TRAVEL DEMAND MODELING POLICIES AND PROCEDURES

VDOT Project Number: 30681-03-02

Version 2.00

Prepared for

Transportation and Mobility Planning Division
Virginia Department of Transportation

By

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CHAPTER 1. INTRODUCTION TO TRAVEL DEMAND MODELING IN VIRGINIA

This manual has been developed to provide guidance for public agencies in the Commonwealth of Virginia responsible for developing, validating, and applying travel demand models and their consultants. It is intended for readers who have a basic understanding of travel demand modeling concepts and procedures. In this manual, the terms "modeling" and "models" will refer to travel demand models.

This version of the manual, labeled Version 2.00, dated June 2014, is an update to the previous Version 1.30, dated May 2009.

1.1 What Is Travel Demand Modeling?

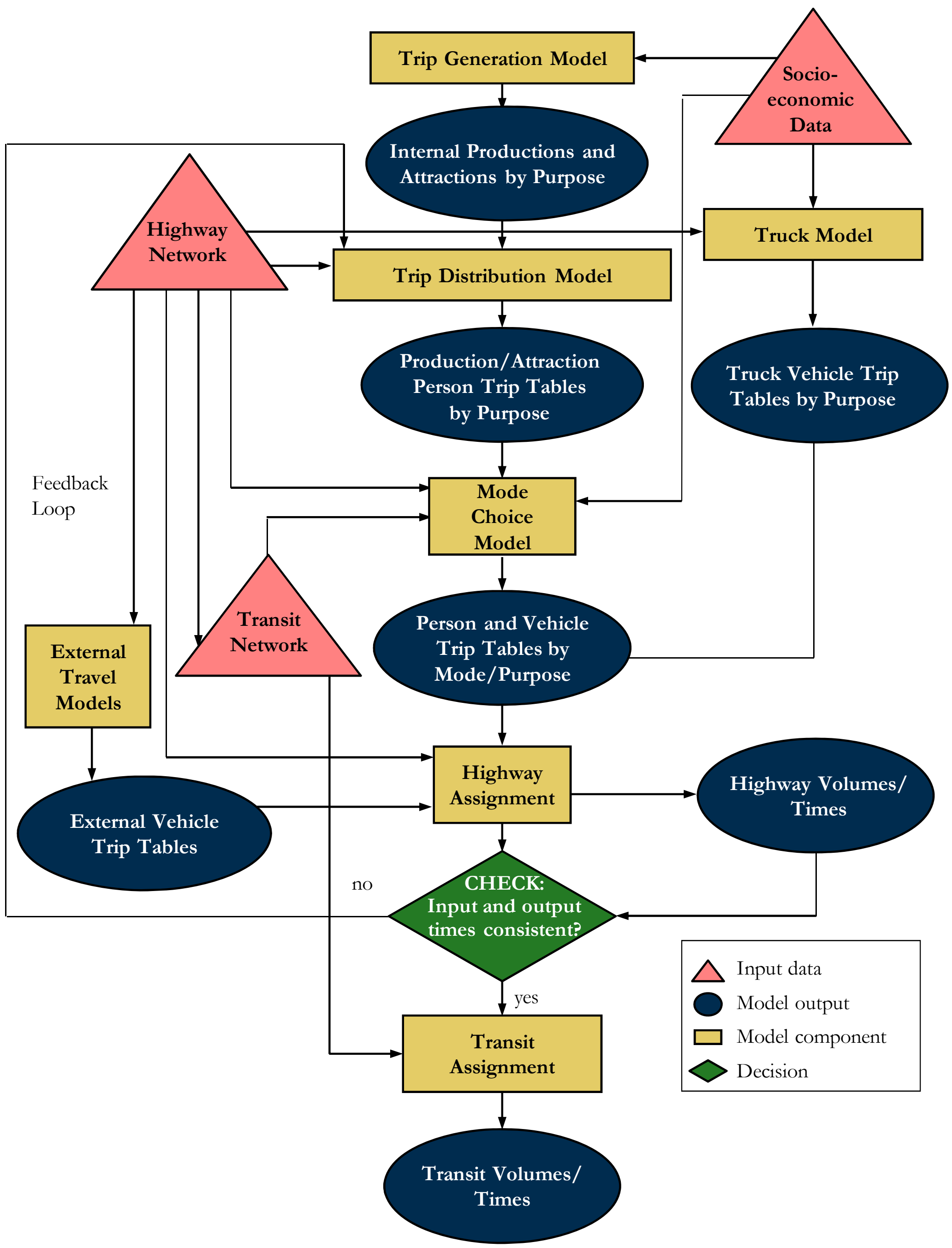
A travel demand model is an analytical tool used to support the transportation planning process. It can be used to develop traffic forecasts, test alternative transportation scenarios, and evaluate transportation systems or policies. Models are developed and applied using demographic, survey, and transportation system data, which are used to develop the transportation networks that are key components of the models. All of these data are used to develop the mathematical relationships necessary for modeling. A typical travel demand model in Virginia has between 10 and 30 input files and several output files.

Several different methodologies exist to perform modeling. The most common method used worldwide and in the United States is the conventional four-step approach. This is an aggregate sequential process with four basic steps:

- Trip Generation = How many trips will be made?
- Trip Distribution = Where will the trips go?
- Mode Choice = What modes of transportation will the trips use?
- Trip Assignment = What routes will the trips take?

Figure 1.1 illustrates a generic four-step modeling process, highlighting the typical major input data elements, model components, and model outputs. Demographic and other necessary model data is aggregated to transportation analysis zones (TAZs) for input to the model. TAZs generally follow census geography and are typically combinations of census blocks and/or census block groups. A discussion of how TAZs are defined appears in Section 4.1.

Figure 1.1 Four-Step Travel Demand Forecasting Process



1.2 Regulatory Requirements Affecting Transportation Modeling in Virginia

This section briefly summarizes regulatory requirements for transportation planning and travel models in urban areas. The requirements are up to date as of the time of the writing but are subject to change based on updated legislative and rulemaking actions.

A number of Federal and state regulations and requirements affect modeling in Virginia. These include:

1. Virginia Employment Commission Population Control Totals;
2. Federal Metropolitan Planning Regulations;
3. Federal Transportation Conformity Regulations; and
4. Federal Transit Administration Requirements.

1.2.1 Virginia Employment Commission Population Control Totals

The Virginia Employment Commission (VEC) is the designated state agency for developing population projections. As a result, population data used in travel demand modeling efforts in Virginia are required to match to VEC population control totals.

Presented in Appendix A is the language from the Code of Virginia in 60.2-113, Section 6 pertaining to the duty of VEC in preparing population data for Virginia. Currently, VEC contracts with Weldon Cooper Center for Public Services for the preparation of annual official population estimates and projections for Virginia and its counties and independent cities. These estimates are generally released at the end of each January. Presented in Appendix B is Code of Virginia 15.2-4208 which states the duty of PDCs in cooperating with VEC in preparing and maintaining population data. More detail related to population data preparation for model use can be found in Section 4.1.2 of this manual. Appendix C presents samples of the VEC Data Request Form and the Data Sharing Agreement for employment data.

1.2.2 Federal Metropolitan Planning Regulations

Excerpts of relevant Federal law are provided in Appendix D. Federal law governing the metropolitan planning process is stated in Title 23 of the Code of Federal Regulations, Part 450, Subpart C, "Metropolitan Transportation Planning and Programming." (23 CFR 450.300-338). Travel demand models are one of the more commonly used tools to satisfy the metropolitan planning requirements. Among the key requirements of the regulations are:

- The metropolitan transportation planning process shall include the development of a transportation plan addressing at least a 20-year planning horizon.
- The Metropolitan Planning Organization (MPO) shall review and update the transportation plan at least every four years in air quality nonattainment and maintenance areas and at least every five years in attainment areas.

