPOs) and regional governments tasked with meeting air quality conformity requirements and responsible for developing transportation improvement programs and long-range transportation plans have engaged in TDF model enhancement programs, including the use of consultants and peer reviews. As a result, all elements of regional TDF models are designed to support the technical and policy decisions that are required in developing a comprehensive, multimodal transportation plan and program in accordance with the Intermodal Surface Transportation Equity Act of 1991 (ISTEA), the 1990 Clean Air Act Amendments (CAAA) and the Transportation Conformity Rule (40 CFR Parts 51 and 93) and the 2005 Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU).

2.3 Limitations of TDF Models

TDF models are limited by the scope of the area they cover, the aggregated nature of the forecast, the input assumptions concerning future land use and the associated transportation network, and the data used to develop the models. A TDF model covers a relatively large region with a focus on the macro level or "big picture" items. The major output of the model is travel demand in terms of the number of person trips or vehicles on roadways in the study area, the mode share for a specific market, and/or the number of passengers boarding a transit line. The structure of the inputs and of the model itself are designed to function at an aggregate level and to inform the higher-level transportation planning studies on complex impacts of large-scale projects. The focus is less on individual movements and choices and more on the outcome of aggregate travel patterns. Even with activity-based TDF models, in which the focus is on disaggregate travel and traveler choices, the outcomes are aggregate impacts of that travel on the transportation network. Therefore, there are certain questions that a TDF model is *not* designed to answer and, therefore, limits to the application of the forecast.

There are times that planners and other stakeholders seek to answer questions with the TDF model that are actually not applicable for the model. Often, such questions focus on traffic operations issues. Because of the geographic area a TDF model typically covers and the corresponding aggregated nature of the calculations, it is unable to directly provide answers like optimal signal timings or the dynamics of traffic flow. While it is technically possible to gather turning movements at an intersection from a TDF model, the process can be a challenge and the results potentially unreliable. TDF model results can provide information that can be used as input in performing these types of analyses, but TDF model results do not directly address these issues. Instead, there are other tools available that can better perform analyses to address these questions. For example, traffic microsimulation models can be used to simulate the movement of every vehicle through a limited size network using car-following logic and can use information derived from the TDF model.

Many TDF model applications also are limited by the data available. Evolving applications for TDF models include analysis of demand for nonmotorized travel, trip chaining, freight and commercial movements, and time-of-day issues. In all of these areas, it is challenging to collect the data needed to develop appropriate mathematical representations of travel decisions. This is especially true when resources and funds for modeling data collection are limited, and the main focus is often on automobile travel and the associated data.

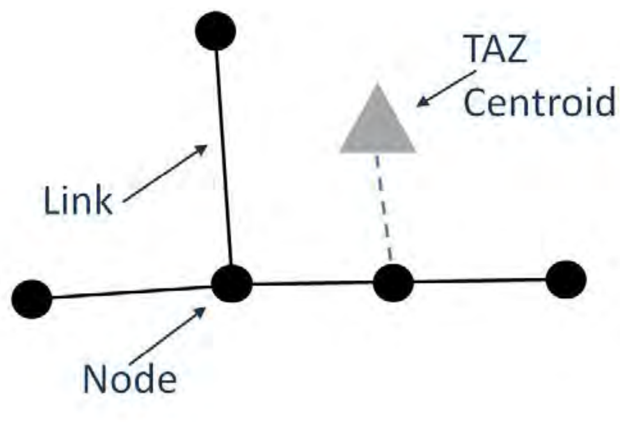
Examples of data collection challenges cover many areas. For example, collecting and inputting data about the availability and quality of facilities for nonmotorized travel is difficult on a large scale, and the appeal of nonmotorized travel can be dependent on the presence of these types of facilities. Collecting data about the chaining of tours, (for example, a traveler going from home to the day care center to work) also is a challenge to adequately capture. Data collection about the movement of freight and commercial goods is difficult because the data are often proprietary business information of private companies such as railroads, trucking companies, or shipping companies. A wealth of data are needed to accurately model time-of-day decisions made by travelers because so many factors go into the complicated decision of when to travel, including the purpose of the trip, the start and ending points, and the level of congestion that can be expected along the potential route. Models with larger and more detailed datasets, such as activity-based TDF models, can address some of these additional questions better than traditional TDF models.

2.4 MODELING TERMINOLOGY

The key basic terms used in TDF modeling are described below. Additional definitions and terminology can be found in Appendix B: Glossary.

- **Network Links and Nodes –** the representation of the physical transportation system in the model. An illustration of the elements of this type of network is shown in Figure 2.2. Links represent transportation connections, such as roadways, transit infrastructure (like dedicated lanes or rail lines), or sidewalks. Nodes exist at both ends of every link. Nodes can represent intersections or other types of junctions, or can represent a point of change in network characteristics or, especially in older networks, can be used to reflect curvature. Links and nodes can have a range of attributes associated with them such as length, facility type, and area type for links and traffic control devices for nodes.

Figure 2.2 Sample Network Links and Nodes



- **Transportation Analysis Zone (TAZ) –** a small unit of geography in which demographic and land use data are typically aggregated. In most TDF models, TAZs represent locations in the physical world and are the starting and ending points for all travel. Each TAZ is represented by a special node type in the network called a centroid, and the demographic and land use data associated with a TAZ are attributed to the associated node. Sometimes alternatively known as "Traffic Analysis Zone."
- **Centroid Connectors** – a link from a TAZ centroid to other links in the network, and is a representation of access from each TAZ to the transportation system or network. The centroid connector is coded with a distance that is representative of the average distance from the TAZ activity to the transportation network. Often the centroid connectors are calculated to have a length equal to half the distance from the center of a TAZ to the roadway network. Centroid connectors have a speed attribute, but typically do not have an assumed capacity.
- **Trip –**defined as one directional movement from one TAZ to another.
- **Trip End –** either the starting or ending location of a trip. Every trip has two trip ends. Trip ends are classified as either a trip production or trip attraction or as a trip origin or trip destination. These distinctions and the concept of trip productions and trip attractions are defined and explained in Section 4.0
- **Trip Table –** stores the number of trip ends traveling between two TAZs. Trip tables are stored in the form of a matrix with each TAZ listed on the vertical axis as a starting point and each TAZ on the horizontal axis as an ending point as shown in Figure 2.3. The value in each cell is the number of trips traveling between the starting and ending TAZs. In the example, 10 trips are shown going from TAZ 2 to TAZ 1.

Figure 2.3 Sample Trip Table

To

From	TAZ 1	TAZ 2	TAZ 3
TAZ 1	35	75	25
TAZ 2	10	50	40
TAZ3	20	60	80

3.0 TDF Model Process

This section provides details about the TDF process, including:

- The most common TDF model structures: trip-end-, tour-, and activity-based;
- An overview of current TDF model practices at MPOs and other planning agencies; and
- The steps for developing and maintaining a TDF model: estimation, calibration, validation, and application.

3.1 TDF Model Structures

Research over the last 20 to 30 years has continued to evolve the structure and formulation of TDF models. The original TDF model structure (and most commonly used today) is the four-step trip-end-based model that sequentially answers the four basic questions about travel patterns. More recently, tour-based models that link individual trips together to capture complex travel patterns have been investigated and developed. Finally, activity-based models have continued to evolve with a focus more on the social and economic activities that drive travel rather than just on the travel itself. Because of this broader focus, activity-based models have the potential to provide more insight into travel demand than traditional four step models. An overview of some of the benefits of the different model types is shown in Table 3.1.

Table 3.1 Overview of TDF Model Structure Benefits

	Trip-End-Based	Tour-Based	Activity-Based
Accommodates latent demand based on changes in the transportation system			X
Accounts for complex intrahousehold travel interactions (limited vehicle availability, etc.)			X
Accounts for complex travel patterns and trip chains		X	X
Accounts for home end of trips	X	X	X
Advanced time-of-day analysis		X	X
Allows for more disaggregate data inputs and analysis			X
Analysis of nonmotorized trips	X	X	X
Ease of data collection	X		
Minimizing computational resources	X		

3.1.1 Trip-End Models

Trip-end models use a series of sequential mathematical models and relationships to answer the four basic questions about travel patterns in four distinct steps as shown in Table 3.2.

Table 3.2 Steps in Trip-End-Based Models

Planning Question	Model Step
How much travel occurs (and why)?	1) Trip Generation
Where does travel occur?	2) Trip Distribution
What modes are used? (e.g., automobile, transit, etc.)	3) Mode Choice
Which path or routes are used?	4) Trip Assignment

Trip-end models are based on land use, population demographics, and employment data in the study region to calculate how much travel will occur for a range of specific travel purposes, such as shopping, school, or commuting. The first step, trip generation, uses this land use data to determine how many trips will occur. The trip distribution step then determines the starting and ending points for each of the trips and creates trip tables. The third step determines what mode travelers will use to make each trip, such as driving, carpooling, or using transit. The final step, trip assignment, forecasts which route travelers will use to make these trips. Each of these steps is calculated on a trip basis, with the questions answered for individual trips aggregated together by TAZ. The outputs from trip-end models include a set of trip tables by trip purpose that can be used to identify major travel markets, the percentage or number of travelers using a certain mode, and estimated traffic levels on major roadways in the study area. The four TDF model steps are described in greater detail in Section 4.0.

3.1.2 Tour-Based Models

A second type of structure used in TDF models is the tour-based model which captures trips that are linked together. In this model structure, the basic unit of travel is the tour instead of the trip. In travel tours, multiple trip ends are linked to account for "trip-chaining," such as in a commuting tour from home to the daycare center to work. In a trip-end model, this pattern would be two distinct trips, and the decisions (such as which mode to use) would be made separately for each trip. The tour-based model focuses on the whole tour and therefore captures the complexity of many modern commuting patterns. Travel decisions, such as the location, mode and route can be made based on the requirements of the whole tour, not just an individual trip. The mode choice and trip assignment steps for the tour-based model remain mostly the same as in a trip-end model.

3.1.3 Activity-Based Models

A third type of TDF model is the activity-based structure. In the activity-based structure, travel demand is derived from the activities that individuals need or wish to perform. Activity-based models aim to predict which activities are conducted where, when, for how long, with whom, the transport mode involved and ideally also the implied route decisions; sequences or patterns of behavior, and not individual trips are the unit of analysis. Activity-based models incorporate spatial, temporal, transportation, and interpersonal constraints within individual households in an effort to recognize the interdependence of a variety of factors in determining trip making.[4]

Activity-based structures take advantage of advanced mathematical choice models and rely heavily on economic theories, including rational discrete choice. Activity-based models do not follow the same sequential pattern of steps as the four step models. The nature of the activity-based model structure – particularly its use of disaggregated individualized data and the focus on activity patterns – allows these models to answer a wider range of more complex transportation and land use planning questions than traditional trip-end-based models. Activity-based models have thus far been implemented in several larger metropolitan regions, sometimes in replacement of or in addition to trip-end models.

Beginning in the 1990s, Federal funding was applied towards the development of the Transportation Analysis Simulation System (TRANSIMS), designed to advance activity-based approaches. The TRANSIMS program has emphasized and quantified aspects of activity-based travel demand methods, intermodal trip planning, and traffic microsimulation. TRANSIMS was developed in order to better evaluate questions concerned with congestion pricing, alternative land development patterns, transportation control measures, motor vehicle emissions, as well as Intelligent Transportation System (ITS) requirements and impacts.[5]

3.2 CURRENT PRACTICE

TRB *Special Report 288,* "Metropolitan Travel Forecasting Current Practice and Future Direction" (2007) was based on survey results from 219 MPOs. One of the goals of the survey was to get a snapshot of the state-of-practice in TDF models

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[4] Zwerts, E. (in cooperation with E. Moons and D. Janssens). *Activity-Based Modeling: An Overview.* PowerPoint Presentation. Transportation Research Institute, Limburgs Universitair Centrum, Diepenbeek, Belgium (2005).

[5] The Regents of University of California, *Transportation Analysis Simulation System (TRANSIMS), Version: TRANSIMS-LANL-1.0 Volume 0 – Overview*, Los Alamos National Laboratory, Los Alamos, New Mexico (1999).

for a wide range of MPOs in the United States. The study grouped MPOs into three categories:

1. Small metropolitan areas under 200,000 population;
2. Medium metropolitan areas with populations between 200,000 and 1 million; and
3. Large metropolitan areas with populations greater than 1 million.

3.2.1 Model Structures

The *Special Report 288* survey found that the four step sequential trip-end model was the most common structure, with larger regions tending to use the more complex TDF models. As noted in Section 3.1.1, a trip end model focuses on population and employment data aggregated by TAZ to develop the number of trips between TAZs. With all of the different TDF model structures, the same basic steps have to be addressed in a serial process, with each step building from the previous step:

1. Determine how many trips go between TAZs (and why);
2. Determine where those trips are going;
3. Determine what mode of transportation those trips will use (e.g., automobile, transit, etc.); and
4. Determine the paths used for travel between each origin and destination.

Often, there are feedback loops in the process and the process takes on an iterative form until a steady state can be reached.

3.2.2 Trip Purposes

The *Special Report 288* survey showed that for all metropolitan areas most TDF models develop trips for the following trip purposes:

- **Home-Based Work –** any trip from home to work or from work to home.
- **Home-Based Shopping –** any trip from home to a shopping location or from shopping to home. There are different types of shopping trips which may have different characteristics, such as an errand to a local store versus a trip to a regional shopping mall, but most TDF models group these types of retail trips together as general shopping trips.
- **Home-Based School –** any trip from home to school or from school to home. For some models there also can be a college or university purpose as well as a general school purpose.
- **Home-Based Other –** any trip from home to a destination not covered by prior trip purpose descriptions or vice versa. This purpose can include trips

to professional services, recreational trips, or similar types of nonwork and nonshopping trips[6].

- **Non-Home-Based –** any trip that starts and ends at a non-home location. These diverse trips can include the linked portion of a trip from a store to a school, a midday trip from an office to lunch, a delivery run, or a skilled tradesman's trips from site to site[7]. This is often the purpose category with the most trips, but the distances are very short and they typically occur outside of the peak hours.

3.2.3 Submodels

The *Special Report 288* survey was designed to identify the most common submodels being used by MPOs to address each of the key questions that are part of the travel demand forecasting process. This subsection highlights the findings as a way to familiarize the reader with the most common approaches. Section 4.0 goes into more detail on each of the sequential steps in the travel demand forecasting process (i.e., Trip Generation, Trip Distribution, Mode Choice, and Trip Assignment).

Trip Generation – The most common trip generation model structure for trip productions[8] in trip-based models, is a cross-classification model (essentially, a look-up table) using household size and vehicles per household as the variables. The most common trip generation model structure for trip attractions[9] in trip-based models is a model using a direct relationship to the number of employees by type of employment.

Trip Distribution – The most common trip distribution model structure is a gravity model, which focuses on attractiveness among TAZs. A gravity model matches up production trip ends with attraction trip ends based on some impedance, which is usually time. The second most common trip distribution model structure is a destination choice model. A destination choice model looks at the probability of a choice and weights all the characteristics that could impact that choice. Typically, an impedance is included along with other variables, such as accessibility. Destination choice models were most likely to be reported by the larger MPOs.

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[6] Some models have additional designated home-based trip purposes beyond the most common trip purposes found in the survey, including social/recreation, university, airport. These trips would then not be included in the home-based other trip purpose.

[7] Many models handle trips for commercial vehicles separately.

[8] "Trip production" refers to the home end of home-based trips or the origin end of non-home-based trips; this is explained more fully in Section 4.0.

[9] "Trip attraction" refers to the non-home end of home-based trips or the destination end of non-home-based trips; this is explained more fully in Section 4.0.

Mode Choice – The most common mode split model structure is the discrete choice model (or logit model). The logit model computes the probability of selecting a mode choice for each specific origin and a destination based on the characteristics of the trip maker and the time, cost, and potentially other attributes related to the utility of the different mode choices available. In many of the smaller MPO regions, there is a limited choice of modes. The primary travel mode is often limited to automobile, so in these areas the use of a mode choice is not necessary. Frequently, if person trips are being developed in the model process, an automobile occupancy factor is applied to the person trips by trip purpose to calculate vehicle trips. Vehicle trips are ultimately loaded onto the network to produce the traffic forecast for specific roads. Auto occupancy calculations and the conversion of person trips to vehicle trips can serve as a surrogate mode choice model in terms of carpools and shared rides. This is most applicable in some smaller MPOs where there are limited modal options.

Trip Assignment – The most common model structure used to determine which routes will be used for travel on the roadway system between each origin and destination is the equilibrium assignment model. The equilibrium assignment assumes that between each origin and destination, trips will find all possible routes so that the travel time between them is basically equal. Section 4.0 discusses this process in more detail.

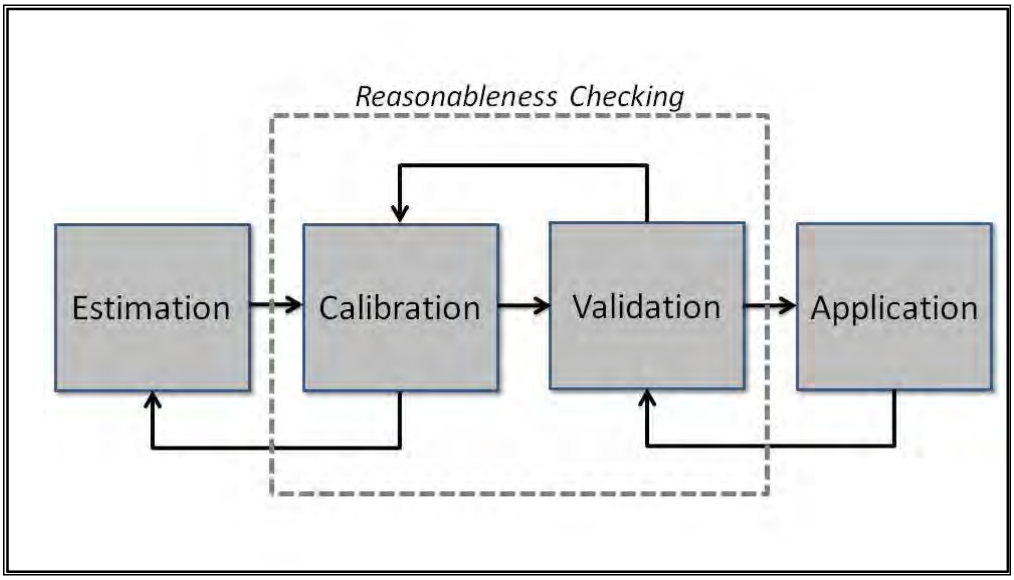
3.3 Model Development Process

TDF models are a composite of different submodels linked together in a serial process. The development and construction of a TDF model also is a serial process. The steps in TDF model development are to estimate, calibrate, and validate before there is an application of the model (Figure 3.1). An effective model is developed based on local data and tested to see how well it replicates base year travel patterns. First, the submodels that make up the TDF model must be estimated. Then the model must be checked and tested for reasonableness in two stages defined as calibration and validation. After validation is successful, the model is ready for application.

3.3.1 Model Estimation

Statistical procedures are used to estimate the model values for model parameters which maximize the likelihood of the model fitting the observed travel data. The focus is on specifying the form of the model and determining the statistical significance of the variables used in the model. This step in the process is dependent on local data being available. There are cases where local data are not available, and nearby regions or national data may be substituted, however this can often lead to challenges when calibrating and validating the model set later on, and extreme care must be exercised.

Figure 3.1 Travel Demand Forecasting Model Development Process



Source: Barton-Aschman Associates and Cambridge Systematics (2001)[10]

3.3.2 Model Calibration

Model calibration is used to adjust the submodel coefficients and parameters until the predicted outcome matches observed data after the model structure has been defined and the variables estimated. Each submodel in the travel demand forecasting process is calibrated in isolation of the next model. The calibration focuses on adjusting the submodel estimated equations. The variables are adjusted until the base year data can be matched by the submodel. There is interaction between the calibration effort and the model estimation phase. If the model cannot be calibrated satisfactorily, then often the estimation phase must be revisited. Calibration targets and observed data are often grouped by some type of market segmentation, which may include income or geographic area within the region.

3.3.3 Model Validation

The term validation is often confused with the term calibration. Validation involves checking the model results against observed data, sometimes at the aggregate level, and adjusting the calibration until the model results fall within an acceptable range of error.

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[10] Barton-Aschman Associates and Cambridge Systematics. *Model Validation and Reasonableness Checking Manual*, Federal Highway Administration Travel Model Improvement Program, Washington, D.C., (June 2001).

Validation is performed at different levels corresponding to the different focus levels of transportation studies discussed in Section 2.0. For the whole model set, a regional validation effort will be done to look at how the model predicts travel demand for the region, as well as at more aggregate levels such as jurisdictional summaries. For a corridor or subarea study, the model will need to be validated for the study area. In these cases, the same metrics are evaluated for each step in the process. For example, if you are using total vehicle miles traveled (VMT) by facility type, at the regional level this would include all the VMT on freeways by jurisdiction or total, but for the lower levels of study, this would include only those freeway segments in the study area.

Many times in aggregating observed data and the modeled results, the values average out. So there might be an area in the model that is very low in VMT on freeways but another area in the model that is very high, with the end result being total VMT close to the observed. When drilling down into lower levels of studies, these errors often come out and require revisiting calibration so they won't distort the study outcome. In general, validation of the model set is usually done on a continuing basis as well as on a project basis, while calibration is only done when new survey data are collected or modifications are made to the models.

3.3.4 Model Application

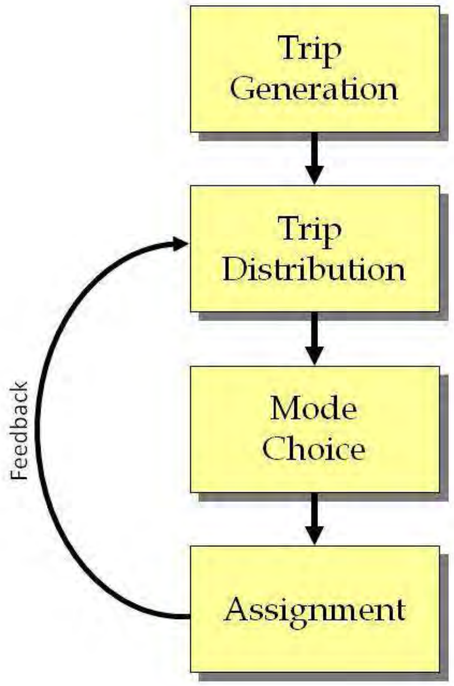
Depending on the level of study, there will be a validation effort of some scale to ensure that the model is predicting observed trends adequately. There are no set national *standards* for validation and the level of detail is a function of the application needs, but there are several guides on *acceptable practice*. It is important to note that the reasonableness of the application results is tied to the validation. Though a TDF model is estimated and calibrated on observed data, major societal changes affecting travel behavior can change the model estimation and impact the accuracy of the application results.

An example of this type of change is when women entered the work force in large numbers during the 1970s and 1980s. This represented a societal change that was not anticipated and therefore not accurately reflected the forecast future year trip rates for households (i.e., they did not account for the increase). Large societal changes do not happen often, but they do sometimes happen. Understanding that the model is estimated and calibrated for a set time period is important in applying and understanding the application results. Because of this, travel model development is often revised cyclically over time. Within these cyclical periods, even when model estimation is not done, calibration and validation are often performed to ensure a coordinated, continuing, and comprehensive transportation planning process.

4.0 Sequential Travel Demand Forecasting

The first three sections of this guidebook provided an overview of the role, structure, and basic steps in TDF models. Section 4.0 provides details about the inputs, outputs, and submodel structures of the sequential process used in most TDF models. The entire four step process is sequential, with each step dependent on the outputs from previous steps. The process is not totally static and there is often feedback within the sequential steps. Figure 4.1 provides an illustration of the four step TDF model process.

Figure 4.1 Four-Step TDF Model Process



Roadway or travel conditions, specifically congestion, play a role in people's daily travel decisions, including where they work, shop, and play. It is customary to run through the TDF model steps iteratively until a steady state is reached, in which the travel patterns as detailed in the trip table – or where people travel to and from – do not change in relationship to the congestion in the transportation system. This "feedback loop" allows the sequential TDF process to account for the effects of congestion on travel patterns by restarting the TDF process.

Feedback loops work after an initial run through the TDF process is completed. In an uncongested system it might be possible to travel 25 miles in 30 minutes. In a congested system, that 30 minutes might only take a person 15 miles. In this case, the steps of the TDF model, specifically trip distribution, mode choice, and assignment would need to be rerun using the travel times that resulted from the prior iteration. Although it is possible to use a feedback loop to consider congestion effects on the trip generation step, typically this submodel is not impacted by congestion on the network.

The remainder of this section is organized into five subsections. Section 4.1 details the inputs needed for the TDF process. Section 4.2 outlines the trip generation process. Section 4.3 details the submodels used for the trip distribution step of the process. Section 4.4 details the methods used for modeling mode choice. Section 4.5 addresses the final step in the TDF process, trip assignment.

