Small Area Travel Demand Model Guidelines

Prepared for:

North Carolina Department of Transportation
Transportation Planning Branch

Prepared by:

Parsons Brinckerhoff

August 27, 2008

Guidelines - Revision Date: October, 2012

Preface

These model guidelines (along with the companion Small Area Travel Demand Model Procedures Manual) recommend a best practice approach for North Carolina, but are not to be viewed as policy that dictates how travel demand models are to be developed. The purpose of these guidelines is to recommend *"best"* practice for the development of travel demand models for large non-Metropolitan Planning organization (MPO) areas and small MPOs in North Carolina which may deviate from what is considered "best" practice in other states or regions. The guidelines focus on model development practices considered best for North Carolina. When considering these guidelines for application in a given area, large non-MPO areas can be loosely defined as a single or combination of several small urban areas with a planning area population in the range of 15,000 and 50,000 and small MPOs can be loosely defined as MPOs with a population up to approximately 150,000. It should, however, be noted that population alone should not be the criteria for determining whether or not these guidelines and procedures manual should be applied. Transportation and study area issues that are unique to a region should also be considered to determine if these guidelines or a less or more advanced approach would be warranted. Throughout the guidelines and procedures manual, references are made to small areas and large areas. In this context, a small area is generally considered any study area falling within these guidelines that is not an MPO. A large area would generally be any study area falling within these guidelines that is an MPO. Exceptions to this rule may exist and it is left up to the analysts to make this decision based on their knowledge of the study area in question.

1 INTRODUCTION

1.1 Background and Objectives

In response to a changing workforce and the increased emphasis being placed on travel forecasting tools for long range transportation plan development, air quality analysis and key inputs for project development work, the North Carolina Department of Transportation (NCDOT) has undertaken a broad scale effort to improve the development and application of travel forecasting tools for the state of North Carolina. This effort has been multifaceted covering a broad range of study area sizes with varying issues. The guidelines presented herein are intended primarily for large non-MPO areas (with population in the range of 15,000 and 50,000) up to small MPO areas (with population in the range of 50,000 and 150,000). While population values are provided to give a sense of scale, it is important to note that population alone should not be used for making a determination on the applicability of these guidelines to a given study area. These values are intended as a guide to be used in conjunction with a consideration of a study area's unique characteristics as well as with regard to the types of transportation issues and anticipated transportation projects for a given study area.

Travel demand models are mathematical tools applied in the analysis and evaluation of transportation systems and related policies. They are used to forecast travel demand and analyze corresponding levels of performance and service on transportation facilities in response to assumed changes in economic, demographic, and transportation system characteristics. Transportation planners use such models to provide a wide range of quantitative information to help inform decisions on the future development and management of transportation systems, especially in urban areas where travel demand typically is greatest and congestion most severe.

These mathematical tools (or just models) are based upon observations of the underlying purpose for which travel occurs and the way in which travelers behave in response to available transportation facilities. A clear understanding of the modeling process is important to making judicious use of model outputs in the development of transportation plans and recommendations.

1.2 Purpose and Use of Guidelines

With notable exceptions, MPOs, counties, and urban areas (one or more cities) within North Carolina rely on NCDOT to provide technical assistance and guidance in developing and applying travel demand models to the wide spectrum of planning and design study needs in their communities. With this in mind, it is important for NCDOT to be well-positioned to offer consistent and sound technical support.

These guidelines recommend a best practice approach for North Carolina in that regard, but are not to be viewed as policy guidance that dictates how travel demand models are to be developed. Recommendations and default parameters covered in these guidelines and the accompanying Small Area Travel Demand Model Procedures Manual are based on the North Carolina Combined Survey Database. This database was developed from household travel survey data from five MPO areas or regions across the state. These include the Wilmington, Greenville, and Goldsboro MPOs, and the Triangle and Metrolina regions. If local data can be obtained for the study area in question, it is always preferable to the use of default parameters. Analysis of locally collected data may lead to the specification of different model equations and preference for different variables. This deviation from the guidelines is acceptable and even preferable to the use of default parameters as locally collected data will better capture any unique travel characteristics that may exist for a given study area.

The purpose of these guidelines is to define, illustrate, and document *"best"* practice travel demand model development for large non-MPO areas and small MPOs in North Carolina which may deviate from what is considered "best" practice in other states or regions. The guidelines focuses on model development practices and options considered best for North Carolina. In the following chapters, the data preparation needs, methodologies, and mathematical and statistical tools used in travel demand model development are explained. The town of Sanford is used as a primary case study for this effort. The case study gives model developers and users insight into the details and mechanics of best practice travel demand model development.

1.3 Model Development Overview

The proposed overall structure of the recommended travel demand model system is displayed in Figure 1. This schematic demonstrates that the application of the model begins with two key sets of inputs: the demographic (including socioeconomic data) and land use information (at the Traffic Analysis Zone (TAZ) level and the highway networks (transit and other transportation modes are not considered in the guidelines).

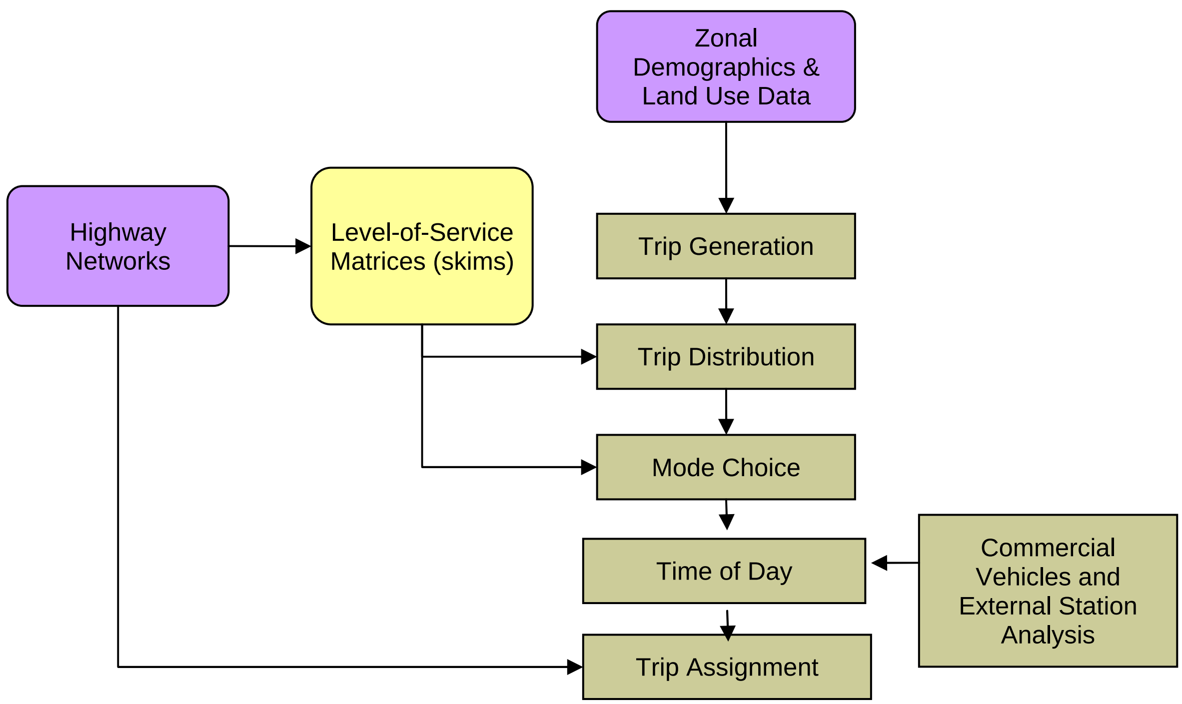


Figure 1 Travel Demand Model System Diagram

The first model in the sequence is the trip generation model. Estimation of the magnitude of trip making is considered in terms of the range of possible types of trip purposes (i.e., Home-Based Work (HBW), Home-Based Other (HBO), Home-Based School (HBSCH), Non-Home Based Work (NHBW), and Non-Home Based Other (NHBO)). Following trip generation, the linking of trip origins and trip destinations is accomplished by the trip distribution model, while the choice among transportation modes is estimated using simple mode split factors. The implementation of a mode choice model is left as a future enhancement to these guidelines. Prior to time-of-day analysis, commercial vehicle trip generation and distribution are performed for commercial autos, pickups and trucks, and external trips are also estimated. The next step is to estimate the proportion of travel (by trip purpose) occurring during peak and off-peak periods as determined by a time-of-day factor. The final component of the model system is embodied in the assignment of travel to the highway network, or in cases where mode choice is a component of the model, to the highway and transit networks.

1.4 NCDOT Traditional Modeling versus NCDOT Advanced Modeling

The purpose of this section is to highlight the major changes between the traditional approach to model development at NCDOT as compared to the new approach recommended in these guidelines and the accompanying procedures manual.

Table 1 NCDOT Traditional Approach vs. Newly Recommended Approach

Traditional	Recommended
Data Collection	
▪ Field inventory ▪ Dwelling Units by rating ▪ Employment by 5 SIC codes	▪ Census ▪ Worker and auto data
Highway Network	
▪ Field inventory ▪ NCDOT Street Universe File	▪ More data attributes ▪ Hourly capacity ▪ Alpha parameter to support new Volume Delay Function (VDF): Conical Delay Function (CDF) ▪ Standardized facility type ▪ Standardized formula for calculating initial link travel time
Rates and Parameters	
▪ Borrowed from other studies	▪ Derived from North Carolina Combined Survey Database
Trip Generation	
▪ Trip rates by dwelling unit classification ▪ Basic regression equation	▪ Cross classification for trip productions ▪ Regression models for trip attractions
Trip Distribution	
▪ Friction factor table ▪ Free flow travel time as impedance measure	▪ Gamma function ▪ Generalized cost as impedance measure
Time of Day	
▪ No time-of-day element	▪ AM-peak (AM), Mid-day (MD), PM-peak (PM), and Off-peak (OP)
Assignment	
▪ Primarily all-or-nothing with manual capacity constraint	▪ User equilibrium
Calibration/Validation/Reasonableness Checking	
▪ Traffic counts	▪ In addition to traffic counts, secondary sources of data such as: NHTS, census data, HPMS VMT, travel speeds, CTPP

1.5 North Carolina Combined Survey Database

As noted in the previous section, the traditional approach to determining rates and parameters for modeled areas lacking observed travel survey data was simply to borrow these rates and parameters from other areas. The state of North Carolina in partnership with various NC MPOs has collected travel survey data over the course of the past 10 years. This survey data was combined into a North Carolina Combined Survey Database and analyzed to create default trip production and attraction rates, gamma coefficients, mode split factors, time-of-day factors, and vehicle occupancy rates. This database was developed from household travel survey data from five MPOs or regions across the state. These include the Wilmington, Greenville and Goldsboro MPOs, and the Triangle and Metrolina regions. The advantage of this approach is that areas using these guidelines will be able to utilize as a starting point for model development a standard set of parameters and default rates based on observed North Carolina travel behavior.

1.6 Report Structure

Following this brief introduction, the guidelines contain additional twelve chapters, covering each of the recommended model components and supplemental analysis as follows:

Chapter 2: Network and Database Development
Chapter 3: Networks and Shortest Paths
Chapter 4: Trip Generation Submodels
Chapter 5: Trip Generation
Chapter 6: Trip Distribution
Chapter 7: Mode Split
Chapter 8: Commercial Vehicles
Chapter 9: External Trips
Chapter 10: Time of Day Analysis
Chapter 11: Highway Assignment
Chapter 12: Overall Model Validation
Chapter 13: Model Application Guidelines

Chapter 2 is an extensive documentation of data development encompassing the TAZ system, networks, socioeconomic data, survey data, and traffic counts. Chapter 3 covers networks from the standpoint of traffic flow and data structure and how this structure is used to create minimum paths. Chapters 4 and 5 focus on the household classification submodels and trip production and attraction models, respectively. Trip distribution is covered in Chapter 6 including model estimation and aggregate validation. Chapters 7, 8, and 9 cover mode split factors, commercial vehicle modeling, and external station analysis respectively, while time-of-day factoring is covered in Chapter 10. The last stage of the modeling process, highway assignment, is covered in Chapter 11. Chapters 12 and 13 present examples and suggested standards for overall model validation based on comparison of model estimates and actual traffic counts as well as guidelines for model application.

2 NETWORK AND DATABASE DEVELOPMENT

2.1 Introduction

The full specification of a travel demand model includes not only the structure of the model and independent variables, but also the method of preparation of the input data. A major source of error in travel demand forecasting is the data (or lack thereof) that is used in both the calibration and application of the travel demand models. Models can only be calibrated to the degree of accuracy reflected in the databases used in their development. It is important to define the input data so that they are manageable, internally consistent, and contain/produce accurate output.

The spatial representation of the transportation system is one of the most important aspects of travel demand modeling. The scope and level of detail in the network and TAZs have wide implications on model design and development, computer hardware and software, and related data requirements. The transportation system elements that should be included range from basic roadways to be modeled to transit system for more advanced models. A “network” is developed for each primary travel mode, in most cases automobile and transit, and provides the model with information relative to the time and cost of travel. While the base highway network is fundamentally a map of routes that represents the highway system, it is defined in a manner that can be read, stored and manipulated by TransCAD.

TransCAD is a travel demand modeling program built within a geographic information system (GIS) framework. This feature provides the flexibility to address the complexity of the data needs of the travel demand modeling process, from the creation and thematic display of TAZ database containing land use and demographic variables to model network development and model calibration. The GIS interface can also improve model accuracy by allowing link lengths to be calculated based on actual street length rather than straight line estimates and by providing a visual check on network coding. Finally, the GIS interface provides a mechanism for maintaining travel demand model-related inputs and outputs and can serve as a tool for sharing this information with non-model applications.

2.2 Study Area/Planning Area Boundary Considerations

One of the first steps in the development of a travel demand model is the determination of the geographic area of analysis, or study area. When defining the study area, a common guideline is to include an area large enough such that 90% of the trips begin and end within the study area over the duration of the planning horizon, typically 20 – 30 years. Other considerations when identifying the study area boundary include:

1. Minimization of roadway crossings. Each roadway crossing the study area boundary will need to be considered for inclusion in the highway network. At a minimum, the traffic flow on major roadways will need to be taken into consideration and this can increase data collection efforts. For this reason, it is best to limit as much as possible the number of roadway crossings, in particular those of major freeways, expressways, and arterials.
2. Consistency with census geography. Where possible, the study area boundary should follow census geography as this will be an important building block for TAZs.
3. Consistency with area features. The study area boundary should take into consideration, and follow, wherever feasible, natural boundaries. For example,

following rivers/ streams, where appropriate, can also help to limit the number of roadway crossings.

4. Consideration of political boundaries, including extra territorial jurisdiction (ETJ), municipal service boundaries, and any existing or proposed annexation agreements need to be reviewed to make certain that the planning boundary covers an area great enough to include the proposed future expansion areas. For study areas that border other study areas, careful planning and coordination should be executed to assure that the study area boundary does not overlap the neighboring boundary or ETJ except in such cases where not doing so would result in an illogical model boundary. These instances are rare and would require special coordination with the adjoining region to assure consistency in data inputs.
5. Consideration of future growth. Include in the study area boundary all land anticipated to be urban in nature during the planning horizon, typically 20 to 30 years.
6. Avoidance of highly irregular boundaries. The study area boundary should be defined to avoid shapes that form extended “bays” or “peninsulas”, as this necessitates trips that make multiple crossings of the study area boundary, and can lead to assignment distortions near these boundary shapes.

2.3 Zone System Definition

Traffic Analysis Zones (TAZs) are geographic areas dividing a transportation study area into homogeneous areas of land use (zoning), land activity (development), and aggregate travel demand. Because of the extensive computational requirements necessary for modeling travel at the individual level, most models in application today still use the TAZ system as the level of analysis. TAZs are geographic polygons representing areas of trip production and attraction activities within the study area. The TAZ system should be the basis for all data collection and forecasting throughout the study area. TAZs must be formed carefully to ensure compatibility between TAZs and networks, and to ease the collection and manipulation of data. TAZ-network compatibility helps ensure that assignment results are as accurate as possible given the level of detail sought and the objective of the study. TAZ and network systems must be very closely coordinated in order to achieve the desired and most accurate results. Primary considerations for constructing TAZs are:

1. Consistency with census geography. Where possible, TAZ boundaries need to follow census tracts, block groups, or blocks to fully utilize census data at the lowest level of geography.
2. Consistency with area features. TAZ boundaries need to follow physical and topographical features such as the major street network, railroads, and waterways to allow representation of unique travel characteristics. In particular, TAZs should generally “nest” within the modeled network roadways so that the modeled roadways do not bisect the TAZ. Alternatively, TAZs that are too small in relation to the modeled network, called micro zones, are superfluous and may result in access connectors that cross one another. Other features such as key landmarks, municipal limits, urban growth boundaries and MPO boundaries should also be included in the databases for special representation, completeness, and presentations.
3. Homogeneous land use. A TAZ should have as little variation in land use as possible, though care must be given not to define micro zones. In general, TAZs in

the CBD will be smaller than those in outlying areas, but still need to have the properties to generate significant levels of demand in the forecast year. The TAZs must also be sized and defined appropriately to retain a level of detail consistent with the intended analysis process.

4. Consistency with data availability. TAZs can only be created to a level of detail that is consistent with the lowest level of available data. For each TAZ, production and attraction data must be generated and stratified. Care must be given to prevent creating TAZs smaller than the detail and accuracy of the available base data. A typical example might be trying to create a TAZ for each block in a downtown area. Due to disclosure limitations, other security reasons, or simply lack of specificity in the data, you may not know very precisely how much employment is actually on that specific block. An example might be a central parking facility that serves a number of nearby buildings, as is often found in a campus environment, trying to split up the component blocks would not give any more detail in the assignment ultimately if all the vehicles headed there end up at a central parking facility.
5. Consideration of future development. Care should be taken to identify regions of anticipated high development in future years so that the TAZ structure can accommodate this future growth. In general, the number of trips generated by each TAZ should be less than 10 to 15 thousand.
6. Consistency with NC Statewide Travel Model (NCSTM) boundaries. The statewide model has established TAZ boundaries to guide the development of statewide issues. In order to maintain data consistency throughout regions of the state, TAZs for small area models should easily nest inside the NCSTM zone system so that data sharing can occur easily.

With the introduction of GIS based travel demand modeling software such as TransCAD, it is easier to visualize and depict the TAZ boundaries in relation to the transportation system being evaluated.

2.3.1 Building TAZs

The creation of the TAZ structure provides a geographic basis for the tabulation of model data such as household and employment-related data, and the associated trip generation (production and attraction) within the given area. TAZs can be developed within TransCAD using existing geographic data files such as census block files and geographic line layers. In addition to providing a structure for data management, TAZs maintained in GIS software provide the ability to: spatially analyze the attached data within a visual boundary; aggregate data to a larger boundary (e.g., a district composed of several TAZs); and aggregate information up from smaller areas (e.g., data from census geography). Figure 2 displays the TAZ system for the Sanford Urban Area.

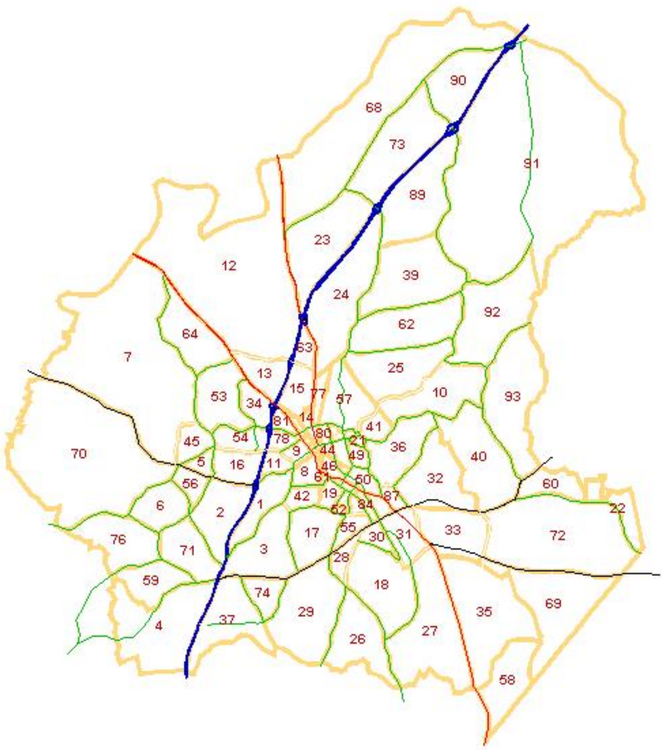


Figure 2 Sanford TAZ System

2.3.2 Traffic Analysis Districts

Districts are geographic regions dividing the study area into relatively homogeneous groups or aggregations of TAZs based on land use, land activity, and aggregate travel demand characteristics. Area type designation, such as urban/ suburban/ rural, is closely based on measures of population and employment densities within districts. Districts are used in the Trip Attraction model and for review, reporting, and display purposes.

Primary considerations in developing districts are:

1. Consistency with TAZ boundaries, as districts are simply groups of TAZs;
2. Homogeneity with respect to TAZ land use variables and characteristics, levels of congestion on the network within the district, and trip attraction/generation characteristics;
3. Sizing. For urban areas with travel survey data, districts should be large enough to have a minimum of 30 observed attraction records (trip ends) and to ensure that the average trip attraction rate per independent variable is approximately correct when using linear regression models to calibrate the attraction model at the district level; and
4. Perceived barriers to mobility. Since districts are commonly used to evaluate trip flow data, physical barriers limiting mobility should be kept in mind (e.g., a bridge, river, or railroad) when defining the districts. As such, these barriers should be utilized as boundaries rather than having these barriers cross through the district.