- The metropolitan transportation plan shall, at a minimum, include the projected transportation demand of persons and goods in the metropolitan planning area over the period of the transportation plan.

Appendix A to Part 450, "Linking the Transportation Planning and NEPA Processes," further emphasizes good practice when engaged in the transportation planning process, including recommending that "assumptions have a rational basis and are up-to-date" and that "data, analytical methods, and modeling techniques are reliable, defensible, reasonably current, and meet data quality requirements."

1.2.3 Federal Transportation Conformity Regulations

The Clean Air Act of 1990 established the first national air quality standards. These standards were amended in 1997 and renamed the national ambient air quality standards (NAAQS) to include some additional pollutants. The list of pollutants addressed by the NAAQS is:

1. Ground-Level Ozone (O_3 One-Hour and Eight-Hour);
2. Carbon Monoxide (CO);
3. Nitrogen Dioxide (NO_x);
4. Lead (Pb);
5. Sulfur Dioxide (SO_2);
6. Particulate Matter (PM_{10}); and
7. Fine Particulate Matter ($PM_{2.5}$).

Metropolitan areas that do not meet NAAQS are designated as nonattainment areas. Figure 1.2 shows the air quality planning areas for the Commonwealth of Virginia. Table 1.1 shows that, with the exception of Northern Virginia, all MPO urban areas in Virginia are in attainment of the NAAQS as of July 31, 2013 [1]. However, areas which had previously been under subject to conformity rules under prior designation are urged to consult with Federal and state air quality and transportation agencies to determine their current requirements for reporting.[1]

Nonattainment areas are required to adopt State Implementation Plans (SIP) to achieve and maintain attainment. For transportation projects in a particular area to receive Federal assistance under Title 23, the MPO for the area must perform air quality analysis to assess

[1] The "anti-backsliding" provisions of the Clean Air Act Amendments are unclear as to the requirements for areas that were previously NA or Maintenance but now have a "clean bill of health." Those areas should consult with their former Interagency Coordinating Committee for Air Quality to determine their obligations.

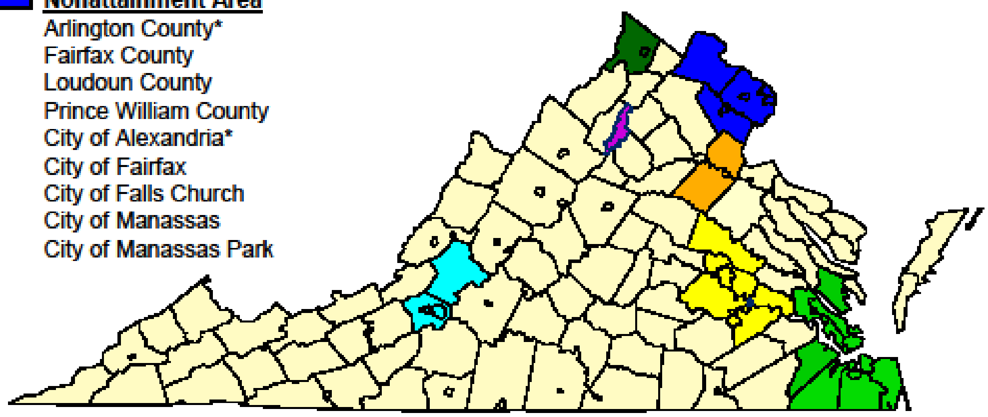
the impact of the planned improvements. This analysis is performed on the MPO's adopted Long-Range Transportation Plan (LRTP) and Transportation Improvement Program (TIP) using a combination of Travel Demand Management (TDM) and Air Quality (AQ) modeling processes. The vehicle emissions estimated for these plans must conform to the emissions budgets established by the SIP. Regional air quality analysis must meet additional requirements for metropolitan planning areas with populations greater than 200,000 and that are in nonattainment for serious, severe, or extreme ozone or serious carbon monoxide. These requirements are stated in 40 CFR §93.122(b), which is excerpted in Appendix D. The population requirement applies to the size of the entire area and not only the portion in Virginia. For that reason Table 1.1 shows the entire multistate population, not only the portion in Virginia.

Figure 1.2 Air Quality Planning Areas for the Commonwealth of Virginia

Frederick County Ozone Early Action Compact Attainment Area
Frederick County
City of Winchester

Fredericksburg Ozone Attainment/Maintenance Area
Spotsylvania County
Stafford County
City of Fredericksburg

Northern VA/DC/MD PM2.5 and Ozone Nonattainment Area
Arlington County*
Fairfax County
Loudoun County
Prince William County
City of Alexandria*
City of Fairfax
City of Falls Church
City of Manassas
City of Manassas Park



*Alexandria and Arlington are also attainment/maintenance for CO.

Roanoke Ozone Early Action Compact Attainment Area
Botetourt County
Roanoke County
City of Roanoke
City of Salem
Town of Vinton

Shenandoah National Park Ozone Attainment/Maintenance Area
Shenandoah National Park
(the portions in Page and Madison Counties)

Richmond-Petersburg Ozone Attainment/Maintenance Area
Charles City County
Chesterfield County
Hanover County
Henrico County
Prince George County
City of Colonial Heights
City of Hopewell
City of Petersburg
City of Richmond

Hampton Roads Ozone Attainment/Maintenance Area
Gloucester County
Isle of Wight County
James City County
York County
City of Chesapeake
City of Hampton
City of Newport News
City of Norfolk
City of Poquoson
City of Portsmouth
City of Suffolk
City of Virginia Beach
City of Williamsburg

Table 1.1 NAAQS Status of MPOs in Virginia[2]

Urban Area	MPO	States	2010 Census Population	Attainment Status	NAAQS Problem
Washington, D.C. region (includes Northern Virginia)	National Capital Region Transportation Planning Board (TPB)	D.C., Maryland, Virginia	4,991,324	Marginal Nonattainment	Marginal: Eight-Hour Ozone 2008[a]; NA $PM_{2.5}$; NA CO
Hampton Roads	Hampton Roads Transportation Planning Organization	Virginia	1,618,505	Attainment	
Richmond/ Tri-Cities	Richmond Area MPO	Virginia	934,060	Attainment	
Fredericksburg	Fredericksburg Area MPO	Virginia	275,639	Attainment	
Roanoke	Roanoke Valley MPO	Virginia	227,507	Attainment	
Lynchburg	Central Virginia MPO	Virginia	153,316	Attainment	
Petersburg	Tri Cities Area MPO	Virginia	149,029	Attainment	
Kingsport	Kingsport MPO	Tennessee, Virginia	125,260	Attainment	
Charlottesville	Charlottesville-Albemarle MPO	Virginia	113,074	Attainment	
Bristol	Bristol MPO	Tennessee, Virginia	93,307	Attainment	
Christiansburg	Blacksburg-Christiansburg-Montgomery Area MPO	Virginia	79,260	Attainment	

[2] Source for attainment status of each MPO: http://www.planning.dot.gov/mpos1.asp?stateID=VA&bysort=des&order=desc&prev=pop2010.

Table 1.1 NAAQS Status of MPOs in Virginia (Continued)

Urban Area	MPO	States	2010 Census Population	Attainment Status	NAAQS Problem
Front Royal	Winchester-Frederick County MPO	Virginia	78,440	Attainment	
Staunton	Harrisonburg-Rockingham MPO	Virginia	74,365	Attainment	
Martinsville	Danville MPO	Virginia	65,689	Attainment	

[a] See Appendix E for EPA designations for the Washington region for Ozone Season Volatile Organic Compounds (VOC), Nitrogen Oxides (NO_x), Fine Particles ($PM_{2.5}$), and Wintertime Carbon Monoxide (CO).