4.1 TRAVEL DEMAND FORECASTING MODEL INPUTS

The two most basic inputs into the TDF modeling process are:

- Land Use and Socioeconomic Data; and
- Transportation Network.

These inputs define the scenario being analyzed and shape the results of the TDF model.

It is extremely important to carefully review model inputs and assumptions. A key source of errors or uncertainty in forecasts is the quality of the inputs used. If the input future land use patterns or transportation network or services are not accurately represented, it cannot be expected that accurate travel forecasts would be output by the TDF model.

For example, if the level of future transit service is assumed to be greater than is ultimately provided there can be a tendency for the model to overpredict transit ridership and mode share as compared with the actual results. This might happen if a service that was envisioned in the project planning phase becomes too costly to fund after the project opens.[11] Similar problems can occur if planned roadway networks do not actually materialize – future conditions would not then be as predicted. For these reasons, it is typical to rely on

[11] Pickrell, D. *Urban Rail Transit Projects: Forecast Versus Actual Ridership and Cost*, Urban Mass Transit Administration, Washington, D.C. (October 1989).

regionally adopted land use forecasts and financially constrained long-range transportation network and service plans for most project forecasting activities.

4.1.1 Land Use and Socioeconomic Data

Land use and socioeconomic data are quantitative representations of activity in the study area in the analysis year, usually defined by residential population and employment levels. These data are the primary input into the trip generation step of the model (as detailed in Section 4.2).

Land use and socioeconomic data are typically aggregated into a series of Transportation Analysis Zones (TAZs) that cover the entire study area. TAZs are usually split at major roadways, jurisdictional borders, geographic boundaries, and defined by homogenous land uses, if possible. The number and size of TAZs can vary but should generally obey the following rules of thumb[12]:

- The number of residents per TAZ should be greater than 1,200 but less than 3,000;
- Each TAZ should yield less than 15,000 person trips per day; and
- The size of each TAZ should be between a quarter to one square mile in area.

The TAZ structure in a subarea of particular interest may be denser than in other areas further away.

For analysis purposes, TAZs can be grouped further into study districts or other levels which can help with summarizing and comparing inputs and results. An example of this type of aggregation is provided in Figure 4.2, which shows an older TAZ and study district structure for Baltimore, Maryland. The smallest level of aggregation, typically the TAZ in most models, is the level at which TDF model calculations for all steps of the process are made. Both the land use data and the network inputs are structured to analyze travel between the TAZs.

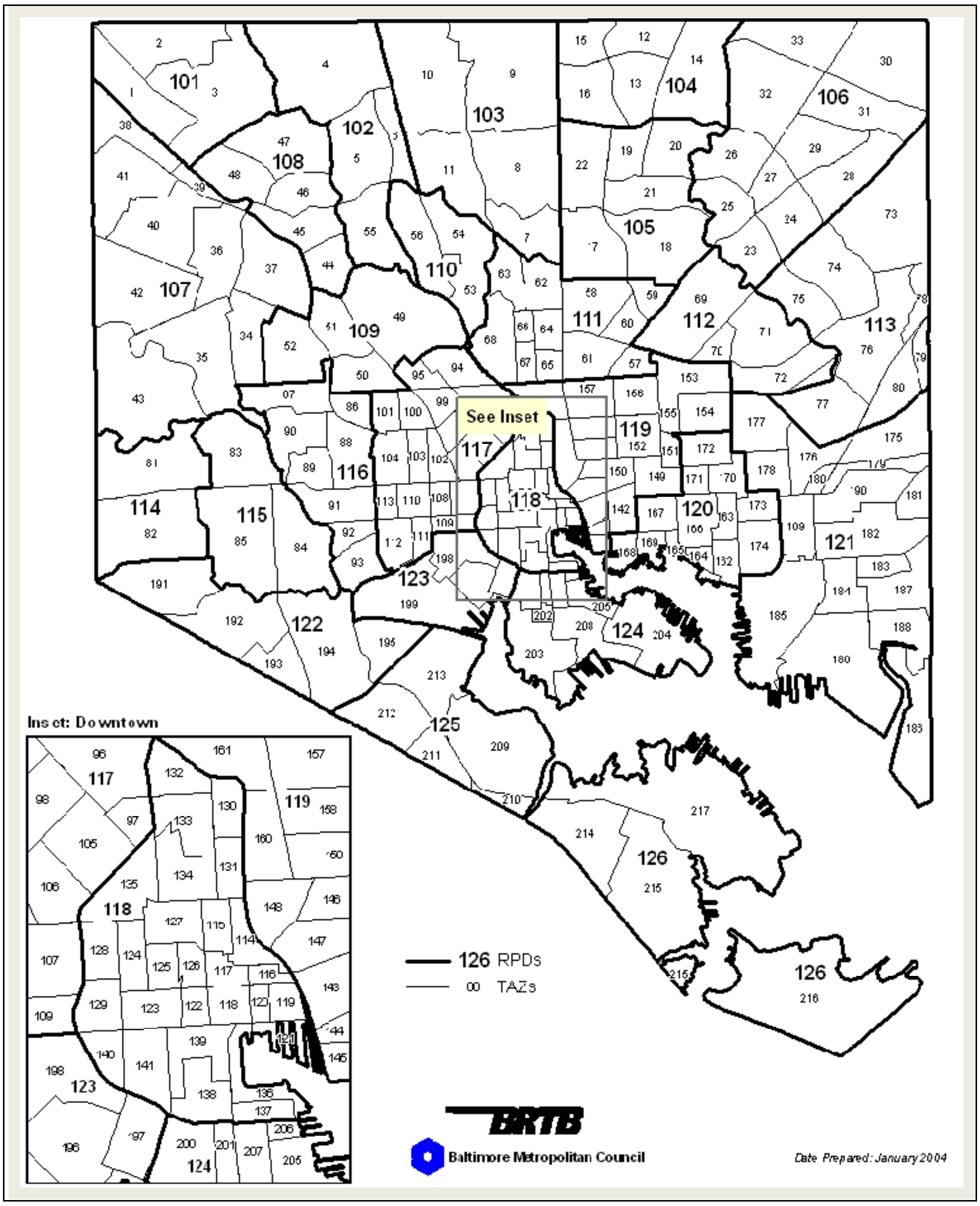
Base year data assembly is a first step in developing or applying a TDF model. All necessary data must be assembled or collected by TAZ for a base year. Base years are often selected as a decennial year to take advantage of the availability of comprehensive Census data, but any year in which survey data is collected can be used. After the base year data is assembled, land use and demographic data must then be forecast for the necessary future year(s) in a process called land use forecasting or activity forecasting.

Land use or activity forecasting is a separate process that must occur before the TDF model process moves on to model application. The land use forecast is always one of the major drivers of results from the TDF model. While some jurisdictions use land use forecasting models that are linked to their TDF model,

[12] Cambridge Systematics. *A Recommended Approach to Delineating Traffic Analysis Zones in Florida.* Florida DOT Systems Planning Office (2007).

more often the processes are separate and land use forecasts are tied to policy decisions. Methods for forecasting land use range from simple straight-line projections to dynamic econometric models.

Figure 4.2 Sample TAZ and Planning District Structure



Source: BMC (2007)[13].

[13] Baltimore Metropolitan Council, *Baltimore Region Travel Demand Model Version 3.3 2000 Validation*, Baltimore, Maryland (2007).

The land use forecast is developed for each TAZ in the model. Each TAZ will then have land use, socioeconomic, and demographic data associated with it, e.g., employment and population levels. The amount of detail included about each data element varies based on the needs of the model. Population is typically represented in terms of the number of households, which are often then further categorized by demographic variables such as size, number of workers, income, and auto-ownership. Employment data, or the number of jobs located in a TAZ is usually divided into retail and nonretail categories, although it can be further subdivided. Other socioeconomic data also can also be included for each TAZ, depending on the complexity of the trip generation submodel (e.g., school enrollment).

An important note with land use and demographic inputs is that all of the data need to be collectable and then need to be able to be forecasted. Using variables that are not easily collected or forecasted can result in additional error and uncertainty being introduced into the TDF model right from the beginning, degrading and devaluing the final results. Similarly, it is usually best to use objectively determined variables versus subjectively determined variables as inputs. This can help avoid unintended consequences or biases from being introduced in the results and can aid significantly in establishing the future year values for the variables.

4.1.2 Transportation Network

The transportation network is the other key input to the TDF model process. The transportation network provides the model with a representation of the transportation system supply in the study area. Roadways, transit system elements, and facilities for other modes, such as pedestrian pathways and bicycle routes also may be included as part of the network depending on the complexity of the model.

Not all roadways are included in the network, and smaller roadways like local streets are often not included. Typically, the level of detail included in the roadway or highway network is related to the forecasting needs and the TAZ structure. A general rule is that roadways should be included at one level of classification below the focus of the study. For example, in order to study the transportation impacts on major collectors, all facilities at or above this level need to be included in the network, in addition to all facilities one level below, which would be minor collectors. Further, there has to be a balance between the number of TAZs and the level of detail included in the network, so that where the TAZ structure is denser more roadways are included.

Transit networks are linked to the roadway networks. A transit network will have data describing each specific transit route and mode, including starting and end points. For modes of transit that operate on regular streets (e.g., most buses), the transit service is linked directly to the relevant portions of the roadway network by considering the nodes that constitute the route. For fixed guideway modes and those that operate on separate rights-of-way, including bus rapid transit (BRT), light rail transit (LRT), or other rail, the facilities may be included in the roadway network or may be represented in a separate file or network. For fixed guideway transit, TDF model inputs typically include network elements representing walk and drive access links as well as park-and-ride lots. Route descriptions for all transit services include a list of the nodes along the route and some designation of which nodes serve as stops[14]. The transit service is described further by indicating the frequency (headway) and run time of the route, the time at stops, and/or the speed.

Facilities for nonmotorized travel are more likely to be included where walking or biking comprise a major component of trip making, such as in a downtown area where walking can be an important mode for accessing transit. Sometimes, the quality of the pedestrian environment may be represented by zonal attributes rather than as a network element. As noted above, where fixed guideway transit is modeled, walk access links are commonly coded.

The physical transportation system is represented in the model by a network comprised of links and nodes. Links and nodes can have a range of attributes associated with them that defines their locations and describes their important characteristics. An example of a highway network is provided in Figure 4.3.

Nodes

As noted in Section 2.0, nodes represent locations in the transportation system. Nodes can represent intersections and junctions or can be simply used to connect two links to each other. All nodes have certain attributes associated with them, the most important being the coordinates that describe the physical location of the node. These coordinates describe the nodes location in the physical world and can be used to map the network, such as in a GIS program. Many times the coordinates are based on the State Plane Coordinate System (SPS or SPCS). The SPS is a set of 124 geographic zones or coordinate systems designed for specific regions of the United States.[15] They may also use coordinates based on Latitude and Longitude. Nodes also can have other attributes associated with them, such as if it is an intersection, the type of control device being used (i.e., stop sign, signal, etc.), descriptive information, or the closest TAZ.

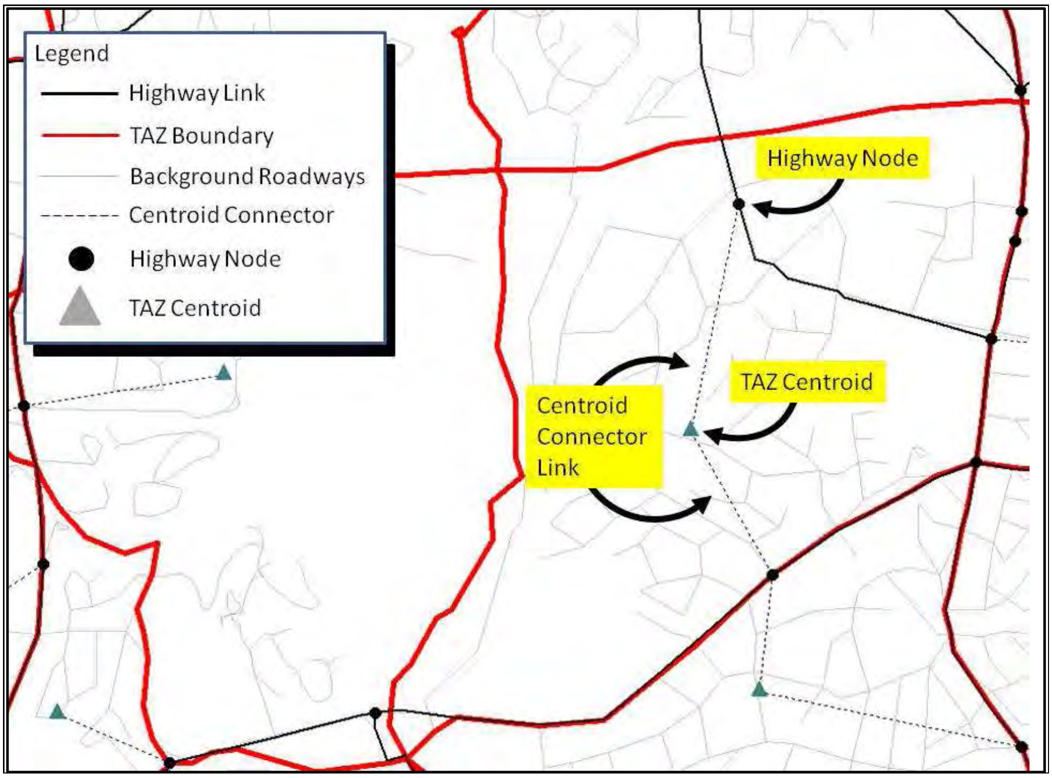
A special type of node called a centroid is used to represent each TAZ. Centroid connectors are a special type of link used to link the TAZs centroid and its associated land use data to the transportation network. The land use data may be included as attributes of the node, or the data can be associated with the

[14]Although the specific modeling software used may maintain this list "behind the scenes;" it is still important to understand that the transit service and highway network carry a linkage which requires special care when making modifications to either.

[15]Kennedy, M. and S. Kopp, *Understanding Map Projections*, Environmental Systems Research Institute, Inc. (1994).

centroid node by some type of external file not linked directly to the network. Centroids are shown as triangles in Figure 4.3.

Figure 4.3 Highway Network Example



Links

Nodes are connected by links. Links represent transportation connections, such as roads, pedestrian facilities, or rail segments. Links also can be associated with a range of attributes that help to describe them and are useful to the TDF process. Roadway links primarily include attributes that describe the facility in terms of speed and capacity, such as the roadway classification (i.e., freeway, arterial, collector, etc.) and the number of lanes. In reality, a wide range of conditions impact roadway operation and the exact capacity; however networks must include only a level of detail that can be feasibly collected, updated, and forecast for the entire study area. Typical attributes to include in a transportation network include the number of lanes, the facility type or roadway classification, and the surrounding area type.

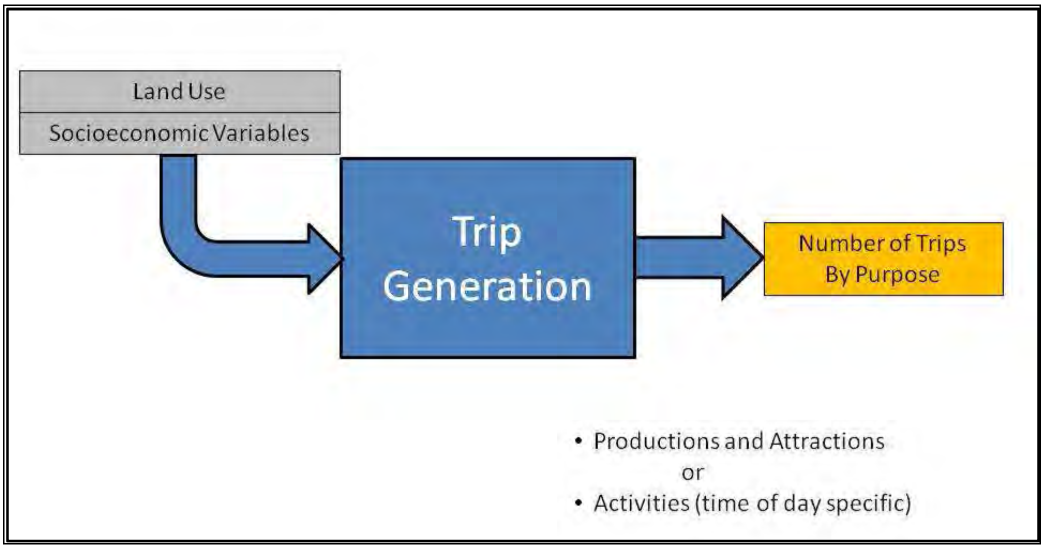
Centroid nodes are connected to other network nodes by centroid connectors. Centroid connectors represent the local roadways that are not included as links in the network, and are therefore meant to represent the average travel time or distance from the centroid to the rest of the network. Each centroid can have more than one centroid connector, but the average access travel time or distance must still be reflected. Centroid connectors represent a system of multiple local streets that access main roads, and therefore do not have capacity constraints.

As noted before, some links in a network may represent dedicated transit facilities, such as a subway, a commuter rail line, or a busway. Exclusive transit links include attributes that impact transit speeds, capacity, or operating conditions. Links for other modes, such as pedestrian access links to transit, include appropriate attributes like distance, walk time, or slope. In networks that model multiple modes, links also will include an attribute than indicates which modes are able to use a facility.

4.2 Trip Generation

Section 2.0 and 3.0 introduced the purpose of the trip generation step of TDF models. This section discusses the trip generation submodel in additional detail. Trip generation determines the number of trips of each purpose that will begin or end in each TAZ. The trip generation submodel determines the number of trips produced by and attracted to each TAZ. Trip productions and trip attractions are calculated by trip purpose. Figure 4.4 provides a simplified overview of the inputs and outputs for this step. Socioeconomic and land use data are the basic inputs to the trip generation process because trips are assumed to exist in order to achieve some social or economic purpose.

Figure 4.4 Trip Generation



4.2.1 Productions and Attractions

TDF models use the concepts of productions and attractions as a method of accounting for trips generated in a region. Productions and attractions should not be confused with origins and destination, which represent a different method of accounting for trips. Under the traditional trip-end-based model structure, trip generation produces trip ends, which are categorized as productions or attractions. Each trip has one production and one attraction. Tour-based and activity-based model structures, while not directly generating trip ends, also can generate productions and attractions although these are based on the generation of tours or activities, respectively.

Definitions

Productions – Trips are said to be produced by people traveling to an activity, and thus the production end of a trip is the location where population is located. For home-based trips, the production is always at the home end of the trip, whether home is the starting point or the ending point. In trips without a home end (non-home-based trips), productions are defined as the starting point of the trip.

Attractions – In the trip-end-based model, trips are said to be attracted by some sort of activity; therefore, the attraction end of the trip occurs at the location where the activity occurs. Each attraction represents a trip that is attracted from somewhere else. For all home-based trips, the attraction end of the trip is the non-home end of the trip, whether that location is the starting or ending point of the trip. This is because "being at home" is not defined as an activity. For non-home-based trips, attractions are defined as the ending point of the trip.

In summary, the following rules can help define productions and attractions:

1. For trips that begin or end at home, the home end is always the production;
2. For trips that begin or end at home, the attraction is always the non-home end; and
3. For trips with no home end (non-home-based trips), the production is always the starting point, and the attraction is always the ending point. [16]

Illustrations

The concept of productions and attractions can be confusing. Therefore, it may be helpful to consider a few examples.

As a first example, the accounting for a typical pair of home-based work trips is illustrated in Figure 4.5, from home to work and from work to home. Each of

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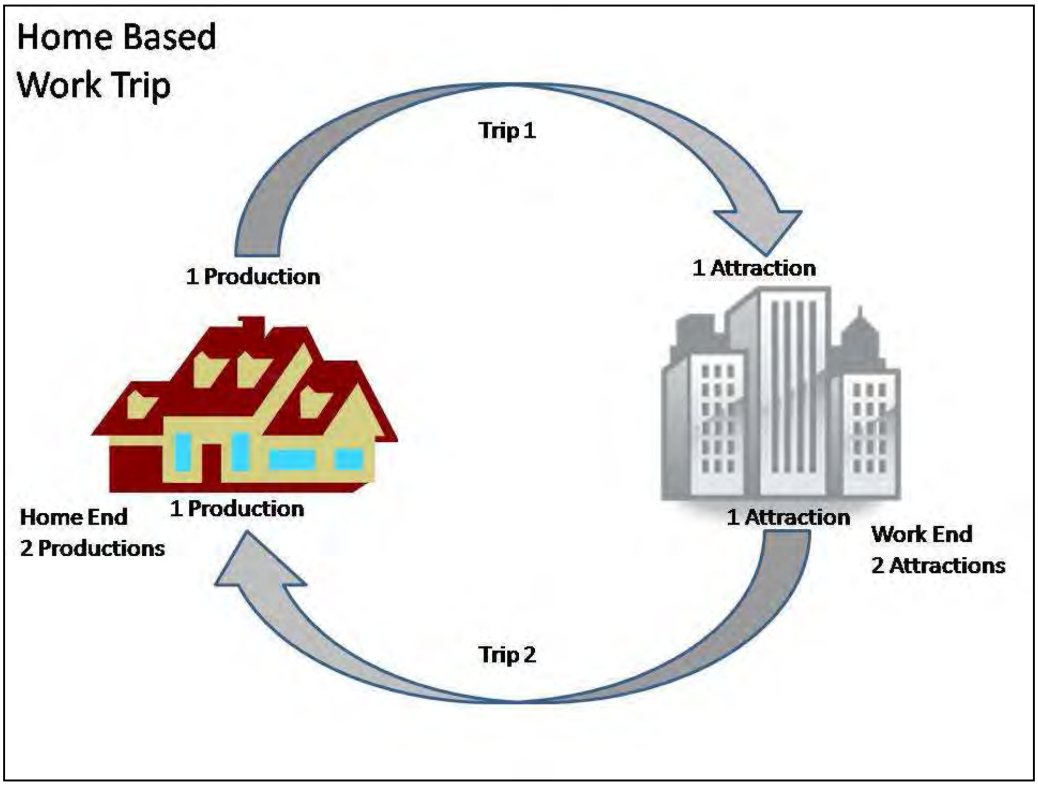
[16]Federal Highway Administration and Urban Mass Transportation Administration. *An Introduction to Urban Travel Demand Forecasting – A Self Instructional Text*. (1977).

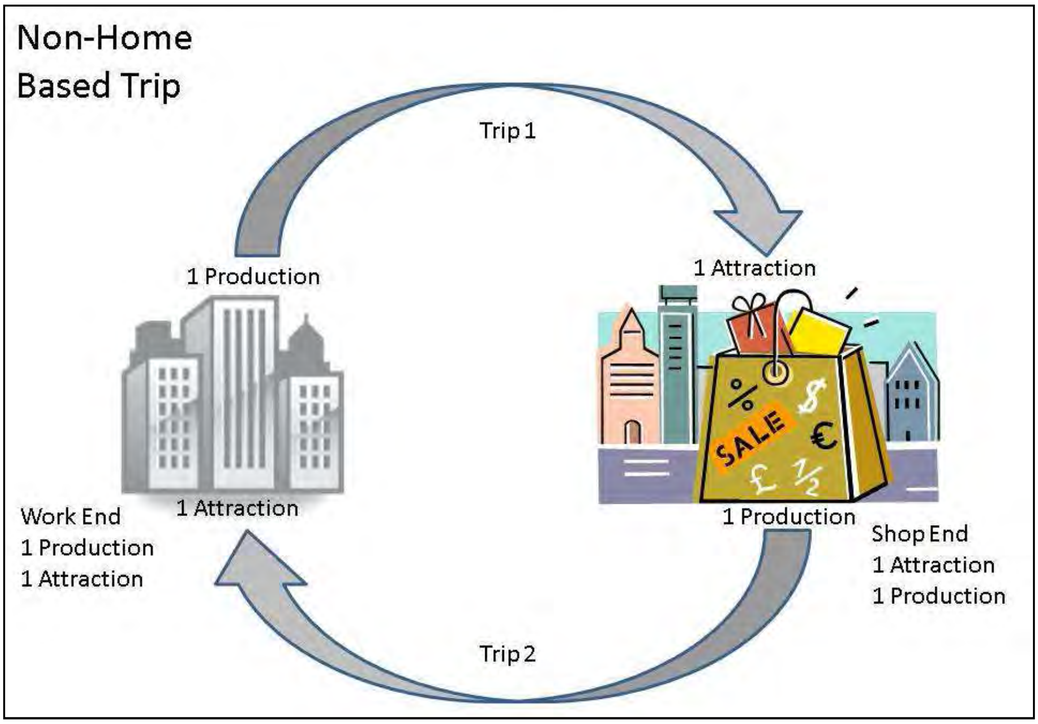
these trips will have one production and one attraction, for a total of two productions and two attractions for the day. In the first trip from home to work, the home is the production end of the trip and the work site (where the activity "work" occurs) is the attraction end of the trip. For the reverse trip back home from work, the home end again produces the trip. The work-site where the activity of "work" occurs again represents the attraction end of the trip. The daily total for these two trips will be two productions at the home end and two attractions at the work end.