The GIS functionality of TransCAD is useful for creating districts. With the TAZ information already stored as a geographic layer within TransCAD, creating districts is straightforward. TransCAD allows simple, accurate aggregation of population and employment by category numbers to potential districts, but choosing which TAZs to be included in any given district is a more subjective part of the process. In many cases, more than one district system may be required. For example, an urban area with travel survey data will need to define Attraction Districts specifically to calibrate the Trip Attraction model. It may also be desirable to construct separate Reporting Districts for the purposes of reviewing model output, evaluating transportation plans, or presenting data.

2.3.3 Attraction Districts

For urban areas with travel survey data, attraction districts aid in the calibration of the Trip Attraction model. Regression models are most often the primary method used to estimate trip attractions, as the number of trips made shows a high correlation with independent variables such as employment and office/retail space. The data normally available for this analysis constrain the investigations to large area analysis. Districts are used because typically the dataset available for calibration is relatively small, and the variation by TAZ is too great to allow stable regression analysis at the TAZ level. By aggregating the data to a district level, the variation is reduced and more meaningful regression analysis is made possible.

The strategies for developing a set of districts are: 1) large enough that the average trip attraction rate per independent variable is approximately correct; and 2) small enough to ensure enough districts to allow reasonable regression equations to be estimated. The districts should have enough attraction trip ends to reduce the unexplained variation and they should also be composed of contiguous TAZs. Districts should be reasonably homogeneous with respect to land use, and have approximately the same number of attractions (at least 30 individual data records, not expanded attractions). This may require reducing the number of districts and/or removing some of the districts from the calibration file.

Creating attraction districts is an iterative process; if the first set of attraction districts does not provide a trip attraction model that reasonably fits the household survey data then the districts may need to be adjusted until an adequate fit is achieved. An example of districts for the Sanford Urban Area is presented in Figure 3.

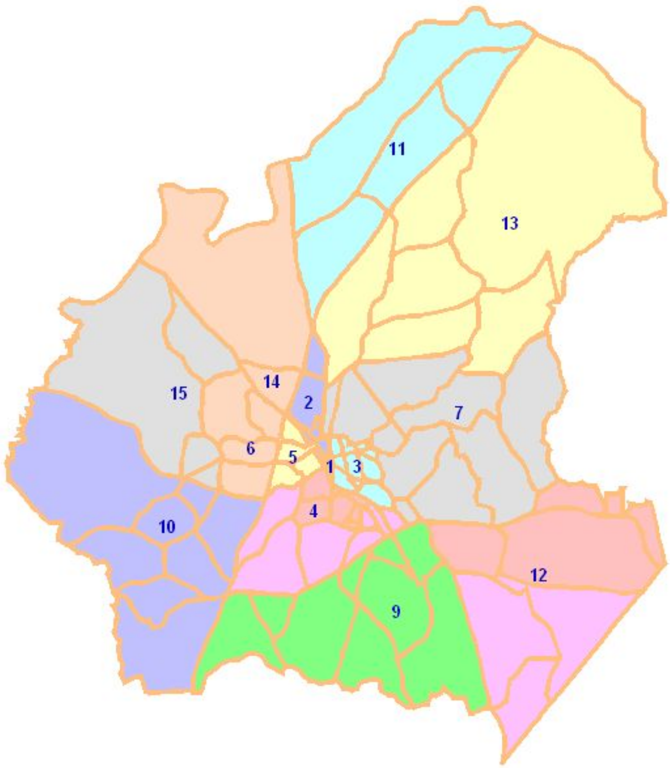


Figure 3 Sanford Districts

2.3.4 Reporting Districts

While the TAZ system reflects the level of aggregation for travel demand analysis within the study area, the TAZ geography is often too detailed for reviewing and presenting certain types of information like land use summaries, person trip interchanges, and certain performance measures. For this reason, it is often beneficial to develop a set of districts to be used for reporting and displaying purposes. When defining reporting districts, all the factors discussed previously should be considered with an additional mind towards representing key geographic regions where reporting and displaying information will be important. Your local knowledge of the study area will serve as your best guide for developing these districts.

2.4 External Zones/Stations

External zones, commonly referred to as external stations, are similar to traffic analysis zones in that they represent travel activity. For external zones, this travel activity has an origin and/or destination outside of the study area. Unlike TAZs, they are not represented by a geographic polygon and demographic data, but are represented as a node in the highway network with an associated traffic count. More attention will be given to the selection and treatment of external stations under the discussion of highway network development.

2.5 Land Use and Demographic Data

In a travel demand modeling context, it is common to refer to population and employment as land use data and elements like average number of workers per household and household income as demographic data. Both land use and demographic data at the TAZ level are a primary input to the modeling process. There are *two* categories of candidate variables for inclusion in the land use and demographic dataset: 1) those that are inputs to the models and must be forecast to the future; and 2) those that are computed or estimated based upon simple computations or sub-models. Table 2 lists a typical set of recommended forecast variables and specifies the context of their use. The household submodels and trip production and attraction models are covered in Chapters 4 and 5, respectively.

Table 2 Typical Land Use and Demographic Data Variables

Variable	Household Submodels	Trip Production Models	Trip Attraction Models	Mode Choice Models	Need to Forecast?
Population	x	x	x	x	Y
Workers	x	x		x	Y
Average Income	x				Y
Households	x				Y
Household Size	x	x		x	N
Income Level	x	x		x	N
Auto Ownership	x	x		x	N
Total Employment			x	x	Y
Retail Employment			x		Y
Service Employment			x		Y
Office Employment			x		Y
Industrial Employment			x		Y
School Enrollment			x		Y
University Enrollment			x		Y

It is recommended practice that local agencies take the lead in the collection, summarizing, and forecasting of land use data necessary to support travel demand modeling. For smaller areas, assistance from NCDOT may be requested by local staff. It is also recommended practice for the transportation analyst to perform validation checks on the data and to work closely with the local agencies to understand and/or resolve any potential discrepancies.

Land use and demographic data describe the population either working in, or living in the geographic area defined by a TAZ, and/or the physical characteristics of that TAZ. Land uses within the TAZ are influenced by the human and natural characteristics of the TAZ which may include: zoning, comprehensive plan designations, vacant land and/or recreational land. Housing data refers to the number of households stratified by type. Note that these are households and not dwelling units. The census defines a household as an occupied dwelling unit. A dwelling unit refers to the structure and can be either occupied or unoccupied. These guidelines recommend using the household data from the census. Employment data include the number of workers by industry type. Socioeconomic data may include number of workers per household and mean household income. Land use, as it relates to travel demand forecasting, has three basic dimensions: type, intensity, and location.

2.5.1 Population and Housing

Population is the most important demographic data element needed for travel pattern analysis and forecasting, along with the number of households by size. Population and household data for the model can be obtained from a variety of sources. A widely used and reliable source for population and household data is the US Census. For more detail or to download the data you can link to the Census website (http://www.census.gov). Caliper also tabulates Census data into a TransCAD compatible format and provides a user interface for extracting the data. The accompanying procedures manual outlines additional steps for getting population data for your area.

2.5.2 Socioeconomic Data

Population and housing counts alone are not enough to produce reliable forecasts of travel as the type and amount of travel is highly correlated to the socioeconomic characteristics of the households. Socioeconomics can be thought of as the intersection of economics and social activities, or more precisely the economic factors that drive our participation in various activities. Socioeconomic characteristics commonly used in travel demand models are household income, auto ownership, and workers per household. Workers per household is highly correlated with home-based work trips (HBW) and non home-based work trips (NHBW). For this reason, it is recommended that workers per household be considered as a key input variable. For other trip purposes, household size and auto ownership have proven to be highly correlated with trip making and are, therefore, key input variables. For smaller areas income is not nearly as important as the other variables and is, therefore, not recommended as an input variable.

As with the population and housing summaries, the US Census data is the most common source for obtaining socioeconomic data. Reporting constraints with the census data may result in the suppression of certain data elements, like income, at the block level. For this reason, the data can only be summarized at the block group, tract, or TAZ if the MPO or State DOT submits a block/TAZ equivalency table to the Census Bureau requesting that data be tabulated for this geography. As shown in Table 2, simple household size and auto ownership submodels are used to forecast these variables negating the need for local planning agencies to forecast this data. These sub-models are discussed more fully under the Trip Generation Submodels portion of this document.

2.5.3 Special Generators

In some areas, the need to reflect the unique characteristics of special generators and special markets may be a consideration. A special generator can be thought of as a specialized land use such as a regional shopping center or small college that have trip generation characteristics that cannot be reflected by the standard trip rates. A special market is much more comprehensive in nature and refers to a specialized land use such as a large university or airport that have trip generation, distribution, time-of-day and/or mode choice characteristics that cannot be reflected by the models developed for other trip purposes. The handling of these two special cases varies. For a special generator, it may be sufficient to specify a separate independent variable in the attraction equation. For special markets it is recommended that at minimum, a separate trip purpose be developed, and in the case of an airport, a special submodel is actually desired to capture the true unique characteristics of this special land use. For rate based special generators, the best source of data is the site itself. The number of employees or other appropriate measures can be obtained from the central business office and trip rates can be developed through the collection of traffic counts taken at access/egress points or along a well placed cordon around the site. If traffic counts are not available or cannot be obtained, a good secondary source of information is the ITE trip generation manual. However, caution should be exercised if selecting this approach as ITE rates are land use based rates, not trip based rates and differences may exist. For special markets, a targeted travel behavior survey and the development of a specialized submodel is recommended. It is not often that this level of detail will be required for study areas covered by these guidelines.

2.5.4 Employment

Employment is an important factor in developing trip attraction models but is generally more difficult to estimate and forecast than population. Employment data, which specifies employers by industry (NAICS code) and number of employees, is most often obtained from North Carolina Employment Security Commission (ESC). Improvements to the data collected, maintained, and tabulated by the ESC has resulted in data records that include data elements such as business owner information, address, phone number, NAICS code, number of employees, etc. Upon request, the geographic coordinate data for the business can also be provided. The inclusion of geographic coordinate data facilitates the use of this data set as address level geocoding is no longer required. However, weaknesses with this data set must be understood and addressed in order to increase the level of confidence. Perhaps the most difficult to overcome is the tendency for such data to be tabulated by mailing address rather than by physical geographic location of the actual employment. For example, a local chain store might have a mailing address in the downtown area, but most of the employment may be physically located in branch stores throughout the area. One approach to overcoming this weakness is to conduct phone interviews for all employers who have more than 50 employees to confirm the geographic location of employees. Private vendor data overcomes this challenge, but offers a few other challenges that must be overcome, such as an inconsistent time-frame for when the data is collected and the cost of obtaining the data.

Recent research conducted by Martin/Alexiou/Bryson (MAB) recommends the use of 8 potential employment categories as opposed to the traditional 5 categories used by NCDOT. (At the time that these guidelines were finalized the final report for this work was unavailable. At such time that this report is finalized it is recommended that it be included in these guidelines as an appendix.) Additionally, this research developed an equivalency between the old SIC codes and the new NAICS codes for each category. The recommended employment categories are:

- Industrial
- High-traffic Industrial
- Retail
- High-traffic Retail
- Service
- High-traffic Service
- Education
- Office

A correspondence table from this research is provided in Table 3.

Table 3 Correspondence Table for SIC and 2002 NAICS Codes

SIC Code	Traditional NCDOT Category	Recommended Category	NAICS 3-digit codes
1 – 49	Industrial	Industrial	111-115, 211-213, 221, 311-339, 423,424, 482, 483, 486, 488, 493
		High-traffic Industrial	236-238, 481, 484, 491, 492, 562
50-54, 56, 57, 59	Retail	Retail	441-444, 446, 448-453
55, 58	High-traffic Retail	High-traffic Retail	445, 447, 722
70-76, 78, 79, 80-84, 86-89, 99	Service	Service	485, 532, 622-624, 811, 813, 814
		High-traffic Service	487, 621, 711-713, 721, 812
		Education	611
60-67, 91-97	Office	Office	425, 454, 511-519, 521-525, 531, 533,

It is important to note that with employment data, there is no single best source. The analyst must weigh the tradeoff between accuracy and reliability against ease of obtaining the data and cost to obtain the data. The recommendation for best practice is to construct the input employment data from multiple sources. In this manner, the weaknesses between the various data sets can be offset by the strength in the others. More specifically, employment data should be obtained from ESC and a private vendor such as InfoUSA or Dunn and Bradstreet. These data sets should be compared against one another and supplemented by either field checks or phone interviews for all employers who have more than 50 employees.

Here is a list of additional checks(some of which have procedures outlined in the procedures manual)

- Compare to Dunn and Bradstreet Data layer
    - Compare larger employers
        - Employees
        - Address
        - Names
    - Look for “home office issues”
    - Do summaries by NAICS codes between databases
- Review XY Location compared to TAZs
    - Move if necessary
- Compare Special locations
    - Universities –University website
    - Schools –local websites
    - Hospitals https://www.ncha.org/nc-hospitals-# of beds http://www.cgia.state.nc.us/ -locations of hospitals

- Use ESC data to compare top employers
  http://esesc23.esc.state.nc.us/d4/QCEWLargestEmployers.aspx
- Use ESC data to look at totals by NAICS grouping
  http://esesc23.esc.state.nc.us/d4/QCEWSelection.aspx

TIP: The guidelines specify a more detailed grouping of the employment data, but that grouping is not followed here due to limitations in the data sets used to create the procedures manual. If more detailed data is available in the future, these procedures should be updated to reflect the more detailed employment groupings as reflected in the guidelines.

2.5.5 School Enrollment Data

School enrollment data is useful for modeling and evaluating K-12 school trips. The geographic location of existing K-12 schools can be obtained from local planning staff. The local school planning staff can provide existing student enrollment data for each of these locations. The local school board and planning staff should also be used as a resource in identifying potential future school locations and estimated future student enrollment. If the school district does not maintain data on future enrollment projections, then a relationship can be developed between existing population and existing student enrollment data. This relationship can then be applied to forecast population to obtain an estimate of forecast enrollment. The future enrollment should be allocated as appropriate to existing school locations and future school locations.

2.5.6 Data Validation

The collection of the land use and demographic data is only the first step in the process of developing robust input for the travel demand model. The critical second step is data review and validation. This starts with a simple inspection of the data through the use of thematic mapping. It is recommended that checks be performed at the TAZ, district, and regional level. The reporting districts defined in Subsection 2.3.4 are useful for these comparisons. A regional level review should include the full planning region. Basic checks include mapping and review of population, households, total employment and employment by category. Various ratios should be created and reviewed including persons/household, population/employment, income ratios (zonal average income/regional average income) and vehicles per household. Look for anomalies, such as zero population and non-zero households, or very low or non-existent employment in a TAZ surrounded by employment. For forecast data, trends in the data and derived statistical measures over time and location should be reviewed to identify any unusual or extreme changes, and corrections should be made where necessary. In medium to large regions, participation and review of the data by local communities and neighborhoods should be encouraged. Finally, select a small set (3-5) of "peer communities" that have similar overall size and characteristics, and compare current and future land use data. Identify any areas where your study area differs significantly from the peer communities. If so, try to understand the reasons for this difference, or make corrections if it seems erroneous.

2.6 Highway Network Development

Representation of transportation infrastructure in the form of a computerized network is mechanically implemented within TransCAD using a GIS data layer and the TransCAD 'Create Network' function.

The highway network serves several purposes in the analysis of transportation systems. First, it is an inventory of the existing road system of interest represented in a GIS data layer, serving as a catalogue of facilities. Basic information such as length of roadway, roadway configurations and cross-section, capacity, and volume can be stored in the highway network GIS database. Second, the network is used in demand analysis to estimate the highway impedance between TAZs in the region. This process is often referred to as "skimming" and is covered in Chapter 3. Impedance is usually described in terms of the in-vehicle travel time and distance associated with the minimum time path between each origin and destination pair. This information is used in a number of the phases of travel demand analysis, most notably in trip distribution and mode choice. The third major use of the network is in estimating auto travel volumes and their associated impacts.

The process of translating the highway system into a computer usable format is known as network coding. This process is made much more efficient with the use of integrated GIS and travel demand modeling software as the basic elements of the network file, nodes and links already exist within the GIS line layer. Links represent individual roadway segments and nodes represent the intersection of roadway segments or are used to separate roadway segments with different data attributes. In addition to nodes and links, the network contains special nodes called centroids. Centroids represent the TAZs and are located at the center of activity in the TAZ. They are the imaginary points at which trips originate and end, and where the trips are loaded on the highway network through a special link called centroid connector. Each TAZ contains one centroid and about one to four centroid connectors. External stations are also centroids, but represent the points at which external trips enter or leave the study area. External stations also represent the locations where the highway network crosses the study area boundary.

2.6.1 Transportation Network Geographic Data Sources

The transportation network can be developed using a variety of methods, but the availability of existing data sources often guides the methodology used. Two recommended techniques for network development include editing an existing GIS database from a previous model development effort or cleaning and coding an existing GIS geographic line layer.

Sources for existing network databases are: regional or local GIS/planning agencies, Census Bureau TIGER/Line files, NCDOT GIS Unit, or commercial distributors.

In the Sanford case study, a base GIS data layer was obtained from the Triangle Regional Model Service Bureau. The original source of this GIS data layer was the Lee County GIS Department.

If census geography is used as the foundation of the TAZ system, then compatibility between TAZ boundaries and street centerlines may be an issue depending on the source of the geographic line layer. The advantage of obtaining data from a local or regional planning agency is that these files are often based on Census Bureau files and will, therefore, correspond nicely with the TAZ layer. Another advantage is that many municipalities maintain roadway data attributes within the geographic line layer that can aid in the coding of attribute data for modeling. If the geographic line layer is obtained from the NCDOT GIS Unit then incompatibility issues between the TAZ layer and the street centerlines may need to be overcome. If this is required then the best approach is to use TransCAD GIS tools to "conflate" or match the geographic lines to the TAZ boundaries.

2.6.2 Study Area Boundary Considerations

The first step in formulating a highway network in an urban area is to overlay the study area boundary. The development of the study area boundary, the TAZs, and the highway network is an iterative process. This iterative nature is necessary to assure that these building blocks are consistent in scale with one another. The network system will also need to account for all pertinent analysis that the transportation model will need to address, as they establish the basis for the entire travel demand modeling process. The study area boundary should be reviewed by the appropriate parties to assure acceptance of the proposed area of analysis before proceeding with model development.

2.6.3 Coordinate System Consistency

When importing any external GIS data layer into TransCAD, the data in the geographic file will be stored in degrees of longitude and latitude. For GIS data layers to be compatible within TransCAD it is important to know the coordinate system of the data that you are importing so that it can be properly converted. TransCAD has all the standard coordinate systems built in so that the only information required to achieve the proper projection in TransCAD is the source data coordinate system class, zone, and units. An example of class, zone, and units is: North America NAD83 (U.S. State Plane); 3200 North Carolina; and feet. Before importing any GIS data files, this information will need to be verified with the supplier of the source data.

2.6.4 Network Nodes

Nodes primarily indicate the intersection of roadway segments within the network. Nodes are identified by a unique ID, longitude, latitude, and any number of data elements that the user would like to input into the database, such as node type or intersection control type. Three node types are included in highway networks:

1. **Centroid**. A unique type of node that represents the origin or destination of trips to or from a TAZ and can be described as the center of the trip-making activities of the TAZ. The determination of the center of activity and the placement of the centroid is a judgment call based on maps and aerial photographs of the area as well as knowledge of the region. Centroids are connected to multiple points on the network using centroid connectors. Centroid connectors should reflect the impedance of the available paths of travel; these impedances are affected by the attributes of the links connecting the centroids to the network. Link attributes are covered in Subsection 2.6.7. The followings are guidelines related to the placement of centroid connectors:
    - Using only a single centroid connector is discouraged as this may result in a large jump in volume between the two network links connecting to it. For some TAZs a single centroid connector may be suitable, but this decision should be

based on the underlying roadway system and an assessment of how traffic should "load" to the network.

- Centroid connectors should not connect directly to an intersection, but rather should connect at the mid block area, or at a location along the highway link most closely reflecting the true underlying access from the TAZ to the roadway system. When possible utilize an existing node rather than creating a new node unless the new node is needed to best reflect true access.
- Centroid connectors should not be linked directly to access controlled facilities such as freeways.
- Only one centroid connector should connect a centroid to the network link between any two intersection nodes.
- If a TAZ is bounded by a barrier, such as a river with no access, or a railroad with no crossing, a centroid connector should not be coded.

2. **External stations**. Located at the boundary of the study area, external stations define where trips enter and leave the study area. Connector links are usually used to connect these stations to the network. It is not practical to include an external station at every roadway crossing the study area boundary. The decision of which roadways to include should take into consideration factors such as the regional significance of the route and the average annual daily traffic (AADT) on the route. The other factor that will guide the selection of external stations is whether or not the roadway has been selected as part of the system to be modeled as described in Subsection 2.6.6.
3. **Link node**. Link nodes can simply be defined as nodes used to separate links where attribute data is different between adjoining links or to represent roadway intersections.

TransCAD does not require that nodes be sequentially numbered starting with centroids, followed by external stations, and ending with link nodes. However, for data management purposes it is recommended that sequential numbering be used at a minimum for centroids and external stations starting with centroids and followed by external stations. It is good practice to leave a gap between the highest centroid and the lowest external station. In older software, such as Tranplan, a gap was not allowed and the user had to code a set of dummy centroids (TAZs) in the network. With TransCAD this is not necessary and the numbers between the highest internal centroid and the lowest external station can simply be left out.

The link nodes can be numbered with virtually any node number larger than the highest external station. It is good practice to leave a gap between the largest external station number and the first link node number. Using GIS spatial relation tools with an existing TAZ and highway network layer, nodes can be tagged (i.e., data are imported from another layer based on proximity) with the appropriate TAZ number, area type, intersection control, or other data as available and desired. A schematic graphic which displays centroids, external stations, and other nodes for the Sanford case study is displayed in Figure 4.