1.2.4 Federal Transit Administration Planning Requirements

Model applications intended to support application through the Federal Transit Administration (FTA) New Starts Program can lead to additional requirements beyond those specified for metropolitan planning and conformity. Under MAP-21, FTA offers two main paths for project consideration. The primary application path involves use of their national simplified trips-on-project software (STOPS), which can still involve additional modeling by applicants to represent, for example, special generator trips. As a second application path, FTA will also permit use of locally developed models but will review them for validity and reasonableness. In general, regardless of the application path selected, it would be wise to consult with FTA early on to confirm the latest specific requirements before embarking on the forecasting effort.

The discussion below is based on Appendix A, Section A.3 of National Cooperative Highway Research Program (NCHRP) *Report 716, Travel Demand Forecasting: Parameters and Techniques* [2], which draws on information from an FTA workshop [3]. Readers are referred to *NCHRP Report 716* for more detailed information.

FTA provides guidance on the following key aspects of travel forecasting for New Starts:

- Properties of travel models;
- Rider surveys; and
- Calibration and validation.

FTA's requirements for the properties of travel models are fairly broad. FTA supports a localized approach to travel modeling and forecasting, recognizing that there are no standard or "correct" methods that are universally applicable to all regions. Models need to reflect the fact that each metropolitan area has unique conditions and must be responsive to local decision making.

FTA's requirements are geared toward reasonably accounting for current patterns and predicting reasonable future ridership for the proposed New Starts projects. FTA does not provide rigid targets for parameters in travel models. Rather, FTA recommends methods that can be used to ensure that models reflect current travel behavior and predict reasonable future patterns.

FTA's expectations from travel models and the New Starts process can be summarized as follows:

- Coherent narrative of the model parameters, inputs, and outputs;
- Regular and early communication regarding model parameters and forecasts to ensure that the agency/sponsor is proceeding in the proper direction;
- Reasonable model forecasts in light of the expected land use growth, service characteristics, and other project-related attributes; and
- Proper documentation and uncertainty analysis.

Because models are used to forecast transit ridership, it is essential that they explain the current transit conditions and capture the tradeoffs between travel times and costs. These favorable properties are dependent on model validation procedures (see Chapter 3). In addition to capturing current conditions, models will need to fulfill their ultimate objective of yielding reasonable forecasts. Specifically, FTA requires reasonable "deltas" (changes in ridership between a base year and forecast year) for ridership that are consistent with the underlying socioeconomic growth as well as level-of-service improvements.

Rider surveys (see Section 4.2.1) are an important source of current transit information and are crucial to calibrating models that reflect the current conditions accurately. Where possible, FTA recommends surveys before and after project opening to get a time-varying picture of ridership patterns and also to evaluate the model predictions. The success of rider surveys in capturing the current transit travel patterns depends on the design of the surveys in terms of the sampling plan, the questionnaire, and the data items included in the questionnaire. In addition to the rider surveys, FTA recommends the use of other ridership data, where available, to inform the modeling process. These data could include on-off counts and park-and-ride utilization counts.

FTA emphasizes that forecasts should be based on models that are tested rigorously against current transit ridership patterns. The implications of a careful calibration and validation methodology are threefold: first, it necessitates better current data; second, it calls for a better focus on transit markets; and third, it requires better tests and standards.

FTA recommends that project sponsors take advantage of the funding and guidance opportunities available from the FTA to collect good quality "before" and "after" survey data. The issue of better focus on transit markets can be achieved through an evaluation of model performance by each trip purpose, socioeconomic group, production-attraction area types, and transit access modes. The FTA deems the matching of overall target totals as an insufficient measure of model calibration. The standards for model calibration must rely as much on behavioral significance as they do on statistical significance. The FTA defines validation as a valid description of travel behavior as well as plausible forecasts of "deltas" for the future year. The FTA recommends careful documentation of key transit markets, current transit modes, and calibration forecasts to help evaluate the overall effectiveness of the model.

The FTA has provided guidance on specific properties of travel models to ensure proper calibration and validation. The FTA has found that many travel models have one or more of the following problems:

- Unusual coefficients in mode choice models;
- Bizarre alternative-specific constants;
- Path/mode choice inconsistencies[3];
- Inaccurate bus running times; and
- Unstable highway-assignment results.

Since naïve calibration leads to bad alternative-specific constants and has the cascading effect of producing errors in trips and benefits, the FTA suggests that modelers ask themselves if patterns across market segments are explainable.

The FTA also suggests that there be conformity between parameters used in transit path selection and mode choice utility expressions for transit choices. That is, the path building process must weigh the various travel time and cost components in a manner that is consistent with the relative values of the mode choice coefficients. The FTA requires that level-of-service estimates for transit (and highway) must:

- Replicate current conditions reasonably well;
- Predict defensible deltas by comparing conditions today versus the future; and
- Predict defensible deltas when comparing conditions across alternatives.

1.3 VDOT's Role and Responsibility in Supporting Modeling

As illustrated in Figure 1.3, VDOT Transportation Mobility and Planning Division (TMPD) staff, VDOT District Planners, and MPO/Planning District Commission (PDC) staff all play varying roles in the development, maintenance, and application of travel demand modeling in the Commonwealth of Virginia. All of these stakeholders are active in

[3] This refers to the desirability of having conformance between parameters in transit path selection and the mode choice utility expressions for transit choices (e.g., coefficients on in-vehicle time and out-of-vehicle time).

performing model application and traffic forecasting. Companion Table 1.2 highlights the lead and partner responsibilities across the four work areas and associated tasks.