Figure 4.5 Home-Based Work Trip Productions and Attractions



As a second example, the accounting for productions and attractions for trips that do not start or end at a home are illustrated. Examples of this type of trip include a trip from an office to a gym, an office to an appointment, or from a school to a shopping center. In the traditional trip-end model framework these trips are termed non-home-based trips. These trips differ from home-based trips because an activity occurs at both ends. In these cases, the starting point of the trip is always defined as the production end of the trip and the ending point of the trip (where the next activity occurs) is defined as the attraction end. Figure 4.6 shows a specific example of calculating productions and attractions for a pair of non-home-based trips. In the first trip, from the office to the store, the office is defined as the production and the store (where the "shopping" activity occurs) is defined as the attraction. However, on the return trip, the store is defined as the production and the office (where the "work" activity occurs) is the attraction end. The daily total for these two trips will be one production and one attraction at both the office and the store.

Figure 4.6 Non-Home-Based Trip Productions and Attractions



Benefits of Using

Productions and attractions are particularly useful when looking at travel patterns and understanding travel markets. This method of accounting for trips allows for separate analyses of the home and work ends of trips, or analysis of how travelers are accessing a specific site whether it is an office or a retail store. Planners often require information about the accessibility of a location as an attraction or a production TAZ. For example, on the production side of a trip, a traveler might use an auto to access a park-and-ride lot. As there is no car available on the attraction end of that trip, analysis of walk access at the attraction end is important. The method of productions and attractions allows for this type of analysis and differentiation. If the trip is only accounted for in terms of starting and ending points then this type of differentiation is not possible because, in the home-based work example, it would be impossible to tell if the first trip is from work to home or from home to work.

4.2.2 Trip Generation Methods

There are several methods that can be used to calculate the total number of productions and attractions for each trip purpose that are associated with each TAZ. Some trip generation models focus on items related to activity, some on land use development, and others focus on variables related more to economics. The most common structures used are cross-classification models and regression equations.

Cross-Classification Models

Cross-classification models are typically used for estimating trip productions. A cross-classification model develops average household trip rates by purpose based on household demographic characteristics. Table 4.1 shows an example of a cross-classification table based on household income and the number of workers in the household, although other independent variables such as household size and number of autos also can be used. The variables can be cross-referenced in the table based on the characteristics of the household to get the total number of daily trips made by that household for the stated purpose. This trip production rate can then be applied to all households in the TAZ that share the same characteristics. Productions for all households in the TAZ are totaled in order to determine the total number of productions in the TAZ for each purpose.

Table 4.1 Example Cross-Classification Trip Production Model

		Income Group			
Purpose	Workers per Household	Quartile 1	Quartile 2	Quartile 3	Quartile 4
Home-Based Work (HBW)	1	0.955	1.210	1.222	1.345
	2	1.823	2.098	2.567	2.564
	3+	3.300	3.511	4.001	4.020

Using the example production rates in Table 4.1, and if there are a total of 100 households in a TAZ with the following characteristics:

- 40 households with 1 worker in quartile income group 1;
- 10 households with 1 worker in quartile income group 3;
- 20 households with 2 workers in quartile income group 2; and
- 30 household with 3+ workers in quartile income group 4.

The HBW trip productions for that TAZ would be calculated as follows:

HBW Productions = (40 X **0.995**) + (10 X **1.222**) + (20 X **2.098**) + (30 X **4.020**) = 215.

Regression Models

Regression models are commonly used to estimate trip attractions. Regression models also can be used to develop trip productions, but that is less common. For trip attraction, regression models simply look at the relationship between a set of independent variables and the number of trips attracted to a TAZ. Employment levels of various types in the TAZ are among the most frequently used independent variables. An example of a regression model used to calculate trip attractions for the home-based work purpose in a TAZ is:

HBW Attractions = 1.60 X (Basic Employment) + 1.35 X (Retail Employment)

In this example, if the basic employment in the TAZ was 800 jobs and the retail employment was 200 jobs, the trip attractions for the HBW trip purpose in the TAZ would be 1,550. Constants are typically avoided in regression models developed for trip generation.

Regression models that are based solely on employment or other scale of activity variable (e.g., square footage) are often referred to as trip rate models. Different trip rates may exist for different classifications of (and even locations of) types of employment. Trip rates used in TDF models may differ from trip rates used for site impact analysis due to the differing objectives (person trips versus vehicle trips).

4.2.3 Trip End Balancing

The total number of production trip ends in the region must match the total number of attraction trip ends in the region for each trip purpose, because each trip must have only a single production and a single attraction. The final step in trip generation after the production and attraction trip ends have been calculated for each TAZ is to balance the totals. Typically, the attractions are adjusted to match the regional total of productions because the employment and retail markets are generally more dynamic than the housing market. Also household survey results, capturing the production end, are typically more accurate. The attractions are adjusted on a regional basis. Therefore, it is possible for the forecasted growth in employment for a region or a jurisdiction to not match the final growth rate of attractions developed through trip generation.

In regions where land use forecasts are developed by multiple jurisdictions, differences in the accuracy of employment forecasts can impact the final growth in attractions calculated through trip generation. If one jurisdiction grossly under- or over-estimates employment levels in the future, attraction rates in all of the jurisdictions will be adjusted to compensate. This is among the reasons it is important to have a standardized process in place for cooperatively developing land use forecasts for a region.

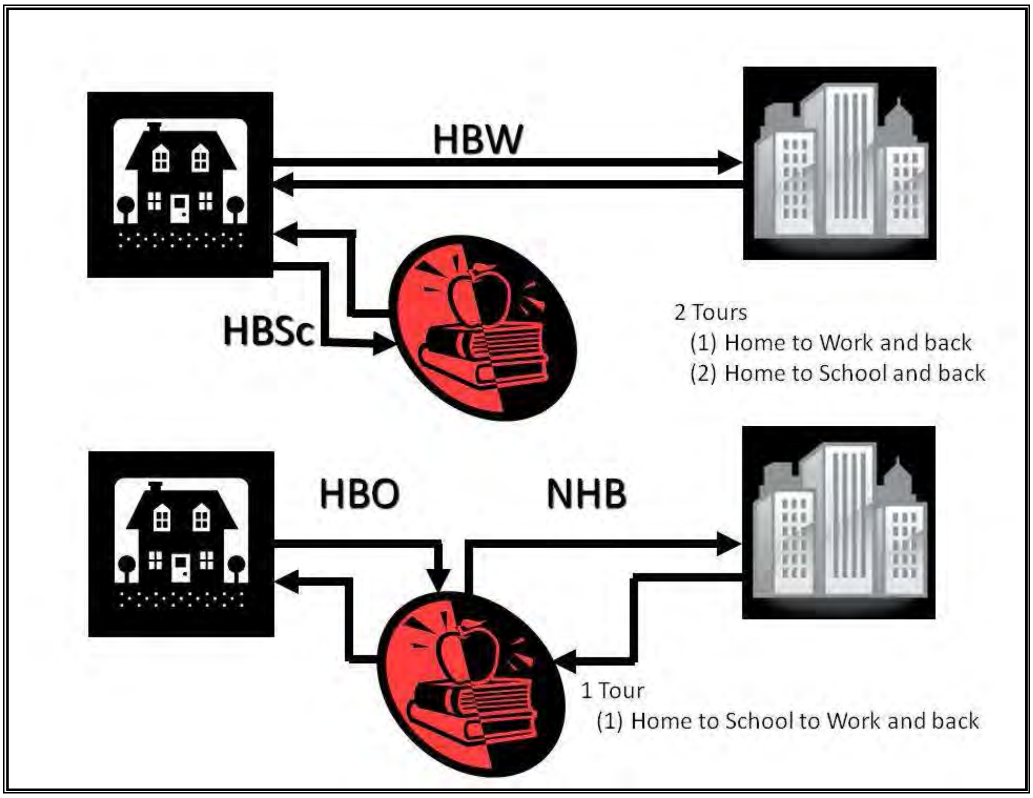
4.2.4 Activity-Based Trip Generation

In traditional trip-end TDF models, trip generation is typically performed at the daily level. It is fairly straightforward to capture a daily activity pattern because for the majority of travelers, the day starts at home and ends at home. The trip-end model generates the number of trips and their purposes (i.e., work, shopping, school, recreation, etc.) produced and attracted by TAZ on an average weekday. While these calculations are based on the concept that people travel in order to participate in activities, the model does not attempt to specify what those activities are, only which category each falls into.

Advanced models address the question of how much travel occurs using a different approach. Activity-based TDF models base their trip generation calculations on a much closer examination of the daily activity patterns of individuals. Characteristics of a sample of households and individual members of households from surveys are used to populate each TAZ with residents and households. Based on the characteristics of each household and its members, an activity record is developed for the household which includes the specific activities, their durations, and whether or not they occur at home. This activity record indicates how many trips members of each household make which can then easily be aggregated to the TAZ level.

A benefit of this model structure is an activity record which can be used to better understand the trips that are being made in the region. Travel, when quantified as tours instead of individual trips or trip ends, can more accurately be categorized by purpose. For example, the tour shown in Figure 4.7 is from home to school to work. In the traditional trip-end model, this activity is counted as two separate trips. The first leg would be categorized as a home-based school (HBSc) or home-based other (HBO) trip (depending on the model), and the second leg would be categorized as a non-home-based (NHB) trip. However, the activity-based structure is able to more accurately represent this as a home-based work (HBW) tour. Under this structure, this particular tour would be included when calculating commute mode share or other statistics, while it would be excluded in the trip-end model. Another example of the importance of correctly categorizing the purpose of trips is in analyzing policies designed to affect a specific trip purpose, such as transportation demand management (TDM) programs designed to affect commute trips. When evaluating future TDM programs, the activity-based model allows for a more detailed representation and can better reflect the impacts and costs of TDM measures.

Figure 4.7 Example Tours

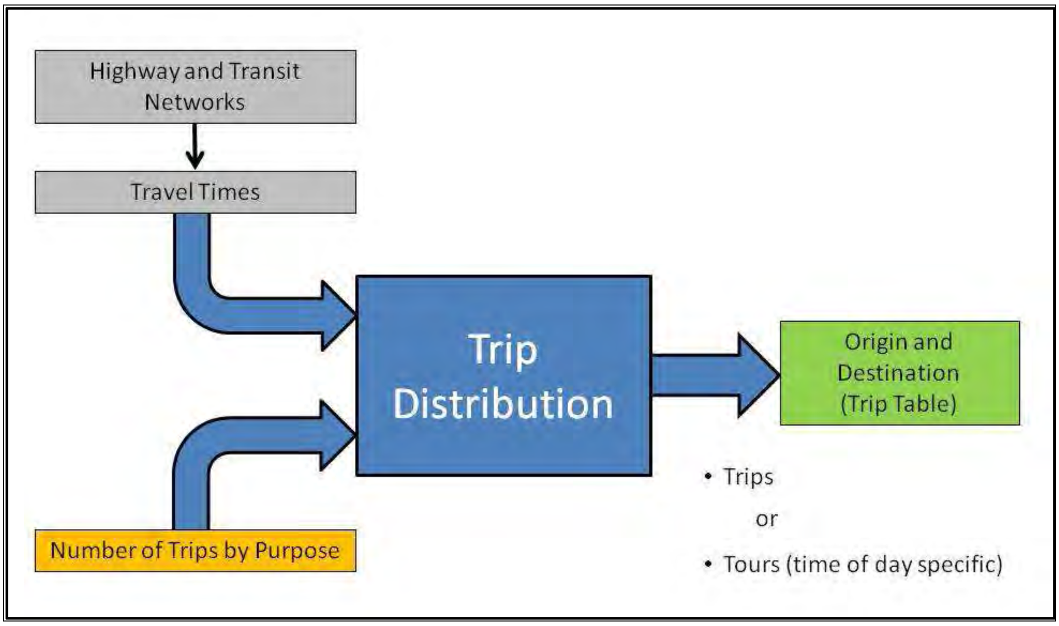


4.3 TRIP DISTRIBUTION

The trip distribution step of TDF models uses output from the trip generation step and information from the transportation network to match trip productions and trip attractions to create trips or tours. Figure 4.8 provides a simplified overview of the trip distribution step. This step typically results in a trip table for each trip purpose. A trip table is a matrix with productions represented in the rows and attractions represented in the columns. As shown earlier in Figure 2.3, the number of trips traveling between any two points can be found by looking at the cell with the row and column corresponding to the points.

Trip distribution models assume that given a time and cost budget, people are likely to make trips in a similar distribution as they do today. It is therefore necessary to know the total time and cost between all TAZs in the model. Impedance, sometimes a composite measure of time and cost although frequently defined only as travel time, is accumulated to and from each TAZ by tracing all paths on the transportation network and saving the shortest path in a lookup table. This process is referred to as "skimming" the network. The definition of "shortest" path may be determined by a weighting of the different attributes of impedance. Typically, the individual attributes composing the impedance are accumulated in a matrix file composed of a set of lookup tables for each attribute to permit them to be used in other portions of the TDF model.

Figure 4.8 Trip Distribution



4.3.1 Trip Distribution Methods

The most common structure used in trip distribution is the gravity model. The gravity model looks at the relative attractiveness and impedance between pairs of TAZs to determine how many productions from one TAZ will be matched with attractions from the second TAZ. On the one hand, a TAZ with a higher number of attraction trip ends will have a high number of production ends pulled or attracted to that TAZ, analogous to the force of gravity between two large masses. On the other hand, two TAZs with high impedance indicating that it takes a long time to travel between them, will have few trips distributed between the TAZs. These two conflicting forces work to balance the attractiveness of potential destinations with the disincentive of long travel times.

This conflict is evened out through the network by the use of friction factors which attempt to represent perceived time. Based on research and survey data, the friction factors account for the fact that people perceive short trips as taking longer than reality, and perceive long trips as shorter than the trips actually are. The friction factors alter the trip distribution results so that they more closely match observed travel time data, with more trips on the shorter end of the spectrum. Figure 4.9 shows an example travel time distribution. The friction factors can be used to shift the distribution in the gravity model to match the observed impedance or travel time distribution.

Figure 4.9 Example Travel Time Distribution

In calibrating the gravity model, friction factors are adjusted so that the travel patterns better match observed data. Even after the model is calibrated, it is possible that some TAZs will not fit the data. In this instance, a K-factor may be introduced on a TAZ by TAZ basis[17] to represent socioeconomic issues that are not captured in the basic gravity model format. For example, there might be an area of lower economic activity adjacent to a central business district. A K-factor would be used in this case because the gravity model might indicate that trips produced in the area of lower economic activity are attracted to the central business district while the observed data shows a different pattern. The use of a K-factor takes into account these types of abnormalities. K-factors might limit the ability of the trip distribution model to capture changes in the future. In most cases K-factors are discouraged in favor of recalibration of friction factors as a first step, assuming household travel survey data are available.

[17] K-factors may be established on a district-level rather than individual TAZ-level.

For the interested reader, the gravity model formula, below, shows how these elements relate to one another mathematically:

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

where

T_{ij} is the number of trips produced in zone *i* and attracted to zone *j*;

P_i is the trips produced from zone *i*;

A_j is the trips attracted to zone *j*;

F(imp)ij is the friction factor for interchange *ij* based on impedance between zone *i* and *j*;

K_{ij} is the socioeconomic factor for the movement between zone *i* and zone *j*;

i is the origin zone;

j is the destination zone; and

n is the number of zones in the study area.

There are structures other than the gravity model which may be used for trip distribution. Destination choice models, for example, can be used to predict the probability of trips occurring between TAZs. Typically employing a discrete choice algorithm such as the multinomial logit model, destination choice models focus on the different attributes that influence the decision to travel between TAZs and can include more attributes from the travel skims than a gravity model such as cost for different modes, travel time for different periods during the day, and other similar attributes. In general, destination choice models analyze desires and opportunities. Destination choice models are most often associated with more advanced tour or activity-based TDF models.

4.3.2 External Trips

TDF models cover fixed regions, and no matter how large the region is there are always trips that enter from outside of the region, trips that are destined to locations outside the region, and trips that pass through the region. These trips are referred to as external trips. There are three types of external trips:

- External to internal trips – trips that start outside of the modeled region and end within the model region;
- Internal to external trips – trips that start inside the region and end outside the region; and
- External to external trips – trips that both start and end outside the region.

Typically, external travel should make up a small portion of the trips in the region. External trips are ideally developed based on survey data collected at the boundaries of the model region. External to internal trips and internal to external trips are included in the trip distribution calculations. External to external trips are often added to the trip distribution results based on traffic count data or other national surveys. The external to external trips are typically not included in the trip distribution model and are forecast from base year levels based typically on some other growth projection.

4.4 Mode Choice

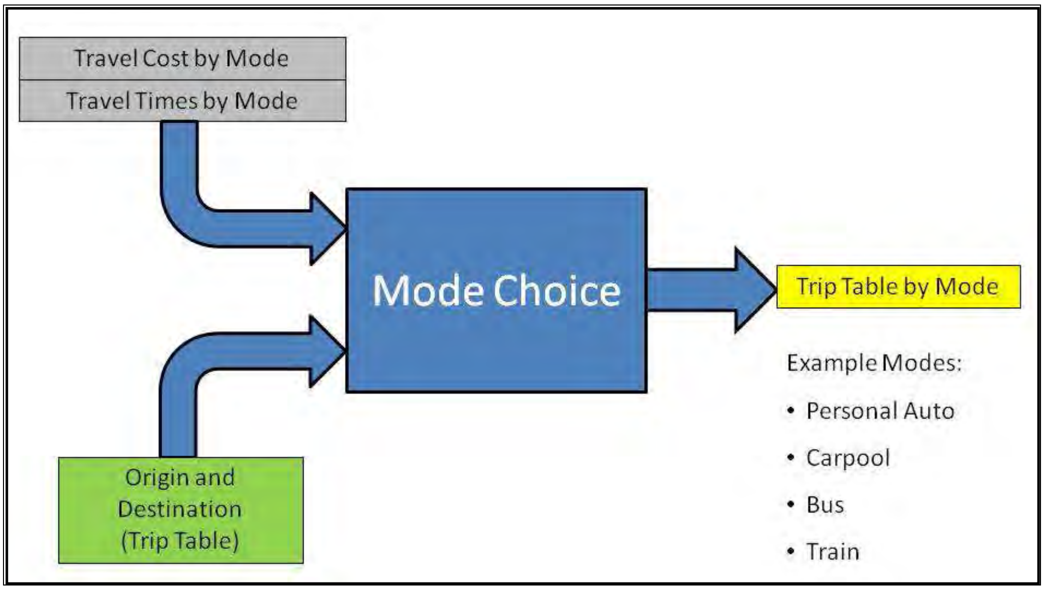
The mode choice step uses output from the trip distribution step, specifically the production and attraction information denoted in trip tables for each trip purpose, and allocates the person trips among specific modes. Figure 4.10 shows a simplified overview of the inputs and outputs used for mode choice.

The choice of which mode a traveler will use is based on characteristics of both the traveler and the trip. Relevant characteristics of the trip may include the following:

- Travel time, which can be divided into multiple elements, including:
  - In-vehicle time – the part of travel time spent actually in a vehicle (driving or riding on a bus, etc.);
  - Access time – the part of travel time spent accessing the vehicle (i.e., walking to a bus stop or driving to a train station);
  - Wait time – Time spent waiting for a vehicle (typically only used for transit modes); and
  - Transfer time – time spent waiting to transfer between transit vehicles.
- Travel cost, which also can be composed of multiple elements, including:
  - Vehicle operating cost – costs associated with operating a private vehicle, including gasoline, insurance, and maintenance. Typically only counted in automobile modes;
  - Parking cost – the cost to park at the destination or at a park-and-ride facility; and
  - Transit fare – only included for transit modes.

In order to access data for all possible origin-destination pairs and for all potential modes, the transportation network is skimmed for the necessary variables. The product of the mode choice model is a series of trip tables with the number of trips by mode for each TAZ pair.

Figure 4.10 Mode Choice



4.4.1 Mode Choice Methods

There are different types of mode choice methods used in TDF models. The method used will depend on the number and types of modes available, the available survey data, and the overall complexity of the model structure. In regions with no transit service, this step may be skipped altogether or it may focus on automobile occupancy, determining (or asserting) the percentage of trips that involve carpooling. In regions with limited and stable transit service, the percentage of trips using transit may be calculated by using a static factor based on the proportion of the population that does not own a car or is otherwise deemed to be dependent on transit. In other limited models, proportions for each mode may be developed using a set of curves that indicate the mode share based on the trip purpose, origin and destination, and travel time. In regions with more-robust transit systems and travel options discrete choice models are usually applied for the mode choice step.

Discrete Choice Models

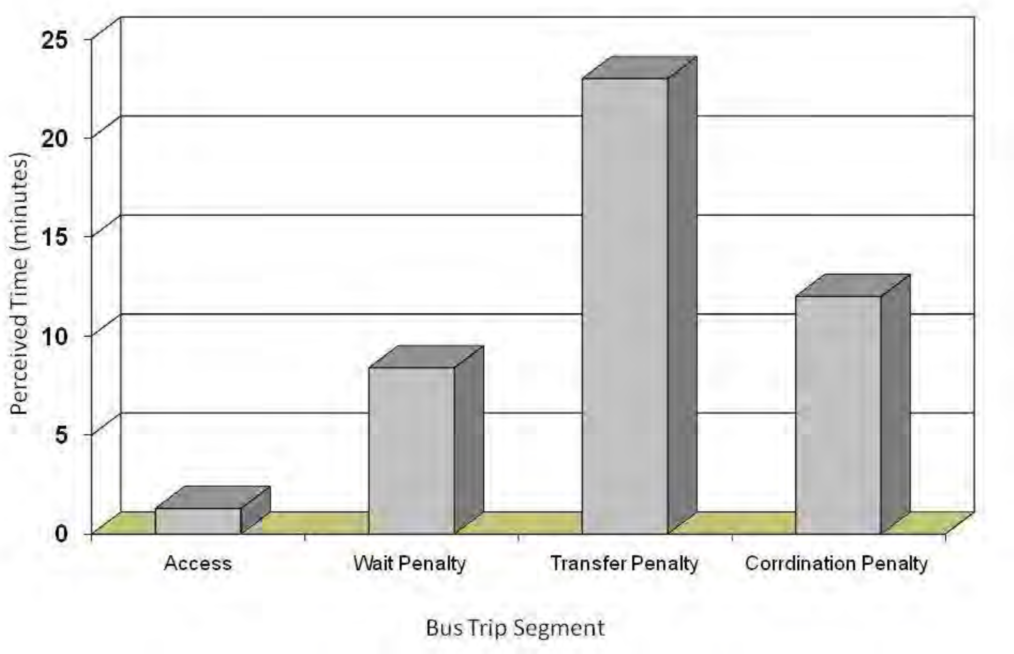
In regions where mode choice plays an important role in transportation planning, the most common method used in the mode choice step is a discrete choice model; usually, the logit model. This is similar in structure to the destination choice model structure used by some regions for the trip distribution step. For mode choice, the decision modeled is choice of mode of travel, and the inputs are characteristics about the trip and about the travelers in terms of possible mode choices.

For each trip, a discrete mode choice model compares the characteristics of the trip on all the potential modes and predicts the probability of a traveler using each specific mode to make the trip. This type of model can successfully compute the probability of choosing any number of modes so long as the necessary data are available. A common choice set includes driving alone (single occupancy vehicle (SOV)), sharing a ride (high-occupancy vehicle (HOV)), using transit. Transit choices may be further divided into including consideration of access modes and transit submodes (e.g., rail versus bus). Nonmotorized modes may also be modeled in mode choice, but it is not a typical practice. In the discrete choice model, each element of travel time and travel cost are skimmed from the transportation network for all potential travel modes.

Travel time is divided into multiple components because time spent in the vehicle is not, for example, perceived the same as time spent waiting. Perceived time is a measure of how long people *think* an activity takes, which can be developed from travel survey data. Figure 4.11 provides an example of the differences in perceived time between the different components of a bus trip. Each time component shown in Figure 4.11 is compared to one minute of actual in-vehicle time. So two minutes spent traveling in the bus is perceived as being the same as to one minute of walking to access the bus. Seven minutes on the bus is perceived as being the same as one minute waiting for the bus at the stop. When a transfer between buses is required, one minute waiting for the transfer feels like 23 minutes on the bus. If that bus transfer can be coordinated, meaning there is some information about when the next bus is coming, one minute of waiting is perceived as being the same as 12 minutes on the bus.