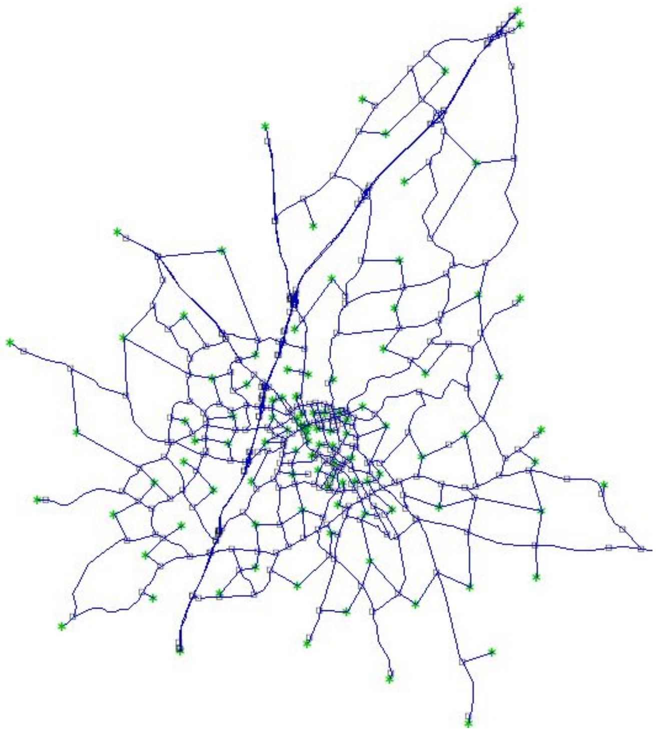


Figure 4 Sanford Highway Network

2.6.5 Special Considerations for Centroids and Centroid Connectors

In the case of centroids and centroid connectors, there are special considerations that are worth noting with respect to coding changes that may be required for the future year analysis based on future year land use changes that were unanticipated when the original TAZ structure was developed. The first case addresses TAZs that need to be split in the future year. The second case addresses TAZs where the center of activity shifts significantly between the base year and the future year.

The practice of TAZ splitting can be addressed from both a theoretical and a practical viewpoint. Theoretically, whenever the TAZ structure is changed, it will affect trip distribution, since it will influence the number of intrazonal trips, and create more “choices” for destinations. In practice, if kept to a small number (on the order of 10 to 20) that does not involve splitting relatively large TAZs, the impact is likely minimal. TAZ splitting is generally done in the context of refining a highway assignment for a small area. In this case the vehicle trip table is split as well, and then another highway assignment is done. The model is not re-run through trip generation, distribution and mode split, which insulates the impact of TAZ splitting from other model procedures. If the TAZ guidelines covered in Section 2.3 are followed, the need to split large rural TAZs in the future will be minimized, if not eliminated.

As already discussed, centroids should be placed at the center of activity (population and employment) of a TAZ. If a TAZ is not uniformly developed in the base year, this may mean that some centroid connectors are shorter than others, which would favor a particular exit from the TAZ. If future development shifts the center of activity within a

TAZ, it's entirely justifiable to shift the centroid (or adjust the centroid connector lengths). This can be considered a change in inputs, and would not require re-calibration of the model. In most cases, the effect on assignment of such a change would be localized.

2.6.6 Roadway Network Links and Link Selection

The highway system in the study area is represented by a system of links connecting pairs of nodes. Each link record in the TransCAD GIS database contains, by default, a unique ID, the link length and the link direction (DIR field). In addition the user may define any number of additional fields such as link type, the number of lanes, or capacity. Recommended attribute fields are discussed in more detail in Subsection 2.6.7. The DIR field deserves special mention here because it is a special field that TransCAD uses to keep track of one-way streets. For two-way streets, the value of this field is zero, if the value of the field is either 1 or -1 then the link is a one-way link. The sign designates the direction of flow as it relates to the link topography. Link topography refers to the direction in which the coordinates of the line feature are stored (how it was originally digitized). If a link has a value of 1, travel is one-way in the direction of the link topography. If it has a value of -1, travel is one-way in the opposite direction of the link topography. It is recommended that one-way links be designated using TransCAD editing tools and not by changing the value of this field directly as you run the risk of making a link inaccessible if the direction of flow and the topography are incompatible.

The network should include all facilities that carry a significant level of traffic, including all federally, functionally classified facilities, collectors and above. It is difficult to concretely define the significant level of traffic in terms of what would apply to all areas covered by these guidelines, but depending on the size of the area this value could range from 2,500 to 5,000. Other local classified or unclassified roadways may be needed to provide a reasonable representation of travel patterns and to allow for connectivity. The intent in creating the network is to replicate to some degree of accuracy the current conditions on the road system. Harvey and Deakin[1] recommend coding facilities one functional class below that for which reliable traffic loadings are required; centroid connectors generally load to the lowest functional class on the network, and reliable traffic projections at this level can be difficult to attain.

2.6.7 Roadway Network Link Database Attributes

Each link in the GIS network database has several attributes associated with it. The number and type of link attributes are not limited by the software, but are only limited by the user's ability to collect and maintain the data. For small MPOs, and large non-MPO areas, the data attributes described in Table 4 are recommended as a minimum.

Table 4 Recommended Roadway Link Attributes

[1] A Manual of Regional Transportation Modeling Practice for Air Quality Analysis, 1993

Link Attribute	Type	Description
ID	Integer (4 bytes)	TransCAD generated, required fields
Length	Real (8 bytes)	
DIR	Integer (2 bytes)	
Posted Speed	Integer (2 bytes)	
Facility Type	Character 23	See Table 5
Area Type	Character 5	See Table 6
Divided	Character 14	See Table 7
AB Lanes	Integer (4 bytes)	Number of lanes by direction
BA Lanes	Integer (4 bytes)	
HOV	Integer (2 bytes)	Logical (0/1) indicating facility is/is not an HOV facility
Toll	Integer (2 bytes)	Logical (0/1) indicating facility is/is not a Toll facility
Functional Class	Character	See Table 8
AB Capacity	Integer (4 bytes)	See Section 2.7 and Table 11
BA Capacity	Integer (4 bytes)	
AB Initial Time	Real (8 bytes)	Initial link travel time by direction, calculated from Posted Speed. See Table 9
BA Initial Time	Real (8 bytes)	
Alpha	Real (4 bytes)	Parameter used in the Conical Delay Function See Table 10

Table 5 Values for Facility Type

Facility Type	Definition
Freeway	Roads with uninterrupted flow and fully restricted access including interstate facilities, freeways, and expressways.
Multi-lane Highway	Partial access control two-way facility. No traffic signals or with traffic signals spaced at least 2 miles apart. Directional traffic is divided or with a continuous turn lane.
Two-lane Highway	Rural, undivided, two-way highways. Intercity or commuting route serving longer trips in rural areas.
Urban Arterial I	Principal arterials of high speed design
Urban Arterial II	Most suburban designs, and intermediate designs for principal arterials.
Urban Arterial III	Generally urban design for principal arterials, intermediate design for minors
Urban Arterial IV	Minor arterials of intermediate or urban design
Collector	Urban suburban locations with lower speeds than arterials. Can be rural roadways with low free-flow speed or frequent interruptions.
Local Road	Coded to provide connectivity. Low speed collectors
Diamond Ramp	
Loop Ramp	
Freeway to Freeway Ramp	
Centroid Connector	

Area type is typically used in the model to further characterize facility types and is sometimes used to modify trip rates. Therefore, before defining area type, the modeler should ascertain the extent to which area type will indeed influence

- Speed and/or capacity of similar facilities – do major arterials have different performance characteristics based on the area type, all other features being the same?
- Trip generation differences – does area type have an influence on the trip rates for either households or commercial facilities?

If either of these is true, then area type can be a useful attribute. In addition, area type may be specified to provide the user with the ability to summarize model results by area type.

Table 6 provides a general description of basic area types. Typically, an area type model is developed that defines area type by population and employment densities, based on a “floating TAZ” system in which adjacent TAZs’ densities are included. This technique tends to ensure that the resulting area type patterns change in a rational and regular fashion geographically and over time. It is recommended that area types be defined based on: 1) their ability to differentiate between trip generation and/or speed and capacity characteristics; and 2) local knowledge of and commonly-held definitions of the area types. For example, there is usually a common consensus on what constitutes the Central Business District (CBD), or “downtown” area.

Table 6 Values of Area Type

Area Type	Description
Rural	Very low population density, large lots, often no central sewer and water utilities available
Urban	Developed and developing, characterized by residential and low-density commercial land use
CBD	Concentrated employment in a small, compact area that serves as the business focal point of the region.

A facility is determined to be divided if it generally operates as if there is no opposing traffic that would affect operational capacity. Facilities with a median and center turn lane are considered divided as are all ramps. Roadways with a 3-lane or 5-lane cross section where the center lane is a continuous left turn lane (CLTL) should be treated as a special case since the capacity of these facilities is slightly better than a facility with no turn lane, but not as good as a facility with a median and center turn lanes. For these special cases the divided field should be coded as CLTL and capacity values specific to this cross-section included in the lookup table.

Table 7 Values for Divided Facilities

Type
Divided
Undivided
CLTL

Values of **functional class** are defined by the Federal Functional Classification System and are required for air quality analysis, but not for model functionality. In North Carolina, if a roadway is not classified then it is assumed to be local.

Table 8 Values for Functional Class

Classification
Not Classified
Rural Principal Arterial - Interstate
Rural Principal Arterial - Other
Rural Minor Arterial
Rural Major Collector
Rural Minor Collector
Rural Local
Urban Principal Arterial - Interstate
Urban Principal Arterial - Freeway/Expressway
Urban Principal Arterial - Other
Urban Minor Arterial
Urban Collector
Urban Local

The initial travel time is calculated based on the posted speed, facility type, number of lanes, whether or not the highway is divided, and as mentioned above, in some cases area type. The initial travel time is the travel time at which traffic will travel if there were no other vehicles on the road to impede travel. The selection sets used to identify appropriate links for each formula are shown in Table 9.

Table 9 Initial Link Travel Time Calculation Criteria

Description	Selection Set	Formula
Higher level highways	Where Facility Type = "Freeway" or ((Facility Type = "Multi-lane Highway" or Facility Type = "Two-lane Highway") and Divided = "Divided")	Initial Travel Time = Length/(Posted Speed + 5.0)*60
Lower level highways and arterials	((Where Facility Type = "Multi-lane Highway" or Facility Type = "Two-lane Highway") and Divided = "Undivided" or Divided = “CLTL”) or Facility Type contains "Urban Arterial"	Initial Travel Time = Length/(Posted Speed - 5.0)*60
Local Roads, collectors, ramps and other links	Where Facility Type= "Centroid Connector" or Facility Type= "Collector" or Facility Type= "Diamond Ramp" or Facility Type= "Loop Ramp" or Facility Type= "Local Road" or Facility Type= "Freeway to Freeway Ramp"	Initial Travel Time = Length/Posted Speed*60

The application of a facility type specific conical delay function (CDF) during highway assignment requires that the function parameters be coded as a data attribute in the highway line layer. The CDF parameter controls the level of speed sensitivity to changes in congestion. This concept is discussed more fully in Chapter 11, Highway Assignment. The CDF parameter is coded in the attribute table based on the value in field Facility Type. Any links that are not coded with a valid Facility Type will not be coded with the essential parameter value. Table 10 shows an example of Alpha parameter lookup table values.

Table 10 Example Lookup Table Alpha Values for Conical Delay Function

Facility Type	Alpha
Freeway	10
Multi-Lane Highway	8
Two-lane Highway	6
Urban Arterial I	6
Urban Arterial II	6
Urban Arterial III	6
Urban Arterial IV	6
Collector	4
Local Road	4
Diamond Ramp	8
Loop Ramp	8
Freeway to Freeway Ramp	8
Centroid Connector	NA

2.7 Network Link Capacity

The specification of highway network capacity in a travel demand model relates the supply characteristics of the urban roadway system to the network representation used by travel demand models and application software. An accurate portrayal of highway system supply is very important as it is related to the highway travel demand through a feedback or equilibration process resulting in a well understood and accepted model of individual route choice behavior.

Capacity, as typically used in urban travel demand models, is a descriptive measure of vehicle throughput for the link; as such, capacity is characterized by a number of other link characteristics or attributes rather than being analytically determined as might be done in a detailed traffic operations analysis.

The term capacity refers to the maximum rate of vehicle flow. Use of the term *rate* indicates that capacity is a “per unit of time” measure. In detailed capacity analyses, capacity is defined in 15-minute intervals, the shortest period for which flow is thought to be stable. The capacity of a roadway is thus the maximum rate of flow during a fifteen minute time interval and is considered to be uniform along the section of roadway being considered; that is, during the fifteen minute period, the capacity of the roadway is the same along the entire stretch being considered. In travel demand models, capacity is determined for a fixed time interval – that is, for the length of the modeling analysis period (e.g., peak hour, mid-day period, and 24 hours). Capacity is assumed to be uniform over the entire length of the segment or link during that period.

Roadway network links usually describe aggregations of actual roadway segments. Several segments, separated by intersections, may be described by a single link. If traffic control devices, lane widths, or parking characteristics are not uniform along the link, it may be necessary to define separate links to accurately represent the roadway capacity in the model. Other physical influences that may affect capacity are extreme roadway grades, high percentages of heavy vehicle traffic (commercial vehicles and public transit vehicles), and significant interaction between bicycle, pedestrian and motorized traffic at intersections and along the roadway. Changes in these characteristics along network links may warrant the splitting of links to account for change in capacity.

2.7.1 Network Attributes That Affect Link Capacity

The objective for travel demand models is to be able to describe measurable traffic conditions in terms of variables that are sensitive to policy actions and that can be forecast. Highway network capacity must, therefore, be described by variables that yield sensitivity and can be forecast. For example, traffic signal timing plans have a large impact on intersection capacity but cannot be used to directly describe capacity since future year timing plans cannot be realistically assumed. The vital information related to traffic control, however, can be represented in the model by characterizing signal timing information by the types of intersecting facilities (facility type) and the underlying land use (area type). Network attributes are used in this manner to characterize details of the roadway system with information that can be collected for model estimation and validation as well as be forecast for future years.

2.7.2 Highway Network Link Capacity Specification

NCDOT has adopted the NCLOS Analysis Software[2] as its standard tool for calculating LOS for roadway facilities in travel forecasting models. A large number of factors have

[2] NCLOS Analysis Software, North Carolina Department of Transportation, Version 2.0, Developed by: ITRE at North Carolina State University, 2005

been identified that affect the capacity of a link. For large non-MPO and small MPO areas these factors can be captured through the unique combination of three overriding characteristics: facility type, area type, and divided/undivided status. To facilitate the implementation of the LOS tool into the travel demand modeling process for large non-MPOs and small MPOs, it is recommended that roadway facilities be identified and analyzed based on these three characteristics. The exclusive use of these three variables can ease the data collection and coding burden related to factors such as intersection control and underlying land use, as mentioned above.

Once the values for facility type, area type, and divided/undivided status have been coded into the link database the unique combinations of these three variables can be identified. The NCLOS Analysis Software can then be used to calculate the appropriate capacity for each unique facility combination in the study area. A standard look-up table can then be utilized to assign link capacity based on the unique combination of these three characteristics as coded on the link. An example of how this approach is applied is demonstrated in Table 11.

Table 11 Example Capacity Lookup Table

Facility Type	Area Type	Divided	Capacity(Hourly/Lane)
Freeway	CBD	Divided	2,100
Freeway	Rural	Divided	2,100
Freeway	Urban	Divided	2,100
Multi-lane Highway	CBD	Divided	1,700
Multi-lane Highway	CBD	Undivided	1,400
Multi-lane Highway	Rural	Divided	1,700
Multi-lane Highway	Rural	Undivided	1,400
Multi-lane Highway	Urban	Divided	1,700
Multi-lane Highway	Urban	Undivided	1,400
Two-lane Highway	Rural	Divided	1,200
Two-lane Highway	Rural	Undivided	1,000
Two-lane Highway	Urban	Divided	1,200
Two-lane Highway	Urban	Undivided	1,000
Freeway to Freeway Ramp	CBD	Divided	2,100
Freeway to Freeway Ramp	Rural	Divided	2,100
Freeway to Freeway Ramp	Urban	Divided	2,100
Loop Ramp	CBD	Divided	1,000
Loop Ramp	Rural	Divided	1,000
Loop Ramp	Urban	Divided	1,000
Urban Arterial I	CBD	Divided	1,500
Urban Arterial I	CBD	Undivided	1,400
Etc…			

2.8 Zone and Network Relationship

As mentioned in the section on TAZ development, the network and TAZ systems should be compatible with each other in scale and coverage. A very detailed network should be supported by a detailed TAZ system, and conversely a sparse network supported by a larger, more aggregate TAZ system. This type of balance ensures that network links are properly assigned, and that there are no redundant or useless links and/or centroids in the network.

2.9 Roadway Network Quality Control

Maintenance of the roadway network database in a GIS environment facilitates the identification and correction of erroneous network data items. Color coded plots, with varying degrees of detail, of the following network attributes should be produced and reviewed:

- Facility type,
- Functional class,
- Number of lanes,
- Posted speed,
- Area type,
- Capacity, and
- Direction of flow.

Additionally, TransCAD queries should be run to check all two way links to ensure the data is symmetric such as number of lanes or alpha values of conical delay function (CDF).

Other important checks include network connectivity and path testing. Link connectivity can be checked by using the TransCAD connectivity tool. This process will identify dangling links, disconnected link segments, and disconnected nodes. Highway network paths (or skims) are useful for creating time contours between regions of interest, like a CBD. Contour maps can be analyzed to ensure that all centroids with particularly long or short travel times as compared to surrounding centroids are properly connected to the line layer and that all surrounding highway links are properly coded. Skimming will be covered in more detail in Chapter 3.

2.10 Travel Survey Data

Travel surveys provide the underlying strength of any model and serve as the fundamental data upon which it is built. While there are a variety of surveys that can be designed for this purpose, the primary objective of this data collection activity should be reflective of the data necessary to estimate and calibrate a set of travel demand models for a region. A household travel survey forms the basis of any model development project. An on-board transit survey may also be essential for model estimation, specifically in the construction of a choice-based sample for mode choice estimation. Finally, an external station survey provides data for estimating the external-internal, internal-external, and through trips.

The North Carolina Department of Transportation (NCDOT) in cooperation with its Metropolitan Planning Organization (MPO) partners has collected travel survey data for MPO regions across the state. This effort has provided the state with a wealth of information about travel for various study areas in all parts of the state. When embarking upon the development of a new travel demand model, it is ideal to collect travel survey data so that local data can be used to estimate and calibrate the various model components. However, due to the cost of obtaining this type of data, it is not reasonable to expect that travel survey data can be collected for the majority of the study areas that these guidelines cover. Instead, the North Carolina Combined Survey Database (Section 1.5) was used to develop default rates and parameters that can be used as a starting point for areas covered by these guidelines.

The purpose of this section is to provide the reader with a general overview of the most common travel surveys that might be administered for a small MPO region.

2.10.1 Household Travel Survey

A household travel survey is used to collect information about the travel characteristics of households in a region. Data is collected from a sample of households in which the travel of each person in the household is documented in detail for a designated day. Information such as start time and end time of trips, origin and destination locations, trip purpose and mode are recorded. In addition, general information about the household and its members is recorded such as number of persons, number of workers, number of children, number of autos, household income, employment status, gender, and age. This type of survey is usually the major source of information for developing a set of travel demand models to estimate travel behavior in a region. A travel survey is desired when a model development process is being undertaken. Survey sampling techniques usually require a *minimum* of between 1000 and 1600 households to be surveyed. While these figures are based on sampling statistics and the size of the region, there is a minimum threshold of 1,000 households for even small areas to maintain statistical significance. Larger samples are often necessary to construct models with the full range of explanatory variables. For example, a cross-classification trip generation model may consist of four auto ownership categories cross-classified by five household size and four worker categories. A basic or practical guideline for determining the appropriate number of samples required suggests that a minimum of 30 samples (or households) be present in each cross-classification stratum so that adjacent strata may be compared to gauge statistical significance. In this example, a minimum of 2,400 (=4*5*4*30) usable observations would be required[3]. If the available sample size is less than the desired number, compromises with respect to variable inclusion and/or statistical significance of one or more cells will be the result. Zero auto and larger households are typically cells which tend to be missing or under-reported in smaller sample surveys.

2.10.2 On-Board Transit Survey Data Preparation

On-board transit surveys are often performed to complement and enhance the data and information obtained in a household travel survey. The data is considered to be "choice-based" rather than random, given the emphasis placed on a single mode. Typically, riders are interviewed with respect to their current trip. Information such as the origin, destination, boarding and alighting locations, transfer characteristics, trip purpose, fare-class utilization, auto ownership, and income are all collected from the participant while on board. On-board transit survey data can be useful in a variety of contexts including short-term or operational planning exercises as well as model development, calibration, and validation. The sample of households randomly selected for interviews in a household survey may not be able to provide a sufficient number of transit trip observations to reliably develop mode choice models or assist in the calibration or validation of the models. An on-board transit survey specifically designed for model development purposes can contribute directly to each step in the model development process.

Designing a sampling plan for an on-board survey involves two major considerations. The first consists of determining the total number of bus trips to be sampled. General system characteristics such as route, route direction, and time-of-day should be

[3] 4 (auto ownership categories) * 5 (household size categories) * 4 (worker categories) * 30 samples=2400

considered when designing the sample plan. The second consideration consists of selecting the specific bus trips to be sampled balancing surveying efficiency in a consistent manner with the overall survey design.

There are two fundamental approaches to the design aspect. One approach attempts to achieve an equal precision per route, while the other allocates samples as a direct function of individual route ridership, but provides for a minimum precision per route. The former approach is typically followed in instances where the primary use of the data will be for short-range or operational planning. The latter is the method normally employed when model development and application is the primary use of the data.

To obtain rich transit ridership information, an on-board survey is highly encouraged, but is not required for a “best practice” model set.