Figure 1.3 Virginia Travel Demand Modeling Stakeholder Responsibilities

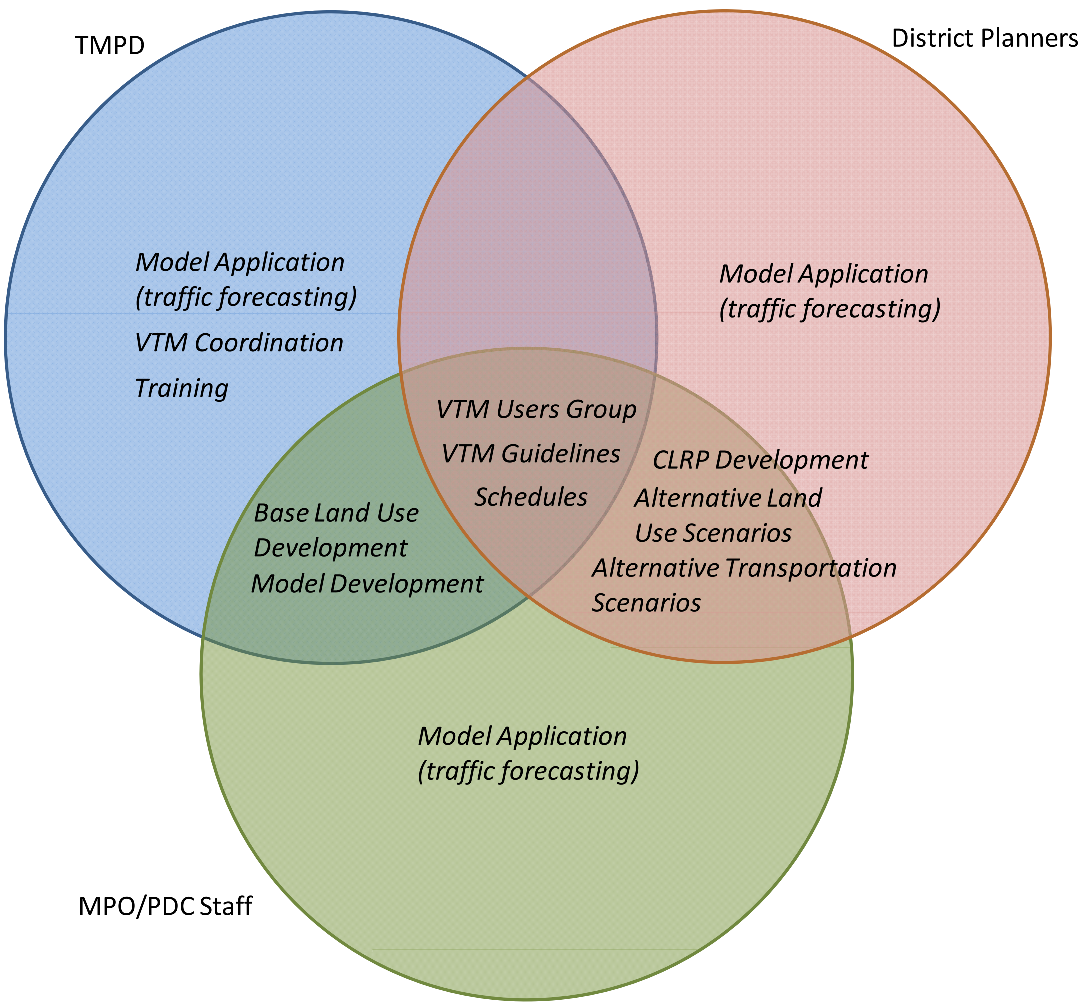


Table 1.2 Travel Demand Modeling Responsibilities

Work Area	Task	VDOT-TMPD Planning Systems Staff	VDOT-District Planning Staff	PDC/MPO Planning Staff	VDOT-TMPD Long- and Short-Range Planning Staff
Model Coordination	VTM User's Group	Lead	Partner	Partner	Partner
	VTM Connection Newsletter	Lead	Partner	Partner	Partner
	Training for VTM Members	Lead			
	Software Purchasing for VTM Members	Lead			
	Develop VTM Policies & Procedures	Lead	Partner	Partner	Partner
	Implement VTM Policies & Procedures	Lead	Partner	Partner	Partner
	Respond to Third Party Model Requests (TDM Request Form)	Lead			
	Maintain Central Repository of Official Modeling Files	Lead			
	Provide Guidance on Federal/State Requirements for Travel Demand Modeling	Lead			
Data Development	Determine Necessary Land Use Variables	Lead		Partner	
	Base Year Land Use Development by TAZ (VEC, Esri Business Analyst, etc.)	Partner		Lead	
	Census TAZ/TAD Delineation Process	Partner	Partner	Lead	
	Model TAZ Delination Process	Partner	Partner	Lead	
	Travel Surveys (NHTS,OD, Etc.)	Lead		Partner	
	Traffic Data (TMS, INRIX, Etc.)	Lead		Partner	
	Base Transportation Networks (RNS, NAVTEQ, Etc.)	Lead	Partner	Partner	
	Alternative Transportation Networks	Partner	Partner	Lead	
	Alternative Land Use Scenarios by TAZ	Partner	Partner	Lead	
Model Development	Research other Modeling Efforts	Lead		Partner	
	Develop Modeling Research for Practice	Lead		Partner	
	Model Development Schedule	Lead	Partner	Partner	
	Model Sensitivity Needs are Defined	Partner	Partner	Lead	
	Model Enhancements (short term, long term)	Lead			
	Develop Modeling Tools (land use density, reporting, etc)	Lead		Partner	
	Documentation of Model Methodologies	Lead		Partner	
	Consultant Contract Management	Lead			
	Sign Off on Calibration/Validation Results	Partner		Lead	
Model Application	MPO Long Range Plan Analysis (Vision, CLRP, TIP, Scenarios, etc.)	Partner	Partner	Lead	Partner
	MPO air quality conformity project listing	Partner	Partner	Lead	Partner
	Provide Necessary Air Quality Conformity Data to VDOT EQD	Partner	Partner	Lead	
	Regional Analysis Requested by MPO/PDC		Partner	Lead	
	Project Analysis by MPO/PDC		Partner	Lead	
	MPO Subarea Analysis		Partner	Lead	
	Corridor Studies crossing multiple MPO areas	Lead	Partner		Lead
	Regional Analysis Requested by State (BRAC)	Lead	Lead		Lead
	Project Analysis Requested by State	**Lead**	**Lead**		**Lead**

VDOT maintains two modeling staff groups. Both VDOT modeling groups work together to advance the practice of travel demand modeling within the State.

The first staff group is based in VDOT's Central Office location in Richmond and is responsible for establishing statewide modeling policies and procedures and for the development and maintenance of the statewide model and all urban travel demand models except those in the Northern Virginia Region. The Central Office currently is responsible for 10 urban models located throughout the State, the Richmond/Tri-Cities/Hampton Roads Superregional Model, and the Virginia Statewide Model (VSM).

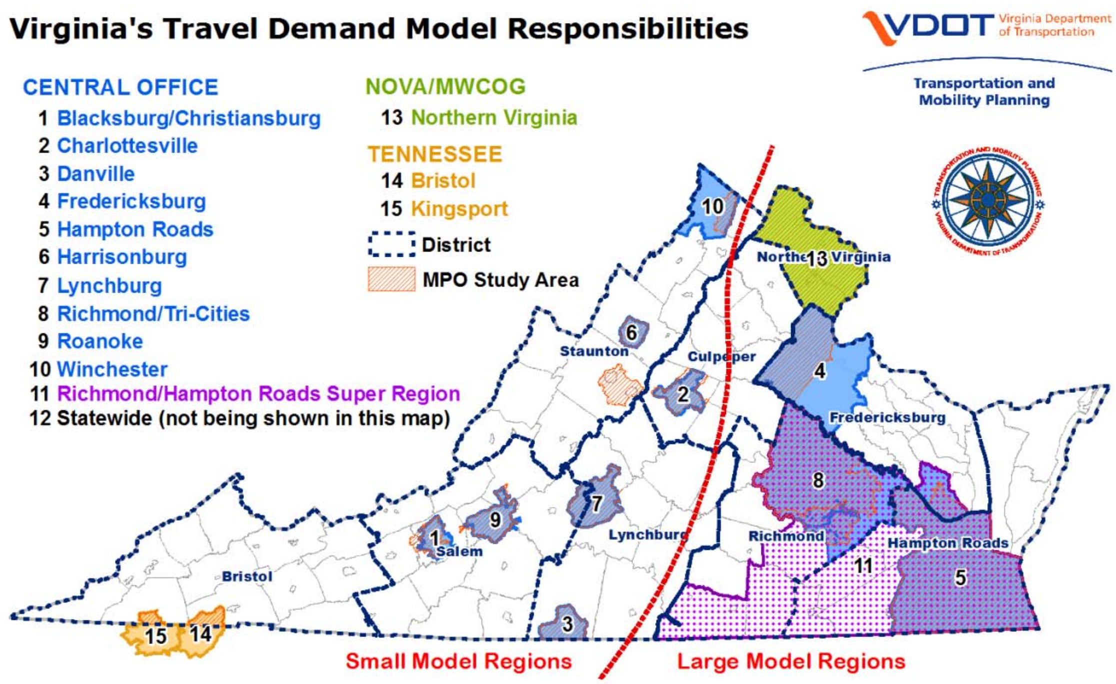
The second staff group is based in VDOT's Northern Virginia District Office location and is responsible for modeling in the Northern Virginia (NOVA) district. District staff work closely with the Metropolitan Washington Council of Governments/National Capital Region Transportation Planning Board (TPB) to perform modeling in the NOVA district. District staff also assist local governments with their modeling activities. Urban models maintained by VDOT staff are shown in Table 1.3 and Figure 1.4.