The concept of perceived time is important because it directly impacts how travelers choose a mode. Transit trips that require multiple transfers are not very attractive to travelers because of the high perceived time, no matter what the actual travel time is. Likewise, transit routes with very long wait times are not likely to have very high ridership due to the perception of wait time. Understanding how travelers perceive the different components of travel time is important to anticipating model results and is also helpful in planning transit routes that will be attractive to travelers in the future.

Figure 4.11 Perceived Transit Time



For the interested reader, the logit model formulation is as follows:

$$P_{g,i} = \frac{\exp[U_{g,i}(x_{g,i})]}{\sum_{g,m} \exp[U_{g,m}(x_{g,m})]}$$

where

$P_{g,i}$	is the probability of a traveler from group *g* choosing mode *I*;
$X_{g,m}$	are the attributes of mode *i* that describe its attractiveness to group *g*;
$U_{g,m}(x_{g,m})$	is the utility of mode *m* for travelers in group *g*; and
$\sum_{g,m}$	indicates the summation of utilities over all available alternatives.

Typically, the utility function for each alternative takes the following form:

$$U_{g,m}(x_{g,m}) = a_m + b_m LOS_m + c_{g,m} SE_g + d_m TRIP$$

where

LOS_m	represents the variables describing levels of service provided by mode *m*;
SE_g	represents the variables describing socioeconomic characteristics of group *g*;
TRIP	represents the variables describing characteristics of the trip;
b_m	is a vector of coefficients describing the importance of LOS_m variables;

$c_{g,m}$ is a vector of coefficients describing the importance of each $SE_{g,m}$ characteristic of group g with respect to mode m;

d_m is a vector of coefficients describing the importance of each *TRIP* characteristic with respect to mode m; and

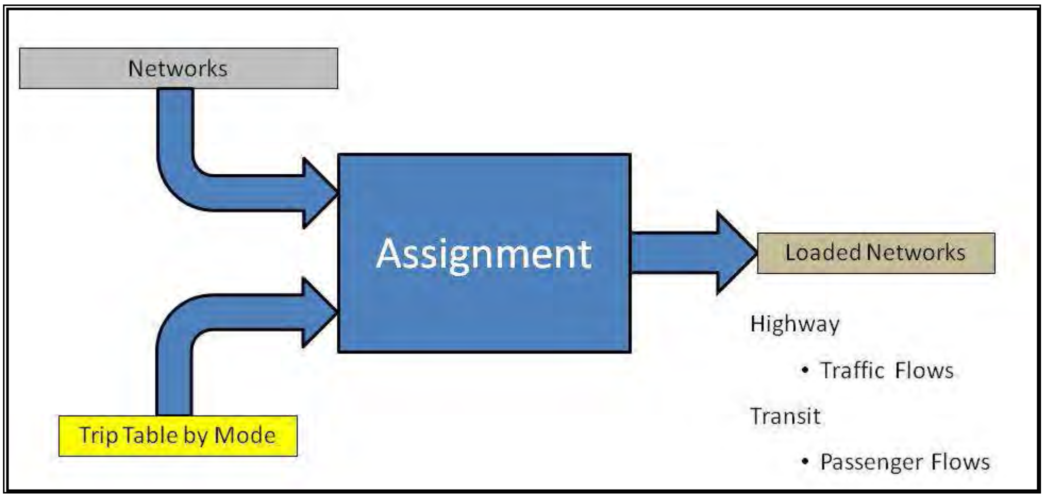
a_m is a constant specific to mode m that captures the overall effect of any variables missing from the expression (comfort, safety, and so forth).

4.5 Trip Assignment

The final step of the TDF model, trip assignment, determines which route travelers will use to make their trips by calculating the path that trips will take between origins and destinations. Figure 4.12 presents a simplified schematic of the inputs and outputs to the assignment model. The inputs are the transportation network and trip tables by mode, and the output is a network with traffic volume flows or transit riders on each link. This is sometimes referred to as the loaded network.

The general theory behind trip assignment is that travelers will pick the best path between each origin and destination. The determination of the "best" path is based on selecting the route with the least impedance, based on distance, time, cost, or some combination. Typically, it is defined based on time, with cost added and equated to time. The cost in this case, usually a toll or fare, is equated to a time penalty based ideally on data from a stated-preference survey. As the assignment process progresses, travel time on each link in the network is updated based on congestion levels and the cost elements are added where applicable to the total link congested time.

Figure 4.12 Trip Assignment



4.5.1 Preparing for Trip Assignment

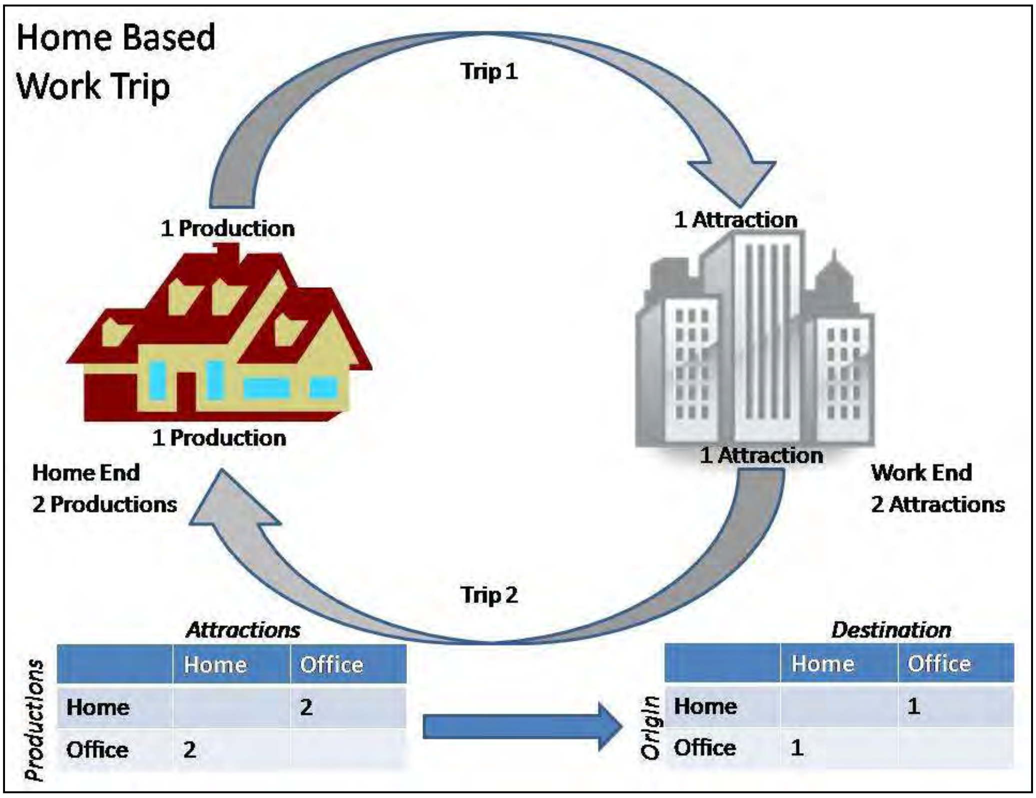
The mode choice step typically outputs trip tables by purpose and mode at the person-trip level, representing the flow of people between TAZs. For assignment on the roadway network, the trips between TAZs need to be expressed in terms of vehicle flow. The roadway trip table results from the mode choice step are factored from person trips to vehicle trips based on vehicle occupancy rates. Automobile trips, which already may be divided into automobile occupancy groups as part of the mode choice step, are divided by the average occupancy of each group to calculate a vehicle trip table. For example, a mode-specific trip table of two-person carpools would be divided by two to get the vehicle trip table for that occupancy group.

The trip generation, trip distribution, and mode choice models typically function with trip tables stored in production to attraction format. Once trip tables have been compiled based on productions and attractions, they can then be transformed into origins and destinations format. This is also a typical pre-assignment step. In order to convert the daily table of productions and attractions to origin and destination trip tables, the production/attraction trip table has to be added to its transpose, or inverse, and then divided by two. The resulting origin/destination trip table is as shown in Figure 4.13.

Origins and destinations are conceptually simple. An origin is defined as the starting point of a trip and a destination is defined as the ending point of a trip. Figure 4.13 provides an example of origin and destination calculations for two home-based work trips and illustrates the difference between the production and attraction framework and the origin and destination framework. In this example there are two trips, one from the home to work and one from work to home. In the first trip, the home is the origin and work is the destination while in the second trip work is the origin and home is the destination.

Origin and destination trip tables are used in the final assignment of traffic on the network. These trip tables can be disaggregated to account for different time periods during the day prior to assignment. Using time-of-day factors, assignment can be performed for any period of interest, although weekday peak periods are the most common.

Figure 4.13 Production/Attraction to Origin Destination Conversion



4.5.2 Transit Assignment

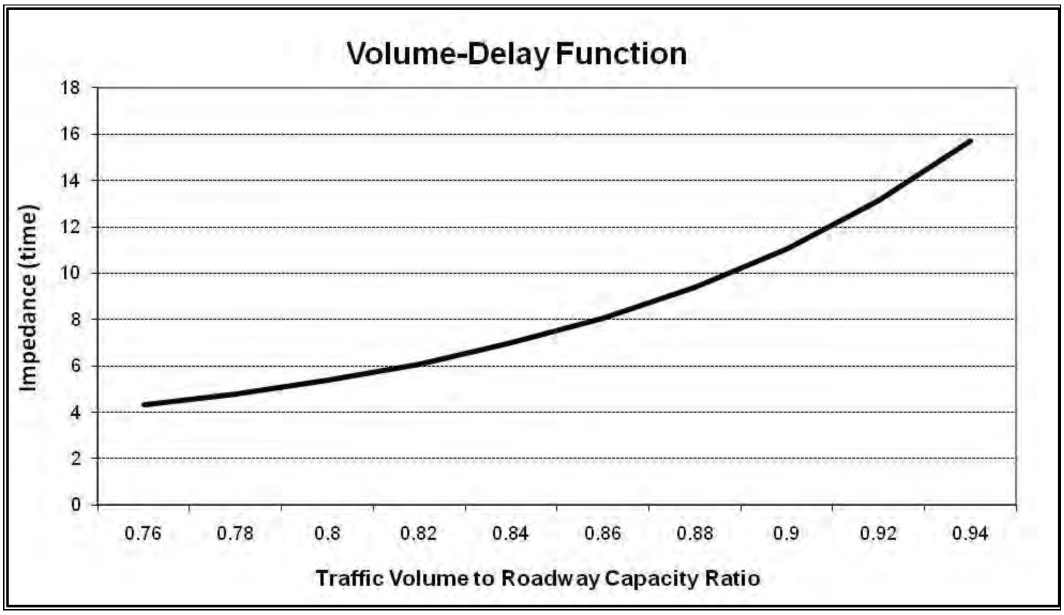
The transportation network for the TDF model typically has two components: highway and transit. Not all models include a transit assignment, but there are many MPOs that do. Transit assignment captures passenger flows on transit routes. Transit assignment is particularly challenging because of the complexity of the potential transit paths; transit assignment has to account for several segmentations of the trip, including mode of access and egress, transfer time, and fare penalties. These time and cost segmentations make the path calculation very complex. Transit trips are commonly assigned to the shortest available transit path. More complex algorithms are used for areas with complex transit systems with overlapping coverage and multiple alternative transit paths.

4.5.3 Highway Assignment

For highway networks, the congested travel time on a link is calculated as a function of the ratio of vehicle volume to capacity on the link. Each link in the network has a designated capacity based on an estimation of the traffic flow a link can handle. For convenience, capacity is usually presented in terms of hourly flow, (e.g., 1,800 vehicles per hour per lane). The capacity is determined based on characteristics of the facility, including the number of lanes, the facility type or classification, and the surrounding area type. Different area types which can range from rural to urban give an idea of traffic conditions on the link. Rural areas typically have fewer traffic control devices (such as signals and signs) while urban areas typically have many signals and short blocks.

As traffic increases on a link and the volume approaches the capacity, the travel time on the link increases exponentially as shown by the volume delay function in Figure 4.14. The x-axis shows the ratio of the volume to the capacity. When this ratio reaches one, the link is estimated to be at capacity. Traffic can still move through the link, but the flow of traffic has broken down and travel is very slow and speeds become sporadic. The y-axis represents the impedance, which is typically time in terms of minutes.

Figure 4.14 Congested Travel Time



Traffic assignment has evolved over time as faster computing has become available. The most common algorithm used in traffic assignment is the user equilibrium approach. User equilibrium is based on the principle that while selecting the best path, travelers will use all possible paths between the origin and destination that have an equal travel time, so that no traveler can save time by switching paths. Many different algorithms have been developed based on these concepts; the user equilibrium approach attempts to optimize the travel time between all possible paths, reflecting the effects of system congestion.

4.5.4 Microsimulation

TDF models help answer questions that impact large geographic regions. The transportation network correspondingly covers a large area. Because of the size of the network and the data needs for the included links and nodes, the network only provides a coarse representation of the actual roadway system. Given that the network representation is coarse and the assignment algorithm rather simplistic, TDF traffic assignment models function on a macroscopic level, providing traffic forecasts that are accurate on a regional scale.

Traffic microsimulation models provide forecasts at a more detailed level, and use advanced car-following logic algorithms to simulate the actions of the variety of individual vehicles on a network. This means that traffic microsimulation can answer more-detailed questions that TDF models cannot. However, the increased level of detail involved in microsimulation projects also requires increased details about the transportation network, including many more attributes related to how an individual driver perceives the road such as steepness of the road, lane width, and the driver's vision along the road. The need to input these detailed attributes leads to most traffic microsimulation practice and networks being developed to cover much smaller geographic areas than do regional TDF models.

As with other planning analyses, the questions which need to be answered generally guide whether a traffic microsimulation or the TDF model is the appropriate tool to use to obtain the answer. In either case, the TDF model may provide key inputs to the development and application of a traffic microsimulation model.

4.5.5 Post-Processing

The coarseness and simplifications inherent in the TDF assignment model require additional analysis in order to develop detailed traffic information. Post-processing refers to processes applied after the TDF model is complete. The more detailed the information required, the greater level of post-processing that maybe needed. Standard procedures have been developed to post-process highway assignment results for use in detailed traffic analysis; for example *NCHRP Report 255*[18] presents a method which remains commonly used.

Using results of TDF models is discussed in Section 6.0, but it may be useful to note that the direct output from the assignment model can be used to evaluate travel patterns on an aggregate level. For example, screenline analyses combine traffic flows across competing facilities and capture major movements in the

[18] Pedersen, N. J. and D. R. Samdahl. "Highway Traffic Data for Urbanized Area Project Planning and Design," *NCHRP Report 255*, Transportation Research Board, Washington, D.C. (1982).

network. Also, it is common to use the results of the traffic assignment at some aggregate level while understanding the limitations of unrefined model output.

5.0 Applications of TDF Models

The application of TDF models has evolved over time. This section reviews historical applications of TDF models and their primary uses, followed by discussions of current model applications and evolving model applications.

5.1 Historical Applications

The 1962 Federal-Aid Highway Act prompted the need for traffic forecasting. This act mandated that the use of Federal highway aid money by state departments of transportation (DOT) in urbanized areas be tied to the existence of a long-range transportation plan (LRTP). The legislation continues to dictate the requirement that these plans be based on a continuing, comprehensive transportation planning process, carried out cooperatively by state and local communities.[19] This requirement is sometimes called the "Three C's of transportation planning." These plans required travel forecasts, and stimulated the development of appropriate tools for the task. This established the value of TDF models in the transportation planning field. Transit planning was not a focus of the earliest TDF model applications even though the 1962 Federal-Aid Highway Act did mention the importance of various modes in transportation. The primary role of early TDF models was to develop highway forecasts for project planning studies.

Legislation in the 1970s dictated that long-range transportation planning occur for a 20-year time horizon. A 20-year planning horizon was deemed necessary in order to account for the investment needs of proposed roadway facilities. The objective was to show that projects receiving Federal aid would function adequately in 20 years and could therefore be considered good investments. In this context, "adequately" came to be defined as operations at level of service "C" conditions (or approximately 70 percent of capacity). While early planning efforts focused on achieving this level of service "C" condition, recent developments have resulted in the acceptance of level of service "D" or "E" for some projects.

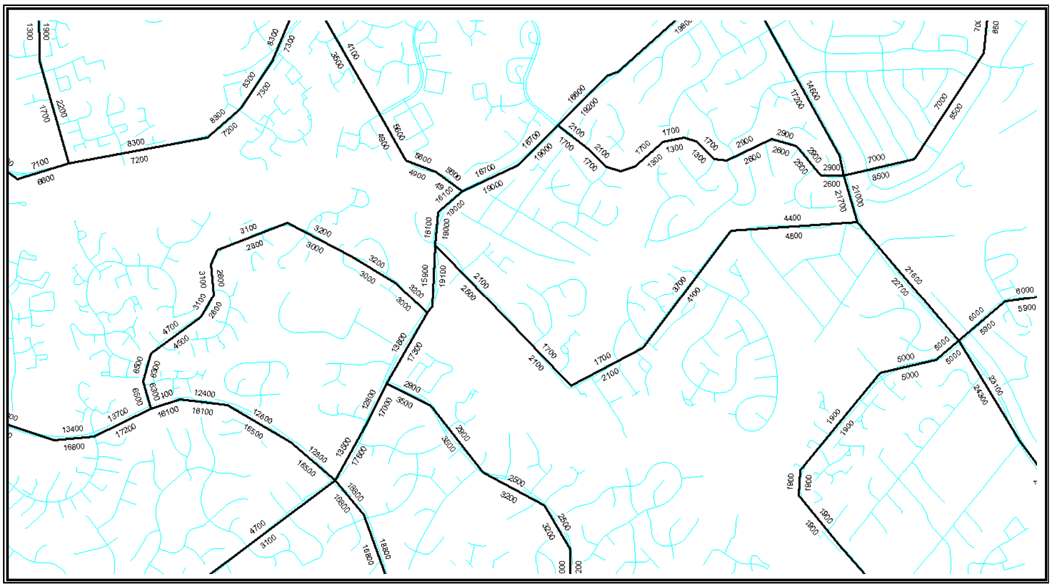
TDF models were initially used to look at questions of where roads needed to be built or expanded. This type of application included balancing the performance of the transportation system against proposed land use changes. Many early urban transportation studies involved analysis of measures such as accessibility to and from downtown areas, commercial centers, and suburban housing.

[19]Papacostas, C. and P. Preveourous, *Transportation Engineering and Planning*, Second Edition, Prentice Hall, Englewood Cliffs, New Jersey, (1993).

Accessibility, as measured by the ease of travel from the suburban areas to the central business districts, was the primary transportation challenge in the early days of TDF modeling.

For many years, TDF models have provided traffic forecasts that were used to determine the width of roadways, bridge design requirements, pavement depth, and interchange location and design. The forecasts were critical to understanding the design requirements and the associated cost of the proposed highway facilities. A typical traffic forecast volume plot showing the results of a TDF model is shown in Figure 5.1. These plots have traditionally been used for traffic engineering and roadway design engineering activities.

Figure 5.1 Typical Traffic Forecast Volume Plot



5.2 CURRENT APPLICATIONS

TDF models are still used to produce traffic forecasts for input into the highway design process. But as the transportation system has grown and increased in complexity, so has the need for understanding future transportation planning issues. TDF models now play a role in other aspects of the transportation planning process, such as air quality analysis, alternatives to roadway expansion, transit planning, and congestion pricing.

5.2.1 Environmental Issues

Environmental policies and questions related to traffic growth are now routine TDF model applications. One of the first major environmental issues to be tied to TDF models was air quality. The outputs from TDF models are regularly used to estimate the air quality level for many metropolitan areas. Vehicle miles traveled (VMT), which is the volume on the links in the network multiplied by the distance of links, is a key input to air quality conformity analysis and a direct output of the model. Congested speeds are another key input to the air quality process. These speeds are often calculated in a post-processing step based on the traffic forecast. Federal requirements exist for urban areas to develop LRTPs that meet air quality requirements.

5.2.2 Transportation Alternatives

TDF models are required to look at a range of other transportation issues beyond development of roadway designs. Expanding roads has become increasingly more difficult and costly as urban areas have become more built-out and developed. Obtaining the necessary land is not always feasible or desirable. Thus, alternatives to roadway expansion must be considered to accommodate future growth, such as transit service expansion, transportation system management (TSM), and travel demand management (TDM). The effects of these strategies should ideally be reflected in the TDF models.

TSM strategies ensure efficiency of transportation investments by determining if benefits from roadway expansion or other large capital investment projects could not also be realized from less costly improvements. These strategies put a special emphasis on less capital intensive multimodal improvements which in turn puts greater emphasis on mode choice modeling and transit assignment in the TDF process. TDM strategies include carpool programs, parking pricing policies, and other similar measures that can be used to manage single occupancy vehicle travel. As these programs have become of interest, new ways to estimate the impacts of them have been developed. While many factors in both TDM and TSM programs cannot fully be reflected in the traditional trip-end model structure, there are parameters in the modeling process that can account for many of these types of programs, including:

- Land use density factors;
- Parking prices;
- Nonmotorized network elements;
- Park-and-ride facilities; and
- Carpool or HOV lanes.

5.2.3 Transit Planning

Many urban areas have as a goal providing regional mobility to promote economic growth and development. Transit system improvements are among the solutions being considered. TDF models are used to evaluate the viability of new and expanded transit facilities and services. The mode choice model is at the heart of most transit analyses performed using TDF models. The more robust the model (and the data supporting the model) the wider the array of questions which may be answered.

Special analysis is required as part of application for funding of major transit fixed guideway investments through the Federal Transit Administration (FTA) New Starts program. FTA requires careful validation procedures for TDF models and the careful analysis of likely benefits from development of new fixed guideway transit. FTA has developed and released software (called SUMMIT) to assist agencies in the review of their input data and the calculation of user benefits from the model outputs.

5.2.4 Toll Modeling

Consideration of tolled roadway facilities or geographic areas is a current application of TDF models. Among the policies needing to be tested are fully-tolled facilities, congestion priced facilities, high-occupancy toll lanes, and areawide pricing schemes. Congestion pricing uses variable tolls to help limit traffic levels on a facility to keep traffic moving. Users pay a toll tied directly to demand; the toll increases as congestion threatens to increase, so that demand can be reduced and higher speeds can be maintained. On high-occupancy toll lanes, transit vehicles and carpools are typically allowed to use the otherwise tolled facility free of charge.

In many cases, financing for tolled facilities is backed by private sector sources, whether the project sponsor is a government or the private sector itself. Issuance of these revenue bonds requires investment-grade TDF model forecasts to be performed. Such forecasts require extreme care in developing network inputs, occasionally new mode choice and trip assignment submodels, advanced post-processing of the TDF model results, and rigorous validation of the TDF model.

It should be noted that the full range of effects of some of the newer tolling policies are not readily reflected in TDF models. The mode, route, and time-of-day diversions caused by dynamic congestion pricing and areawide pricing are not easily captured in typical trip-end TDF models. Improving the ability to address the need for toll modeling is thus also among the evolving applications of TDF models.

5.3 Evolving Applications

The range of travel choices and transportation policy options available in regions has grown in recent years. Planning emphasis on livability, including consideration of the travel impacts of changed land use policies, enhanced nonmotorized facililties and services, expanded transit systems, usage of congestion pricing, and widespread teleworking, are demanding that TDF models evolve to better reflect the dynamics of this environment. That is, new questions are being asked to be answered with the results from TDF models.

Examples of evolving applications of TDF models include but are not limited to:

- Environmental justice issues such as the impact of transportation facilities on different income levels;
- Interaction between land use form and travel demand;
- Analysis of congestion pricing, both facility and areawide;
- Analysis of transit-oriented developments;
- Analysis of enhanced parking and travel demand management policies; and
- Project prioritization scenarios.

These types of questions challenge the limits of the traditional trip-end-based modeling approach. With the focus of the questions being asked by planners shifting beyond aggregate travel demand figures, additional consideration must be given to evolving the tools being used to provide answers.

6.0 TDF Model Results

TDF models produce large amounts of data and it is important to ensure that the results are interpreted and communicated effectively and accurately. It is also important to communicate the assumptions, uncertainties, and limitations that go along with the results. Activities to interpret and communicate TDF model results have the most interface with stakeholders not involved in the modeling. TDF model results are used by civil engineers, planners, decision-makers, and the general public.