2.10.3 External Surveys

External surveys provide information for travelers that have one end of their trip outside the region or subsequently for travelers that have both ends of their trip outside the region (external-external), but simply pass through. Travelers are asked to provide origin and destination locations, trip purpose, auto occupancy, and some information on other trips made while in the region. A survey of this nature allows complementary models to be developed for two trip purposes related to external trip making:

- Internal-External (and External-Internal) and
- External-External.

The external survey should include a simultaneous external station count so the surveyed vehicles may be expanded properly to the regional total of external trips. Two common methods of performing an external survey are:

- License Plate Survey and
- Personal Intercept.

The license plate survey is usually at least 50% more expensive than an intercept survey, and experiences very low response rates (i.e., 5-20 percent). The personal intercept survey is more efficient since response rates are 90%-100%, and the quality of the data is much higher since a wide variety of questions may be asked about the trip being made. Additionally, the quality of the information can be carefully controlled. Sometimes, due to traffic volume and/or speed, an intercept survey is not feasible and a license plate survey must be used. Roadways with volumes under 10,000 AADT will not, however, return sufficient responses from a license plate survey to provide a statistically significant sample. In addition, NC laws do not allow intercept surveys on Interstates.

External surveys also are not required, but are highly recommended if external travel comprises a reasonable measure of overall area travel.

2.10.4 Other Surveys

There are several other surveys that bear a brief mentioning here for informational purposes. These include workplace surveys, truck surveys, visitor surveys, and stated preference surveys.

Workplace surveys, also known as employment or destination survey, are performed to provide specific and detailed information about trip destinations. The data is particularly useful for estimating and calibrating trip attraction models. Data from a workplace survey can also be used to develop a parking cost model, and/or to provide information about visitors and commercial vehicle traffic.

Truck surveys are used to collect information about truck characteristics and goods movements. Truck surveys are most often conducted to support statewide and regional models, but the data can also be useful in developing a truck generation and distribution component within an MPO model.

A visitor survey can provide information on non-resident travel and is useful for study areas where visitors or tourism makes a significant contribution to travel within a region.

Stated preference surveys are used to identify how respondents view various choices or tradeoffs among a given set of alternatives. For example, a stated preference survey might be used to assess how respondents might respond to new transportation services or infrastructure such as HOV lanes, urban rail, or toll facilities.

2.11 Calibration, Validation and Reasonableness Checking Data

Calibration and reasonableness checking takes place at each step in the travel model development process. In best practice modeling, each model component is subjected to a series of checks or reasonableness tests following estimation or assertion of the model parameters. Calibration is the process of adjusting the parameters and constants of equations to replicate observed data. Validation is the process of applying the model equations and comparing the model estimated values to a source of data independent from the data used to calibrate the equations. Reasonableness checking is used here interchangeably with calibration to describe model checks that should be performed even when locally observed calibration data is not available.

Highway assignment validation is the final step in the model development process, but should never be the first step in the model calibration and reasonableness checking process. While a comparison of the model assignment in the base year with observed data serves to indicate how well the model is replicating existing travel patterns, it is equally important to review model inputs as well as model outputs for trip generation, trip distribution, and mode choice. Combined, the overall model calibration and validation process is an aggregate set of comparisons, and represents a test of the model's ability to accurately reflect existing travel behavior. The various data used for reasonableness checking and model validation are covered in this section.

2.11.1 Traffic Count Data

Traffic counting is the process of recording the number of vehicles passing a given point during a specified period of time. The most basic count technique is not sophisticated enough to register the difference between types of vehicles and the total count must be adjusted to account for vehicle mix. More sophisticated techniques allow for the collection of vehicle classification data and speed data. Traffic volumes are the total counts within a specified time period.

Traffic count data is used to compare the model's estimated roadway volumes to observed roadway volumes. This comparison can be used to evaluate the difference between observed roadway segment volumes and estimated model volumes. It is essential that the traffic count data used in this comparison represent counts taken during the same year as the model validation year, or as close to the model validation year as possible. It is also important that the counts be taken in a consistent manner, and adjusted to reflect average weekday traffic (AWDT), since most models are designed to generate average weekday volumes. A consistent database of traffic counts is necessary and if no current database exists, one must be developed for the validation year, ideally at the level at which validation will be performed (e.g., peak period counts for a peak period model). The process of identifying count sources and peak periods, collecting data and manipulating files, and applying factors to raw counts to provide base year average daily traffic (ADT) figures essentially reflects the required processes. The amount of time needed for this task will differ depending on the urban area and the degree of existing count database maintenance.

The North Carolina Department of Transportation has a comprehensive traffic count program that provides a robust data set for the validation of models. This program is administered by the Traffic Surveys Group whose mission is to provide high quality traffic information to support the planning, design, operation, and research activities. This program supports the travel modeler by providing, upon request, traffic count data by location for a specified time frame coinciding with the validation year of the travel demand model.

<u>Terminology</u>
An understanding of count data requires a definitional knowledge of various count types.

Raw Count
A count that has not yet been factored is referred to as a raw count. As previously mentioned, most traffic count data is collected using equipment that is not sophisticated enough to record vehicle type data. This raw count data is actually a count of the number of axles passing over the count device. This raw count data must be factored using a vehicle axle adjustment factor before the raw count can be considered a vehicle count.

Average Daily Traffic (ADT)
ADT is an average 24-hour traffic volume at a given location during a given time period, greater than one day and less than one year, typically over a 48-hour time period. ADT does not account for seasonal variations in traffic and is only representative of the time period in which the data is collected.

Annual Average Daily Traffic (AADT)
AADT is an average 24-hour traffic volume at a given location taken for a period of 48-72 hours. AADT are calculated by using factors obtained from permanent traffic count locations that actually record count data 365 days a year and applying these seasonal correction factors to convert ADT to AADT.

Average Weekday Traffic (AWDT)
AWDT is similar to ADT in that it is an average 24-hour traffic volume at a given location during a given time period. This difference is that AWDT represents weekday traffic only.

Annual Average Weekday Traffic (AAWDT)

AAWDT is an average 24-hour traffic volume at a given location taken for a period of 48-72 hours. This data is most useful for regions where weekend traffic is significantly different from weekday traffic and where the averaging of weekend traffic with weekday traffic may mask the true impact of weekday traffic. AAWDT are calculated by using factors obtained from permanent traffic count locations that actually record count data 365 days a year and applying these seasonal correction factors to convert the AWDT to AAWDT.

Hourly Count
Hourly counts provide a distribution of traffic volumes by hour of the day. These counts are important for understanding peak demand and variations in traffic across the day. In best practice modeling the vehicle assignment model considers both peak and off peak assignments to arrive at an average daily assignment. As a result, traffic counts are needed for more than a single time period. For the peak hour model validation, it is important to make sure that the traffic count data represent the same hour to which the model is being estimated and the hourly traffic counts are therefore required for time-of-day assignment validation.

Classification Count
Classification counts are particularly important for roadway facilities that have high volumes of truck traffic. A classification count involves the direct collection of vehicle type data.

NCDOT Count Program
Various types of counts are available by request from the NCDOT Traffic Survey Group. These include, but may not be limited to:

Biennial traffic counts
Historic count data collected at predetermined locations on a predetermined schedule. This data is used primarily for system monitoring, but can also be useful for model validation work if appropriate factors are applied. Count factoring is discussed further in a later section. These counts are reported as AADT.

Special project counts
These are counts that are requested to support special project needs. The counts can be requested in various formats including ADT, AADT, hourly, or classification. The scale of the data collection effort will determine the amount of time required to collect and process all data. The Traffic Survey Group should be consulted to determine the length of time required. The count request should clearly specify the time period when the counts are needed and any count factoring that is required. The request should be accompanied by a table that provides a unique ID, location description, and type of count. A legible map that clearly delineates the location of the requested count with the corresponding unique ID is also required. Table 12 shows an example request form. The NCDOT procedures manual covering traffic counts is also a good source of information.

Table 12 Example Count Request Form

Count ID	Type	Route	Reference	Duration	Directional

Count Factoring and Adjustments

Adjusting raw count data for daily, weekly, and seasonal variation is a critical step in the data development process. There is often a wide variation in traffic count data depending on the month and day of the week that the individual traffic counts were taken. Traffic counts should be geared towards the season to which the model is being validated, or adjusted to approximate an average daily value. For example, traffic counts are not often taken in the summer because school is out of normal session and this affects the home-based school trips as well as home-based work trips.

After building the count database, adjustments will likely be made based on the month and year each traffic count was taken. Permanent traffic recorder data can be used to determine factors to adjust for the month, and historical data can be used to determine a compound growth rate by which to adjust for the year. The final product of the process is a set of AWDT and adjusted peak and off-peak period volumes. Due to the greater depth of knowledge and understanding of traffic count data by NCDOT Traffic Survey staff, it is recommended that all factoring and adjusting of count data be performed by these staff. This additional effort must be taken into consideration when requesting and scheduling the delivery of project count data.

In theory AAWDT is more appropriate to validate to, but in practice there may be very little difference between AADT and AAWDT. If the difference in factors between AWDT and AAWDT is only within the range of a few percent, then that is well within the variation in the travel demand model and it would be acceptable to use either count. The best guideline and recommendation is to become very familiar with the traffic count data for the study area, how the day of week and the month of year create variations in the raw counts, and how factors are computed and applied to convert the count to either an AWDT or AAWDT that is representative of the average day that your are modeling. This is further justification for utilizing the skills and expertise of the Traffic Survey staff for preparing count data for calibration and validation.

Selecting Counts at Screenlines, Cutlines, and Cordon Count Locations

Screenlines, cutlines, and cordons are imaginary lines that assist in the validation of the model. Screenlines typically run north south and east west from one end of the study area to the other end of the study area. These imaginary lines are used to validate regional flows. When possible, screenlines should be associated with geographic features such as rivers or railroads in order to minimize the number of roadways that cross the screenline. When laying out a screenline, care should be taken to cross roadways in such a way that the true directional flow is captured. Back tracking and crossing the same roadway twice should be avoided as should passing a screenline through the downtown or central business district (CBD), even if a railroad goes through the center of town. The circuitous nature of travel in a CBD can often lead to distortions in the traffic count as it relates to the traffic flow represented in the model.

Cutlines are very similar to screenlines except that they typically do not run from one edge of the study area to the other, but are most often used as an effective means of evaluating flows along a particular axis or corridor.

A cordon is most often used to refer to the imaginary line that encompasses the study area, but cordons can be used to represent more than just the study area boundary.

Internal cordons are useful in identifying unique regions within the study area. Good examples of where internal cordons may be useful include the CBD, college campuses, unique districts, and small communities within a multi-community region. These internal cordons can serve as a useful check in determining whether the model flow into and out of the cordon area is reflective of what has been observed through traffic counts.

Once these imaginary lines have been identified the process of identifying where traffic counts are needed becomes relatively straightforward. Counts should be requested for all roadways crossing the screenlines, cutlines, and cordons regardless of whether or not the roadways are included in the modeled network. The traffic count data for roadways not in the network should be added to the traffic count for the most logical nearby roadway represented in the network. It is recommended that all screenline, cutline, and cordon counts for NC routes and above be hourly counts (contingent upon available resources). Major routes with a US or Interstate designation should be an hourly vehicle classification count (contingent upon available resources).

<u>Selecting Coverage Counts</u>

Coverage counts can be defined as all counts not located at screenlines, cutlines, or cordons. The selection of coverage count locations is not as clearly defined as the selection of locations for the other counts. The available literature on model validation is clear on the need to select counts at all screenline, cutline, and cordon locations. It is less clear on how to select locations for coverage counts. The analyst must select count locations to provide enough data to validate the traffic assignment with a certain degree of confidence. However, the analyst should also be cautioned against selecting too many counts such that validation becomes difficult to achieve as a result of variation due to day, season, incidents, or special events. FHWA recommends count coverage of 65 percent or greater for freeways and principal arterials[4]. This reference makes no specific recommendation on the required percentage of counts for minor arterials and collectors where a value of less than 65 percent seems appropriate. From this information it can be inferred that fewer count samples are needed for lower classified facilities. In practice, the number of observed counts used in model validation varies on a case by case basis, depending on the availability of data and resources.

Hourly and classification counts should be requested for key routes geographically dispersed across the region. Once selected, thematic maps of counts by count type should be created and examined to assess whether adequate coverage and magnitude in coverage count locations have been achieved.

<u>Reviewing Count Data</u>

Once a regional traffic count database has been created the count data should be reviewed and validated in an effort to identify errors in the data. Several techniques exist for validating count data including:

1. Visual inspection of the count data plotted on the highway network to identify count locations that appear inconsistent with other nearby count locations.
2. Review of historic count data where available.
3. Thematic map showing count to capacity ratio in order to identify counts with very high or very low count to capacity ratio. These locations should be further investigated for reasonableness.

---

[4] Calibration and Adjustment of System Planning Models, FHWA, December 1990

4. Using an existing seed matrix, the count set can be used to generate a synthetic O/D matrix that closely matches, in aggregate, the available counts. TransCAD has a built-in feature for synthetic matrix estimation. This matrix is then assigned to the network. The synthetic loadings can then be compared with counts, and any large discrepancies may indicate that the counts are inconsistent with those nearby.

2.11.2 Vehicle Miles Traveled

Vehicle miles traveled (VMT) is an important measure to assess the system wide performance of the travel model with respect to highway assignment. Validation of the model using VMT addresses all major steps in the travel demand models, including trip generation (the number of trips), trip distribution (the trip lengths), and assignment (the paths taken). VMT validation is particularly important in urban areas that are designated by the Environmental Protection Agency (EPA) as non-attainment areas. Observed VMT data is a required reporting statistic for the Highway Performance Measure System (HPMS). HPMS is a system for managing and monitoring transportation data related to the condition, performance, use, and operating characteristics of the nation’s highways. In essence, it is an information support tool for FHWA in communicating with Congress. It should however be noted that in North Carolina there is required factoring of the HPMS VMT data that makes it unusable for comparisons of modeled VMT at any geography lower than a county. For this reason, it may be best to develop VMT validation data using the count database. In this case, only those links with counts are used for comparison with the model results. Using the traffic count data VMT validation summaries should be created for each facility type in the model.

2.11.3 Highway Travel Speeds

Link travel speeds are used in the assignment process and fundamentally determine which paths will be used on the network when traveling between TAZ pairs. There are several reliable methods to collect data on travel speeds. Floating car runs can provide a useful source of information on not only free-flow, but also congested speeds. Pneumatic traffic counters can also be used to provide speed data. The speeds calculated from a model run can be compared to the observed travel times on a link-by-link basis to determine if the coded link speeds are accurately reflecting traffic flow. Caution should be used, however, when observed speeds are affected by upstream bottlenecks and congestion. Model speeds will not reflect queuing. The estimated link speeds will be derived from a set of calibrated travel time functions for the region. It is recommended that a small sample of observed travel times for various facilities in the region be collected for calibration of the highway travel speeds.

2.11.4 Trip Length Data

Trip length information is most often used to calibrate a set of trip distribution model for a region. Trip length information can also be used in the calibration of the mode choice model. The observed and estimated average trip lengths for each purpose are compared to make a determination of how well the model is calibrated. Several factors can influence the average trip length, including the spatial distribution of productions and attractions as well as the initial highway link speeds used in the calibration process. Each of the appropriate factors influencing the estimated trip length should be reviewed if the comparison of the observed and estimated trip lengths is not favorable.

Information regarding the average length of trips by trip purpose is important in determining how the model is reproducing traffic flows on the network. A household travel survey can serve as a primary source for data on trip lengths. The US Census data for Journey-to-Work information can also be used if it is available. Aggregate household travel survey data and Census data can also be used to calibrate/validate trip distribution on a district-to-district basis. The North Carolina Combined Survey Database developed as a part of this project will also provide a source of information for obtaining this data. It is recommended that information from the Census Journey-to-Work and the North Carolina Combined Survey Database be used for trip length calibration data.

2.11.5 Transit Boarding Counts

Transit boarding counts are mentioned briefly for informational purposes only as these guidelines do not cover mode choice models or transit assignment. Transit boarding counts are generally taken concurrent with an on-board transit survey. The process involves a tabulation of all passengers boarding and alighting the transit vehicle at each stop. These counts are used to validate the transit assignment.

2.11.6 Other Comparison Data

As mentioned previously, the best source for calibration data is a local household travel survey. If a local household survey is not available, other secondary sources of data that should be utilized include the Census Transportation Planning Package (CTPP) and the National Household Travel Survey (NHTS). Both provide statistics and measures related to travel that can be useful in providing insights for checking the reasonableness of model results. The household travel survey and CTPP data can be useful in generating overall trip rates such as trips per person or trips per household. These rates can be used as an overall check on the trip rates in the model. Similarly, aggregate census data at the TAZ level can be used to calibrate and validate trip attractions, household size models, auto ownership models, worker models, and household income models.

Finally, to support these guidelines, the North Carolina Combined Survey Database was created and used to provide comparison data that can be used for reasonableness checking. This data is summarized in the companion document for these guidelines: *NCDOT Small Area Travel Demand Model Procedure Manual*. Both this data source and CTPP data should be used to create comparison data and summaries for model reasonableness checking.

3 NETWORKS AND SHORTEST PATHS

3.1 Concept of Networks and Paths

In Chapter 2, Sections 2.6 and 2.7 discussed the development of the highway network with respect to links, nodes, and the various data attributes that define the highway system. Those sections described what can be considered the visual components of the system. In this chapter, the concept of a network from the standpoint of the structural and mathematical components of the system is introduced. In other words, for the computer to be able to understand the visual components that are represented through the links, nodes, and attributes that have been coded, those components must be translated into a structure that the computer algorithms can read and understand. In the TransCAD Users Guide, a network is defined as a special data structure that stores important characteristics of the transportation system needed to solve transportation problems, such as shortest paths. The Users Guide describes a shortest path as a route over the transportation network that has the lowest generalized cost, where cost can be any combination of factors such as distance, time, or cost of travel.

3.2 Network

To understand the concept of a network, it is helpful to think in terms of what we humans see when we look at a map, generally a combination of straight and curvy lines, as compared to what the computer "sees" which is movement or flow rather than lines on a map. The process of coding the network creates a computer version of the roadway system in the form of a geographic line layer. The process of creating a network creates a computer version of the direction of flow. Figures 5 and 6 below show a visual depiction of the differences between a geographic line layer via the representation of the transportation system -, and the computer abstraction of the transportation system via network flow.

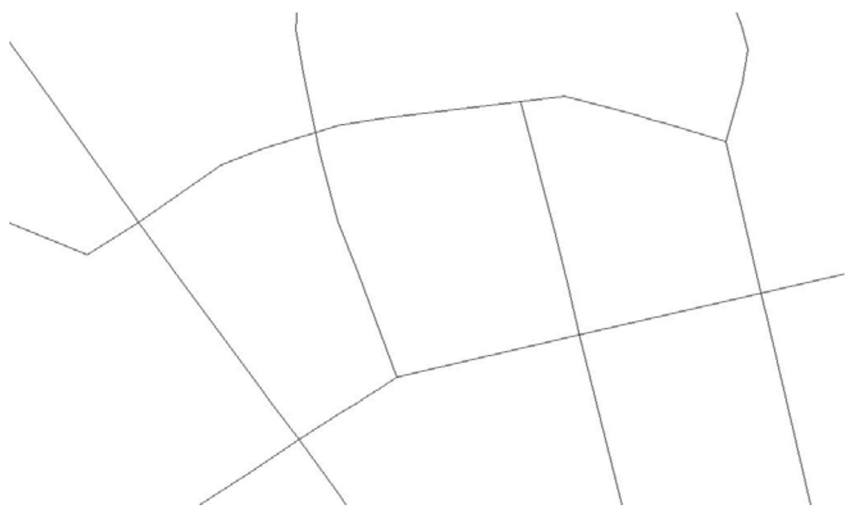


Figure 5 Geographic Line Layer

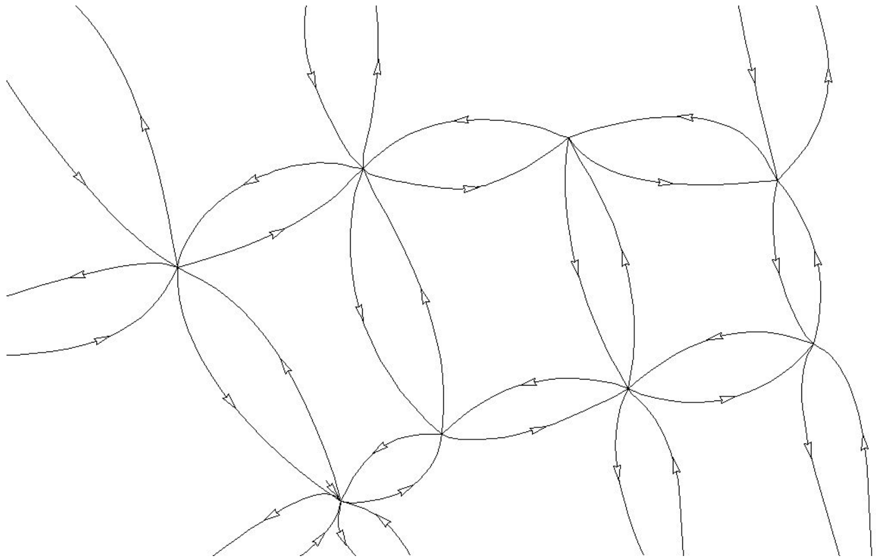


Figure 6 Transportation System “Network”

In the figure depicting the network, each link has been represented as two one-way links, with a direction of flow specified. Each of these links will have user defined data attributes such as time or distance associated with them. The path building algorithm can now read both the direction of flow and the link from one node to other nodes in order to calculate the minimum path. The minimum path is computed by the path building algorithm in a sequential manner, starting with the origin and determining the shortest path, link by link, to each node using a procedure known as the “Moore algorithm”.