Table 1.3 Existing Urban Travel Demand Models

Model Region	Area (Sq. Miles)	Number of TAZs
Metropolitan Washington, D.C. (includes Northern Virginia)[4]	6,796	4,643
Hampton Roads	2,020	1,063
Richmond/Tri-Cities	2,195	1,064
Fredericksburg	1,572	851
Roanoke	216	225
Lynchburg	352	282
Charlottesville	212	248
Winchester	425	167
Blacksburg	155	206
Danville	197	176
Harrisonburg	106	174

[4] The TPB model is a core tool used to address Northern Virginia planning needs; figures presented are for the entire TPB modeled region, not just for Northern Virginia.

Figure 1.4 Virginia Travel Demand Modeling Regions by Areas of Responsibility



1.4 Purpose and Use of Policy and Procedures Manual

The Commonwealth of Virginia is the 12th most populous state with a population of over 8 million population[5] [4] and is experiencing rapid growth and increasing traffic congestion in many urban areas. As a result, the need for additional and more sophisticated models to serve Virginia's transportation planning requirements has grown in recent years. More development and congested travel have resulted in a greater need for consistency in model development and the requirement for guidelines on acceptable modeling practice. The purpose of this manual is to establish specific and uniform modeling policy and procedures for the Commonwealth of Virginia for use in model development and application by VDOT, MPOs, PDCs, and their consultants. This manual applies to all models in the Commonwealth of Virginia used for MPO planning activities with the exception of the three multistate MPOs whose central cities lie outside Virginia. These are the following:

[5] 2012 U.S. Census Bureau estimate is 8,185,867. 2010 U.S. Census Bureau figure is 8,001,024.

- National Capital Region Transportation Planning Board (TPB), the MPO for the Washington, D.C. metropolitan area;
- Bristol Metropolitan Planning Organization (Bristol, Tennessee); and
- Kingsport Metropolitan Planning Organization (Kingsport, Tennessee).

For the Northern Virginia District area, TPB staff maintains the MPO model and VDOT Northern Virginia District Staff have historically maintained modeling tools used for subarea studies in the Virginia part of the region. The cities of Bristol and Kingsport provide the support necessary to maintain the models in their respective MPO regions.

Throughout this manual, modeling practices are defined as "acceptable practice" or "recommended practice." *Acceptable practice* represents the minimum standard for modeling in Virginia and applies to all existing models; it can apply to future models if resources do not permit meeting recommended practice guidelines. *Recommended practice* is the preferred standard of practice and should apply to all future model updates if resources permit. In some cases, *unacceptable practice* may be cited if practices that are sometimes used or have been typically used in the past are now considered unacceptable.

Additionally, a distinction between small and large model regions is made for both acceptable and recommended practice. In the context of this manual, "small model regions" are model regions with less than 500,000 population which do not overlap with any large model region. "Large model regions" are 1) metropolitan statistical areas (MSA) of population greater than or equal to 500,000 or 2) have at least 200,000 population and are part of a MSA with a population of more than 500,000.

Large model regions require that transit travel be explicitly modeled, although transit may be modeled in small regions if the model needs to be used for planning of transit operations or improvements, or the effects of policies and projects being modeled have the potential for significant mode shifts. The sections of this manual pertaining to the modeling of transit, therefore, may not need to be referred to by readers dealing with models in smaller regions. The sections that may be unnecessary for these readers include:

- "Transit Networks" under Section 4.1.3;
- "Transit Rider Survey" under Section 4.2.1;
- Section 4.2.3, Transit Ridership Counts;
- Chapter 9, Mode Choice;
- Section 10.2, Transit Assignment Practice;
- Section 10.4, Transit Network Skimming; and
- Section 10.6, Transit Assignment Validation.

Table 1.4 displays the existing small and large model regions in Virginia. All large model regions have more than 500,000 population with the exception of Fredericksburg which is included in the large category because it is part of the MSA for Washington, D.C. It should be noted that all of the MSAs for large model regions in Virginia have populations greater than 1 million, meaning that Virginia currently has no model regions in the 500,000 to 1 million population range.[6]

Table 1.4 Existing Small and Large Model Region in Virginia

Small Model Regions <500,000	**Large Model Regions >500,000**
Roanoke	Northern Virginia
Lynchburg	Hampton Roads
Charlottesville	Richmond/Tri-Cities
Winchester	Fredericksburg[7]
Blacksburg-Christiansburg	
Danville	
Harrisonburg	

1.5 Organization of the Manual

The remainder of this policies and procedures manual is organized to provide coverage to a variety of important modeling topics.

Chapter 2 describes how travel demand models are used in Virginia and the processes for developing and updating the models and for coordinating with VDOT. Chapter 3 describes the data used as inputs to the model as well as the data used for model development and validation. The main sources for the data are discussed in this chapter. Chapter 4 provides an overview of the model validation process. Further details about model validation are provided in later chapters dealing with specific model components.

Chapters 5 through 11 deal with individual components of travel demand models – trip generation, trip distribution, modeling external travel, truck and commercial vehicle travel, mode choice, trip assignment, and feedback loops respectively. The mathematical processes used in the model component, the guidelines for performing this model step in Virginia, and an overview of model validation for the component is provided in each of these chapters.

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6 Although *National Cooperative Highway Research Program Report 716* [2] discusses a few MPO size categories, the two-level stratification is deemed satisfactory for the situation present in the Commonwealth of Virginia.

7 Fredericksburg had a 2010 population of 327,773 and is classified as large because it is part of the Washington, D.C. MSA.

Chapter 12 discussed model documentation and the requirements in Virginia. Chapter 13 describes the process for applying models in Virginia. A list of references is provided following Chapter 13.

The appendices include several pieces of important information related to modeling in Virginia. Appendix A contains the language from Code of Virginia 60.2-113, Section 6 pertaining to the use of information from VEC. Appendix B contains Code of Virginia 15.2-4208 which prescribes the general duties of PDCs. Appendix C provides samples of the Data Request Form and the Data Sharing Agreement for employment data from the VEC. Appendix D provides complete citations of applicable federal law pertaining to modeling in Virginia. Appendix E includes the EPA designations for the Washington region. Appendix F provides a glossary of travel demand modeling terms used in this manual. A list of current VDOT staff modeling contacts is provided in Appendix G. Appendix H has the Travel Model Data Request Form for Virginia. Appendix I provides VDOT's Travel Demand Model Application Checklist. Appendix J presents a list of web sites pertinent to travel demand modeling in Virginia.

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CHAPTER 2. TRAVEL DEMAND MODEL USAGE IN VIRGINIA

This chapter describes in general terms the ways that travel demand models are used in Virginia.

2.1 Purpose and Need for Modeling in Transportation Planning Analysis

Travel demand models can be useful technical tools in many types of transportation planning analyses. Some examples of planning procedures where models can provide relevant information include:

- Evaluation of transportation system performance;
- Long-range transportation planning, including the development of transportation plans for metropolitan areas and states;
- Short-range transportation planning, including the development of Transportation Improvement Programs (TIP);
- Air quality conformity analysis;
- Evaluation of transportation improvements and infrastructure investments for highways, transit systems, and pedestrian or bicycle facilities; and
- Evaluation of the effects of transportation and planning policies (such as pricing and land use).

Models require resources to develop, apply, and maintain, including staff time, hardware and software, data, and other costs. When considering model development, updates, or improvements, planning agencies should carefully weigh the development and maintenance costs. For small urban areas, other technical and sketch planning tools for traffic forecasting may sometimes be considered in place of a model.

2.2 Type of Model Needed

As noted in Chapter 1, the most common type of modeling used in transportation planning applications is the four-step approach. In areas where only highway travel is analyzed, a "three-step" approach, omitting the mode choice component, may be used. Currently, all models in Virginia use a four-step or three-step approach and this is considered both **acceptable practice** and **recommended practice**. Activity-based and tour-based models, considered more-sophisticated practice, are employed in a few locations outside Virginia (mainly large urban areas) and could find use in Virginia at some point in the future.