6.1 Interpretation

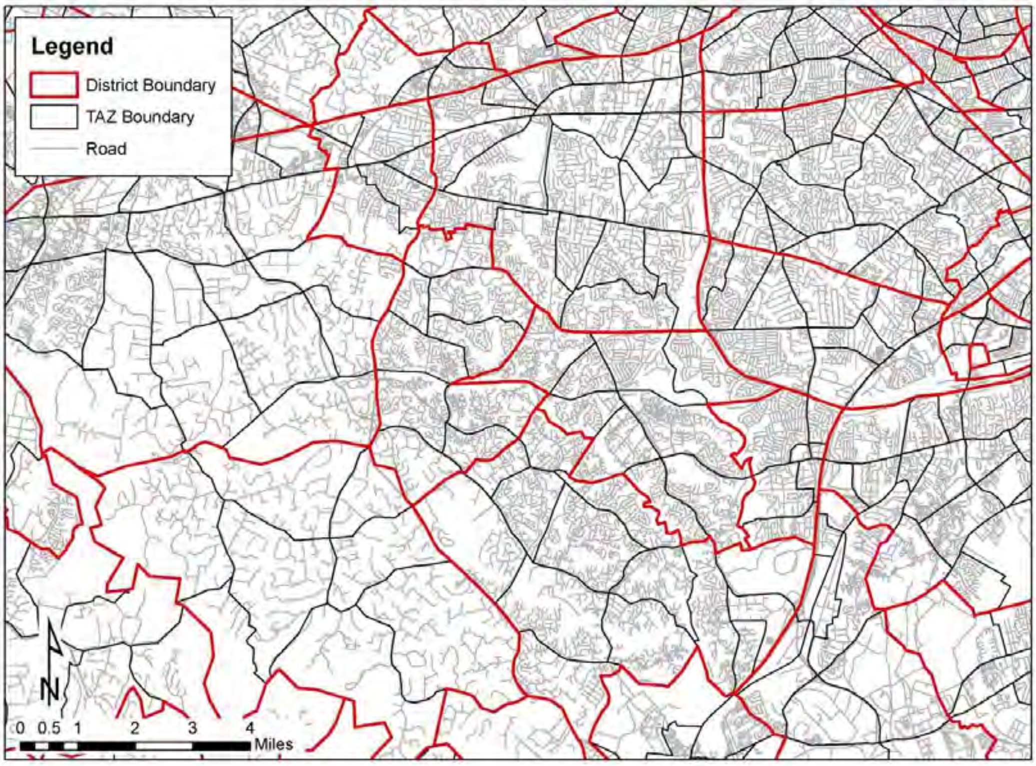
This subsection is organized into a series of discussion areas: "Organizing and Presenting Data," "Interpreting Trip Generation Results," "Interpreting Trip Distribution Results," "Interpreting Mode Choice Results," and "Interpreting Trip Assignment Results." In providing guidance on how to interpret results, typical model analysis framework has been applied which utilizes a baseline scenario compared against different alternative scenarios. The baseline scenario usually makes use of an adopted forecast and adopted regional transportation network plan. Not to be confused with the baseline scenario, there is also a model run produced for a base year which corresponds to the validation year of the model. The TDF model results for the different alternative scenarios are usually compared against the baseline scenario, and sometimes also against the base year. When performing these comparisons, focusing on both the absolute results and relative changes among scenarios can be very useful.

6.1.1 Organizing and Presenting Data

One of the difficulties of interpreting TDF model results can be the sheer amount of data that is output. Properly organizing and presenting the data is a first step in looking at the data and determining what the results can mean. The main data outputs from the modeling process are trip tables and networks with assigned trips. As it can be overwhelming to look at a large matrix of trip tables or network of thousands of small links and determine patterns and useful comparisons, one way to organize the data is to aggregate it into larger geographies, which are easier to interpret. Also, although calibrated and validated TDF models provide a representation of regional travel patterns, they are not built to provide the same level of confidence in results at the TAZ level.

Therefore, it can be beneficial to aggregate TAZ-level data and results to a district or jurisdictional level, as shown in Figure 6.1. If the particular area of interest is the downtown area of a city or central business district (CBD), TAZs in that area can be aggregated into a set of smaller districts, while outlying areas can be aggregated into larger districts. When working with large metropolitan regions, it can be useful to summarize trip tables using meaningful labels such as counties, towns, or cities in the region, so that it is easier to relate to versus using arbitrary TAZ numbers. Trip table aggregation can be built into the model process or can be done outside the model setup in spreadsheets or in a geographic information system.

Figure 6.1 Aggregating TAZs into Districts



In addition to examining the results in a geographic context, it is possible to examine them in a temporal context. Typically, results can be presented at the daily level, or split into morning peak, evening peak, and off-peak. For many transportation planning applications, travel must be estimated for specific hours or periods of the day. Daily results can obscure important details of the results as trip-making patterns such as commuting tend to be directional (i.e., traffic into the CBD is heavy in the morning and light in the evening, while traffic leaving the CBD is light in the morning and heavy in the evening). When looking at the daily traffic in and out of the CBD, commuting patterns may not be apparent.

While it is useful to look at these time-of-day patterns, there are frequently limitations on how time of day is modeled, and this should be made clear in presenting these results. Time-of-day factors can be stratified by both trip purpose and mode if mode-specific surveys and counts are available, otherwise the same mix is assumed across all trip purposes. *NCHRP Report 365*[20] discusses time-of-day characteristics in detail and presents diurnal distributions for different size urban areas (although more recent data from the National Household Travel Survey or local data may be preferable to use). As a common rule of thumb, peak-period volumes can be estimated by multiplying the daily volumes by a factor ranging between eight and 12 percent.

6.1.2 Interpreting Trip Generation Results

The trip generation step outputs trip ends for each TAZ, both productions and attractions, by trip purpose. From these data, it is possible to see where trips are starting and ending, which is useful for comparing different land use scenarios and patterns. A common summary of trip generation data would be the number of trips starting and/or ending in a particular set of TAZs such as a central business district (CBD), as shown in the example in Table 6.1.

Table 6.1 Home-Based Work Trip Attractions for CBD Comparison Across Scenarios

Trip Attractions	Baseline Scenario	Added Employment in Suburbs Scenario	Added Employment in CBD Scenario
Total Region	4,000,000	4,500,000	4,500,000
CBD	750,000	750,000	1,000,000
CBD percent of Total	19%	17%	22%

The total number of trip ends in the region as a whole also is a good result to check at this stage, to ensure that the general level of trip-making is consistent with expectations. These summaries also can be reviewed at the trip purpose level for a more detailed level of information and understanding. While the later steps of the model are typically of more interest to the general public, it is important that the trip generation results are summarized and reviewed, to understand the level of trip making intensity in the region and to ensure that errors in this step are not propagated through the model. When the error propagates it can be harder to diagnose resulting problems later on in the modeling process.

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[20]Martin, W. and N. McGuckin, "Travel Estimation Techniques for Urban Planning," *NCHRP Report 365,* Transportation Research Board, Washington, D.C. (1998).

6.1.3 Interpreting Trip Distribution Results

The trip distribution step outputs trip tables by trip purpose in production and attraction format (although these can be easily converted to origin and destination format as described in Section 4.0). Trip tables present the number of trips between each pair of TAZs.

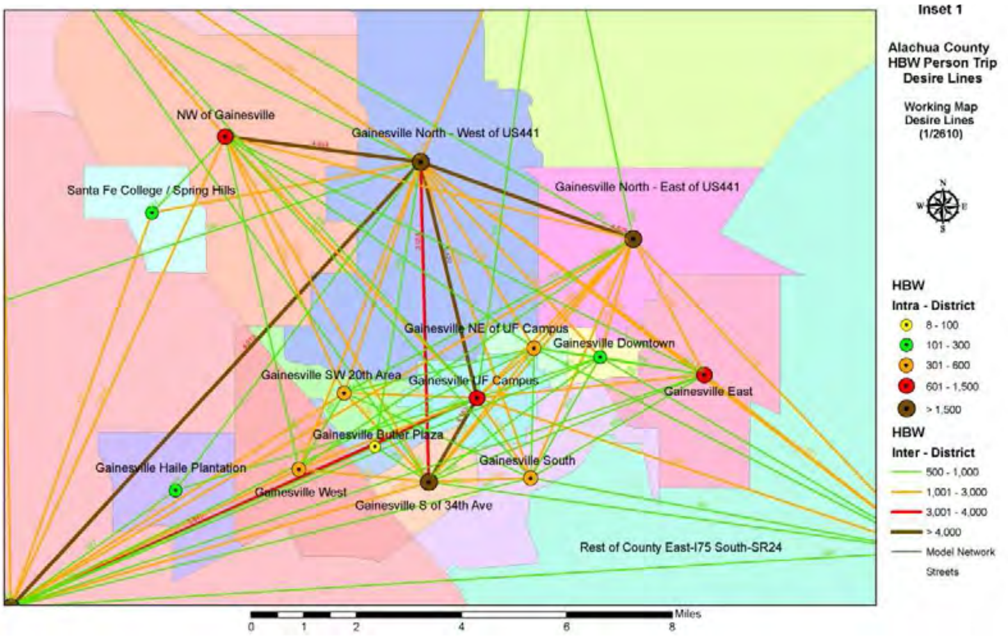
Whereas trip generation results indicate the number of trips that begin or end in an area of interest, trip distribution results indicate where these trips are headed to and from. Trip distribution results also reveal the dynamic of trip interchanges between residences and employment locations. As with trip generation results, since trip distribution results are output at the TAZ level, it is helpful to summarize results at a district or jurisdictional level.

One common method of presenting model results is to look at either the total number of origins or the total number of destinations to or from a particular area of interest. By comparing this metric across scenarios, it is possible to see how travel patterns change with different land use and network inputs. For example, if the area of interest gains a large amount of employment in a particular scenario, it is possible that the trips attracted to these areas could come from farther away than in the other scenarios.

Another format in which trip distribution results can be interpreted is to summarize the number of trips between a particular pair of interest areas, for example, the number of total trips from the financial district to the theatre district or the number of home-based work trips from a suburban district to a university district. Also of interest can be the number of trips that start and end in the same district, such as the number of trips that begin and end in the CBD.

A graphical way of interpreting trip distribution results is to generate a set of desire line maps using any of the commonly available GIS software. Many of travel demand forecasting model software packages also have built-in tools to create these maps. Apart from providing a quick visual interpretation of trip distribution results, they also present an opportunity to identify any potential issues at the trip distribution level. A sample desire line map is presented as Figure 6.2.

Figure 6.2 Sample Desire Line Map



6.1.4 Interpreting Mode Choice Results

The mode choice step outputs trip tables similar to the trip distribution step, but split by mode of transportation used. The different modes output vary according to the model design, but at a minimum typically include driving alone, shared ride (carpooling), and transit. Some models provide splits of transit into access mode (e.g., walk to transit and drive to transit) and specific submodes (e.g., bus transit and rail transit). Mode choice results can be of particular interest, as many model analyses are done to evaluate attempts to use carpool or transit strategies to ease congestion.

Since model results for the mode choice step are similar to those from the trip distribution step (i.e., trip tables) the same techniques outlined in trip distribution can be employed to summarize and present the trip tables in a manner that can be effective. For example, mode share for trips originating or destined for a particular region of interest such as a CBD can be summarized, as illustrated in Table 6.2.

Table 6.2 Home-Based Work Mode Share Comparison Across Scenarios, Destined for CBD

Mode	Baseline Scenario	Added HOV Facilities Scenario	Added Transit Service Scenario
Drive Alone	70%	68%	69%
Shared Ride	15%	17%	14%
Transit	15%	15%	17%

When reviewing mode choice step results, it is important to look at the relative results across scenarios to see the impact of changes such as adding transit service. Particularly for areas which do not have a high transit mode share, such as suburban and rural areas, and for trip purposes other than home-based work, it can be helpful to examine the total number of transit trips and look at the differences in transit use only between scenarios. Tables 6.3 and 6.4 provide an example of such a case, showing the overall transit mode share and the summary of transit trips for a test that added employment in a CBD and looked at two alternative network enhancements. Table 6.3 does not show a large change in the magnitude of transit mode share with added transit service, but looking at the number of trips made in Table 6.4 highlights the size of the transit usage increase which occurs with the added transit service.

Table 6.3 Non-Home-Based Mode Share Comparison Across Scenarios, Destined for CBD

Mode	Baseline Scenario	Added HOV Facilities Scenario	Added Transit Service Scenario
Drive Alone	60%	55%	59%
Shared Ride	37%	42%	36%
Transit	3%	3%	5%

Table 6.4 Non-Home-Based Transit Trip Comparison Across Scenarios, Destined for CBD

	Baseline Scenario	Added HOV Facilities Scenario	Added Transit Service Scenario
Total Trips	200,000	250,000	250,000
Transit Trips	6,000	7,500	12,500
Percent Increase over Baseline	–	25%	108%

Many times there is interest in nonmotorized travel. Most TDF models are not designed to address nonmotorized travel explicitly or, if they do, it is not addressed through all steps in the model (e.g., may only be addressed in trip generation). There are a number of reasons for this, including challenges with data availability and challenges with the scale of the trips relative to the scale of the TDF model detail. In cases where the TDF model does produce information on nonmotorized travel, it should also be summarized and reported as part of the interpretation of results.

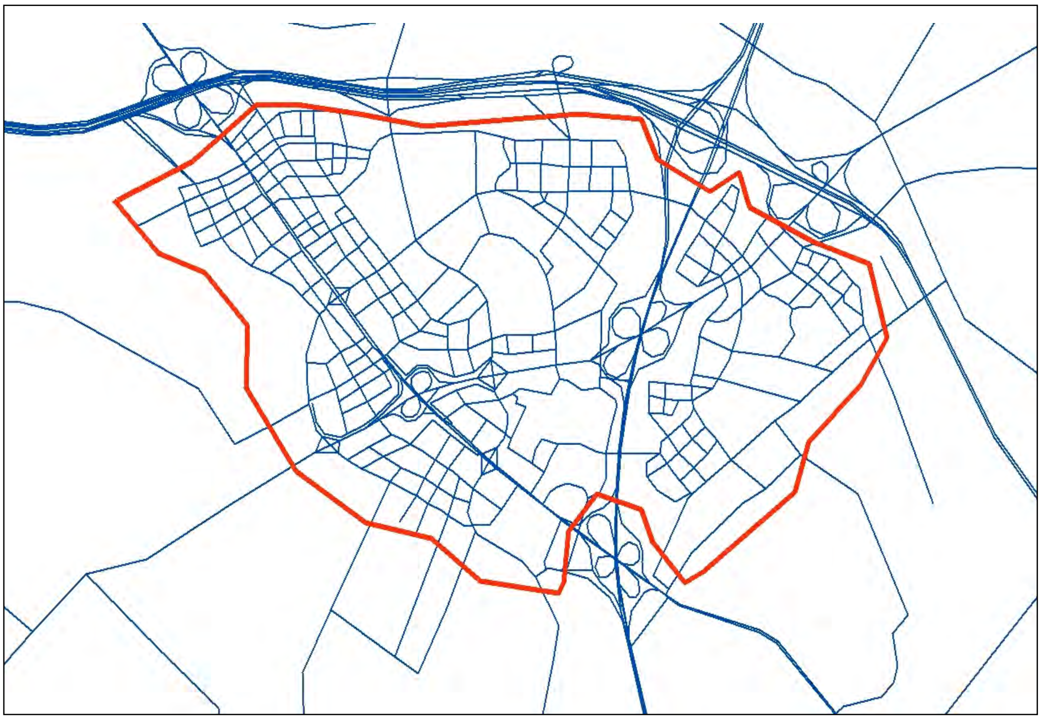
6.1.5 Interpreting Trip Assignment Results

The trip assignment step produces the results which often receive the most scrutiny. This step outputs roadway and transit networks with the traffic volume identified on each link by each mode, and typically with the time of day they are taken when a time-of-day model is available. As with the previous model steps, the complexity of the results grows the further along the model stream, and therefore in trip assignment there are many ways to examine and present the data.

An example metric which provides an overview of the service consumed from the assignment is vehicles miles traveled (VMT). VMT is a measure of travel and it sums up the distance of every vehicle trip on the network. VMT is calculated by multiplying the vehicles on a link by the distance of the link. VMT represents service consumed and shows the amount of travel on the network. VMT can usually be classified by facility type or area type. Reviewing the growth and change in VMT can be a a useful metric at a macro level to see how the transportation system performs. However, it is important to understand that changes in congestion levels and VMT are not always correlated (i.e., VMT does not necessarily fall with increased congestion).

Macro-level results can be assessed by using screenlines or cordon lines. Screenlines and cordon lines are imaginary lines that are placed across all roadways covering a specific movement. Screenlines usually follow a natural barrier, such as a river or railroad tracks, dividing the study area into districts. Cordon lines are similar to screenlines but are circular. Cordon lines often enclose an area such as a CBD in an effort to sum up all traffic crossing the identified links, which is useful in looking at traffic entering and leaving an area, rather than looking at individual links. An example of a cordon line can be found in Figure 6.2.

Figure 6.3 Network Cordon Line



Using screenlines and cordon lines, it is possible to analyze access and egress points and identify deficiencies and capacity constraints of the network. Cordon lines are especially helpful when used with time-of-day results, due to directional traffic patterns. Taking an example of testing the adding of employment in the CBD, looking at the traffic entering the CBD in the morning peak and comparing it to the capacity of the access points will help determine if the network can support the added jobs. The goal for any screenline or cutline comparison is to have 100 percent of the observed traffic replicated by the model, but there is a generally accepted tolerance of +/- 10 to 20 percent for screenlines and cordon lines. Acceptable deviation from the count data can be different depending on the highway facilities and the magnitude of the volume of traffic.

Travel demand forecasting models typically are not validated for travel time in the network, but model travel times can provide useful information when presented in a comparative way. Table 6.5 shows an example of changes in model travel time for scenarios adding employment only, and adding employment and roadway projects. Changes in model travel times also are a good way to show network impacts and compare different alternatives. However showing model travel times might confuse stakeholders and the public. People can become fixated on the model travel time value as it compares to their daily travel experience. The important things to remember are that model travel time represents impedance in the model and that the relative changes among alternatives is of most value.

Table 6.5 Home-Based Work Travel Time Comparison Across Scenarios, Trips Destined for CBD

	Baseline Scenario	Added Employment Scenario		Added Employment and Roadway Projects Scenario	
	Travel Time	Travel Time	Difference	Travel Time	Difference
From Suburb A	20 minutes	22 minutes	10%	18 minutes	-15%
From Suburb B	30 minutes	35 minutes	17%	25 minutes	-7%

Level of service (LOS) is a measure that determines the effectiveness of a transportation element. LOS for highway links is usually specified with letters ranging from "A" to "F," "A" being the least congested and "F" being over capacity. LOS "A" represents near free-flow conditions and LOS "F" represents traffic flow break down and poor conditions. There are several techniques that can be used to calculate LOS by roadway type, and volume-to-capacity ratios (V/C ratios) have been commonly used as a proxy for LOS. Although not a direct output of the TDF model, the assigned traffic volumes can be used to calculate V/C ratios and hence interpret the LOS offered by the link.

Due to the complexity and large amount of data produced by the TDF model, it is often necessary to apply post-processing activities to the results to get a useful and manageable set of metrics for comparison against various scenarios or alternatives. Post-processing refers to technical procedures that are applied to the results of the TDF model for later application. As mentioned in Section 4.0, technical reports such as *NCHRP Report 255* provide standard procedures for post-processing highway traffic forecasts from raw model outputs. These refined or smoothed results are key inputs into the project planning process and *NCHRP Report 255* provides an example of how model results can be used in project planning studies.

6.2 Communicating Results

When communicating results, it is important to keep the message simple and concise. When preparing a presentation on model results to the layperson, it is best to focus on three major take away points for the audience that sum up the analysis. Providing information overload can cause people to lose sight of the key results and findings. The role of the forecast is not to make a decision but to inform those who have to make decisions of potential impacts of the scenarios being studied.

A successful communication effort involves transparency of the TDF model process and being able to explain:

- Assumptions that were made, such as the cost of travel, and the underlying land use patterns;
- Adjustments that were made to the results: how they were made and why; and
- Key observations from the model results across scenarios.

Clearly describing the TDF model process is an important part of communicating results and will determine how well the audience understands the results and the extent to which the audience perceives that the process and results are valid. Portraying the process as a black box does not serve anyone well.

The remaining subsections provide context for the TDF modeling process, including a discussion of roles and responsibilities and an acknowledgment of uncertainty in forecasting.

6.2.1 Roles and Responsibilities

Transportation planning is a very dynamic process and requires the active involvement of many parties. From traffic engineers to city planners to the general public, each contributor has something distinct to offer to the process. It is therefore necessary that the strengths of each party are realized and maximized through collaboration. For example, traffic engineers know about traffic flow and traffic analysis; city planners know about socioeconomic data and development trends within their community. All the parties involved need to work together for successful outcomes.

As Section 2.0 highlighted, the TDF model cannot dictate final outcomes of the planning process. That is, the TDF model is one input to the process – it is does not make a decision, rather it informs decision-making. The model takes a set of inputs defined by planners and engineers working together, usually transportation networks and planned land use, and generates a travel demand forecast. The TDF model is based on the best data on how travel choices are made, and the goal of the TDF model is capture how individuals make the decisions that impact travel demand given a set of future year conditions. The model is often the best tool available, but it has limitations which must be balanced when making decisions with it.

6.2.2 Acknowledgment of Uncertainty

There are limitations inherent in the modeling process which must be acknowledged, as discussed in Section 2.4. These limitations lead to uncertainties in the results, which must be taken into account when examining the model results. Uncertainty can come from all parts of the model, including the assumptions, inputs, type of model, and type of application. It is therefore important to thoroughly document the model process undertaken to obtain a travel demand forecast, and clarify areas of uncertainty or steps that were taken to illuminate areas of uncertainty, such as reasonableness checking and sensitivity analyses. Section 7.0 discusses this topic in more detail.

Regional TDF models are developed to reasonably represent travel patterns on a regional basis. Uncertainty with results increases as the geographic area under consideration become smaller and the questions asked of the model become more nuanced. For instance, model output covering a particular corridor or subarea would be viewed as having a higher level of confidence than would model output for a particular link of the network within that corridor. Many times there is strength in aggregation, but other times aggregation can hide mistakes. Finding the balance can be a challenge but understanding the level of validation can provide guidance on using the results.

Another type of uncertainty that can be introduced into model results has been termed optimism bias[21]. Optimism bias is a demonstrated tendency of people to overstate a positive outcome of a situation and to minimize the risk for negative outcomes. In a modeling setting, this translates into peoples' biases shaping the results such as not adequately checking high demand figures for a proposed new toll road or high ridership forecasts for a transit fixed guideway that are popular with project stakeholders. Keeping optimism bias out of the TDF model process and analysis is important and can be mitigated by having a transparent process with documented assumptions and defined roles between modeler and planner. The role of asking questions about model assumptions can fall to planners and decision-makers.

Potential limitations and uncertainty with results should not be reasons that planners should be scared away from wanting to use a TDF model to help inform decision-making. This discussion is meant only to encourage good due diligence and concern for appropriate use of TDF models. Even though no TDF model is perfect and all TDF models have limitations, if one works without the benefit of a TDF model forecast then by default there will still be forecasts made of what will happen. But, these forecasts may not have the benefit of any of the rigor of a TDF model process. The use of non-modeled forecasts can thus have a higher cost than simply working with and acknowledging limitations of the TDF model.

[21] Flyvbjerg, B. How Optimism Bias and Strategic Misrepresentation Undermine Implementation. *Concept Report*. No. 17 Chapter 3 (2007).

7.0 Reasonableness and Sensitivity

Model validation tests the ability of the model to predict future travel behavior by comparing the model predictions with data other than what was used in estimating the model. Validation procedures are important in establishing the credibility of the TDF modeling process with planners, policy and decision-makers, and members of public. Validation results also are useful in establishing that the model results are accurate enough to be used for planning analyses.

The two major categories of validation checks are reasonableness checks and sensitivity tests. Reasonableness checks and sensitivity tests are used to evaluate the reliability of models and can range from a simple assessment of the reasonableness of model outputs to sophisticated statistical techniques. The type of analysis being supported by the model, such as policy analysis or project planning, can dictate the type of validation exercises employed. Model validation required for the analysis of a highway expansion will differ slightly from model validation for policy analysis; in other words, it must be context specific. Model validation required for FTA New Starts projects, will be different from model validation required for subarea, sector, or corridor studies.

The remainder of this section discusses reasonableness checks and sensitivity tests in more detail.

7.1 Reasonableness Checks

Reasonableness checks include logic checks, checks of error levels, and comparison of benchmark statistics:

- Benchmark statistics should be checked against observed values, estimates in other regions, national averages, as well as secondary data sources for consistency. Examples would include aggregate trip rates, percentage of trips by purpose, and average trip lengths.
- Models should be evaluated in terms of their ability to perform according to theoretical and logical expectations.

The remainder of this subsection discusses important aspects of reasonableness checking, including "Source of Error," "Sources of Validation Data," "Trends Checking," "Typical Mode Splits for Urban Area Types," and "Traffic Count Accuracy and Validity of Traffic Forecasts to Identify Project Needs."