When building the network, the attributes associated with the network are dependent upon the type of analysis to be performed. For example, a simple minimum path from point A to point B using distance would only require that you specify values of distance when creating the network. However, a complex cost function might require the inclusion of various link variables that describe the function. It is important to remember that in order for a variable to be included in the network definition, it must be included in the data attribute table for the highway geographic line layer, but there can be data attributes in the geographic line layer that are not required for network specification. For large non-MPO areas and small MPOs -, it is recommended that values of distance, travel time, and capacity be included in the network definition.

Highway and transit networks are used in the final three steps (trip distribution, mode choice, and trip assignment) of the four-step process. In trip distribution, networks are used to produce an impedance (often travel time) matrix. The matrix shows the impedance between all TAZ pairs. In mode choice network impedances are important because, in very simple terms, mode choice is based in part on a comparison of the time and cost of an auto trip to the time and cost of a transit trip. Finally, in trip assignment highway and transit trips for each TAZ interchange are assigned to (or “loaded onto”) the highway and transit networks. Network attributes are used to choose the minimum impedance or time path on either the highway or transit network. Information on the number of trips assigned to each link is then stored in output, or “loaded” network files.

Each of the steps described above will be covered in more detail in later chapters. However, it is important to realize that the development of networks is a very critical step. The preparation of highway and transit networks for model calibration, model validation, and travel forecasting is a time consuming process that must be completed with great accuracy to ensure good model performance.

3.3 Path Building and Skims

Path building involves finding the minimum path between every TAZ interchange. The minimum path is determined based on the user defined impedance such as time, distance, cost, or a composite impedance function that may include both cost and time, for example. The path can be different depending on the impedance variable that is used. Path building is the basis for the assignment step in travel demand models, but it also plays an important role in error checking and validation of networks, trip distribution, and mode choice. In trip distribution, the TAZ to TAZ impedances are used as an input to the gravity model.

3.3.1 Trees

A minimum path tree describes the graphic display of the minimum path through the network from one TAZ to another, or from one TAZ to all others. Plotting or mapping minimum path trees is a very useful tool for reviewing the reasonableness of the paths.

3.3.2 Skim matrix

The skim matrix is the final output from the path building exercise. Travel time and travel distance matrices are examples of skim matrices. It is a two-dimensional array, with each TAZ represented on each dimension. Therefore, there is a cell for each origin/destination zone pair in which can be stored the minimum user defined impedance for that zone pair. For large non-MPO areas and small MPOs -it is recommended that the user define a combination of distance and travel time as the impedance values. An example travel time matrix for a five zone model is provided below.

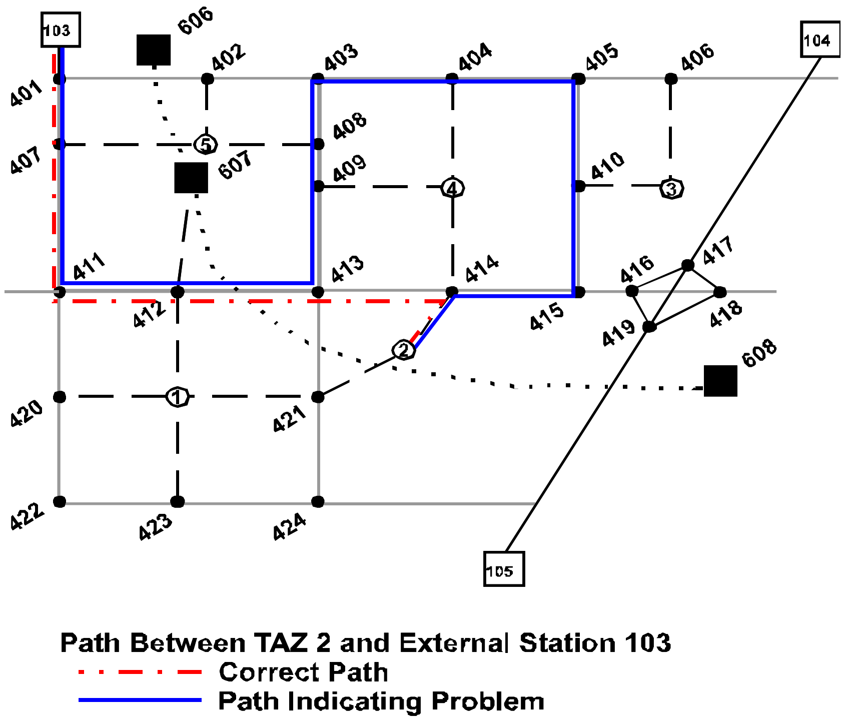
Table 13 Example Travel Time Skim Matrix

	To Zone					
From Zone		1	2	3	4	5
	1	1.59	3.90	2.47	5.92	5.92
	2	3.90	2.06	4.34	6.64	8.34
	3	2.47	4.34	1.66	4.18	4.18
	4	5.92	6.64	4.18	1.72	2.70
	5	5.92	8.34	4.18	2.70	1.72

3.4 Validation

Because minimum paths and zone to zone impedance is a critical input to multiple steps in the travel demand modeling process, it is essential that network paths and skim matrix values be reviewed for reasonableness. This should include a visual inspection of minimum paths to determine if there are any missing links or nodes, to identify incorrectly coded one-way links or ramps, and to be sure that paths do not build through centroid connectors. Figure 7 below shows an example of how path building can be used to identify network coding errors. As was mentioned in Section 2.9, time contour maps should be developed and reviewed to check the reasonableness of travel times between key destinations in the region.

Figure 7 Path Building Example



4 TRIP GENERATION SUBMODELS

4.1 Introduction

The recommended form of the trip production model, cross-classification, requires as an input an estimate of households jointly stratified by household size and auto ownership. Therefore, a set of trip generation submodels is required prior to the trip generation step that will estimate this joint stratification for each zone. Since direct forecasts of this level of detail are not feasible, these submodels must start with the basic variables of households as defined in Section 2.5 and population. Auto ownership may be based on a direct estimate of autos by TAZ, or through an auto ownership model which calculates households by auto ownership level, based on density, accessibility, population, and/or income.

4.2 Household Size Submodel and Marginal Distribution Curves

The first step in calculating a joint distribution of households by size and auto ownership is to calculate the distribution of households by just one dimension, such as household size. A household size submodel uses as input the average household size by zone, and produces a set of shares that indicate what proportion of households are in each size category. This relationship is fairly stable across time and even geographically.

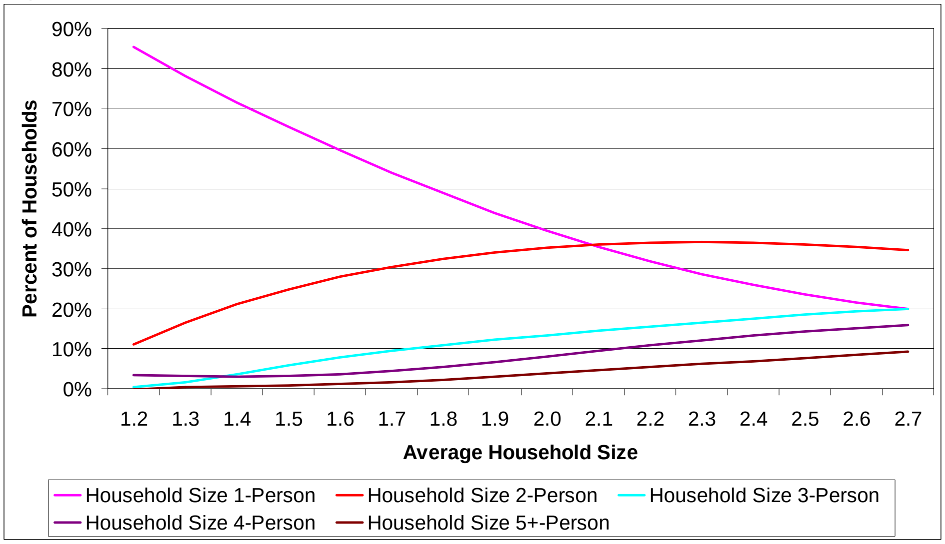
A set of equations is estimated that uses the average household size as the independent variable, and results in a number between 0 and 1, which indicates the share of households for a particular household size. These equations are usually 2nd or 3rd order polynomial linear equations. An example is shown below and in Figure 8:

1PPH Share = -0.0039*$AHHS^3$ + 0.1404*$AHHS^2$ + -0.8335*AHHS + 1.6971
2PPH Share = 0.0036*$AHHS^3$ + -0.1550*$AHHS^2$ + 0.5200*AHHS + -0.3687
3PPH Share = 0.0077*$AHHS^3$ + -0.0906*$AHHS^2$ + 0.4278*AHHS + -0.3449
4PPH Share = -0.0047*$AHHS^3$ + 0.0605*$AHHS^2$ + -0.0289*AHHS + -0.0269
5+PPH Share = -0.0070*$AHHS^3$ + 0.0623*$AHHS^2$ + -0.1238*AHHS + 0.0685

Where:
xPPH Share = the share of households with x persons (a value between 0 and 1)
AHHS = Average household size for a zone

Note that these equations, when summed, equal 1.0, and that the average household size that is computed equals the input average household size. These checks are used as final calibration adjustments to the coefficients.

Figure 8 Typical Household Size Curve Set



The household size curves can be estimated directly from census data at the census block or block group level.

4.3 Auto Ownership Submodel

A similar curve set can be generated to forecast households by auto ownership. Alternatively, a separate auto ownership model may be developed. It is typically logit-based model, which estimates the probability of households owning 0, 1, 2 or 3+ autos. Independent variables usually include population density, transit and auto accessibility, income and household size. While providing sensitivity to the zones, it requires a significant model development effort and is more effective when a transit system is included in the model as well. For small urban areas, use a forecast of autos by zone and a marginal curve set, as described above.

4.4 Joint Distribution Model

The final step in the trip generation submodels is to use the household size and auto ownership marginal distributions to compute the joint distribution of households by size and auto ownership groups. This is done by balancing a seed matrix with each zone's marginal household distributions, which form the row and column totals of the seed matrix. The seed matrix needs only to provide a reasonable joint distribution for the region and is usually derived from the regional joint distribution of households by size and auto ownership, which can be obtained from the Census CTPP data.

4.5 Default Disaggregate Model

Experience has shown that the shape of the disaggregate curves has very little variation over time and geography. As such, the North Carolina Combined Survey Database will be used to develop a set of default curves and distribution models that can be applied to study areas covered by these guidelines.

5 TRIP GENERATION

5.1 Introduction and Overview

5.1.1 Trip Generation Definition and Purpose

Trip generation is step one in the traditional 4-step model approach. A trip generation model estimates the number of trip-ends generated for each zone in a model system. Only trips with both ends in the modeled area are counted. A separate external model is used to account for external trips to and through the modeled area; this information is covered in Chapter 9. The number of trips estimated is based on socioeconomic characteristics such as the number of persons, households, autos and the employment for each zone. This estimate is typically done on an average day basis, and usually for an average weekday. A trip rate is applied to these socioeconomic values to calculate trip ends.

5.1.2 Definition of a trip

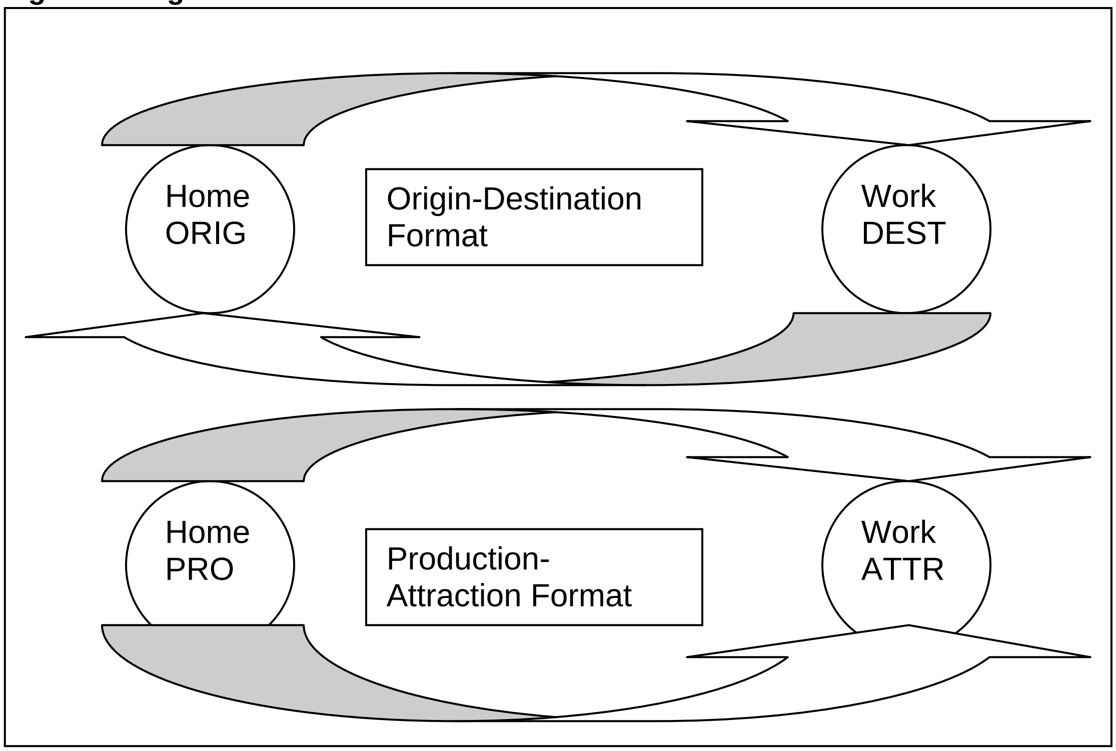
Before discussing trip generation further, it is important to clearly identify what we mean by a trip for the purposes of travel demand forecasting. Simply put, a trip is any travel by any mode by one person from one place to another within the modeled area. The actual starting point of the trip is the origin, and the actual ending point is the destination. These are the trip ends that define the trip. Most trips are a derived activity, that is, travel is for a purpose other than the trip itself and those purposes define the trip. Note that estimates are for person-trips, so two persons traveling together would constitute 2 trips for the trip generation model.

In some cases, short stops on the way to a more primary destination may be removed, forming one longer trip. This often occurs in the case of mode change, such as driving to a park-and-ride lot and boarding a bus, or a serve-passenger purpose, such as dropping off a child at school or daycare. It may also occur for short, convenience stops such as a stop at a gas station, particularly if that stop is less than about 5 minutes in duration and is “on the way” to the next destination. The removal of these stops and combining of trips is known as trip linking, and is done with the observed trips used to formulate trip generation models. Therefore, the resulting model implicitly assumes these trips are removed. While removal of these trips appears to result in an under-estimate of actual trips, it is done to reduce the occurrence of non-home based trips, which are very difficult to accurately model. The result is a more accurate model overall, with very little effect on vehicle-miles of travel.

5.1.3 Productions and Attractions

A trip is defined as one person traveling from her/his actual origin to her/his actual destination. This characterization of a trip is known as O/D format, and depicts how trips are actually made. However, trip generation models estimate trip ends in production/attraction format (P/A format) in which the trip ends are defined based on the purpose at each end. The home end of a trip, if it exists, is always the production end, regardless of whether it is the actual origin or destination. The non-home end of a home-based trip is always the attraction end, regardless of whether it is the actual start or end of the trip. For trips with neither end at home, the actual origin is arbitrarily the production end, and the actual destination is arbitrarily the attraction end. So for example, a person traveling from home to work in the morning, and from work to home in the evening will generate two production trip ends (at home) and two attraction trip ends (at work). Every trip will be counted at both the production and attraction end, as defined above. This is illustrated in Figure 9 below.

Figure 9 Origin-Destination and Production-Attraction Format



5.1.4 Market Stratification

Another basic concept for trip generation models and indeed all of the 4-step models, is market segmentation or the identification of separate categories to reflect differences in travel behavior. Most models use some form of market stratification to identify sub-groups of trips that share common characteristics. By treating these markets separately, parameter estimates (trip rates in the case of a trip generation model) are more accurate since there is less observed variation within each market group.

For trip generation, market categories include:

- General trip purposes such as home-based work (HBW), home-based other (HBO) and non-home based (NHB). As a minimum, these three trip purposes should be used in the trip generation model. Households and other attraction land uses will have significantly different trip rates depending upon the trip purpose. If the observed data is sufficiently robust, further trip purposes can be identified, such as non-home based work and non-home based other. School trips (k-12 and College/University) should also be included if school enrollment data is available. The default trip purposes in the standard model Graphical User Interface (GUI) are HBW, HBO, HBSCH, NHBW, and NHBO.
- Household characteristics such as household size, auto ownership, income, and/or number of workers may also be used to define specific markets for trip

production models. Attraction models may make use of specific kinds of employment, such as retail and non-retail employment types, as they have distinctly different trip attraction rates.

5.2 Trip Production Models

A trip production model constitutes one half of a trip generation model, and estimates the number of trip ends associated with the production, or home end of trips. As such, it uses household data (such as persons, autos, income, workers) as independent variables, and trip rate that is associated with these variables, by market.

5.2.1 Required Estimation Data

Trip production models are best estimated from observed data from household travel surveys (HTS). The observed data is prepared by summing all the observed linked trips by household according to the chosen market segments. In the most common form of trip production models – cross-classification – this data is disaggregate in nature (that is, by household and not aggregated to a zone level) and does not use expansion factors. A typical trip production estimation data set would include one record for each household, followed by the observed characteristics of that household (size, autos, income, and/or workers). On the same record, the observed number of trips by trip purpose for all members of that household would be included, so the number of HBW, HBO, and NHB trips in a three-purpose model would be listed.

Often, a local household travel survey will not be available, particularly for smaller study areas. As a substitute, the North Carolina Combined Survey Database was developed using travel survey data from Wilmington, Greenville, and Goldsboro MPO areas, the Triangle Region, and the Metrolina Region. This database was used to generate default trip rates and models for study areas that lack local data. Though not specific to one area, it offers the advantage of being large enough to support good quality trip rate estimates and offer the possibility of more detailed purposes and markets. If a local survey does exist, the North Carolina Combined Survey Database can serve as a valuable reasonableness check on locally-derived rates in addition to comparisons against rates from other areas with travel surveys and NCHRP 365. All references to HTS in these guidelines either refer to a locally collected HTS if available, or to the North Carolina Combined Survey Database.

5.2.2 Model Forms

When developing a trip generation model, the analyst must first decide on the form of the model. One of two forms is commonly used, including linear regression and cross-classification.

A linear regression model uses a linear equation to estimate trip productions, based on zone totals for the independent variables. A simple trip generation model might consist of a trip rate multiplied by the number of households. Other variables, such as autos/household, or income may be used. However, this model form assumes a linear relationship between the size of the variables and the trip-end productions. This may not, however, be the case. For example, it is unlikely that trip-end productions increase proportionately to income. Linear models also do not reflect socioeconomic market stratification.

The recommended model form for trip productions is a cross-classification model. The cross-classification model uses a simple trip rate per household, but classifies the households according to discrete characteristics. For example, a 2-variable cross-classification model might use household size and auto ownership as the classification variables. Household size might vary from 1 to 5+ persons (5 categories), while auto ownership might vary from 0 to 3+ autos (4 categories). This model would provide a trip rate for 20 separate household types, or markets/categories. These trip rates (by purpose) would then be applied to the number of households in each household type, by zone. The resulting trips will then be summed to provide the zone's total trip productions, by purpose. A cross-classification model does not assume a linear relationship between the classification variables and trips, and is therefore able to reflect the non-linear nature of the trip production behavior. This model form also lends itself to summarizing trips by different classes or categories for use in subsequent model steps.

An example (Table14) below of a cross-classification Home-Based Other Trip Production model shows average weekday household trip rates.

Table 14 Example Cross-Classification HBO Trip Production Rates

<table>
<tr><th>HBO HH
TRIP RATE</th><th colspan="5">AUTOS</th></tr>
<tr><td>HHSIZE</td><td>0</td><td>1</td><td>2</td><td>3+</td><td>TOTAL</td></tr>
<tr><td>1</td><td rowspan="4">1.312</td><td colspan="3">1.588</td><td>1.551</td></tr>
<tr><td>2</td><td colspan="3">3.017</td><td>2.986</td></tr>
<tr><td>3</td><td colspan="2" rowspan="2">4.392</td><td rowspan="2">4.789</td><td>4.062</td></tr>
<tr><td>4</td><td>5.113</td></tr>
<tr><td>5+</td><td colspan="4">7.444</td><td>7.444</td></tr>
<tr><td>TOTAL</td><td>1.312</td><td>2.320</td><td>3.691</td><td>4.200</td><td>3.432</td></tr>
</table>

Trip rates increase with increasing household size and autos, as would be expected. Note that classes (categories) are aggregated. This was done to assure that the rates were statistically significant and different from one another.

5.2.3 Model Variables

When designing a trip production model, the choice of variables should be based on the availability of the variable descriptors, and an understanding of the local trip characteristics. There must be variables that can be forecast for each category in order for it to be useable, and there should be a logical reason for including that category as an explanatory factor in trip productions. For example, household size and auto ownership are logical variables, since it is reasonable to conclude that household trip ends are influenced by both the number of persons and the number of autos available. This conclusion may be supported by examining the observed data and demonstrating that these variables are highly correlated with observed trips. Secondly, it is important to make sure that the descriptors are readily available both in the base year, and can be reliably forecast. As an example, licensed drivers may be a highly correlated variable with trip end productions and available from the base year. However, forecasting this variable may not be feasible and may be largely based on population and household growth. In this case, little is gained by using licensed drivers, which may be a close proxy for population.

In all cases, trip production models should be stratified by trip purposes. The trip production model should use household size and auto ownership as explanatory variables. These variables are highly correlated with trip productions and provide opportunities to stratify by important classes of households, including 0-auto households, which is a useful distinction in trip distribution and mode choice models. Other variables, including income group and number of workers might be considered if there are sufficient observations in the observed data set.