2.3 Model Specification

Model specification refers to a model's structure, features, and capabilities. Models should be specified to meet the transportation planning analysis needs for the study area in the foreseeable future while being cost-effective and practical for application. For example, a sophisticated model able to analyze the impacts of tolls, HOV lanes, and various transit options makes good sense for a large urban area but probably is overkill for a small urban area with limited transit and no expectations for toll or HOV lanes.

2.4 Types of Model Improvements

Model improvements include a broad range of different types of model changes, from creating new models to correcting minor errors with model inputs and scripts. As discussed in Section 1.3, VDOT has two modeling staff groups, Central Office and Northern Virginia. Each staff group is responsible for model improvements to models that they maintain. This section classifies model improvements into the three categories shown in Table 2.1: model development, major revisions, and minor revisions. Table 2.1 also shows the scope, implementation frequency, and examples of each type of model improvement. The list of examples is not an exhaustive list, but, rather, a representative sample.

Table 2.1 Classification of Types of Model Improvement

Type of Model Improvement	Scope	Frequency	Examples
Model Development	Changes to structure which require updates to input data and extensive validation and calibration	At least once every 10 years	• Recalibrate model based on new survey data • New trip generation model • New trip distribution model • New mode choice model • New trip assignment model
Major Revisions	Adding modules or revising inputs or parameters with only minimal changes to structure. Validation and calibration are required.	Review for need at least once every five years and perform as necessary	• New volume-delay function • New speeds/capacities • New trip purpose(s) • New truck model • New toll model • New GIS-based network • New vehicle occupancy rates • New trip rates • Incorporate time of day
Minor Revisions	Minor changes to correct errors and update model inputs and files based on the latest assumptions. Some validation may be required.	Review for need annually and perform as necessary. Should be performed in advance of major model applications.	• Correcting land use errors • Correcting network errors • Correcting minor errors in model scripts • Updating networks based on revised short-term plan assumptions

2.4.1 Model Development

Model development is large scale in scope and is associated with the creation of new models or redevelopment of existing models and usually involves a new "base year" for the model. Model development involves extensive validation and calibration efforts based on data sources for the new base year. It is desirable for the base year to change at most every 10 years because trip making characteristics and demographics can change rapidly, especially in larger urban areas and rapidly growing regions.

The model development process should be coordinated with the availability of major Federal data sources such as the decennial U.S. Census and local and national survey data sources (see Chapter 4). Model development also should include a review and update of TAZs and updates to the major data inputs, namely the socioeconomic data and the transportation networks. Data used for model validation, including surveys and traffic and transit ridership counts, also should be current to the new base year. The use of new data and potentially a revised model structure means that the model parameters will be updated in the model development process.

Model development can be time- and resource-intensive and requires extensive data collection and analysis. As such, model development efforts should be done separately from other transportation planning activities. To avoid project schedule issues, the timing of model development efforts should not coincide with or occur immediately before major model applications.

2.4.2 Major Revisions

Major revisions are medium scale in scope and may include adding new modules to existing models, such as a new truck model or incorporation of time-of-day analysis, or significant revisions to model inputs or parameters. Major revisions can result in some minor changes to model structure and generally require the revised model to be revalidated. The major difference between major revisions and model development is that major revisions do not result in significant changes to the model structure.

Each model should be reviewed by the VDOT designated modeler at least once every five years to determine whether a major revision is needed before the next model development effort. The necessary model revisions should incorporate updated model input data (land use/socioeconomic data and transportation networks) as well as updated data for validation. Model updates should be completed for use in all large-scale model applications such as MPO long-range plans and corridor studies. By the conclusion of the MPO long-range planning process, model transportation networks and other components should be updated based on the adopted long-range plan.

2.4.3 Minor Revisions

Minor revisions are relatively small updates to model inputs and files needed to correct minor errors in model input data or changes in model assumptions, such as the list of projects included in short-range plans. The VDOT designated modeler continuously maintains a list of minor changes that need to be included in the next model revision. The VDOT designated modeler reviews this list annually in light of known upcoming model applications. If a major model application will be done in the next year, a minor revision should be performed on the model in advance of the upcoming application. Examples of major model applications include:

1. MPO Long-Range Plan;
2. MPO Short-Range Plan (TIP);
3. Air Quality Conformity; and
4. Project Studies.

If no major model application is coming up in the next year, the project manager should make a judgment on whether or not the revision is needed at that particular time.

2.5 Model Improvement Process

2.5.1 Version Naming System for Model Improvements

The Virginia version naming system for the three types of model improvements documented in the previous section is illustrated in the example in Table 2.2. Model development initiates a new version name with this format: "Base Year" Version 1.0. For example, a new model created with a 2000 base year would be called Base 2000 Version 1.0. Major revisions and minor revisions cannot change the base year, but alter the version number. A major revision causes the version number to increase to the next integer. For example, a major revision to the Base 2000 Version 1.01 model, would result in a new model called Base 2000 Version 2.0. Minor revisions simply increase the version number in increments of one-hundredth. For example, a new minor revision to the Base 2000 Version 1.0 model, would result in a new model called Base 2000 Version 1.01.

Table 2.2 Example of Version Naming System for Types of Model Improvements

Type of Model Improvement	Original Base Year	Year of Model Improvement	Version Names	Version Numbers
Model Development	2010	2012	Base 2010 Version 1.0	2010.1.0
Minor Revision	2010	2013	Base 2010 Version 1.01	2010.1.01
Major Revision	2010	2015	Base 2010 Version 2.0	2010.2.0
Minor Revision	2010	2017	Base 2010 Version 2.01	2010.2.01
Minor Revision	2010	2018	Base 2010 Version 2.02	2010.2.02
Major Revision	2010	2019	Base 2010 Version 3.0	2010.3.0
Minor Revision	2010	2020	Base 2010 Version 3.01	2010.3.01
Model Development	2020	2022	Base 2020 Version 1.0	2020.1.0
Minor Revision	2020	2024	Base 2020 Version 1.01	2020.1.01

2.5.2 Request Process for Model Revisions

If a VDOT district, MPO, or PDC desires that a model serving their area undergo model development, major revision, or minor revision, staff should contact the appropriate VDOT staff member to discuss the agency's needs. A list of staff contacts for the different modeling areas in Virginia is shown in Appendix G.

2.5.3 Creation and Expansion of Models

If a VDOT district, MPO, or PDC that is not served by any existing model desires that a new model be created for their planning area, they should first contact the VDOT designated modeler to discuss their needs. If the planning area is adjacent or close to the area for an existing model, it is preferable to expand the existing model to include the additional planning area. For rural areas, transportation planning needs could potentially be addressed through the use of the Virginia Statewide Model (VSM) or other technical tools.

For instances where a VDOT district, MPO, or PDC desires that an existing model be expanded to include a new area, the following guidelines exist:

1. Expansion should only include entire jurisdictions;
2. Data needed to support the model expansion should be available using existing funding and resources; and
3. New jurisdictions added to the model should be within the boundaries of Virginia unless approval is obtained from MPOs, local jurisdictions, and state DOTs affected in any of the states or districts adjacent to Virginia.

2.5.4 Requesting Travel Demand Model Data and Files

Travel demand model data and files can be requested from VDOT staff using the Travel Model Data Request Form. Except for MPO staff, model data and files cannot be obtained without filling out this form. This form is available on the VDOT intranet site and is in Appendix H of this document. For questions regarding this process, contact the VDOT designated modeler.

CHAPTER 3. MODEL VALIDATION PROCESS

Travel models are used to produce information that is used in the transportation planning process. This information consists of aggregations of the results of travel-related decisions made by the thousands of people in the region being modeled. The models use mathematical relationships to produce this information from a set of known or assumed input data describing the transportation system, its users, and other factors that affect travel behavior. However, not only are some of the inputs unknown (particularly forecasted data), but the mathematical relationships in the models themselves are estimated since they represent simplifications of human behavior. Furthermore, many of the factors affecting travel behavior are unable to be observed or quantified, making their representation in models incomplete or absent.