7.1.1 Sources of Error

There are several sources of potential errors in developing a TDF model. These include:

- **Coding Errors** – Errors in coding the highway and transit networks, and errors in recording survey results.
- **Sample Errors** – Errors from bias that occur in the survey sample frame. An example is a telephone survey where only land lines are reached for the survey calls. This would miss households without land lines, potentially resulting in a demographic bias in the observed travel patterns (i.e., missing low income housheholds with no phone, young or very active persons with cell phones only, etc.).
- **Computation Errors** – Errors which occur in developing the model programs.
- **Specification Errors –** Errors from improper structure of the model where key variables or parameters are overlooked in the estimation phase. Errors from transferring model parameters from one region to another.
- **Data Errors** – Error in underlying model data or through aggregation of data where key elements are overlooked.

Being aware that these types of errors can creep into the forecasting process can be crucial for understanding TDF model output.

7.1.2 Sources of Validation Data

A variety of data sources may be employed in performing model validation. These may include both local and national data. Nationally available survey datasets such as the Census Public Use Microdata Sample (PUMS), the Census Transportation Planning Products (CTPP), the National Household Travel Survey (NHTS), and the American Community Survey offer travel behavior data at various geography levels. Other validation data sources include:

- Local household survey data;
- Traffic and transit ridership counts;
- Highway performance monitoring system (HPMS); and
- Nationally collected and compiled travel behavior data sets.

While not an independent source, the calibration data set (typically from a household travel survey) can be used in validation. Other travel surveys may also be available for validation such as transit on-board surveys, workplace/ establishment surveys, roadside intercept origin-destination surveys, and external cordon surveys. Careful review of survey data can lead to an understanding of what should be expected from the model and can help pinpoint potential issues. Summarizing survey data in many of the same ways that model outputs are summarized can greatly facilitate these comparisons.

7.1.3 Trends Checking

A variety of trends or changes should be expected to be reflected in the TDF model output. Simple trend checks are good reasonableness tests for model validity, understandable by planners and policy-makers. Trends affecting travel demand include, but are not limited to:

- Demographic growth;
- Composition of the labor force;
- Immigration and emigration;
- Regional economic development;
- Modal share;
- Vehicle occupancy;
- Average trip length;
- Travel cost; and
- Freight transport.

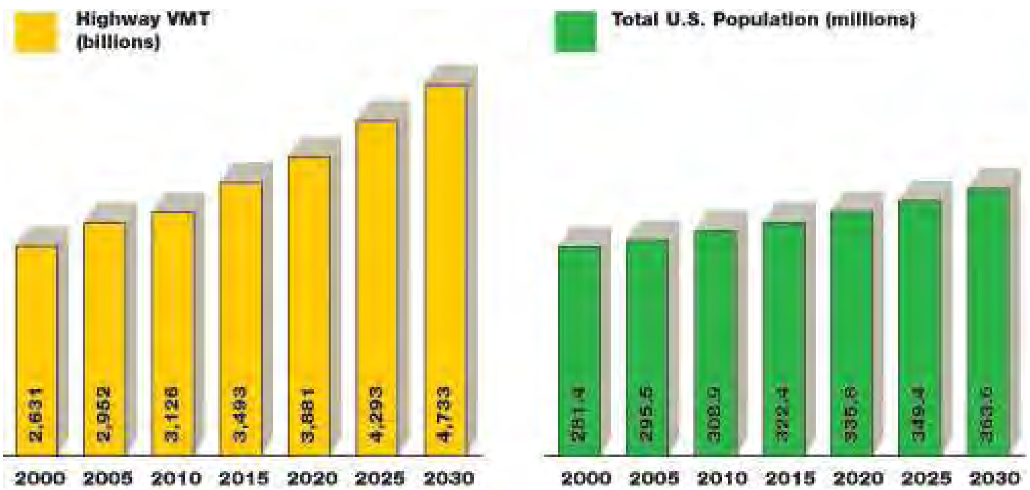
For example, if there is an increase in regional households, there can be an expected increase in travel. If there is a new transit system built, mode share can be expected to shifted towards that transit mode, especially in the corridor where it operates. If port activity is expected to increase, there should be a corresponding increase in truck volumes.

TDF models use socioeconomic data to reflect underlying activity in a TAZ. Significant changes in socioeconomic input data such as households and employment must be evaluated for reasonableness with respect to regional and local growth rates, in absolute and relative terms. A number of relationships among different variables, such as persons per household, jobs per person, jobs per worker, autos per household and employment and population densities can be checked through sorting or mapping and by comparing them to regional and national statistics.

Expectations checking may also be a useful approach to reviewing model results. The planner asks and answers the question "Does that make sense?" when reviewing the model output against the expectations. The purpose is not to try and bias results towards an expected outcome, but to understand why the results reflected in the model output are being obtained. Do tolls introduced on a highway decrease the amount of traffic expected on the highway? Does an increase in transit fare decrease transit patronage? If expected trends do not result from the model then further investigation into the model calibration and validation may be warranted. That is, the result may be correct, but it should be confirmed. Caution should also be used when performing expectation checks so as not to introduce optimism bias into the results (discussed in Section 6.2).

A clear understanding of the planning area's characteristics and typical travel behavior also plays a key role in reasonableness checking. For example, Figure 7.1 shows the U.S. population and VMT estimates from 2000 to 2030 and indicates that VMT is growing faster than the total population in the U.S. most likely due to increasing per-capita auto ownership. However, in large urban areas where congestion is already a major issue and is expected to increase in the future, it is unreasonable to expect the same rate of growth in VMT as experienced in the country as a total. The rationale behind this expectation is that as congestion continues to grow in the urban areas it takes longer to travel the same distance than it did earlier, which means that people are spending more time in their cars traveling shorter distances. Since most people budget a certain amount of time to get to their destination, people will likely decide to drive to closer destinations such as restaurants or shopping malls than before. This might result in a slowing VMT growth trend.

Figure 7.1 U.S. Population and Vehicle Miles Traveled (VMT)
2000-2030



Source: U.S. Department of Transportation[22]

Along with testing the whole model set, individual model components should also be tested by predicting demand for a different base year than what was used for model estimation. This exercise is often referred to as backcasting. Backcasting is a good way to test the validation of the model set. The challenge can be in assembling the land use and network inputs. It is common with model

[22]U.S. Department of Transportation, *Transportation Vision for 2030*, Research and Innovative Technology Administration, Washington, D.C. (2008).

updates to change TAZ structures, but this can make it a challenge to load model inputs compiled in the old TAZ system into the new TAZ system.

7.1.4 Typical Mode Splits for Urban Area Types

Table 7.2 and Table 7.3 provide mode share for major cities and central business districts across the Unites States, sorted by transit mode share. These tables provide reference mode shares and can be used to perform simple reasonableness checks on model results. While the mode shares presented in these tables are derived from survey data, it can also be useful to present reference mode shares from the model for a selection of locally identifiable areas when presenting model results to help show that model outputs for a study area are reasonable. That is, have the model produce mode share output for both the study area and for some familiar known locations.

Table 7.1 Reference Work Trip Mode Shares for Entire Cities

City	Transit	Carpool	Drive Alone
Dallas, Texas	4%	15%	81%
Pasadena, California	5%	16%	79%
Houston, Texas	5%	15%	80%
Atlanta, Georgia	10%	14%	76%
Baltimore, Maryland	14%	14%	72%
Oakland, California	15%	15%	70%
Pittsburgh, Pennsylvania	20%	13%	68%
Boston, Massachusetts	40%	10%	50%
San Francisco, California	41%	16%	43%
New York City, New York	61%	9%	30%

Source: CTPP 2000 for work-trip destinations

Table 7.2 Reference Work Trip Mode Shares for Central Business Districts

Area	Transit	Carpool	Drive Alone
Dallas Central Business District	13%	15%	72%
North End and West End Boston	47%	9%	44%
Downtown Boston	56%	8%	36%
San Francisco Financial District	60%	12%	27%

Source: CTPP 2000 for work-trip destinations

7.1.5 Traffic Count Accuracy and Validity of Traffic Forecasts to Identify Project Needs

Traffic counts are used for validation and also as an important input to the post-processing required to develop design hour volumes from TDF model output as described in Section 6.1.5. Annual Average Daily Traffic (AADT) is the total annual traffic estimate divided by the number of days in the year. Many state DOTs have traffic count divisions that administer traffic count programs. DOTs typically collect 24-hour counts throughout the year at permanent count stations which are referred to as "continuous count stations." Some DOTs augment this coverage by collecting counts once annually or every few years at additional locations on a rolling basis. AADTs at these count locations for the "off" years are estimated based on historic growth rates, professional judgment, and growth rates on other highway links with similar characteristics in the area.

Whenever possible, the highest quality of count data available for the highway link should be used for TDF model validation processes. Manual and mechanical errors such as broken tube counters often creep into the system, so extensive care should be taken in preparing traffic counts for the validation process. For example, a simple reasonableness check is to review multiple traffic counts on the same section of interstate between the same interchanges; if such counts exist, they should be very similar since the entry and exit of all traffic is controlled.

The most desirable time of the year to conduct traffic counts is in the nonholiday months when schools are in session – March, April, and October. It is important to keep in mind that traffic is dynamic and depends on the time-of-day, day of week, season, and other factors that influence driving conditions such as weather or major incidents. Table 7.3 illustrates the variation of traffic flow by month. A traffic count only provides a snapshot in time of the traffic volume but can be used to identify trends and patterns. AADT is one of the most common count statistics but the need for average weekday traffic volumes for travel demand forecasting work is also important. Given the region and the concerns of that region, weekend traffic also might be important in validating certain areas such as major shopping districts or entertainment attractions.

Table 7.3 Variation of Traffic Flow by Month

Average Wednesday Traffic by Month for I-270	Average	% of AADT
January	87,580	89.28
February	95,187	97.03
March	100,925	102.88
April	101,038	103.00
May	100,278	104.84
June	104,857	106.89
July	107,144	109.22
August	106,330	108.39
September	100,586	102.54
October	100,117	102.06
November	101,430	103.40
December	99,496	101.43

Source: Maryland State Highway Administration, Highway Information Services Division (2009)

7.2 Sensitivity Tests

Proper model sensitivities are important in both project planning and policy testing. In other cases, the need to reproduce observed roadway and transit volumes might be relaxed for models used for policy testing if the model sensitivities are reasonable. This might be due to the available of resources and/ or differences in the project focus.

Different types of changes in the transportation system have different impacts on travel behavior. Sensitivity testing in TDF models relates to the analysis of the variation in the model outputs and how it can be apportioned to the variation in the model inputs. Sensitivity testing can also measure how robust the model is, be used to test alternatives, support decision-making processes, improve understanding of relationships in the model, and help in identifying errors in the model.

Sensitivity analysis should be used for all components of the modeling process prior to the application of the model for forecasting. Sensitivity tests can be used to test the response of the model to changes in the transportation network, socioeconomic growth, policy changes, and change in costs. Typical sensitivity test may include:

- An increase in households and corresponding increase in travel;
- An increase in transit fare and the corresponding decrease in transit mode share; and

- The removal of key highway infrastructure and the changes in VMT from changes in travel routes.

7.2.1 Elasticity of Demand

Sensitivity is commonly measured using elasticities. A comprehensive guide to calculation and usage of elasticities appears in the *TCRP Report 95*, Chapter 1, Appendix A, "Elasticity Discussion and Formulae" (available as *Research Results Digest 61*[23] at this writing).

Elasticity quantifies the responsiveness of travel demand to changes in the value of an influencing variable. For example, elasticity of demand to transit fare can be roughly defined as the percentage change in transit ridership resulting from every one percent change in transit fare. In the transportation arena, a number of elasticities could be of interest, including the elasticity of demand to changes in parking price, transit fare, transit service level, travel time, and vehicular operation costs.

There are two major components of an elasticity value. The "magnitude" or absolute value and the "sign."

- A positive sign indicates the cause and effect are in the same direction, which means that if the value increases or decreases, the demand correspondingly increases or decreases; and
- A negative sign indicates that the effect operates in the opposite direction of the cause.

Take as an example the elasticity of demand for a consumer product (milk). As the price of a gallon of milk increases, the demand for it goes down, so it therefore has a negative elasticity. The same concept applies to transit ridership. A transit fare elasticity of -0.3 means that with every 1.0 percent increase in transit fare, transit ridership decreases by 0.3 percent.

A high elasticity indicates that a relatively small change in value will cause a relatively large change in demand. A low elasticity indicates that price changes have relatively little impact on demand. Elasticity of demand absolute values less than 1.0 in magnitude indicate that the quantity is inelastic, meaning that a change in its value causes less than proportional and relatively small changes in its demand. For example, a 10 percent increase in gasoline prices only reduces auto usage by two percent. Elasticity of demand absolute values greater than 1.0 are called elastic, meaning that a slight change in its value leads to a relatively larger change in its demand.

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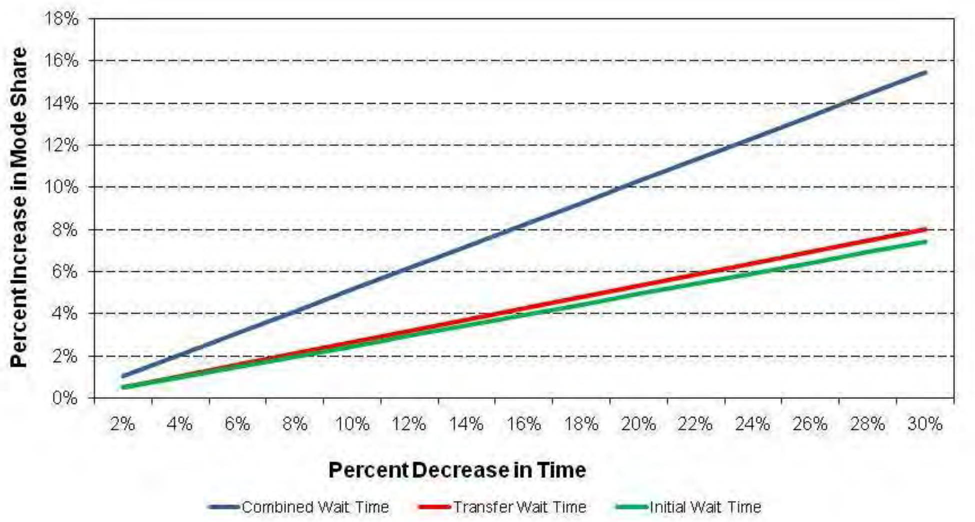
[23] Transportation Research Board, "Traveler Response to Transportation System Changes: An Interim Introduction to the Handbook," *Research Results Digest 61*, Washington, D.C. (September 2003).

Figure 7.1 shows an example of transit wait elasticities with respect to transit model share. The x-axis shows the elasticity values for initial wait time, transfer wait time, and combined wait time (initial wait time plus transfer wait time) and the y-axis shows the transit mode share. If there is a four percent improvement in the combined wait time, transit ridership increases by about two percent, as the elasticity value of the wait time increases to 0.20, the transit mode share increases to 10 percent.

Figure 7.2 Elasticity for Wait Time to Mode Share



Elasticities are a measure of responsiveness and should not be used as a precise predictive measure, but rather as a tool that indicates the relative change in a variable to changes in it parameters. There are three different methods commonly found in the transportation literature for computing elasticities:

- Point elasticity;
- Arc elasticity; and
- Shrinkage ratio.

These three measures of elasticity yield approximately equal values for relatively small price changes. For larger differences, results differ depending on the formula used. The shrinkage ratio begins to deviate significantly from the other two for large changes. *TCRP Report 95* provides the formulae for all three approaches.

7.2.2 Sensitivity Model Runs

Elasticities can be helpful to evaluating the expected outcome of single attribute changes, but the TDF model is capable of analyzing multiple changes simultaneously. For many studies, it is useful to perform model runs with limited-changes to evaluate the sensitivity of the model outputs. When the planner or decision-maker is presented with the results from these limited-change scenarios, it may be possible to understand the relative importance and impact of the various change agents and help inform the decision-making process. Knowledge of elasticities can be helpful in viewing these model results for reasonableness, because they can inform expectations for outcomes.

7.3 Additional Resources

For the interested reader, a number of additional guidebook resources exist which could prove useful in further building upon the planners ability to understand, evaluate, and communicate model results. As part of the development of this guidebook, several such resources were reviewed (this review appears as Appendix A). For planners, the following may be among the best quick picks:

- *Introduction to Travel Demand Forecasting Self Instructional CD-ROM*[24] is designed for managers, executives, and policy-makers. It provides a broad overview of the Travel Demand Forecasting process. This type of material helps users to understand the results and processes without getting mired in the details.
- *A Transportation Modeling Primer*[25] provides an overview to modeling and attempts to shine light on the assumptions underlying the urban transportation modeling process and how it works. The primer identifies some of biases and other problems that can affect the forecasts that modeling produces and offers suggestions for how to advocate ways to improve the model sensitivity to land use and transportation policies designed to promote alternatives to driving.
- Finally, the website of the FHWA Travel Model Improvement Program offers a wealth of linked and referenced resources (http://tmip.fhwa.dot.gov/).

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[24]FHWA, *Introduction to Travel Demand Forecasting Self Instructional CD-ROM,* Washington, D.C. (2001).

[25]Beimborn, E., *A Transportation Modeling Primer,* Center for Urban Transportation Studies University of Wisconsin-Milwaukee, (May 1995, updated June 2006).

A. Literature Review

A1.0 Introduction

Travel demand modeling is often considered to be a complex and complicated field dominated by highly specialized technical practitioners. The task of making the forecasting process and its results readily understandable for non-technical planners and the general public has long been a challenge.

This section is a literature review, undertaken in order to ascertain what work has already been done in this field and what resources already exist. This literature review covers readily available guidebooks, user manuals, training materials, glossaries, and web sites discovered as part of an extensive review of potential source materials. Selected examples of text and visuals from these sources are replicated with appropriate references. These sources were used as a starting point for development of the guidebook. The materials were primarily reviewed to ascertain their design, methods used to convey technical information, and general contents, with a focus on four topics:

- Components of the guide;
- Understanding the forecasting process;
- Interpreting and applying model output; and
- Communicating results.

The documents and agencies mentioned in this review were found to be useful with respect to the goals and objectives of this task. They were not the only documents or agencies reviewed, but were judged to be the ones that had the most relevant material in terms of the stated objectives. The selected sources provide insight into how modeling information can and should be conveyed to non-technical professionals, but may not contain the most up-to-date information about state-of-the-art or state-of-the-practice modeling techniques.

A1.1 Audience of the Materials

Currently available guides and courses are aimed at a variety of audiences including policy-makers, senior executives, forecasters, planners, and the general public. The Federal Highway Administration (FHWA) Travel Model Improvement Program (TMIP) designed the *Introduction to Travel Demand Forecasting Self Instructional CD-ROM* for managers, executives, and policy-makers. It provides a broad overview of the travel demand forecasting process (FHWA, 2001). This type of material helps users to understand the results and processes without getting mired in the details. FHWA also periodically offers

Introduction to Travel Demand Forecasting as a webinar targeted at transportation modelers who have a low to moderate level of familiarity with the estimation and validation of travel models (FHWA, 2010). The language used assumes a familiarity with the modeling and forecasting process as well as the basic principles involved. Key terms are not defined because they are assumed not to be needed.

Travel Demand Forecasting: A Compilation of Plans, Reports, and Data for the Bureau of Transportation Statistics (BTS) and TMIP is designed towards an audience of forecasters (1997). In this case the writer includes more graphs, reports, and plans as the audience is typically expected to have a stronger grasp on the technical jargon and concepts and would therefore not need as many definitions. *The Geography of Urban Transportation* (Hanson and Giuliano, 2004) is a textbook geared towards planning and geography students who do not have a technical understanding of the modeling process. Chapter 5 of the textbook is devoted to the Urban Transportation Planning Process, and incorporates descriptions of the modeling process, the necessary inputs, and how the results may be used at a broad level. Similarly, Chapter 8 of *Transportation Engineering and Planning* (Papacostas and Prevedouros, 1993) also provides a basic introduction to the subject of modeling for technically-oriented students.

The National Highway Institute (NHI) offers a four-day course, *Introduction to Urban Travel Demand Forecasting*. Through classroom lectures and interactive workshops, this introductory course covers the traditional four-step modeling process of trip generation, trip distribution, mode choice, and trip assignment. The course includes presentations on land use inputs, network and zone structures, time of day factoring, and reasonableness checking. The course is designed for an audience which has already covered the FHWA *Introduction to Travel Demand Forecasting Self Instructional CD-ROM*, and has experience with college-level algebra, computer usage, and a scientific calculator (FHWA NHI, 2007).

The *FSUTMS (Florida Standard Urban Transportation Model Structure) Online Training* is written towards two distinct audiences. The *Executive Summary Modeling Seminar* (FSUTMS, 2010b) is designed for managers and other non-modelers who review model outputs. It is less detailed and provides a broader subject overview. The *Comprehensive Modeling Workshop* (FSUTMS, 2010a) is designed for more technical staff who need to learn how to use and operate models. Since technical staff are more familiar with the jargon and basics, the focus of this seminar is on the details and technical specifics.

The audience for both *A Transportation Modeling Primer* (Beimborn, 2006) and *Transportation 2040, Data Analysis and Forecasting at the PSRC, New Tools within Integrated Modeling Framework* (Puget Sound Regional Council, 2009b) are non-technical staff and the general public. Therefore both guides include an abundance of definitions and clarifications to make the overview of the travel demand forecasting process easier to comprehend. They include fewer figures, and those that are included are explained in detail. *A Transportation Modeling*

Primer is the more basic of the two guides, as the guide consistently breaks down the contents with clear headings, keeps sections short, and nearly every other sentence explains the previous one. PSRC assumes that readers have a somewhat higher level of familiarity and comprehension of the complex processes that are described. While each section is individually comprehensible, the excessive level of detail may overwhelm non-technical readers causing them to forget what has been previously introduced.

The Sacramento Area Council of Governments (*SACOG) Regional Travel Demand Forecasting Tools* (2009), presentation to the planning committee, is similar to the National Capital Region Transportaton Planning Board (TPB) article, "Forecasting Future Travel" (2003) in that forecasting knowledge is not assumed of the audience. The websites of SACOG, Atlanta Regional Commission (ARC, 2010), and St. Charles County, Missouri (2010) are designed for use by members of the public who may be interested in regional travel demand forecasting models. The websites include maps and information on specific regions.

Overall there are a variety of materials available aimed at audiences with different knowledge-levels and backgrounds. Some of the guides are general and others are specific to a certain MPO model and explain more the process of that model than provide an overall guide. There are some materials that speak to general audiences but are very lengthy and detailed. They do not fully lend themselves to being easily referenced material on the subject.

A1.2 BASIC FORMAT OF THE MATERIALS

The literature reviewed illustrates that there are numerous possible formats for a travel demand forecasting guide, including several different media types. For an audience that is comfortable with technology, the FHWA *Introduction to Travel Demand Forecasting Self Instructional CD-ROM* provides a course with two tracks (certificate and executive) which include audio as well as visual information and case studies. The instructional attitude lets the user feel as though the presentation is being given directly to them while allowing users to follow at their own pace, and start and stop the lesson whenever necessary.

SACOG and other presentation-style slideshows follow the same general principle although not as technologically advanced. ARC and St. Charles County offer "interactive" mapping that allows the user to view and query transportation geographic data or create customized maps. All of these materials provide for some level of user interaction to boost retention and comprehension of the information.

The use of exercises and homework to "test" the user is another format used in some of the source materials. The *Introduction to Travel Demand Forecasting Self Instructional CD-ROM* provides simple exercises periodically throughout the course to check that users understand the concepts being presented. *Transportation Engineering and Planning* includes example calculations on simplified networks of each step of the modeling process. An extensive selection of exercises is also included for use as homework.

FSUTMS Online Training includes two online seminars at varying levels of detail. An *Executive Summary Modeling Seminar* provides an overview of the transportation planning and modeling processes which takes about four hours to complete and results in a certificate. The *Comprehensive Modeling Workshop* is more detailed and also provides instruction in running and using a model. Exercises provided in both seminars are used to ensure comprehension of the presented concepts.

The FHWA Travel Model Improvement Program over the Web (Cambridge Systematics, 2009) includes nine online workshops which introduce the development of model estimation data sets, the structures of the various model components, and the procedures for estimating models. The workshops include lectures, discussion, and "homework" and materials including the presentation slides, question-and-answer, and homework are available online for download after the live workshop. Audio recordings of most workshops also are available online. Each of these allows the users to test their knowledge to ensure thorough comprehension.

Another approach found in the existing literature is to provide a broad spectrum of information for the user to search and read at their own individual speed. An example is the website for the National Capital Region Transportation Planning Board (TPB) which couples detailed text with flowcharts to describe the purpose of modeling, modeling process, and inputs to and outputs from the models. More technical documents such as the modeling manual guide and the calibration and validation reports are also available on the website. This allows the reader to delve into as much or as little information as desired, but does not provide a structured introduction to the topic and does not ensure that a non-technical reader is introduced to all the necessary and important information. The depth and content of the TPB website reflects the many demands on them, as well as the active citizen environment that exist in the region.