5.2.4 Categories

Once the classification variables are defined, the specific class categories and trip purposes should be identified. This is based on the depth and statistical strength of the observed data, usually the HTS. For each class/category within the variable, there should be sufficient observations to support a trip rate that is statistically significant from 0 and from adjacent categories. For example, in a cross-classification model with three purposes, household size and auto ownership, the rate for HBW, 2-person, 1-auto households should be statistically different (based on the available observations for that category) from HBW, 2-person, 2-auto households. As a rule of thumb, at least 30 observations (in this case, household) are required as a minimum for statistical significance for each category.

It is common that not every category has sufficient observations, particularly in rare categories, such as 5+ person, 0-auto households. In this case, a category should be combined with adjacent classes until the combined rate is itself statistically significant. Statistical significance can be computed using the “student –t test” with a confidence limit of 90 or 95 percent. The number of observations, variance, and average values for each market class are required to compute this statistic.

5.2.5 Estimating Rates

Production trip-end rates in a cross-classification model are computed by simply dividing the observed number of trips by the observed number of households in each category. Unweighted observations are used. While trip rates are computed, it is a good idea to also compute the standard error of each rate to provide a better understanding of the accuracy of these rates. These calculations may be performed in a spreadsheet.

For linear regression models, aggregate data by zone is used. The total trip ends are computed along with the aggregate independent variables, such as households, average income, and average autos/household. A multiple linear regression may then be performed, using available statistical software.

5.2.6 Calibration and Validation of Trip Production Models

Once the initial trip production model is estimated, the model form can be implemented within TransCAD. This can be accomplished through the use of the TransCAD standard procedures or through the development of a GISDK script. The model is applied to aggregate zone data and trip productions are calculated and summarized by zone. The total productions should be compared with expanded totals from a household travel survey or other source such as the census journey-to-work or National Household Travel Survey data to ensure that the overall trip productions are in line with observed aggregate estimates. In addition, overall trip rates per person and household should be compared with normal ranges developed from the North Carolina Combined Survey

Database and documented in the Small Area Travel Demand Model Procedures Manual or from drawing comparisons to data available in NCHRP 365.

Validation of trip production models should involve applying the model to recent data, a few years prior to or subsequent to the base year. Compare the changes in demographic data to the changes that the trip production model predicts and evaluate for reasonableness. The model should respond in a logical and predictable way in response to these changes.

5.3 Trip Attraction Models

A trip attraction model constitutes the other half of trip generation and estimates the number of trip ends associated with the attraction, or non-home end of trips. As such, it uses primarily employment data (such as retail and non-retail employment) as independent variables, and trip rates that are associated with these variables.

5.3.1 Required Estimation Data

Trip attraction models are usually estimated from two sources of aggregate observed data. One source is the zone-level estimate of employment by type. This is often obtained from local business organizations, state employment agencies, or private data sources as was discussed previously in the Database Development chapter. The number of households by zone is also often used as independent variables in trip attraction models. The second set of data is the observed trip attractions. This is typically obtained from a household travel survey, by summing the expanded observed attraction trip ends by zone. A typical trip attraction estimation data set would include one record for each zone, which includes the observed employment and household totals, and the observed trip attractions by purpose.

5.3.2 Model Forms

The discussion under Section 5.2.2 applies to trip attraction models as well. However, due to the aggregate nature of attraction model estimation, a linear regression model is recommended for use with trip attraction models.

Example of a Home-Based Other (HBO) trip attraction equation is:

HBOA = 1.5*Retail + 0.5*NonRetail + 2.2*HHLDS

Where:
HBOA = Home-Based Other trip attractions,
Retail = Retail employment,
NonRetail = Non-Retail Employment, and
HHLDS = Number of households.

5.3.3 Markets or Categories

When designing a trip attraction model, the choice of variables should be based on the availability of the variable descriptors and an understanding of the local trip characteristics. There must be variables that can be forecast for each market in order for it to be useable, and there should be a logical reason for including that category as an explanatory factor in trip attractions. For example, employment is strongly correlated not only with work trip attractions, but also serves as a good indicator of shopping, service and office trips. Depending upon the trip purpose, different types of employment will have different attraction rates. Even households may be used as an explanatory variable for some types of trips. These conclusions may be supported by examining the observed data and demonstrating that these variables are highly correlated with observed trips. Secondly, it is important to make sure that the categories are readily available both in the base year, and may be reliably forecast. Employment may be one of the most difficult variables to forecast, as it is subject to market conditions that cannot be entirely foreseen. The variables recommended for use in developing linear trip attraction models include retail and non-retail employment and households. If a school trip purpose is used, school enrollment in terms of full time equivalents should be used as the primary attraction value.

In all cases, trip attraction models should be stratified by the same trip purposes as trip production models. With regard to markets such as income groups, both the production and attraction models must share the same market segments and classes for these to be used in subsequent model steps. Note that it may still be advantageous to use other variables in trip generation alone (such as household size) even if it is not carried forward to trip distribution or mode choice.

5.3.4 Estimating Rates and Equations

Attraction trip-end rates in a linear regression model are computed by conducting a multiple linear regression on the observed zone-based data. While trip rates are computed, it is a good idea to also note the standard error of each rate to provide a better understanding of the accuracy of these rates. There is a number of commercially-available statistical software available for this use such as STATA or SAS. Note that the final linear equations should be computed without a constant.

Trips made in the study area by non-residents are called non-home based non-resident trips (NHBNR) and will not be reflected in a household travel survey dataset. These trips may be quantified from an external survey data set, if it includes questions about subsequent trips made by travelers who live outside the region. This data can be used to calculate a trip rate, or trip share of the observed external trips. These trip ends can then be allocated to zones based on relative employment distribution, similar to how NHB trips are treated.

5.3.5 Calibration and Validation of Trip Attraction Models

Once the initial trip attraction model is estimated, the model form can be implemented within TransCAD. This can be accomplished through the use of the TransCAD standard procedures or through the development of a GISDK script. The model is applied to aggregate zone data and trip attractions are calculated and summarized by zone. The computed zonal attractions should be compared with expanded totals from a household travel survey or other source such as the census journey-to-work or National Household Travel Survey data to ensure that the overall trip attractions are in line with observed aggregate estimates. Of course, since the HTS data is typically used in the estimation phase, we would expect to match the area totals. However, the analyst should examine the results on a zone and district basis, looking for zones or districts that are exceptionally different from observed values. This may indicate other factors that have not been included in the trip attraction equations should be considered. For example, shopping trip attractions for zones that contain large malls may need to be treated as a special generator if the general trip attraction equations are not matching observed totals. Other types of land use, such as CBD, Hospitals, Colleges, and Universities may also exhibit unique trip attraction characteristics that are not fully captured by the general trip attraction models. Finally, overall trip rates per employee and household should be compared with normal ranges derived from the North Carolina Combined Survey Database and other established models in North Carolina.

Validation of trip attraction models should involve applying the model to recent data, a few years prior to or subsequent to the base year. Compare the changes in socioeconomic data to the changes that the trip attraction model predicts and evaluate for reasonableness. The model should respond in a logical and predictable way to these changes.

5.4 Trip Balancing

Once the trip production and trip attraction models have been estimated and calibrated, the area totals for each, by purpose, should be compared. Since every trip has exactly one production trip end and one attraction trip end, total area production and attraction trip ends for each purpose must be equal. However, since trip production and attraction models are independently developed, this equality is not guaranteed.

A set of area control trip totals, by purpose, should be established from the household travel survey for the calibration year. The production model and attraction model rates should be factored, as necessary, to equal these totals. This is called normalization. Note that in future years, because of independent estimates for population, households and employment, future productions and attractions from the model may not match. In this case, the analyst must decide to either normalize the attractions to the production total, or normalize the productions to the attraction total, by purpose. The decision as to whether to normalize to productions or attractions is based on selecting the model in which the analyst has a higher degree of confidence. The recommended practice in NC is that the production model totals be held constant, and the attractions normalized to match the total productions. In the case of Non-Home Based trip purposes, attractions are also factored to match the production total. However, since NHB trips, by definition, do not have a home end, only the trip attractions are ultimately used at the zone level for distribution. They serve to represent both the production and attraction trip ends in the NHB distribution model. Essentially the process is one of setting the zonal productions and the zonal attractions equal for this trip purpose.

6 TRIP DISTRIBUTION

6.1 Introduction

The trip distribution model component connects estimated trip ends (productions and attractions) by traffic analysis zone (TAZ) to each other, in order to determine trip interchanges between each TAZ pair. The model considers the magnitude of activity in each TAZ (in terms of productions and attractions) as well as the impedance or accessibility between TAZs to determine the trip interchange. Accessibility may be measured by travel time (highway time) or some composite measure of cost, which considers highway time and other travel costs.

The trip distribution model structure recommended for all large non-MPO areas and small MPOs within North Carolina is the standard gravity model. In general, the “gravity” model suggests that the number of trips from one TAZ to another is proportional to attractions at the attraction TAZ and inversely proportional to the travel impedance between the two TAZs.

The general formulation of the model can be described as follows:

$$T_{ij} = P_i \times \frac{A_j \times F_{ij} \times K_{ij}}{\sum_{k=1}^{zones} (A_k \times F_{ik} \times K_{ik})}$$

where:

T_{ij}= the number of trips from zone i to zone j;
P_i = the number of trip productions in zone i;
A_j= the number of trip attractions in zone j;
F_{ij}= the friction factor associated with the travel impedance from zone i to zone j;
K_{ij}= the socioeconomic or physically related factor for all movements between zone i and zone j.

The normal calibration process followed in developing each purpose-specific model is to adjust the friction factors (F_{ij}) so that the estimated trip length frequency distribution closely matches the observed trip length frequency distribution. Following this, the need for K-factors is investigated.

In general, proper model specification attempts to avoid the use of K-Factors, the validity of which may be questionable when applied in a future year. K-Factors should only be considered when an underlying physical or geographic barrier is associated with the error in estimation (e.g., river crossing) or when a distinct socioeconomic or land use characteristic introduces the error (e.g., mismatch between worker and job features).

6.2 Data Analysis

A preliminary analysis of data is the most time-intensive and most important phase of trip distribution development. There are several decisions to be made as a result of this analysis. The analysis may help to determine the appropriateness of collapsing trip purpose categories from trip generation to reduce the number of distribution models, based on similarities in trip length and frequency distribution. Second, the analysis of data may help determine whether stratification by one or more household variables (such as income or auto ownership) is desired.

Trip information reported in the household survey is the primary source of data for this analysis. The variables used in this analysis may include: household income, automobile ownership, employment type, and travel cost (time and/or distance).

Typically, *reported* travel time is not used in this analysis due to the tendency of survey respondents to over-estimate actual travel time and/or to generalize time into five and ten minute increments. Instead, travel time and travel distance are obtained from the model network. Congested speeds can be calculated by factoring posted speeds based on facility type, or obtained from a previously estimated model. Posted speeds or free-flow speeds are typically used for off-peak travel times.

For a large MPO or Regional model a stratification of work trips by one or more household variables, such as income and auto ownership, is often useful to adequately distribute work trips from 'blue-collar' households to industrial sector employment, and 'white-collar' households to professional employment. For large non-MPO areas or small MPOs this level of stratification is not recommended. As such, this analysis becomes one of determining whether or not trip purpose categories from trip generation can be collapsed.

This process involves using the household travel survey to determine whether differences in travel time and distance exist between the various trip purposes. If no differences exist between the travel time and distance between any given pair of trip purposes, then the trip purposes are candidates for aggregation. This determination should not be made, however, without also investigating the trip length frequency distribution for each trip purpose. The next series of graphs and a table summarizes findings from the analysis of the North Carolina Combined Survey Database discussed in Section 1.5.

Figure 10 NC Survey Data HBW Trip Length Distribution by Travel Time (minutes)

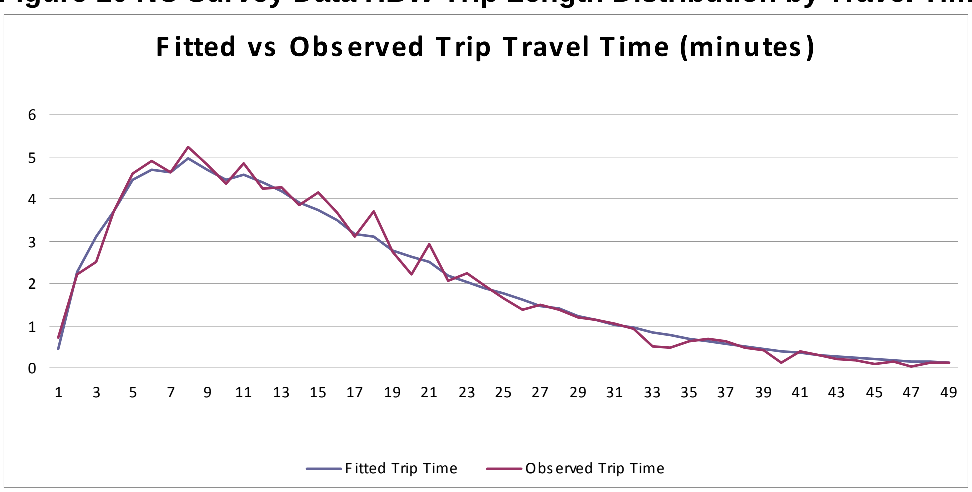


Figure 11 NC Survey Data HBW Trip Length Distribution by Travel Distance (miles)

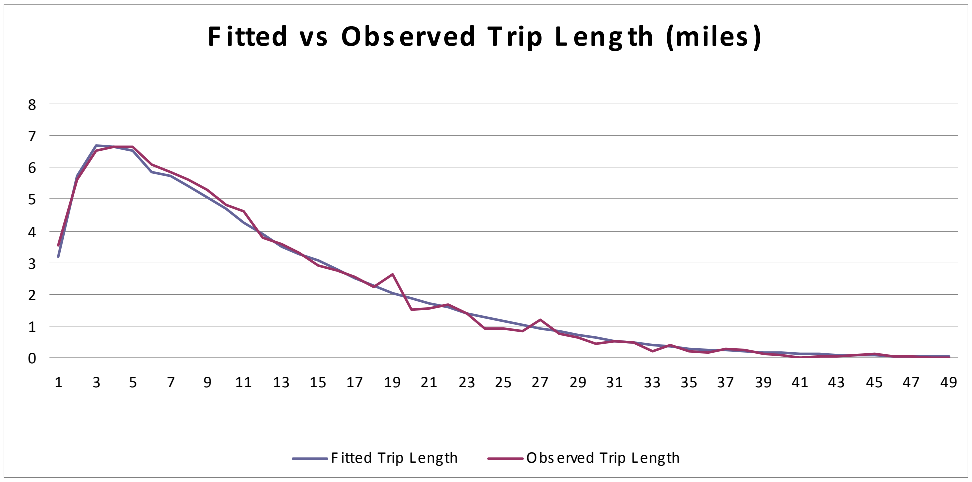


Figure 12 NC Survey Data HBW Trip Length Distribution by Generalized Cost

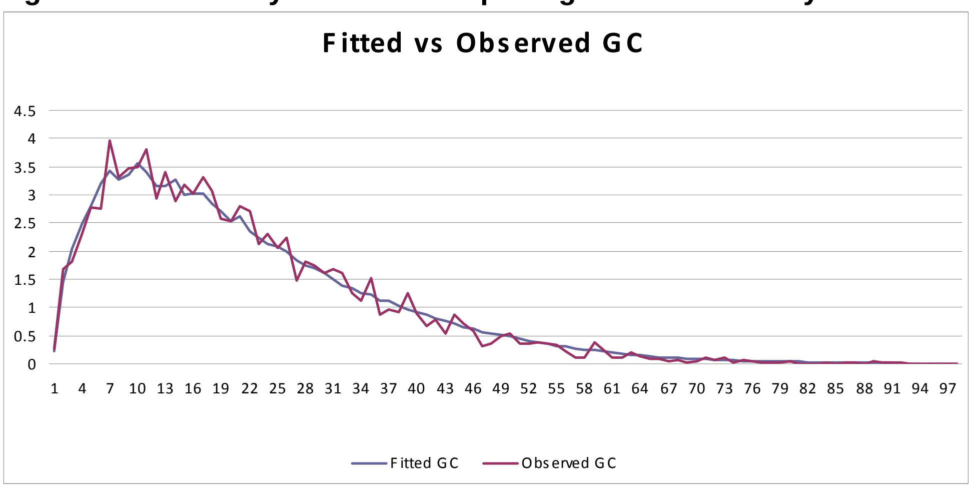


Table 15 Range of Mean Trip Lengths

Purpose	Range of Mean Travel Time (minutes)	Range of Mean Travel Distance (miles)	Range of Mean Generalized Cost
HBW	8.58 – 15.30	6.13 – 11.04	12.68 – 21.70
HBO	7.08 – 9.87	4.97 – 6.55	13.74 – 17.40
HBSCH	8.44 – 9.61	5.19 – 6.26	13.95 – 16.80
NHBW	5.65 – 10.49	3.90 – 7.37	9.22 – 16.17
NHBO	4.47 – 8.87	3.03 – 6.04	7.19 – 13.53

Source: North Carolina Combined Survey Database

The range of mean values highlighted the need to develop two sets of default gamma coefficients for the gravity model, one set for the smaller study areas and the other set for the larger study areas. Most study areas using these guidelines will apply the small area coefficients. The recommended default coefficients are shown in Table 16, following the discussion of the gamma function.

6.3 Gamma Function Definition

Calibration of the gravity model involves fitting a friction factor matrix to a set of observed production and attraction totals such that the resulting trips by impedance match an observed trip length distribution and average trip length. The estimation of a trip distribution model requires that a function be estimated, which produces a trip matrix which meets the following constraints:

1. It must be balanced such that its row and column totals match the productions and attractions for each TAZ;
2. It must produce an average trip time which is within a specified range from the observed average trip time (within 5%);
3. The total trips within each time increment (½ or 1 minute) should resemble the observed trip length frequency distribution. The extent to which the estimated distribution matches the observed distribution can be measured using the 'coincidence ratio', which should indicate a match of 0.8 or better;
4. The gamma function coefficients should have the correct sign (positive a, negative b and negative c); and
5. The estimated district interchanges must be reasonably related to the observed district interchanges.

Since the majority of the study areas covered by these guidelines will not have locally observed travel survey data from which the observed profiles required for b, c, and e above can be developed, the North Carolina Combined Survey Database was used to develop relationships and default parameters to be used as a starting point. These parameters are documented in the companion guide to these guidelines, Small Area Travel Demand Model Procedures Manual.

The recommended functional form for estimating friction factors is the gamma function. The gamma function is specified as follows:

$$\mathbf{F_{ij} = a \times C_{ij}^{b} \times exp(c \times C_{ij})\ -}$$

where:

F_{ij} =friction factor between zone i and zone j,
C_{ij} = generalized cost between zone i and zone j, and
a, b, and c =gamma function coefficients.

The cost measure used to estimate the friction factors should include both time and distance in a generalized cost function. The use of generalized cost as opposed to simply relying on travel time allows the model to consider distance as part of the perceived cost of travel, in a weighted form that is consistent with value-of-time relationships that consider the cost of driving. Without the consideration of distance as part of the cost of travel in trip distribution, the model tends to be too sensitive to travel time variations.

The generalized cost function is specified as follows:

$$\mathbf{C_{ij} = T_{ij} + a \times D_{ij}}$$

where:

C_{ij} = generalized cost between zone i and zone j;
T_{ij} = travel time between zone i and zone j;;
a = distance coefficient; and
D_{ij} = travel distance between zone i and zone j;.

The distance coefficient "a" can be computed by assuming a value-of-time for each trip purpose based on widely accepted practice and considering the perceived cost of driving in cents per mile. The formula to compute the coefficient "a" is specified as follows:

$$a = aoc \div [p \times wr \div 60]$$

where:

a = distance coefficient;
aoc = auto operating cost (dollars/mile) ($0.09 recommended – see http://www.mtc.ca.gov/maps_and_data/datamart/forecast/ass98_tab3.htm);
p = trip purpose coefficient (0.5 for HBW, 0.25 for HBO, 0.375 for NHB); and
wr = average wage rate (dollars/hour) (see http://www.bls.gov/ncs/ocs/compub.htm#NC).

For example, the Home-Based Work distance coefficient "a" for an average wage rate of $13.77 (the 2007 wage rate for Polk County, NC according to the Bureau of Labor Statistics) would be equal to 0.78, which is calculated as $0.09 (dollars per mile) ÷[0.5 × $13.77 (dollars per hour) ÷ 60)]. The generalized cost for a given interchange would then be equal to **time + 0.78 × distance**.

Table 16 Default Gamma Function Coefficients

Trip Purpose	a	b	c
HBW (large area)	93.2694	-0.7903	-0.0616
HBW (small area)	10.5936	-1.0250	-0.0000
HBO	811.0232	-1.0645	-0.0832
HBSCH	354.0846	-0.5874	-0.1291
NHBW (large area)	470.3996	-0.9334	-0.0678
NHBW (small area)	2.3286	-0.7694	-0.0000
NHBO (large area)	2983.1686	-1.0461	-0.0782
NHBO (small area)	4.6750	-0.2916	-0.1390

6.4 Trip Distribution Model Calibration

The same process is used to estimate the trip distribution model for each trip purpose. First, files are created from the master trip file containing the trip records for each trip purpose. Trips for each trip purpose are summed by production zone and attraction zone to generate observed productions and attractions. The observed trip length frequency distribution is calculated for both 1 minute and ½ minute time intervals by summing the number of trips in each interval.

Additionally, matrices consisting of zone to zone peak and off-peak highway travel times and distances, are extracted from TransCAD. It is recommended that peak times and distances be used for work trips, and off-peak times and distances for other trip purposes.