Model validation is the process of checking the models to ensure that their results are reasonable and the mathematical formulations properly sensitive to the input data, in light of the uncertainties associated with the model. The validation process includes checking that the model produces reasonable results when it is applied for a scenario that can be observed and that the results remain reasonable when the inputs are revised to reflect changes in the transportation system or the population of users.

This chapter describes the process for validating travel demand models in Virginia. It draws on the definitive reference source for model validation in the U.S., the Federal Highway Administration (FHWA) *Travel Model Validation and Reasonableness Checking Manual, Second Edition*, [5] hereafter referred to as the "FHWA Validation Manual." For a more complete description of the process, the reader is encouraged to refer to the FHWA document.

3.1 Overview, Concepts, and Definitions

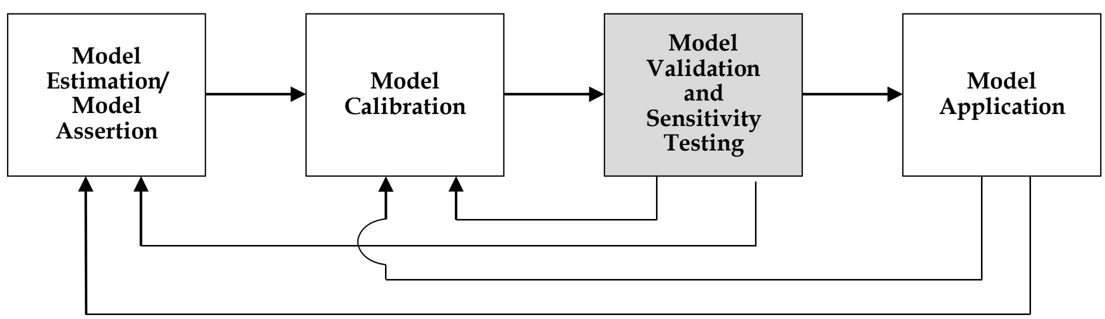
Since not all planners use the same terms to refer to components of the model development and application process, it is important to define the terms in a uniform way for use in this manual. Therefore, the terms are defined as in the FHWA Validation Manual. Some of the relevant terms as they are used in this manual are defined below.

- **Estimation** is the use of statistical analysis techniques and observed data to develop model parameters or coefficients. While model estimation typically occurs at a disaggregate level without bias or correction factors, model estimation also may use statistical analysis procedures to analyze more aggregate data.
- **Assertion** is the declaration of model forms or parameters without the use of statistical analysis of observed data. Model transfer from one region to another is a form of model assertion. The term "assertion" can apply to anything ranging from a single parameter to an entire model set.
- **Calibration** is the adjustment of constants and other model parameters in estimated or asserted models in an effort to make the models better replicate observed data for a base (calibration) year or otherwise produce more reasonable results.

- **Validation** is the application of the calibrated models and comparison of the results against observed data. Ideally, these observed data are not also used for the model estimation or calibration but this is not always feasible in a practical setting. Validation data may include additional data collected for the same year as the estimation or calibration of the model or data collected for an alternative year. Validation also should include sensitivity testing, defined below.
- **Sensitivity testing** is the application of the models and the model set using alternative input data or assumptions. Sensitivity testing of individual model components may include the estimation of the elasticities and cross-elasticities of model coefficients. However, sensitivity testing also should include the application of the entire model set using alternative assumptions regarding the input demographic data, socioeconomic data, or transportation system to determine if the model results are plausible and reasonable.

The processes defined above, as they relate to the overall model development and application process, are illustrated in Figure 3-1. Model validation and sensitivity testing may reveal the need to return to the model estimation or model calibration steps. The application of the model using nonbase-year conditions requires checking the reasonableness of projections and also might reveal a need to return to the model estimation or calibration steps. Issues uncovered during model application never lead directly back to the validation step since it is not possible to improve the model or model forecasts through additional validation. In some cases, however, additional model validation might be helpful in confirming the veracity of forecasts.

Figure 3.1 Model Development and Application Process [5]



3.2 Validation Process Description

3.2.1 General Concepts

The FHWA Validation Manual refers to five primary elements in the validation process:

1. Model validation plan specification;
2. Collection and assessment of validation data;

3. Validation of model components;
4. Validation of model system; and
5. Documentation of validation results.

Developing a model validation plan prior to beginning the validation (and preferably before beginning model estimation) is considered good practice. The development of a validation plan is not discussed in this manual; the reader is referred to the FHWA Validation Manual for information on this topic. The assembly of validation data (as well as other data needed for model development) is discussed in Chapter 4 of this manual. Documentation is discussed in Chapter 12. The remainder of this chapter, therefore, concentrates on Steps 3 and 4, the validation of model components and of the model system.

A critical concept of model validation is that every component of a model must be validated (Step 3), as well as the entire model system (Step 4). For the conventional four-step travel models used in Virginia, each of the four major components – trip generation, trip distribution, mode choice, and mode-specific trip assignment – along with the model input data and other components that might be part of the model system, such as vehicle availability or time-of-day modeling processes, must be validated individually. Since this manual has chapters referring to the major model components, the recommended validation tests that are specific to those components are described in the appropriate chapters.

Generally, it is good practice to perform the validation of the model components as they are developed (as opposed to long afterwards). For example, much of the validation of the trip distribution model can be performed immediately after model estimation (or assertion/ transfer), and the results can be compared to available data such as household travel survey information. However, it is necessary to recheck results for each component after the entire model development has been completed. This is especially important in models where any data are passed "backward," such as through logsums from subsequently applied components or feedback loops.

3.2.2 Accuracy Requirements and Guidelines

Accuracy requirements and guidelines for model validation depend on the intended use of the model being validated. Models used for project design or comparing alternative projects, especially for short-term planning, might require tight matches between modeled and observed travel data for model validation. In other cases, such as the evaluation of alternative transportation policies, the correct sensitivity of the model to the effects of the policies might outweigh the need for a close match of observed data. While the varying uses and requirements of forecasts could lead to the development of multiple models for a region, in Virginia it is common practice for agencies to develop a single model for an area and use it to provide forecasts for different types of analyses.

Reasonable validation guidelines may be important in helping establish the credibility of a model and helping model developers and users determine when the model is "close enough." The definition of acceptability guidelines needs to balance the resources and time available for model development with the decisions that will be supported by the travel forecast obtained using the model.

As in the FHWA Validation Manual, the term "guideline" rather than "standard" is used in this manual. The term standard connotes a formal definition of acceptance ("The standard has been met, therefore the model is valid," or, conversely, "the standard has not been met, and so the model is invalid"). The use of such rigid standards is not considered good practice and is not recommended in this manual. Simply matching model results within fixed percentages is insufficient to declare a model validated, and doing so ignores the differences in error ranges for models based on data from varying sources with different sample sizes, as well as the error inherent in the observed data sets themselves, which can vary substantially from one region to another.

Another reason that hard standards are not recommended is that revising the model during calibration in an attempt to meet a standard might make the model worse in other ways, such as diminishing its sensitivity to important variables. For example, one might introduce adjustment factors (known as "K-factors" in gravity model parlance) to attempt to get a better fit of district-to-district trips in a trip distribution model, but these factors might reduce the sensitivity of the distribution model to travel time because relatively large K-factors would become more significant than travel time and other variables in explaining destination choices. The large K-factors also could make it difficult for other model components to produce reasonable results.

The guidance in this manual therefore does not include requirements that any particular statistics must be within specific percentage ranges of the observed data. For the various model components, guidelines that are shown that can be considered useful targets, but they should not be considered pass/fail tests.