The Victoria Transport Policy Institute maintains an online *TDM Encyclopedia* (2010) that makes extensive use of text and hyperlinks to provide definitions and explanations on a range of related topics. The *TDM Encyclopedia* is a handy resource for information on traveler response to transportation system changes and includes elasticities, before and after results, and potential uses for a variety of strategies.

Documentation and Procedural Updates to the Florida Standard Urban Transportation Model Structure: Trip Generation Model (FSUTMS, 1997) follows a similar principle as the TPB website materials. It is a description of the modeling process, specific to FSUTMS and includes an overview of the model steps and more detailed technical information. Technical flow charts and sample maps are used to explain the process further. Sample calculations also are provided. Another description of the travel demand forecasting process can be found in *The*

Geography of Urban Transportation, a textbook that relies solely on text to describe travel demand models and how they relate to the overall transportation planning process.

The material in *Travel Demand Forecasting: A Compilation of Plans, Reports, and Data* (BTS and TMIP, 1997) is a compilation of a wide range of sources including 150 documents and 27 videos divided into 23 categories on a single CD. Search functionality is included and hypertext links are used to provide additional information or connections between documents. This format also lets the reader choose the level of detail desired, and if looking for a certain topic, the search feature is extremely useful.

A Transportation Modeling Primer and *Transportation 2040, Data Analysis and Forecasting at the PSRC, New Tools within Integrated Modeling Framework* each provide text descriptions of transportation and modeling. Graphics, flow charts, and maps are also used to explain specific points on each page. The guides also provide users with detail about a range of specific topics in descriptive paragraphs.

These materials reviewed highlighted the potential challenge of developing a format to provide sufficient detail while also introducing concepts, processes, and results of modeling to a non-technical audience that is more focused on the big picture. Non-technical audiences could be intimidated by details that a technical audience would require. Generally, it seemed that different formats were needed for different audiences.

A1.3 General Content of the Materials

The contents of each of the sources reviewed varied depending on the intended audience and the goal of each document. Some of the materials were developed to provide a broad overview of the modeling process to non-technical staff and executive-level managers and provide answers to general questions that these types of people are likely to ask. Other materials provide more detailed information on a wider range of topics enabling users to understand the details of using a model, or in some cases, even teach them how to run the model themselves.

For example, the FSUTMS *Executive Summary Modeling Seminar* includes details about each of the steps of the modeling process, the inputs used for each step, and the results of each step in a general way. The FSUTMS *Comprehensive Modeling Workshop* provides enhanced details on each of these subjects. The *Executive Summary Modeling Seminar* covers the trip generation step in 12 slides that cover trip purposes, trip ends, trip definitions, socioeconomic inputs, and types of trips. The *Comprehensive Modeling Workshop* uses 74 slides to cover trip generation and additionally introduces topics including productions and attractions, centroid connectors, input and output files, zonal attributes, special generators, model types, trip balancing, and external trip modeling.

Generally, almost all of the source materials included some basic elements including a definition of travel demand forecasting and a description of the steps of the modeling process at varying levels of detail. Other topics covered by the majority of available sources include:

- Model Networks;
- Trip Generation;
- Trip Distribution;
- Mode Choice;
- Highway Assignment;
- Transit Assignment;
- External Trips;
- Model Results;
- Uses of a Model; and
- Data requirements.

Some of the sources cover additional, more-specific topics such as nested logit models, model validation, model calibration, regression modeling, discrete choice modeling, elasticity, and post-processing. The BTS and TMIP *Travel Demand Forecasting: A Compilation of Transportation Plans, Reports, and Data* includes details on many topics of interest to technical modelers that may not need to be addressed in a guide for non-technical staff or the general public.

Several of the reviewed sources are designed to instruct users on how to use a specific model, and not necessarily about the forecasting process. These sources, including the TPB documentation, the ARC model documentation, and, to some extent, the FSUTMS *Comprehensive Modeling Workshop*, include model structures, input/output files, and instructions specific to the individual model being presented.

Several of the materials also include a larger-scale description of how travel demand modeling is related to the transportation planning process as a whole. Discussions of how the results of travel demand models are used can be found in both of the FSUTMS workshops and the textbook, *The Geography of Urban Transportation*.

A2.0 CONVEYING THE FORECASTING PROCESS

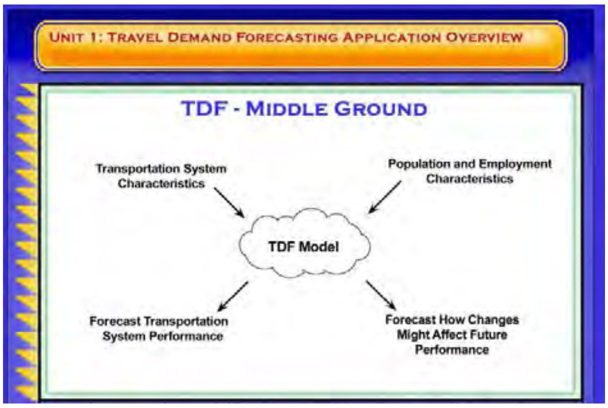
Each source in the literature review included a definition of the travel demand forecasting process. As detailed in the previous sections, a variety of media, technology, and formats were used. The sequential nature of the travel demand forecasting process led the majority of the sources to use graphics and flow charts coupled with text explanations to describe travel demand forecasting as a process. Overall, each source had two main purposes: to define and explain the types of models, and to explain why modeling is important to planners and the planning process. The sources have done this in a variety of ways by including an array of different content elements.

When defining a travel demand model and the types of models, the FSUTMS *Executive Summary Modeling Seminar* uses a mathematical description of a transportation system's characteristics. It then categorizes forecasting in two ways: by mode and by geography. TPB, taking a similar route, indicates that a regional transportation model is a mathematical representation of the supply and demand for travel in an urban area. As an alternative, *The FHWA Travel Model Improvement Program over the Web* outlines that there are four-step models, three-step models (those without mode choice) and tour- and activity-based models. Meanwhile, SACOG defines travel demand forecasting as a computerized representation of a geographic area which includes land uses, roadways, and costs.

For the second purpose of attempting to explain why modeling is important to planners, the planning process, and how forecasting is used, two main paths are apparent in the literature. The FHWA *Introduction to Travel Demand Forecasting Self Instructional CD-ROM* utilizes flow charts and audio recordings to explain the role of travel demand forecasting in the planning process and the relationship between forecasting and legislation. Meanwhile, *A Transportation Modeling Primer* uses text to describe why the "transportation planning" is important, the Federal statutes that demand it, and the results of the process.

In most of the sources, these definitions were coupled with graphics of some sort that were used to describe forecasting visually. These types of graphics, a few examples of which are shown in Figure A2.1 and Figure A2.2, simplify the complex modeling processes into a visual description that is easier for non-technical staff to understand and remember. The visual aids help people see how forecasting works, without needing to know and understand all of the details.

Figure A2.1 Examples of Visual Description of Modeling Processes

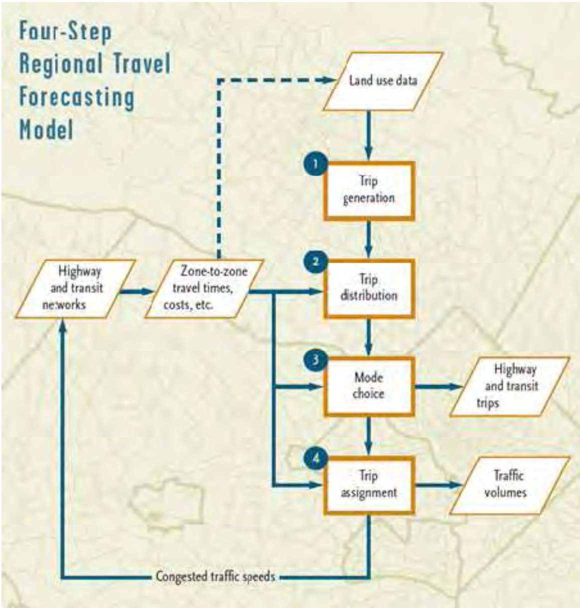


Source: FHWA (2001)

Source: FHWA (2001)

Source: FSUTMS (2010b)

Figure A2.2 Visual Description of Four-Step Regional Travel Forecasting Model



Source: National Capital Region Transportation Planning Board (2003)

In addition to the definitions used to describe the sequential steps in the travel demand forecasting process, several other elements were also found in the reviewed sources to help non-technical readers learn about the modeling process. The sources were reviewed to ascertain how an understanding of the forecasting process was conveyed. The following sections describe these findings.

A2.1 Basic Terminology (Glossary)

A glossary to define and explain terms was not included in all of the reviewed source materials. The FHWA *Introduction to Travel Demand Forecasting Self Instructional CD-ROM* uses a glossary of terms in a separate pop-up window accessible at any time throughout the course. This allows the user to easily review definitions as necessary, thus cutting down on the explanations needed within the actual text. *A Transportation Modeling Primer* and the *Executive Summary Modeling Seminar* do not include a formal glossary (although an extensive glossary is provided in the accompanying FSUTMS workbook), but terms are defined in the text as they are used. The review highlighted that it is helpful to use formatting changes to indicate where definitions are being presented, making it easier for a reader to return to the definition later. This type of formatting also enhances the reader's ability to skim the material.

Important terms in *Documentation and Procedural Updates to the Florida Standard Urban Transportation Model Structure: Trip Generation Model* are presented at the beginning of each section. A more comprehensive list of defined words would help readers with limited knowledge of technical forecasting jargon, and more comprehensive explanations of some terms within the text may also be desirable. The majority of the sources do not have separate glossaries or highlight the terminology used in the text, although the inclusion of a glossary and its level of detail is dependent on the intended audience of each source.

A2.2 SOCIOECONOMIC FORECASTS

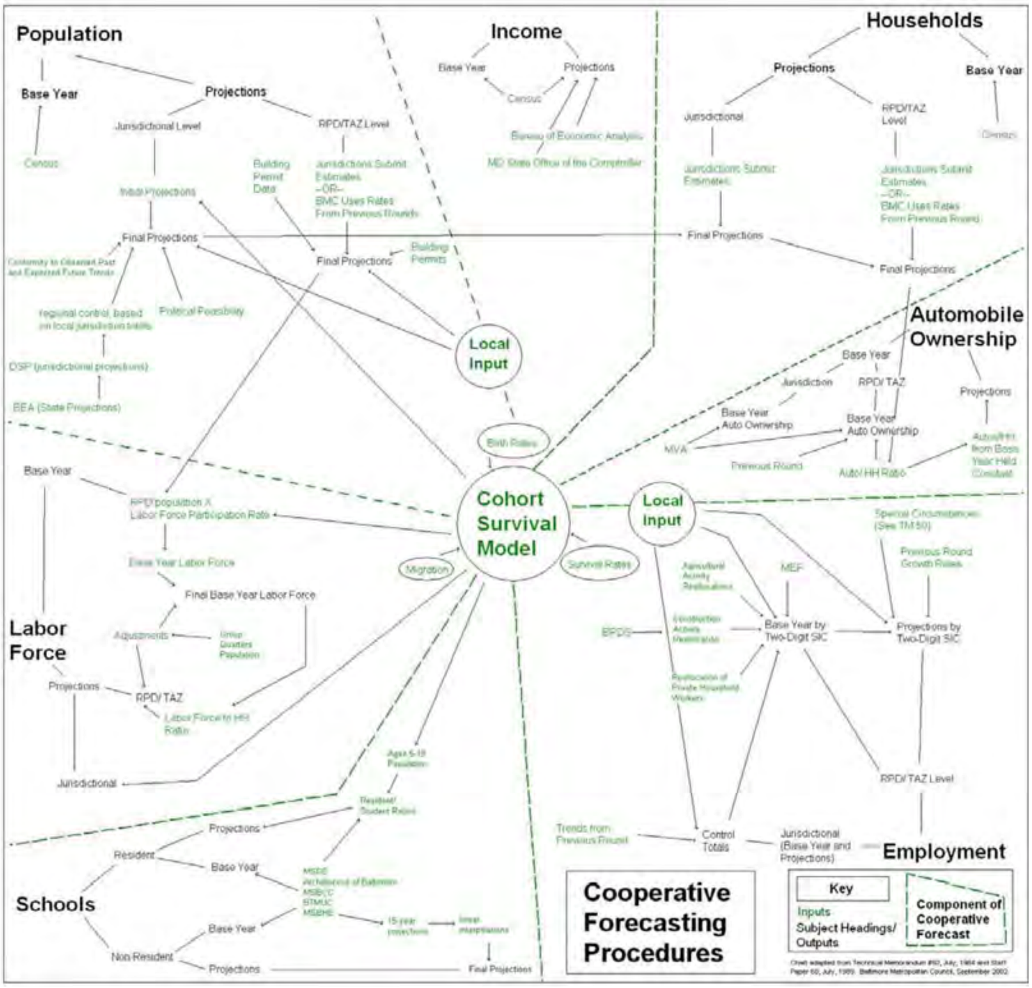
A2.2.1 Addressing Typical Assumptions Used in Base Year Socioeconomic Estimates

The process of developing socioeconomic characteristics is based on a range of assumptions about an area, its growth, and the physical and social characteristics of that growth. As *A Transportation Modeling Primer* states, "Many assumptions are needed to develop these forecasts and it is unlikely that all of these assumptions will prove to be correct." The necessary assumptions and the process for their development are an important aspect of the travel demand forecasting process, and are addressed in a few of the source materials.

A Transportation Modeling Primer explains that population forecasts require assumptions about birth rate, death rate, and migration rate of an area which are usually based on historic trends. These demographic trends, in addition to local plans and the availability of vacant land are sometimes used by an expert committee to create land use forecasts. Because these types of trends cannot be known for certain over a 30-year time horizon, several sets of assumptions are often used to develop a range of potential values for a given horizon year. Each model will of course, carry with it additional assumptions about future land use and socioeconomic characteristics based on the politics of an area and the structure of the model. The implications of these assumptions on the modeling results are mentioned briefly, but a more detailed treatment may be beneficial to help non-technical planners relate the mathematical results to a policy framework. The Baltimore Metropolitan Council (BMC, 2007) has published a primer on socioeconomic data and forecasting which includes a flow chart, shown as Figure A2.3 illustrating the many complexities of the cooperative forecasting method.

SACOG details a series of assumptions existing in land use, demographic, economic, and travel characteristics, including the idea that the land use forecasting model produces land use and buildings by type. PSRC describes its use of the Puget Sound Economic Forecaster (PSEF) to generate regional control totals in the land use forecasting process (PSRC, 2009b).

Figure A2.3 Visual Description of Socioeconomic Forecasting Process



Source: BMC (2007)

The Geography of Urban Transportation includes some discussion of how land use forecasts are developed for use in a travel demand model. The textbook also describes some of the issues that may be encountered during this process, including over/under estimation by local jurisdictions and the potential for significant forecasting errors over the long timeframe of a model.

A2.2.2 Review of Explanation of the Use of Socioeconomic Characteristics in the Modeling Process

The socioeconomic characteristics and forecasts are important elements in the modeling process, and non-technical planners must understand how these characteristics affect the results of a model. Most of the available materials provide information about how socioeconomic data are used, although varying levels of detail are provided. The *Introduction to Travel Forecasting Self Instructional CD-ROM* lists the types of input data that are necessary, and shows how estimates of population and employment growth are used as an input. While detailing each step in the forecasting process, it shows points at which the socioeconomic input data are used.

A list of the types of socioeconomic data that are needed for each TAZ is provided in *Documentation and Procedural Updates to the Florida Standard Urban Transportation Model Structure: Trip Generation Model*. Also included are sample data tables with explanations of the values for each of the major input files. Using graphs, *FSUMTS Executive Summary Modeling Seminar* shows socioeconomic input data requirements. Figure A2.4, for example, is used to identify socioeconomic characteristics such as population, households, and employment as the basic inputs for TDF models.

Figure A2.4 Example of Socioeconomic Inputs

Source: FSUTMS (2010b)

Transportation 2040, Data Analysis and Forecasting at the PSRC, New Tools within Integrated Modeling Framework provides details about socioeconomic characteristics developed by a population synthesizer. While detailing assumptions used in the model, it highlights that a synthetic population database is sensitive to changes in transportation investment and demonstrates how growth patterns vary by investment packages.

A2.2.3 Integrated Transportation-Land Use Models

Integrated transportation-land use models, a modeling approach which attempts to balance the two-way relationships between transportation and land use, are relatively new and have only been applied in limited locations according to *A Transportation Modeling Primer*. While this type of model is recommended, the methodology is not described in detail. PSRC describes how they apply their travel demand model iteratively for each alternative to evaluate how land use is affected by varying levels of transportation investment. *The Geography of Urban*

Transportation provides an overview of land use modeling including the potential effects of induced demand, although no details about integrated transportation-land use models are provided.

A2.3 Explanation of Factors Affecting Transit Ridership and Mode Splits

There are several possible model types that can be used to predict transit ridership ranging from trip table factoring with fixed percentages to complex nested logit models. The model type selected is often based on the specific needs of a metropolitan area, and each type of model will react differently to changes in the assumed land use or network structure. *A Transportation Modeling Primer* discusses the affect of time and cost considerations on mode choice and highlights that other aspects of transit services such as transit amenities, comfort, and safety are often not fully accounted for. *Transit Sketch Planning Tools at PSRC* introduces the Service Planning Tool (SPT) which is used to predict changes in transit ridership which result from changes in the level of transit service (PSRC, 2009a). The sources reviewed did not include details about what factors are likely to influence mode split and transit ridership levels, although this would vary for each model specification. *Transportation Engineering and Planning* states that "the mode choice behavior of trip makers can be explained by three categories of factors: the characteristics of the available modes; the socioeconomic status of the trip maker; and the characteristics of the trip." The textbook describes three potential methods of varying complexity for calculating transit share, including a simple diversion curve, stratified diversion models, and multinomial logit.

A2.4 Knowledge of Regional Travel Behavior from Surveys

Models throughout the country use household travel survey data to understand travel behavior and develop model parameters. Some of the source materials describe the use of these types of surveys and how the data are applied to the forecasting process. According to *Transit Sketch Planning Tools at PSRC,* the household travel survey is used to determine traveler attitudes and subsequently for market segmentation. This source also details how a household travel survey typically works, including the use of travel diaries. FHWA's self-instructional CD-ROM details the kind of information typically collected in a regional travel survey and allows for purchase of additional course information on the topic from FHWA. An introductory discussion entitled "travel information" is included in *An Introduction to Urban Travel Demand Forecasting, A Self Instructional Text*, describing the type of information gathered during household surveys in easy to follow language (FHWA and UMTA, 1977). *The Geography of Urban Transportation* also details the importance of frequent and accurate travel surveys.

A2.5 Roles of Different Parties in the Modeling Process

Transportation planning is a joint effort involving MPO, citizen, and government participation. State and Federal governments work together in designating MPOs to lead the process; however, the relationships between different organizations often vary for each region. The sources were reviewed for discussion of the roles of different parties in the modeling process. The FSUTMS *Executive Summary Modeling Seminar* provides some information about model users and their relative roles, indicating the importance of officials at the local, state, and regional levels. The FHWA *Introduction to Travel Demand Forecasting Self Instructional CD-ROM* also provides an indication of how various players in the modeling process – including modelers, non-technical planners, and government officials – interact and work together to develop and present information to the public. A detailed history of legislation and practice related to travel demand modeling is provided in *The Geography of Urban Transportation*.

A2.6 Review of Validation and Reasonableness Checking

The validation phase of model development is a major issue for many travel demand models. Validation and reasonableness checks of traffic forecasts are addressed to some degree in many of the available sources. The importance of validation and reasonableness checks are described in some, although not all, of the introductory-level materials.

As stated in a model validation and calibration guidance document developed for the Florida Department of Transportation, the terms “calibration” and “validation” are sometimes used interchangeably. Clarification between the two terms can help improve communication between modelers and non-technical planners. For example, in the FSUTMS materials the two terms are distinguished as follows:

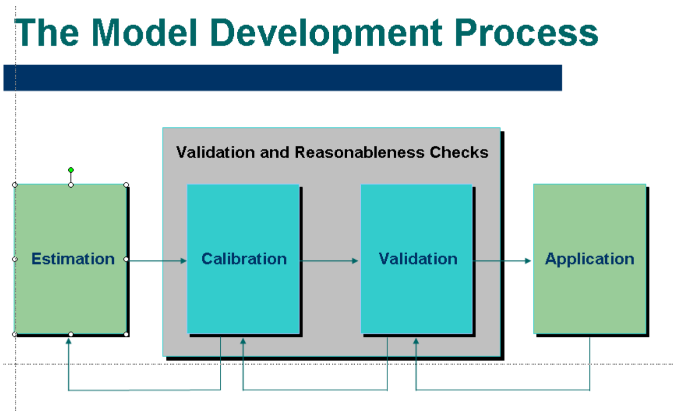
- **Model Calibration –** A process where models are adjusted to simulate or match observed household travel behavior in the study area; and
- **Model Validation –** The procedure used to adjust models to simulate base year traffic counts and transit ridership figures.

The FHWA webinar spends two entire lessons on the subject of validation, defining the process as the “comparison of model results to independent sources” and indicates that this should be done for each step of the modeling process. Validation is described to include: checks of input data, reasonableness/logic checks, comparison of model results to independent data sources, and sensitivity checks. Both calibration and validation are described as processes used to check the reasonableness of model results at various stages in the forecasting process.

The FSUTMS materials describe model calibration checks based on household travel survey data to adjust the model to match observed trip generation rates, trip length frequency distributions, aggregate trip movements, and mode shares. Model validation is described primary as matching traffic counts. TPB defines model validation as comparing a "base year" output against observed data to make sure it is performing adequately and reasonably. It also explains the purpose and the use of checks and when they are performed during the process. *A Transportation Modeling Primer* specifies that a typical reasonableness check for the assignment step of the model is to check if the resulting speeds on the network are realistic after equilibrium.

Overall, the importance of checking results is emphasized in some of the literature. The credibility of the process is said to be largely reliant on the ability of analysts to properly validate procedures and models used and provide accurate forecasts. Figure A2.5 shows the role of model validation in the modeling process. Specific procedures for validation are not provided in these sources, although some metrics for comparison are provided including trips per person, VMT, and traffic speeds.

Figure A2.5 Role of Model Validation



Source: Cambridge Systematics (2009)

Several other sources focus solely on validation data and procedures that are available, although none are geared towards a non-technical audience. The *Model Validation and Reasonableness Checking Manual* (Barton-Aschman and Cambridge Systematics, 2001) includes validation strategies for each step of the modeling process in addition to validation targets.

A3.0 Interpreting and Applying Model Output

A3.1 Uses of Travel Demand Models

Travel demand forecasting is designed to perform certain types of tasks and analyses, but there are limitations as to what TDF models can do well. It is important that policy-makers and non-technical planners understand the limitations and best uses of travel demand models so that they do not try to use the results in inappropriate and/or inaccurate ways. The FHWA *Introduction to Travel Forecasting Self Instructional CD-ROM* indicates that travel demand forecasting is much more useful on a macro-level scale and not as useful for micro-level project analysis. It continues to list some possible uses for model results and some potential model outputs. *A Transportation Modeling Primer* explains that models can be asked to go beyond their capabilities or original design purpose to evaluate such things as: travel demand management, employer-based trip reduction programs, pedestrian and bicycle programs, time of day shifts, changing age structure of the population, and land use policies. The major statistics produced by a travel demand forecasting model are listed in FSUTMS *Executive Summary Modeling Seminar*. TPB also describes the major outputs produced by a travel demand forecasting model including: vehicle volumes, speeds on links, origin-destination patterns, mode splits, and emission levels.

A3.2 Model Sensitivity to Changing Assumptions

In order for a model to produce accurate results, it must account for the current state of that which it is predicting. *A Transportation Modeling Primer* indicates through the use of several examples that a model is only able to test the effects of policies that are explicitly included in the model. Models are therefore not sensitive to all policy changes. Specifically identified are policies related to mode choice elements such as carpooling and nonmotorized trips that are not always included in a travel demand forecasting model.

TPB points out that sensitivity testing is a key component of validation. A good model should be sensitive to both the socioeconomic inputs and assumptions such as time and costs. According to *Transportation 2040, Data Analysis and Forecasting at the PSRC, New Tools within Integrated Modeling Framework,* a synthetic population database, which is the output of the land use models, must also be sensitive to changes in transportation investment. While describing assumptions in the model, PSRC calls attention to the daily activity patterns generated for the tour purposes and the sensitive nature of those changes relative to transportation investment, toll policies, and growth patterns. The Florida DOT calibration and validation guidance documentation states that "model validation should not be considered complete until forecast year sensitivity tests are completed."

A3.3 ELASTICITY OF DEMAND

The elasticity of demand is not addressed in the majority of the introductory-level guides that were reviewed. *Transportation Engineering and Planning* defines both direct and cross elasticities and details how these elasticities can be measured. The potential uses and applications of the demand elasticities in transportation planning is also briefly discussed.