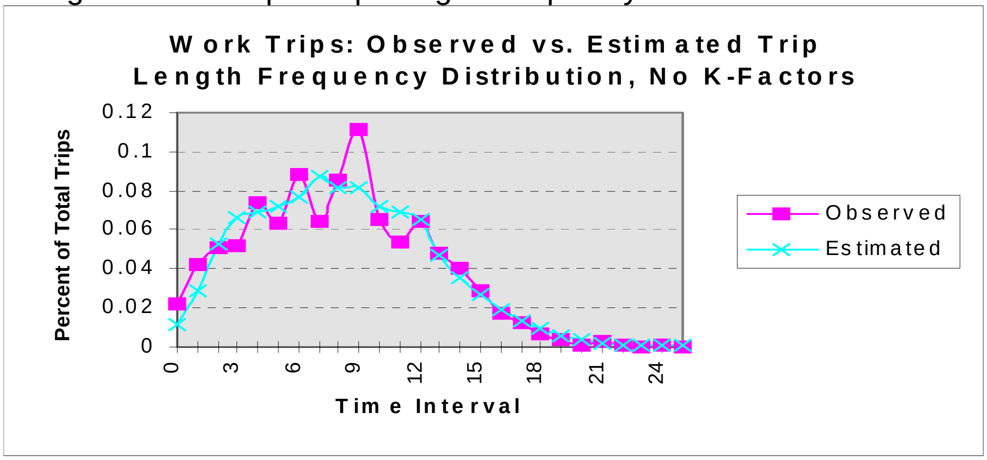
A regression technique is used to estimate gamma function coefficients for each trip purpose and 1-minute time interval. The general flow of the process can be described in the following set of steps.

1. An initial friction factor matrix is created using the initial gamma function coefficients (start with the default coefficients provided by TransCAD).
2. The friction factor matrix is balanced using two-dimensional matrix balancing and the observed productions and attractions by zone.
3. An estimated trip length frequency distribution is computed from the balanced O-D matrix.
4. An estimated mean travel time is computed and compared to the observed mean travel time. If they are within an acceptable range, the model has successfully converged.
5. A new set of friction factors is developed for each time interval based on the difference between the estimated trip length frequency distribution and the observed trip length frequency distribution.
6. A new set of gamma function coefficients is estimated based on the new friction factors using multivariable regression.
7. A new impedance matrix is created using the revised gamma function coefficients, and the process returns to step 2.

6.4.1 Calibration Results and Reasonableness Checking

As a part of the base year model calibration, the modeled mean trip length and trip length frequency distributions by trip purpose are compared to the observed mean trip length and trip length frequency distribution by trip purpose. If the modeled and observed mean trip lengths are within 5%, this is typically considered reasonable. Figure 13 is a graphical depiction of observed and estimated trip length frequency distributions for Home-Based Work. It is helpful to graphically depict and review for reasonableness the estimated trip length frequency distribution for every trip purpose even if no survey data is available for the observed distribution. This visual representation can provide insight into the reasonableness of the trip distribution.

Figure 13 Example Trip Length Frequency Distribution



The coincidence ratio can also be used to measure how close the estimated distribution is to the observed distribution. The coincidence ratio is the ratio in common between two distributions as a percentage of the total area of those distributions. Mathematically, the sum of the lower value of the two distributions at each increment of time (or distance) is divided by the sum of the higher value of the two distributions at each increment of time (or distance). Generally, the coincidence ratio measures the percent of area that "coincides" for the two curves. The coincidence ration lies between zero (0) and one (1), where zero indicates two disjoint distributions and one indicates identical distributions.

The procedure to calculate the coincidence of distributions is as follows:

$$Coincidence = \sum_{t=1}^{T} \min\left(\frac{count_{+T}}{count_{+}}, \frac{count_{-T}}{count_{-}}\right)$$

$$Total = \sum_{t=1}^{T} \max\left(\frac{count_{+T}}{count_{+}}, \frac{count_{-T}}{count_{-}}\right)$$

$$Coincidence\ Ratio = \frac{Coincidence}{Total}$$

where:

$count_{+T}$ = value of estimated distribution at time T;
$count_{+}$ = total count of estimated distribution;
$count_{-T}$ = value of observed distribution at time T; and
$count_{-}$ = total count of observed distribution.

An additional calibration measure is the comparison of district-level trip interchanges. The district definitions discussed in Chapter 2 are useful for this purpose. The balanced trip matrix is compared to the observed trip matrix for district-level interchanges. This comparison can be useful in determining the reasonableness of the trip distribution results as well as in assessing the possible need for K-factors. K-factors account for physical or socioeconomic barriers not represented by impedance or travel time. While the use of K-factors are not recommended there may be instances where they are required to account for barriers to travel that cannot be accounted for with the standard application of the gravity model.

When observed survey data is not available, observed work trip interchanges can be developed from the 2000 Census journey-to-work distribution using the TransCAD census tools. The percent of trip interchange volumes by district from the model can be compared to the percent trip interchange volumes from the Census. A judgment is then made as to the reasonableness of this comparison. Census journey-to-work data can also be used to make a comparison between the journey-to-work average trip length and the travel model average trip length for work trips.

For urban areas, journey-to-work data may be available at the TAZ level, but only for areas (MPO or non-MPO) that made this request to the Census. In other areas, the data may only be available at the county-county commute level. One should always use judgment to determine whether the data is reasonable. In certain urban areas, geocoding problems have introduced error into the observed data. Additionally, one should be cognizant of the inconsistencies between the definitions of a work commute versus a Home-Based Work trip. A work commute measures worker flows from place of residence to place of work, while a HBW trip includes only trips made by workers between residence and workplace that did not include any intermediate stops (worker flows with intermediate stops would have been recoded as Home-Based Other and Non-Home-Based trips). Because intermediate stops tend to occur on longer-distance work commutes, the Home-Based Work trip table tends to be shorter than the journey-to-work data.

Census data is not available for non-work trip purposes, but district trip interchanges should still be summarized and reviewed for reasonableness using judgment and knowledge of the area.

Finally, a check should be performed on the ratio of the number of intrazonal trips and the total number of trips expressed as a percent. Typically, intrazonal trips comprise 3% to 5% of the total number of trips. This value depends on TAZ size as larger zones will typically have a higher percentage of intrazonal trips and smaller zones a lower percentage of intrazonal trips.

7 MODE SPLIT

7.1 Introduction

These guidelines focus primarily on the 3-step process of trip generation, trip distribution, and traffic assignment. However, since the trip generation model estimates person trips, not auto trips, factors must be applied to the person trip tables prior to trip assignment to convert the person trips first to person auto trips and then from person auto trips to vehicle auto trips. In more advanced models, the conversion from person trips to vehicle auto trips is accomplished through the application of a mode choice model. For study areas using these guidelines simple mode split factors are applied to first convert from person trips to person auto trips. The conversion from person auto trips to vehicle auto trips is covered in Chapter 10 – Time of Day.

7.2 Mode Split Factors

A simple mode split approach involves applying mode share factors to the person trip tables for the internal trip purposes (HBW, HBO, HBSCH, NHBW, and NHBO) in order to convert the person trips to person auto trips. The conversion from person trips to person auto trips uses uniform mode share values by trip purpose. Ideally, these mode shares are derived from local survey data since mode shares are very specific to the availability of transit in a region and to the walk-ability of a region. To develop default mode shares for the NCDOT Small Area Model the North Carolina Combined Survey Database was analyzed to develop the default factors shown in Table 17. While these default rates provide a starting point for this analysis, a more robust approach to obtaining mode share factors for a specific region is through an analysis of Census data.

Table 17 Mode Shares by Trip Purpose

	Small Areas		Large Areas	
Purpose	**Auto**	**Non-Auto**	**Auto**	**Non-Auto**
HBW	96.9	3.1	96.4	3.6
HBO	93.2	6.8	93.7	6.3
HBSCH	98.4	1.6	93.7	6.3
NHBW	96.3	3.7	94.6	5.4
NHBO	95.8	4.2	95.2	4.8

8 COMMERCIAL VEHICLES

8.1 Introduction

Thus far the guidelines have addressed internal trip purposes, or trips made by households in the region that stay in the region. Before proceeding to trip assignment, there are two other trip types that must be addressed – commercial vehicle trips and external trips. Commercial vehicle trips are covered in this chapter and external trips are covered in Chapter 9.

8.2 Commercial Vehicle Trips

Estimating commercial vehicle trip demand may use a wide range of estimation techniques including:

(1) Link-based factors or network pre-loads;

(2) Factoring of NHB person trip demand;

(3) Count-based synthetic matrix techniques;

(4) Screenline-survey-based partial matrix techniques;

(5) Roadside and employer-based surveys of truck trips; and

(6) Commodity-flow based techniques.

Historically, commercial vehicle or truck demand estimation has employed simplified techniques such as the first two listed above except in specialized studies. Specifically, link-based factors are applied post-assignment to increase trip link loadings by a fixed amount, reflecting the observed truck share. Network pre-loading employs similar observed data to simply add truck volumes to links prior to the assignment process. Finally, factoring the NHB trip demand provides an estimated truck trip table that may be combined with other vehicle trips for assignment, or assigned separately. Such methods typically increase link level vehicle volumes by up to 15 percent. The percentage of trucks assumed on a link is classically a function of facility type and area type. This practice does neither accurately reflect the actual origins and destinations of trucks nor does it reflect the wider range of variation of resultant volumes on individual roadways. Such forecasting schemes also tend to ignore facilities where trucks are prohibited by ordinance, unless a multi-class assignment is performed, which allows such limitations.

Techniques (3) and (4) are both strategies to obtain a synthetic O-D matrix of truck trips which can then provide a basis for model development or growth-factoring to obtain forecast flows. The count-based approach (3) produces equivalent results to approach (4), is far more common and economic than (4), and is gaining in popularity. Approach (6), commodity flow techniques, is the most rigorous and requires the greatest level of effort. It is usually applied in the context of an inter-regional or statewide travel demand model where truck traffic and related policies and economic factors as well as intermodal facilities and commodity mode choice issues are of concern. Approach (5), roadside and employer-based surveys of truck trips, is considered exemplary of best practice for urban area travel demand models and should be considered for the larger MPOs covered by these guidelines. However, for the majority of the study areas covered by these guidelines, an appropriate technique, and the one recommended here, is a combination of the trip generation component of approach (5) and the NHB component of approach (2) for trip distribution and assignment and follows closely with the approach currently employed by NCDOT. While it is not desirable in larger urban areas to include commercial travel within the NHB purpose due to the difference in travel characteristics between NHB trips and commercial vehicle travel, this approach is widely used and accepted for small urban models in areas with limited resources available for more advanced model development.

This approach is applied to internal-internal trips only and requires the collection or estimation of commercial vehicle data at the zonal level. External-external, external-internal, and internal-external commercial vehicle trips are included in the external trip purpose (Chapter 9). Trip productions are generated by applying trip production rates to the number of commercial vehicles by vehicle type in each traffic analysis zone (TAZ). As with person trip attractions the commercial vehicle trip attractions are based on employment data stratified by employment type. Production and attraction rates can be developed using local survey data or can be borrowed from other regions. Work was conducted by NCDOT in the mid-90s to develop default commercial vehicle rates from a commercial vehicle survey conducted in the Triad region of North Carolina. These rates are documented in Tables 18 and 19 below. It is recommended that the initial production and attraction rates be based on the rates in these tables.

Table 18 Commercial Vehicle Trip Production Rates (trips/vehicle)

CV Trip Production Rates	**Industry CV**	**Retail CV**	**HwyRetail CV**	**Service CV**	**Office CV**
Autos/Vans (CV1)	2.49	2.89	2.89	3.43	3.43
Pickups (CV2)	4.19	5.81	5.81	4.32	4.32
Trucks (CV3)	6.62	7.86	7.86	7.44	7.44

Table 19 Commercial Vehicle Trip Attraction Rates (trips/employee)

CV Trip Attraction Rates	**Employment by Employment Type**					
	Industry	**Retail**	**HwyRetail**	**Service**	**Office**	**Households**
Autos/Vans (CV1)	0.20	0.33	0.25	0.10	0.12	0.02
Pickups (CV2)	0.30	0.40	0.33	0.25	0.13	0.012
Trucks (CV3)	0.75	0.67	0.50	0.21	0.23	0.039

9 EXTERNAL TRIPS

9.1 Introduction

External travel can be defined as through traffic, external-internal travel, and internal-external travel. Through traffic is defined as having both trip ends external to the study area. External-internal or internal-external travel is defined as having one trip end external to the study area.

9.2 External Trips

For external through travel a base year trip table is created from actual survey data and then "growth factored" to the future. For external-internal and internal-external travel a common approach is to develop a basic two-step model (trip generation and trip distribution) specifically for external travel. In the case of external travel, both modeling approaches are considered acceptable for forecasting purposes. It is important to recognize that, in general, as the size of an urban area increases, externally generated travel demand accounts for a decreasing share of the traffic on local facilities. Accordingly, it is appropriate to put relatively more resources into external travel models. The most ambitious approach to modeling travel demand external to urban areas is to develop an inter-regional or statewide model.

A "best practice" set of trip production and trip attraction equations at the external stations differentiates between axle type (2, 3, and 4+). However, this approach requires the collection of classification counts at all external stations and may not be justified for smaller urban areas. In this case, it is acceptable practice to base the trip production and attraction equations on the combined count. A recommended structure for the two approaches is provided below. The coefficients for the equations should be based on survey data when available. If survey data is not available, the initial coefficients can be borrowed from a similar region with survey data and then adjusted as needed during the model validation process. The trip generation estimates at external stations are based upon growth-factored roadway counts, while external trip generation estimates at internal zones are a function of households and employment by type. In application the traffic count at the external station represents one end of the external trip, most often referred to as the production end of the trip although this count actually reflects both productions and attractions, and the other end of the trip is at the TAZ and is dependent upon the housing and employment within the zone as reflected in the equations below. This end of the trip is most often referred to as the attraction end of the trip, but actually reflects productions for trips leaving the area (captured by the household variable) and attraction from trips originating outside the area. Sample internal zone to external station trip generation equations are summarized below:

Sample Equations by Axle Type:

- 2-Axle Vehicles
  - $A = a \times HH + b \times EMPI + c \times EMPR + d \times EMPO$
- 3-Axle Vehicles
  - $A = a \times HH + b \times EMPI$
- 4+-Axle Vehicles
  - $A = a \times EMPI\ b \times EMPR$

Sample Equations for a Combined Count:

$$A = a \times HH + b \times EMPI + c \times EMPR + d \times EMPO$$

Where,

HH	=	Number of Households by TAZ;
EMPI	=	Industrial Employment by TAZ;
EMPR	=	Retail Employment by TAZ;
EMPO	=	Other Employment by TAZ; and
a, b, c, d	=	Coefficients.

It is recommended that the trip distribution model employ a gravity model with uniform impedance factors that can be adjusted as necessary during the trip assignment validation process. In trip assignment, external trips are combined with internal vehicle trips prior to model execution.

10 TIME-OF-DAY ANALYSIS

10.1 Introduction

The need to participate in various activities in most, if not all, study areas varies throughout the day and as such the travel (traffic) required for participating in these activities varies throughout the day. While the need for time-of-day analysis is widely recognized and understood for large urban areas, it is often neglected for smaller urban areas. This approach ignores the fact that peaking characteristics are often much more severe for smaller urban areas than for larger urban areas in part due to less peak spreading as a result of lower overall levels of congestion. Time-of-day factors and peak/off-peak traffic assignments are recommended for any urban area that has or will require design, capacity and level-of-service guidance from the planning process, regardless of its size. Daily traffic assignments cannot reflect the effect of volume delay on route choice and therefore cannot be used to forecast either congested conditions or the effects of increases in highway capacity on traffic congestion.

Time-of-day modeling can be implemented at various stages of the four-step process, including after trip assignment, between mode choice and trip assignment, between trip distribution and mode choice, and between trip generation and trip distribution. Each approach has various advantages as well as limitations. The limiting commonality of all these approaches is that the step(s) prior to the time-of-day application will not account for the influence of time of day and/or volume delay. Given the importance of accounting for the effect of volume delay on route choice and a desire to minimize the complexity of implementation, the recommended approach for time-of-day analysis for study areas falling within these guidelines is to apply time-of-day factors between trip distribution and trip assignment (there is currently no mode choice step for these models).

10.2 Approach

The recommended approach for time-of-day analysis requires that the daily production-attraction (P-A) trip tables from trip distribution be factored by time period and direction to create O-D trip tables by time period, which are ready for assignment. This process requires information related to hourly percent flows, percent departure by hour and percent return by hour. Since these percentages often vary by trip purpose, these factors are typically developed for each trip purpose in the model.

TransCAD provides a default hourly lookup table that is based on NCHRP 187 and represents national averages. The data in the table is provided for four trip purposes: HBW, home-based non-work (HBNW), HBO, and NHB. The North Carolina Combined Survey Database was used to develop an hourly lookup table specific to North Carolina for both small and large study areas. This table more closely reflects time-of-day characteristics in North Carolina and provides factors for HBW, HBO, HBSCH, NHBW, NHBO, and total trips. An example of the fields in the North Carolina default hourly lookup table is shown in Table 20.

Table 20 North Carolina Default Hourly Lookup Table

Field	Procedure	Description
HOUR	Both	Hour in the day for which the record applies: 0 is 12-1 AM
DEP_HBW	PA to OD	The percent of daily HBW P-A trips that depart during the hour
RET_HBW	PA to OD	The percent of daily HBW P-A trips that return during the hour
DEP_HBSCH	PA to OD	The percent of daily HBSCH P-A trips that depart during the hour
RET_HBSCH	PA to OD	The percent of daily HBSCH P-A trips that return during the hour
DEP_HBO	PA to OD	The percent of daily HBO P-A trips that depart during the hour
RET_HBO	PA to OD	The percent of daily HBO P-A trips that return during the hour
DEP_NHBW	PA to OD	The percent of daily NHBW P-A trips that depart during the hour
RET_NHBW	PA to OD	The percent of daily NHBW P-A trips that return during the hour
DEP_NHBO	PA to OD	The percent of daily NHBO P-A trips that depart during the hour
RET_NHBO	PA to OD	The percent of daily NHBO P-A trips that return during the hour
DEP_ALL	PA to OD	The percent of daily P-A trips that depart during the hour
RET_ALL	PA to OD	The percent of daily P-A trips that return during the hour
[% FLOW ALL]	Time of Day	The percent of daily O-D trips that occur during the hour

The combined survey database was used to identify the discernable peaks, and based on this analysis, three significant peaks were identified: morning, evening, and mid-day (MD), leading to the development of four different time periods, AM (6:00 a.m. to 10:00 a.m.), MD (10:00 a.m. to 3:00 p.m.), PM (3:00 p.m. to 7:00 p.m.), and OP (7:00 p.m. to 6:00 a.m.). The application of the time-of-day step will yield O-D trip tables by time period that are the inputs to the trip assignment step. The details for assigning these time period trip tables are discussed in detail in the trip assignment chapter.

10.3 Vehicle Trip Conversion Factors

During the time-of-day procedure, average auto occupancy factors by time-of-day and trip purpose are applied to convert person auto trips to vehicle auto trips. The auto occupancy factors were developed from the North Carolina Combined Travel Survey Database and are shown in Table 21.

Table 21 Vehicle Occupancy Factors by Trip Purpose

	Small Area				Large Area			
Purpose	**AM**	**MD**	**PM**	**OP**	**AM**	**MD**	**PM**	**OP**
HBW	1.07	1.10	1.07	1.09	1.05	1.07	1.05	1.05
HBO	1.36	1.30	1.43	1.45	1.48	1.31	1.52	1.52
HBSCH	1.27	1.13	1.23	1.30	2.07	1.58	1.99	1.23
NHBW	1.05	1.11	1.08	1.14	1.09	1.18	1.09	1.10
NHBO	1.32	1.27	1.45	1.73	1.57	1.39	1.61	1.73

11 HIGHWAY ASSIGNMENT

11.1 Introduction

This chapter addresses the last stage of the travel demand modeling process – network trip assignment.

11.2 Highway Assignment

Traffic assignment involves the estimation of traffic on each individual link of the highway network. This final step occurs after validation and provides the data needed to:

- Test alternative transportation plans;
- Establish priorities between different transportation investment strategies;
- Analyze alternative locations for roadway improvements; and
- Forecast design volumes needed to adequately design and construct new roadway facilities.

The reliability of the output from this step is dependent upon the reliability of all the proceeding steps.

11.3 Assignment Methodology

The algorithms used in traffic assignment attempt to replicate the process of choosing the best path between a given origin and a given destination. Some algorithms assume that all users of the system view the path impedance only in terms of time. Other algorithms assume that the users of the system view the path impedance as a set of weighted variables.

A common assignment methodology for small urban areas is the all-or-nothing (AON) approach. This assignment methodology assigns all trips between an origin-destination pair to the minimum network path. While an AON assignment in combination with manual network adjustments can give reasonable results for a small and relatively uncongested network and is also useful to evaluate total demand on the roadway under ideal circumstances, it is not recommended because it does not reflect the variable nature of path choice among a set of paths. Nor does it reflect the effect of congestion on path choice. It does not reflect the reality of driver choice and perception as it is unlikely that any two drivers will take exactly the same path from one location to another.

For the reasons cited above, the recommended assignment methodology for these guidelines is an equilibrium highway assignment. This is a widely accepted, best practice approach that produces link loadings by optimally seeking user-equilibrium path loadings reflecting user path choices as influenced by congestion on the network. During the assignment process, the trip table for each iteration is assigned to the highway network for multiple iterations. Link travel times are recalculated at the end of each iteration using the total link demand. The number of iterations is determined by a user defined closure parameter (recommended as 0.001) or for a maximum number of iterations (typically set to at least 25). The final assignment is an average of the last and next to the last iterations.

For each iteration, a volume-delay function is used to update the link speeds based on the previous iteration's vehicle demand and the link capacity. As introduced in Chapter

2.6, a conical delay function is recommended. The conical delay function has the following formulation:

$$\frac{t'}{t_0} = 2 + \sqrt{\alpha^2 (1 - \frac{v}{c})^2 + \beta^2} - \alpha (1 - \frac{v}{c}) - \beta$$

where:

$\beta = \frac{(2\alpha - 1)}{(2\alpha - 2)}$, and α is a constant larger than 1.