More technical sources are available on the subject, including *TCRP Report 95, Traveler Response to Transportation System Changes*. Appendix A to the Interim Introduction to this report (published as *Research Result Digest 61*) includes a detailed discussion of the formulation of different types of elasticities, with a special focus on the elasticity of transit demand with respect to price (TCRP, 2003). This measure, among the most commonly used in travel demand forecasting, is described as a way to measure the effects of changes in transit cost on transit ridership.

The importance and understanding of forecast sensitivities for use by planners and decision-makers needs to be expanded upon. The ability to understand forecasts and the impacts of different factors on forecasts can help decision-makers understand the results and not feel that the model is a "black box."

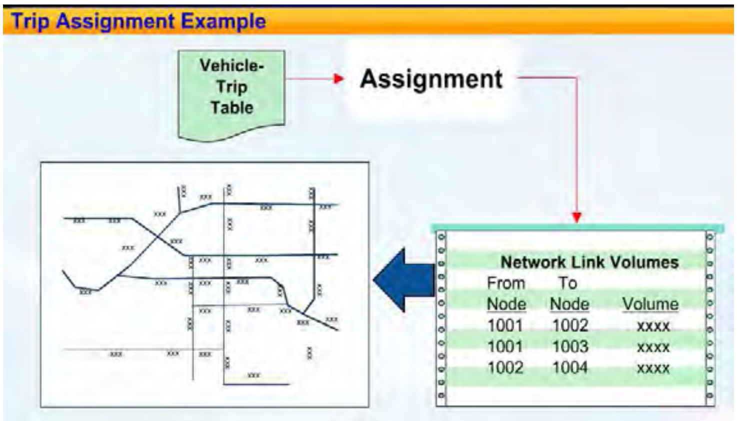
A4.0 COMMUNICATING RESULTS

A4.1 METHODS AND TOOLS FOR COMMUNICATING RESULTS

The importance of being able to communicate the results of a travel demand model to non-technical staff and the general public cannot be overstated. In order for the models to be useful to planners and other decision-makers, model outputs must often be translated into easily understandable text and visuals. Some of the helpful visual communication methods found in the current literature are summarized as follows:

- **Flow charts.** These are most helpful for illustrating complex relationships among multiple objects in a procedure. For example, Figure A4.1 depicts the traffic assignment procedure in a simple manner.

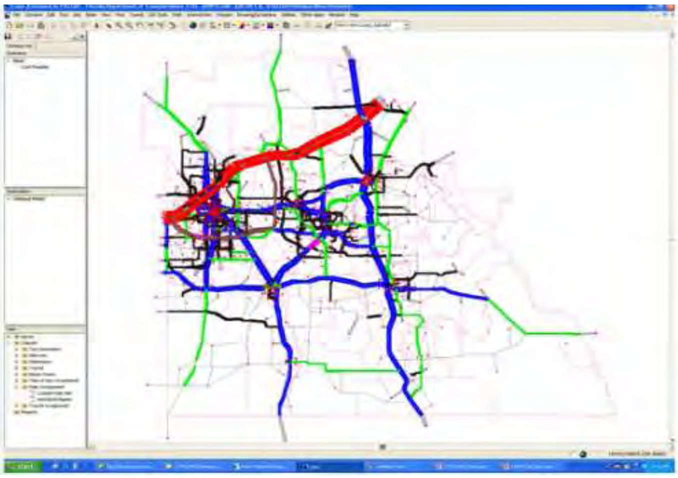
Figure A4.1 Example Flow Chart Illustrating Transit Assignment Procedure



Source: FSUTMS (2010b)

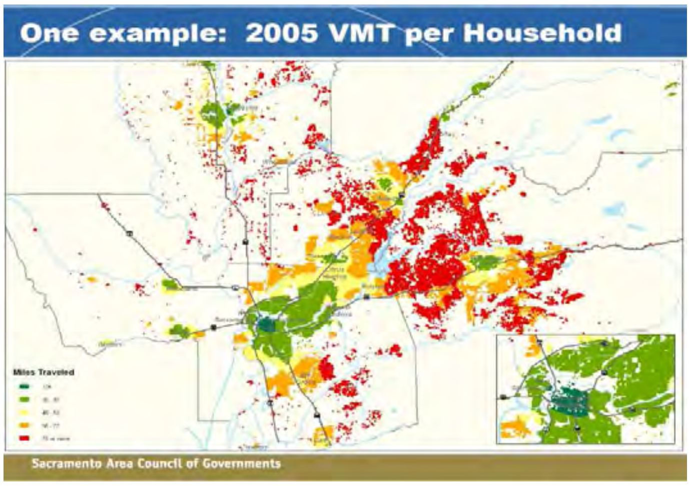
- **Color-coded and bandwidth maps**. *Executive Summary Modeling Seminar* and SACOG show that color coded and bandwidth maps are useful tools for illustrating highway assignment results, such as volume capacity ratios, volumes, speeds, and VMT. Figure A4.2 depicts an example bandwidth map and Figure A4.3 depicts a bandwidth map of VMT.

Figure A4.2 Example Bandwidth Map



Source: FSUTMS (2010b)

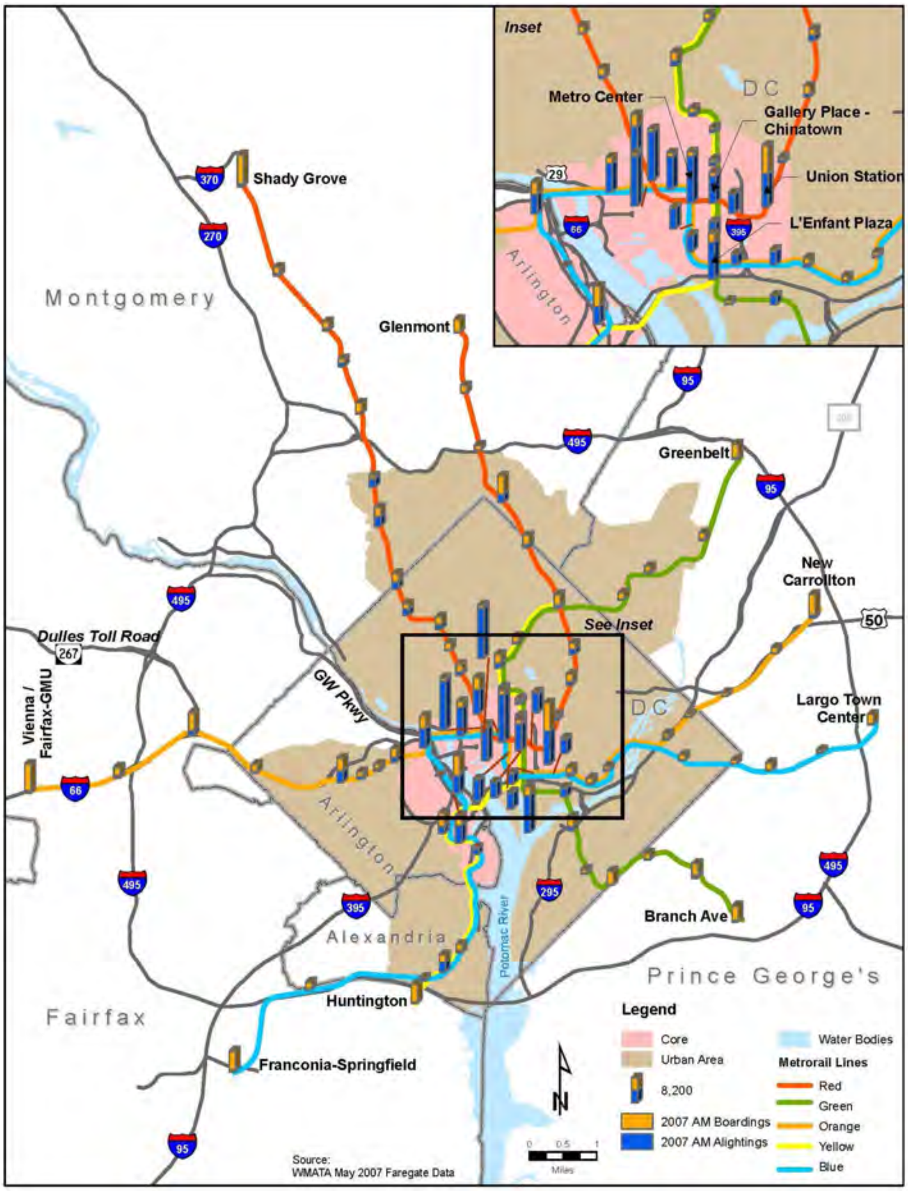
Figure A4.3 Example Bandwidth Map of VMT



Source: SACOG (2009)

While possible, none of the sources reviewed proposed application of this visual method to transit assignment results. Transit assignment is typically portrayed based on boardings and alightings, not passenger volumes, as shown in Figure A4.4.

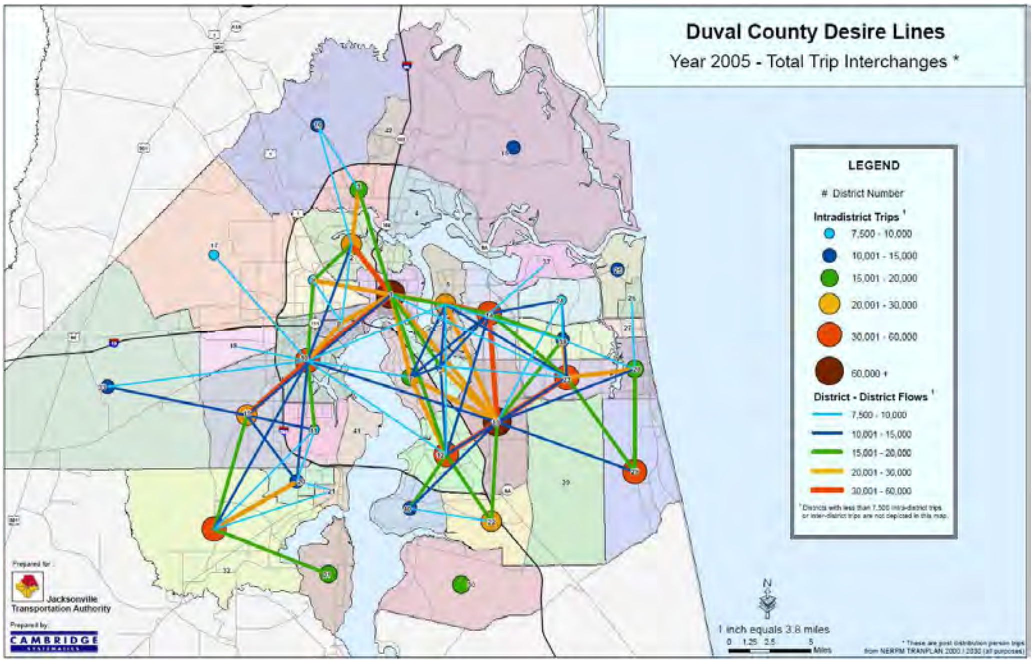
Figure A4.4 Example of Transit Assignment Mapping



Source: Washington Metropolitan Area Transit Authority and Cambridge Systematics (2009)

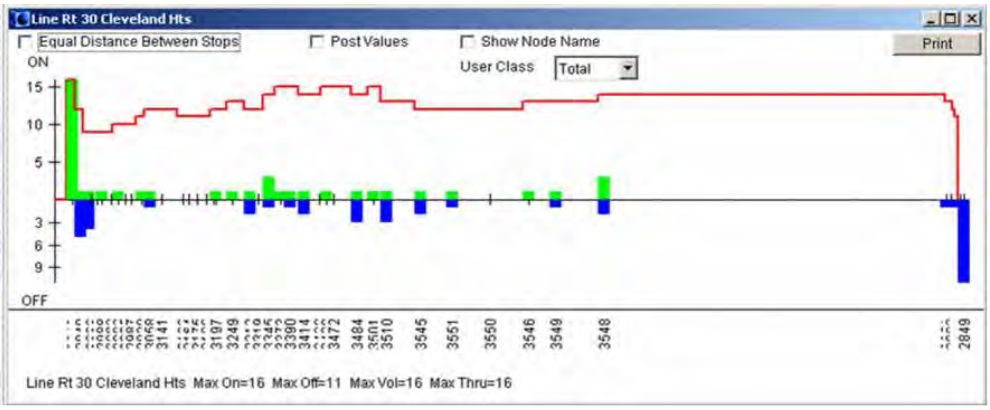
- **Desire line maps.** These are used to display the relative importance of travel movements between subareas within a regional model. Desire lines can be reported using a variety of Census geographies, TAZs, and planning districts or subareas. Such mapping as depicted in Figure A4.5 below requires that data be available in the form of trip origins and destinations but can be derived from models or surveys. Desire lines can be depicted for any mode of transportation for which sufficient flow data are available.

Figure A4.5 Example Desire Line Map



- **Bar charts and pie charts.** These are two other methods used to illustrate model results. They can be used to illustrate boardings and alightings along a transit route as shown below or to compare the statistical performances of each alternative tested with the model. An example is shown in Figure A4.6.

Figure A4.6 Example Bar Chart Describing Transit Ridership



Source: *FSUTMS (2010b)*

- **Tables.** These can be used to compare the statistical performances of multiple alternatives or in comparison with a base year or validation data source.

A4.2 Useful Communication Techniques

There are several communication tools that have been indicated in the literature as potential methods to successfully convey modeling information and results to the public:

- **Interactive public forums.** Interactive public forums are good for persistent discussions, especially for support-type question-and-answer sessions. They are most useful when linked to e-mail for update notifications. For example, the SACOG model operates within a "live" interactive public forum.
- **Web-based maps.** Web-based maps allow the user to view and query transportation information. Usually, GIS technology is needed to create customized maps. For example, the Atlanta Regional Commission offers "interactive" mapping developed for their Comprehensive Planning Department. Another example is St. Charles County, Missouri which provides geographic data including transportation information through a web-based map system.

A5.0 References

Atlanta Regional Commission (ARC). Travel Demand Model. http://www.atlantaregional.com/transportation/travel-demand-model. (Accessed June 2010).

Baltimore Metropolitan Council (BMC). *Primer for Developing BMC Travel Demand Model Socioeconomic Inputs*. http://www.baltometro.org/reports/PrimerSocioEconomic.pdf. (December 2007).

Barton-Aschman Associates and Cambridge Systematics. *Model Validation and Reasonableness Checking Manual*. Federal Highway Administration Travel Model Improvement Program, Washington, D.C. (June 2001).

Beimborn, Edward A. *A Transportation Modeling Primer*. Center for Urban Transportation Studies University of Wisconsin-Milwaukee (June 2006).

Bureau of Transportation Statistics and Travel Model Improvement Program (BTS and TMIP). *Travel Demand Forecasting: A Compilation of Transportation Plans, Reports, and Data*. CD-ROM. BTS-CD-11. (1997).

Cambridge Systematics. *FSUTMS-Cube Framework Phase II: Model Calibration and Validation Standards*. Prepared for the Florida Department of Transportation. (October 2008).

Cambridge Systematics. *The FHWA Travel Model Improvement Program Workshop over the Web*. (2009).

Federal Highway Administration (FHWA). *Introduction to Travel Demand Forecasting Self Instructional CD-ROM.* Travel Model Improvement Program, Washington, D.C. (2001).

Federal Highway Administration (FHWA). *Introduction to Travel Demand Forecasting*. http://tmip.fhwa.dot.gov/webinars/introtdf (Accessed June 2010)

Federal Highway Administration National Highway Institute (FHWA NHI). *Introduction to Urban Travel Demand Forecasting*. Course Materials (2007).

Federal Highway Administration and Urban Mass Transit Administration (FHWA and UMTA). *An Introduction to Urban Travel Demand Forecasting, A Self Instructional Text*. (1977).

Florida Standard Urban Transportation Model Structure (FSUTMS). *Documentation and Procedural Updates to the FSUTMS: Trip Generation Model.* http://www.fsutmsonline.net/images/uploads/reports/TRGEN.PDF (June 1997).

Florida Standard Urban Transportation Model Structure (FSUTMS). *Comprehensive Modeling Workshop*. http://www.fsutmsonline.net/online_training/index.html (Accessed March 2010a).

Florida Standard Urban Transportation Model Structure (FSUTMS). *Executive Summary Modeling Seminar*. http://www.fsutmsonline.net/online_training/index.html (Accessed March 2010b).

Hanson and Giuliano, Editors. *The Geography of Urban Transportation*, Chapter 5: The Urban Transportation Planning Process. Third Edition. The Guilford Press, New York, New York. (2004).

National Capital Region Transportation Planning Board (TPB). Forecasting Future Travel. *Region*. Vol. 42 (2003) pp. 19-25.

Papacostas, C., and P. Prevedouros. *Transportation Engineering and Planning*, Chapter 8: Sequential Demand-Forecasting Models. Second Edition. Prentice Hall, Englewood Cliffs, NJ. (1993).

Puget Sound Regional Council (PSRC). *Transit Sketch Planning Tools at the PSRC*. (March 2009a).

Puget Sound Regional Council (PSRC). *Transportation 2040, Data Analysis and Forecasting at the PSRC, New Tools within an Integrated Modeling Framework*. (March 2009b).

Sacramento Area Council of Government (SACOG). *SACOG's Regional Travel Demand Forecasting Tools*. Presentation to Planning's Committee, Sacramento Area Council of Government. (May 2009).

St. Charles County, Missouri. St. Charles County Map Service. http://map.sccmo.org/GIS (Accessed May 2010).

Transit Cooperative Research Program (TCRP). Traveler Response to Transportation System Changes: An Interim Introduction to the Handbook. *Research Results Digest 61*. (September 2003).

Victoria Transport Policy Institute. *TDM Encyclopedia*. http://www.vtpi.org/tdm/tdm125.htm. (Accessed January 2010).

Washington Metropolitan Area Transit Authority and Cambridge Systematics. *Transit Ridership Trends and Markets.* Washington, D.C. (March 2009).

B. Glossary

Accessibility – measures the relative potential of any given TAZ to interact with other TAZs as a function of its transportation system and land use characteristics

Aggregate – to gather date elements for a set of smaller geographic areas into a total or subtotal representing an overlying larger area

Attraction – the trip end connected to a non-residential land use of a home-based trip or the destination of a non-home-based trip

Calibration – procedure used to adjust models to simulate base year observed characteristics from a household travel survey

Capacity – maximum number of trips that can be accommodated at an acceptable level of service on a specific link in the transportation network

CBD – central business district – the commercial and, often, geographic center of the city; it is the heart of business activity, also often referred to as the city center or downtown

Centroid – a point in a TAZ that represents the center of activity in a TAZ and where the origin or destination of all trips to or from the TAZ are assumed

Centroid Connector – a link from a TAZ centroid to other links in the network; representative of small connector facilities between individual buildings and larger transportation facilities that are included in the network

Demand – a schedule of the quantities of travel consumed at various levels of price or levels of service offered by the transportation system

Destination – location of the ending of a trip, typically defined by the TAZ in which the trip ends

District – is a geographic unit within the model, defined by the aggregation of selected TAZs to represent a region or locality

Employment – each job, filled and unfilled, in a given TAZ

Error propagation – when errors made in one model step are compounded in subsequent steps, increasing overall modeling error

Equilibrium – principle often used in the trip assignment step of a TDF model that travelers will use all possible paths between the origin and destination that have an equal travel time, so that no traveler can save time by switching paths. The user equilibrium approach attempts to optimize the travel time between all possible paths, reflecting the effects of system congestion.

External Trips – trips that start outside the region and either end in the region or pass through the region are referred to as external trips

FHWA – Federal Highway Administration is one of 11 operating administrations within the U.S. Department of Transportation that specializes in highway transportation. The agency's major activities are grouped into two "programs," the Federal-aid Highway Program and the Federal Lands Highway Program

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

FTA – Federal Transit Administration is one of 11 operating administrations within the U.S. Department of Transportation. The FTA provides stewardship of combined formula and discretionary programs totaling more than $10B to support a variety of locally planned, constructed, and operated public transportation systems throughout the United States

Gravity model – mathematical model of trip distribution based on the relative attractiveness of other TAZs and inversely proportional to the impedance between TAZs

Headway – time that separates vehicles moving in the same direction on the same transit line or track

Home-based trip – trip where home of the trip maker is either the origin or destination of the trip

Household – a the basic residential unit in which economic production, consumption, inheritance, child rearing, and shelter are organized and carried out

Impedance – the resistance trips experience from one node to another, it can be distance, time, or cost

Intrazonal trip – a trip that stays within a TAZ and does not load onto the transportation network.

Land use – purpose for which land or structure on land is being used

Link – a network element that connects two adjacent nodes in a highway network or the path of the transit line between two transfer points in a transit network

Local trip – intracity or short mileage trip by vehicle

Model – mathematical formula that expresses the actions and interactions of the elements of a system in such a manner that the system may be evaluated under any given set of conditions

Mode choice – process concerned with the trip-makers' behavior regarding the selection of available or proposed transportation modes

MPO – metropolitan planning organization – defined in Federal Transportation Legislation (23 USC 134(b) and 49 USC 5303(c)) as the designated local decision-making body that is responsible for carrying out the metropolitan transportation planning process. An MPO must be designated for each urban area with a population of more than 50,000 people (i.e., for each Urbanized Area (UZA) defined in the most recent decennial Census)

Network – the physical transportation system is represented in the model by a network comprised of links and nodes

Node – exist at both ends of every link and can represent intersections or other types of junctions, although some nodes represent centroid connector loading points or changes in roadway characteristics

Non-home-based trip – trip where home of the trip maker is neither the origin or destination of the trip

Origin – location of the beginning of a trip, typically defined by the TAZ in which the trip begins

Parameter – an independent variable

Path – the list of links in the network providing a connection from an origin to a destination; the shortest path provides a list with the minimum total impedance

Peak period – time-of-day when demand for services is the highest, and when highways experience the highest volume of traffic. Urban areas typically experience a morning peak period and evening peak period which coincide with the time periods when most people either go to or leave from their workplace

Perceived Time – time envisioned for a particular event to occur; may be different than the actual time

Person trip – a trip made by a person by any mode of transportation for any purpose

Population – the total number of people residing in households in an area

Production – the trip end connected with a residential land use of a home-based trip or the origin of a non-home-based trip

Reasonableness check – method confirming that specific outputs of a validated travel model conform to regional and national trends

Route – a transit line

Simulation – a synthetic reproduction or estimate

Skimming – the process of accumulating travel times between TAZs by tracing all paths on the transportation network and saving the value for the shortest path in a matrix

TAZ – transportation analysis zone – a small unit of geography that is usually delineated by census blocks or block groups for the purpose of collecting, tabulating, and analyzing data in a TDF model

Tour – in a tour, multiple trip ends are linked to account for the effects of trips that are chained, such as in a commuting tour from home to the daycare center to work

Transportation Improvement Program (TIP) – a staged multiyear program of transportation improvement projects that usually receive Federal and State funds

Transportation system – all aspects of available or proposed transportation alternatives that affect the demand, profitability, and nonuser impacts of these services

Travel demand – the desire for people to travel to different places to engage in activities

Trip – one direction movement from one location to another location, measured in person or vehicle equivalents

Trip assignment – process of determining available route or routes of travel in a network and allocating the TAZ-to-TAZ trips to these routes according to one of a number of assignment model algorithms

Trip distribution – process in which the trip volume interchanges between all pairs of TAZs are estimated. The data for each distribution may be measured or be estimated by a growth factor process or by synthetic model

Trip end – either the starting or ending of a trip. Every trip has two trip ends which can be classified as either a production and attraction or an origin and destination

Trip generation – estimates or forecasts the number of trips that will begin from or end in each TAZ; it analyzes and applies the relationships which exist among the tripmakers, the land use, socioeconomic factors, and trip making

Trip purpose – is the socioeconomic purpose for which a particular trip is made, common trip purposes include home-based work, home-based shopping, home base other, and non-home-based trips

Trip rate – the number of trips of a certain type made by a population that meets certain characteristics

Trip table – a table providing the number of trips between TAZs – either directionally or total two-way; often several tables are combined in a file to form a matrix

Validation – tests the ability of the model to estimate current travel patterns. Validation requires comparing the model predictions with information other than that used in estimating the model. Validation is typically an iterative process linked to calibration.

Vehicle trip – a trip made by an automobile for any purpose

VHT – vehicle hours of travel – a measure available from the TDF model to describe vehicle usage. It incorporates both the number of vehicle trips and the duration of those trips in terms of model travel time. It is best used only as a relative measure due to the uncertainty associated with using model travel time.

VMT – vehicle miles traveled – a commonly used measure to describe vehicle usage on a daily or annual basis. It incorporates both the number of vehicle trips and the length of those trips

Volume – amount of estimated trips that use a specific link in the transportation network

V/C ratio – volume to capacity ratio – the ratio of assigned volume to the capacity of a highway link

Zone – portion of the study area, delineated as such for purpose of forecasting land use, trip ends, and trip distribution. The most commonly used types of zones are traffic analysis zones (TAZ) and external zones