The conical delay function requires only one parameter, alpha, and is somewhat less severe (compared to the BPR function) in travel time increases at high volume to capacity ratios, and provides greater speed differentiation at low volume to capacity ratios, leading to more stable assignment results. The α value is roughly equivalent to the exponent in the traditional BPR formula. It is reasonable therefore to expect higher values for freeways and expressways and lower values for arterials, collectors, and local streets, reflecting a greater sensitivity to high v/c ratios on high speed facilities. The recommended α values are shown in Table 10 (page 25).

11.4 Daily vs. Hourly/Peak Period Assignment

Historically traffic assignments performed by NCDOT for large non-MPO areas and small MPOs were done on a 24-hour basis. While this approach has merit from the standpoint of efficiency in application, it presents several challenges, most notably that daily assignments cannot reflect the effect of delay on route choice. While a daily assignment may be justified for some of the study areas covered by these guidelines, hourly or period assignments are recommended as the best practice approach to traffic assignment. This approach is very similar to a daily assignment in application with the exception that rather than assigning a daily trip table, separate time period trip tables are assigned. The hourly capacity in the network is factored to reflect the peaking characteristics within each designated time period.

At the end of the assignment procedure, the time period assignments are summed to produce a daily traffic assignment.

12 OVERALL MODEL VALIDATION

12.1 Introduction

Execution of the complete model system, as it will be applied in any future forecasting setting, provides a series of model results. These range from trips produced by zone (trip generation), to zone-to-zone trip matrices (trip distribution), to assigned estimates of travel volumes on both the highway and transit networks (trip assignment). Model validation is the process of comparing these results against observed data that are independently obtained from the field survey.

By comparing model output against data that was not used directly in the model calibration and development process, these comparisons demonstrate the model's ability to match real-world observations, increasing the model's credibility. In addition, model validation shows the model's ability to accurately reflect the effect of changed conditions. Model validation often reveals problems with model inputs or components, requiring further effort in adjusting inputs or recalibrating those components. Therefore, model validation can often necessitate other model adjustments as one attempts to improve model results and/or better address key travel markets. This chapter will discuss specific model validation measures and make recommendations for standards. Many of the criteria and measures discussed here are from the "Model Validation and Reasonableness Checking Manual".[5]

12.2 Trip Generation Validation

Trip generation validation includes comparisons of trip productions and attractions by district to observed values. Observed values may be obtained from Household Travel Survey (HTS) data (expanded). Even though the expanded data was used to develop trip production and attraction rates, the spatial distribution of trip productions and attractions will reveal how well the model accommodates trip generation by geography. A plot of observed and estimated trips should reveal a good correlation of observed and estimated trip generation. Outliers should be noted and examined for patterns, such as a particular type of development (e.g., mall locations) or geographic location clustering. Significant deviation may suggest that accessibility may play a role in the trip rates and should be included in the trip generation equations, or that the particular land-use type should be treated as a special generator (such as large shopping malls or universities). The analysis may also reveal a problem with household and/or employment input data.

12.3 Trip Distribution Validation

In addition to screenline results, discussed below, the trip distribution patterns may be compared with the Census journey-to-work data for work trips (from the CTPP). Both district-to-district and trip length frequency distributions, compared with this independent data source, will enforce the credibility of the model. Plotting observed and estimated relative shares of trips by district interchange will reveal the correlation between the CTPP data and estimated distribution. Finally, trip distribution to selected districts or area types, such as the CBD, can be displayed on a map with both observed and estimated totals to that destination for each district. This will verify the geographic coincidence to major attractors. Adjustments to the distribution model, when needed may be done through the

---

[5] "Model Validation and Reasonableness Checking Manual". Prepared for Travel Model Improvement Program, Federal Highway Administration. Prepared by Barton-Aschman Associates, Inc. and Cambridge Systematics, Inc. February 1997

use of K-factors, but only when the analyst can tie those movements to real physical or social barriers or incentives. K-factors should be avoided if at all possible due to the uncertainty of their impacts on future year travel.

It should be noted that CTPP data is not completely consistent with model definitions of Home-Based Work (HBW) trips. CTPP counts worker flows by place of residence and place of work. Therefore, there will be only one worker in each interchange while there may be multiple (usually between 1.3 and 1.6) HBW trips on an average day for that worker. This must be accounted for in the comparison method, usually by scaling the CTPP data to the estimated HBW trip data at a production district level.

Also, HBW trips account for only trips that went directly between the household location and the work location. Since stops are often made on the journey to and from work, and the likelihood of making a stop increases with respect to distance, the "leftover" HBW trips will tend to be somewhat shorter than the worker flows reported in CTPP. Therefore the point is not to match CTPP exactly but to look for outlying district interchanges and attempt to reconcile them with the observed data. Household/employment input data and trip production and attraction rates would be the first place to look for problems, followed by the possible introduction of K-factors.

12.4 Vehicle Assignment Validation

There are three basic types of comparisons made when comparing actual traffic counts to estimated auto vehicle volumes: 1) global measures of vehicle miles traveled (VMT), vehicle hours traveled (VHT) for the region, per household, and per person and speeds; 2) screenline, cutline or cordon line comparisons; and 3) link level comparisons.

12.4.1 Global Performance Measures

At the regional level, comparisons to observed VMT provide useful information on the model's trip generation and distributional characteristics. The estimated VMT is obtained by multiplying the estimated vehicle volume by the link length and summing over all links. In addition, VMT may be summed by facility type, county, or area type. Observed VMT may be obtained from NCDOT's Universe File MS-Access application (basis for the Highway Performance Monitoring System (HPMS)), or by summing VMT from links with available counts. Universe File VMT data is usually available by facility type and county. When using Universe File VMT data, make sure that the facility type definitions are compatible with those used in the model. Universe File VMT is typically more accurate in the higher facility types and has a higher level of error in the lower facility types. Using VMT derived from counts offers more flexibility in summarizing by geography and facility type, but the user should make sure that only counted links are included in the estimated VMT total.

Regional VMT should generally be within 5% of observed VMT. The distribution of VMT among facility types for areas with a population between 50,000 and 200,000 are:

18-23% -- Freeways;

37-43% -- Principal Arterials;

25-28% -- Minor Arterials; and

12-15% -- Collectors.

VMT per household and VMT per person typically range in 30-40 miles/day/household and 10-16 miles/day/person for small urban areas, respectively.

Regional average speeds can be generated by dividing VMT by VHT (vehicle-hours of travel). This calculation may be done by area type and/or facility type. Observed average speeds can be obtained from a speed survey. Speeds should be summarized separately by time period (e.g., AM, PM, MD, and OP).

12.4.2 Screenlines, Cordons and Cutlines

Early in the network development process, a series of screenline locations are established that serve a variety of purposes. Screenlines should be established at locations within the region where physical barriers may suggest the need for K-factors (in the trip distribution model) and other locations which attempt to measure major corridor or sub-regional flows. Make sure that the screenline volumes are as complete as possible, with few missing observed volumes. In the event that the comparisons between observed and estimated screenline volumes are not within acceptable tolerance limits, an analysis of the source of the error may require adjustments to one or more of the upper level models (i.e., trip generation, etc.). Screenline comparisons are also a check on the basic household survey data used to develop the model. It is often the case that initial comparison of model demand to ground counts on a screenline basis will indicate the model is generally low. This may be attributable to under-reporting in the travel survey. Screenlines should generally be within 10% of observed values on a daily basis, although this can vary depending on the total volume crossing the screenline. For more on the use and development of screenlines, cutlines, and cordons, please see Section 2.11.1.

12.4.3 Link-level Comparisons

At the link level, several measures should be made. A very common measure is the calculation of percent root mean square error by facility type/area type and a range of volume categories. In the context of model validation, percent root mean square error is computed as follows:

$$\%RMSE = \frac{\sqrt{\frac{\sum (V_e - V_o)^2}{N-1} \times N}}{\sum V_o} \times 100$$

where:

V_o = Observed Volume for link n;

V_e = Estimated Volume for link n;

N = Number of Observations or number of links; and

$\sum V_o$ = Sum of V_o over all N.

Targets for %RMSE are in the range of 30-35%, depending upon the number of low-volume roadway segments included in the count sample. The %RMSE by facility type and observed volume range should show a decreasing %RMSE with a higher level of facility type - (up to Freeway) and with increasing observed volume. Tables 22 and 23 are examples displaying the results of this type of comparison.

Table 22 Example of Percent Root Mean Square Error by Facility Type and Area Type

	Area Type	All

Facility Type	1	2	3	4	5	
Freeway	25.803	30.468	16.803	16.247	25.233	25.470
Expressway	0.0	10.120	24.726	193.668	48.675	44.088
Collector	61.395	54.710	43.645	80.785	126.315	62.686
Six-leg Arterial	18.264	16.097	25.925	15.403	0.0	21.835
Arterials	29.203	27.658	30.046	45.740	82.555	38.474
Ramp	50.226	53.751	57.651	63.889	63.665	59.177
Total (Systemwide)	34.080	35.476	30.663	45.340	75.531	40.599

Table 23 Example of Percent Root Mean Square Error by Link Volume Group

Link Volume	% RMSE
0 to 4999	115.757
5000 to 9999	43.141
10000 to 19999	28.272
20000 to 39999	25.383
40000 to 59999	30.252
60000 to 89999	19.199

On an individual link basis, the following tolerances should be applied for daily flow model validation:

- 75% of freeway link within +/- 20% of traffic counts;
- 50% of freeway link within +/- 10% of traffic counts;
- 75% of major arterial link with 10,000 vehicles per day within +/- 30% of traffic counts; and
- 50% of major arterial link with 10,000 vehicles per day within +/- 15% of traffic counts.

Observed and estimated daily volumes by link can be plotted on a scatter plot. Additionally, running statistics such as the r-squared or coefficient of determination can be easily computed on most spreadsheet software and give an indication of the degree to which the counts and estimated volumes match. Note that the r-squared value is, in part, a function of the number of observations, so fixed standards regarding acceptable r-squared limits are not appropriate. The r-squared and correlation coefficients range between 0 and 1.0, with 1.0 representing a perfect match. So, in general, a high r-squared value is desirable. Similar link criteria can be applied on a volume basis. The following is a set of FHWA standards of deviation by volume group:

Daily 2-Way Volume	Desirable Percent Deviation
< 1,000	60%

1,000 – 2,500	47%
2,500 – 5,000	36%
5,000 – 10,000	29%
10,000 – 25,000	25%
25,000 – 50,000	22%
> 50,000	21%

Still another type of link level comparison is a network plot in which differences between estimated and observed flows can be shown by color-coded bandwidths scaled to the difference or ratio. Most modeling packages have the graphic capabilities to produce such network plots. These plots should be studied to identify patterns in over- or under-estimation that may be tied to the characteristics of the network or underlying trip distribution.

12.5 Sensitivity Testing

Sensitivity tests can reveal the ability of the model to react in a rational way to changes in inputs. Ideally, those changes in input data, either socioeconomic data or network changes, should reflect real changes and be coupled with known results.

Back-casting is one way to test the sensitivity of the model. In this technique, socioeconomic data and network information representing a recent year (5-10 years prior to the calibration year of the model) is used as input to the model. The results, in terms of trip generation, distribution, and assignment information, should be compared with observed data of that same year, to the extent available. Often, in the absence of a HTS for that year, only counts may be available. If a past census year is used, Journey-to-Work (from the CTPP) data may also be useful.

Near-term forecasting may also be an option. In this case, there may be data available for a current year that is sufficiently distant from the calibration year. For example, a model calibrated in 2002 may make use of a set of 2007 year inputs for both socioeconomic and network data. As in back-casting, the observed transportation performance data for the current year should be used if available in the standard validation comparisons.

Finally, simple hypothetical sensitivity tests may be used. While, by definition, no actual outcomes will be available, the analyst can examine the changes in the model outputs for general reasonableness. For example,

- Does a 10% increase in population result in a corresponding increase in trips?
- Does a global increase in freeway speed limits by 5 mph result in more and faster freeway travel?
- How does the addition of a major shopping center affect the trip distribution?

Illogical results in sensitivity testing should point the analyst to look at the values of the model parameters to understand why the model reacted in the way it did. This, in turn, should reveal discrepancies in the estimation process that lead to unrealistic parameters or model designs that are insensitive or inadequately sensitive to changes to demand or supply inputs.

12.6 Adjusting the Model

The validation exercises described here may lead the analyst to re-visit the model parameters and/or specifications. The validation process, therefore, can be recursive and lead to model modifications. This may also necessitate recalibration of some model elements if the model structure and/or parameters have been changed. The end result of the validation process, however, assures that the model is not only capable of a reasonable comparison with the base year observed results, but is also useful for forecasting the results of changes in demand and supply of the transportation system. It should be noted that a model that is validated for purposes of general transportation planning may not be suitably validated for a corridor study. It is important that the model adequately address the travel markets that are relevant for the particular project or study for which that the model will be used. The expectation is that the same model will be used for general planning/AQ as that used for a more detailed corridor analysis. As the specificity of the required analysis grows from regional, to subarea, and to corridor, the model validation requirements grow as well. The requirements of more detailed analyses should be clearly understood at the beginning of a model development process, so that the appropriate level of detail and market segmentation may be built into the model from the start.

13 MODEL APPLICATION GUIDELINES

13.1 Introduction

This chapter addresses model application with a focus on consistency of scenario inputs versus model parameters, evaluations of reasonableness, and sensitivity testing. This process is essential to increasing the credibility of and confidence in the model results.

13.2 Scenario Inputs versus Model Parameters

Proper application of the model is highly dependent upon the proper treatment and differentiation of scenario inputs and model parameters. The scenario inputs covered by these guidelines include the highway line layer, TAZ land use and demographic data, and external station AWDT where the AWDT is the average weekday travel factored to the specific season of the year that corresponds to the base time frame of the model. These values change from one future year scenario to another (for example between 2010, 2020, and 2030) to reflect the changes in land use and the growth in traffic volumes at the external stations. Model parameters on the other hand do not and should not change from one model application scenario to another. Model parameters required by these guidelines include disaggregate curves for household size, disaggregate curves for autos per household, seed matrix for household size by auto ownership, trip production rates, trip attraction rates, gamma coefficients, distance coefficient, time-of-day percent flow, time-of-day percent departure, time-of-day percent return, vehicle occupancy factors, conical delay function, and the highway assignment closure parameter.

13.2.1 Highway Modifications

Changes are made to the highway line layer in order to test systemwide strategies as is often done during the development of the long range transportation plan, or to test specific strategies within an identified corridor. Changes may include the addition of new links to represent new roadways or the modification of link attribute data to reflect changing conditions such as widening from a two-lane section to a four-lane divided section. In general, the guidelines provided in Section 2.6 should be followed when creating a new line layer for future year analysis. In addition to following the guidelines for coding links and attributes, the validation checks covered in Section 2.9 should be performed on all scenario networks.

13.2.2 TAZ Land Use Modifications

As with the highway modifications, TAZ land use changes can either be made for the entire study area to reflect a future year scenario(s) for the purposes of evaluating and developing a long range transportation plan, or for the purposes of testing localized changes in land use. The TAZ data values that are subject to forecast include:

- Population,
- Households,
- Workers,
- Vehicles,
- Industrial Employment,
- High-traffic Industrial Employment,
- Retail Employment,
- High-traffic Retail Employment,
- Low-traffic Service Employment,

- High-traffic Service Employment,
- Education Employment,
- Office Employment, and
- Total Employment.

These categories are described in Section 2.5.4 and are based on the research conducted for NCDOT by the Raleigh, North Carolina firm Martin/Alexiou/Bryson (MAB).

Validation checks should be performed against future year land use forecasts in much the same manner as described in Section 2.5 for the base year data. An additional validation check that is important for future year forecasts is to compare the dispersion and intensity of growth between the base year and forecast year. Special attention should be given to assuring that there is an adequate jobs-to-housing balance, especially in the regions of the study area that are more rural in nature for the base year condition. Experience has shown that forecasts for rural areas converting to suburban in future years are often highly skewed towards residential development. The forecasts should be reviewed to assure that employment is also forecast in these areas, especially service employment that will be needed to support the new residential development. Other useful statistics to use for reasonableness checks include:

- Persons per household,
- Workers per household,
- Vehicles per household, and
- Vehicles per person.

13.2.3 External Station AWDT Modifications

As discussed in Chapter 9, external station travel reflects trips with at least one trip end external to the study area. The input data for this trip purpose is in the form of an AWDT value. This data is forecast for future year scenarios to reflect the growth that is anticipated by trips originating outside of the study area with destinations internal to the study area and vice versa, and also to reflect a growth in trips passing through the region. The most common approach to forecasting this data is to evaluate historic growth trends and then to apply these trends to the base year AWDT. Other factors should also be taken into consideration such as the regional attractiveness of your study area for neighboring communities, growth patterns for neighboring communities, and the jobs-to-housing balance within your study area.

As mentioned in Chapter 2, AWDT is more appropriate to validate to, but in practice there may be very little difference between AADT and AAWDT. If the difference between AWDT and AAWDT is only within the range of a few percent, then that is well within the variation in the travel demand model and it would be acceptable to use either count.

13.3 Examination of Results

The quality of model results should be judged not only at the end of the model application process, but also at intermediate steps. For example, trip production and attraction models estimate trip activity out of and into zones based on observed relationships between individual travel behavior and zonal land use characteristics. Trip productions and attractions are then processed such that total trip productions and total trip attractions balance by trip purpose. An evaluation of the trip production and attraction totals prior to balancing can indicate specific problems in the planning data relationships.

In the model validation chapter, several measures for checking the reasonableness and validation of the model outputs were provided. For the base year these comparisons are easier because comparisons are made against existing or known conditions. In forecast applications, the analyst must evaluate results based on hypotheses and expected results. Cases where results deviate from what is expected must be evaluated and determinations made as to whether the results are curiously counter-intuitive (but accurately derived), are based on an error in the model application data, or are based on an improper application of the models.

13.4 Sensitivity Tests

Sensitivity testing was discussed in Chapter 12, and is also discussed here because testing of this nature should play a role in the model application step. Sensitivity tests evaluate the responsiveness of models to systematic changes in input values. A measure referred to as elasticity is often used to describe the sensitivity of model results to changes in input. It is usually measured for one independent value at a time.

Elasticities of model coefficients are frequently studied and are subjects of research papers. Sensitivities of model inputs may thus be compared to readily available elasticities to evaluate common relationships in different areas between travel choices and independent variables that affect these choices. This concept might best be understood with an example that considers the change in vehicle miles traveled (VMT) between a no-build highway scenario and a build highway scenario with respect to the change in lane miles for those two scenarios. The elasticity can be calculated using the following formula:

$$Elasticity = \frac{\Delta VMT}{\Delta LaneMiles}$$

In general, the greater the value of elasticity the more elastic the model VMT is to a change in lane miles.

In addition to reasonableness checks on model sensitivities, this analysis helps to identify independent variables of significant sensitivity as well as variables of insignificant sensitivity. This information is important to an analyst seeking changes in transportation supply likely to achieve some desired goal. The model elasticities relate isolated changes in transportation supply variables to the expected responsiveness of the model. Model sensitivities also add credibility to the model results and the model is not only replicating base travel conditions, but is sensitive to a number of key model components.

Reference Materials

Manual of Regional Transportation Modeling Practice for Air Quality Analysis, 1993
http://tmip.fhwa.dot.gov/clearinghouse/docs/airquality/mrtm/index.stm

USDOT, Calibrating and Adjustment of System Planning Models, December 1990
http://ntl.bts.gov/DOCS/377CAS.html

USDOT, Model Validation and Reasonableness Checking Manual, February 1997
http://www.ctre.iastate.edu/educweb/ce451/LECTURES/Validation/finalval.pdf

NCLOS Analysis Software, North Carolina Department of Transportation, Version 2.0, Developed by ITRE at North Carolina State University, 2005

Glossary

Calibration – the process of adjusting parameter values until predicted travel matches observed travel

Census Block – the smallest geographic unit used by the US Census Bureau for tabulation of data

Census Block Group – geographical unit between the Census Block and Census Tract used by the US Census for tabulation of data

Census Tract – geographic unit for the tabulation of Census data, can be subdivided into Census Block Groups and Census Blocks

Centroid – point in space that represents the center of activity in a TAZ

Centroid Connector – a special highway link used to load trips from the centroid to the highway network

Demographic Data – workers per household, vehicles per household, household income, etc.

Dependent Variable – the “event” expected to change when the independent variable is changed

Estimation – the process of using statistical procedures to find the values of model parameters

Generalized Cost – a cost function used to capture the effect of cost, distance, and travel time on trip distribution

Independent Variable – a variable in a functional relation whose value determines the value or values of other variables

Land Use Data – spatial location of housing, employment and environmental data

NAICS – North American Industry Classification System

Path Building – finding the minimum path between every TAZ interchange

Reasonableness Checking – checking the outputs of the model against secondary sources of data for generally accepted guidelines in lieu of observed travel data

Screenline – imaginary line used to assist with the validation and calibration of the model that typically runs north/south or east/west from one end of the study area to the other

Skim Matrix – final output from the path building process that contains the zone to zone values of path parameters such as travel time or distance

Socioeconomic Data - population and employment

Spatial – pertaining to or occurring in space

TAZ – contiguous geographic areas that divide the study area into homogeneous areas of land use, land activity, and aggregate travel demand

Thematic mapping – a thematic map displays spatial patterns of a theme or series of attributes

Transportation Network – for roadway analysis this is the spatial representation of the roadway network to be modeled and evaluated. For transit analysis this is the spatial representation of the transit route system to be modeled and evaluated

Trip end – (in the context of an observed attraction record) – represents the destination end of an origin/destination trip record from a household travel survey

Validation – the process of testing the models predictive capabilities, such as comparing modeled highway flows to traffic counts