3.3 Static Validation for the Base Year

Comparisons of base-year model results to observations for a single "base year" are considered **static validation**. Ideally, the observed data sets used for comparison should not be the same data sets used for model estimation. Two typical examples are the following:

1. Traffic counts, which are not used in the development of highway assignment models, are commonly used as validation data for these models; and
2. Transit rider surveys or rider counts can be used in the validation of mode choice and transit assignment models (although such data are sometimes used for mode choice model estimation).

In many practical settings, however, data sets other than the estimation data set are unavailable for the validation of some model components. This is especially true of model components for which travel behavior data – for which the main source is a household survey data set – is required for validation. There are seldom alternative sources for travel behavior information beyond the core survey. The National Household Travel Survey (NHTS) is available in all areas of the U.S., and the Commonwealth of Virginia invested in additional samples within the state, but the number of available household records is still limited when one considers the total number of households present in each region). Typically sample sizes for household surveys are small enough that all of the data must be used for model estimation, and therefore the only data available for validation are the same data used in estimation. In these cases, it is good practice to make comparisons where possible to segments of the data not used for model estimation. For example, if the number of vehicles available is not a variable in the trip generation model, trip generation results can be compared for households with zero cars, one car, etc.

3.4 Dynamic Validation

Most travel models are based on "snapshot" data, such as household survey data collected over a relatively short period of time. The model relationships, parameters, and coefficients estimated from these data therefore reflect travel for the point in time represented by the model estimation data. However, the relationships may not hold true over time; the further one moves from the base year for validation, the more uncertain one should be regarding the appropriateness of the models. For this reason, good validation practice should include temporal validation for at least one year other than the base year for model estimation or calibration. The temporal validation should be performed for a year for which some validation data, such as traffic counts or transit boardings, are available.

This temporal validation, also known as **dynamic validation**, is an important aspect of model validation since it involves comparing model results to data not used in model estimation. Either backcasting or forecasting (or both) may be used for model validation. For example, if a model is estimated using 2010 survey data, the model could be used to backcast to 2000 conditions, and compared to year 2000 traffic counts, transit boardings, census data, or other historical data. Likewise, if a model was estimated or calibrated using 2005 survey data, a "forecast" validation could be performed against 2010 data.

Dynamic validation also includes **sensitivity testing**. Sensitivity testing can be performed by applying the model using alternative demographic, socioeconomic, transportation supply, or policy assumptions to determine the reasonableness of the resulting travel forecasts. The sensitivity of the model to the specific variable being varied can therefore be estimated by comparing the results of the alternative run to the base run.

The types of model inputs that might be varied during sensitivity testing could include the following:

- Land use/socioeconomic inputs – Examples (which may be regionwide or area-specific) might include increases in population or employment or changes in income levels;
- Highway Network – Examples might include travel times/speeds or auto operating costs; and
- Transit Network – Examples might include transit fares, headways, and operating speeds/ times.

3.5 Model Calibration and Troubleshooting

When issues are found during the validation checks, due to significant differences between model results and observed data or to unacceptably high or low sensitivity to input variables, additional model calibration is needed. The appropriate calibration actions depend on the specific validation issues discovered. Generally, calibration consists of adjusting parameters to improve the model results, but other actions, including adding or removing explanatory variables, may be considered. It also is good practice to check the observed data being used for comparison and the model input data for errors that might be indicated by the validation tests. In the chapter for each model component, specific calibration or troubleshooting actions are presented for specific validation issues.

CHAPTER 4. DATA DEVELOPMENT FOR TRAVEL MODELING

This chapter describes the policies and procedures for developing data for models in Virginia. The data requirements include both what are needed as model inputs and data used for model development, estimation, and validation.

4.1 Travel Model Input Data

Data used as inputs to travel models include the following basic categories:

1. TAZ boundary information;
2. Land use/socioeconomic data, typically compiled at the TAZ level; and
3. Transportation networks, including a highway network for all models and a transit network for models where transit is modeled explicitly.

The sources and methods for compilation of these data categories are discussed in the remainder of this section. At the end of the sections on land use/socioeconomic data and transportation networks, a brief discussion of quality/validation checks of these data is provided. The quality of model results relies as much on high-quality input data as it does on well-calibrated model parameters. Reliable travel forecasts require reasonable future-year socioeconomic and network data forecasts. Thus, the success or failure of the modeling process rests on the input data. The old adage "garbage in, garbage out" is appropriate.

Many problems with model results are the result of errors in the input data. Before performing model development and application, a careful and comprehensive examination of all the data inputs to the travel demand forecasting process should be made and approved by the VDOT designated modelers. Additionally, consultants performing modeling work for VDOT may be asked to review or revise model input data if model results do not appear to be reasonable.

4.1.1 TAZ Structure

The following list summarizes recommendations on the best practices in delineating TAZs [6]. While it may not be possible to follow every one of these recommendations for every TAZ, the recommendations provide good guidance for model developers. These recommendations should be considered for both base-year and future-year conditions where feasible.

- The **model area** should be large enough so that most of the trips begin and end within the study area. The percentage of travel that occurs entirely inside a model area will vary depending on the size of the region, locations of political boundaries and geographic barriers (such as bodies of water), presence of major long distance highways (such as major Interstates), and the size and proximity of nearby areas that generate substantial travel. Ideally, 90 percent or more of all modeled trips would have both ends inside the region; however, in small areas, areas with major long distance highways, and areas near other large urban areas, this may not be possible.

- The TAZ structure should be **compatible with the base- and future-year highway and transit networks**. The level of detail in the highway network should be consistent with the TAZ structure (and vice versa) to permit proper network loading. For example, if the TAZ structure is too coarse relative to the highway network level of detail, many roadways could have modeled volumes of zero.

- TAZ boundaries **should be compatible with census, physical, political, and planning district/sector boundaries**. This will allow for compatibility with data sources (discussed further in the next section). The most recent U.S. Census geography (currently 2010) should be followed. Preferably, TAZs should be block groups or combinations of block groups. In some instances, however, it is necessary to create TAZ geography at a sub-block group level. In these instances, TAZ boundaries must be combinations of census blocks. Areas with high employment, but relatively low population and fast growing suburban areas will most likely have block group sizes too large for TAZs.

- **Avoid concave borders** for TAZs. That is, avoid a TAZ shape whereby intrazonal travel could need to leave and reenter the same TAZ.

- TAZs should contain, as much as possible, **homogeneous land uses** in both the base and future year and should consider future significant developments. GIS can be a useful tool to check for homogeneity in population, employment, and other land use variables.

- The **average population per TAZ** should be between 1,200 and 3,000 for the base and future years. The population of most TAZs should fall within this range although there will be exceptions, such as in very sparsely populated parts of the model area or in locations with very high-density multifamily housing. This range provides a reasonable number of TAZs for computation purposes in most areas. In practice, this guideline works best for medium sized urban areas. For small urban areas, more TAZs are usually needed. For large urban areas this guideline is often not feasible computationally.

- Each TAZ should **generate less than 15,000 person trips** per day in the base and future year (trips produced in and/or attracted to the TAZ). Exceptions may occur for individual sites that generate very large numbers of trips.

- The **area of each TAZ** should be between 0.25 and 1.00 square miles. TAZs might be larger in more rural low-density parts of the model area and might be smaller in downtown areas with small blocks containing large buildings in large metropolitan areas.

- There should be a **reasonable (and relatively small) number of intrazonal trips** in each TAZ, based on the mix and density of the land use. (See Section 6.2, Trip Distribution Validation, for more information.)

- To the extent possible, **special generators and freight generators/attractors** should be isolated within their own TAZs.

- **TAZ numbering** should be sequential within jurisdictions, which is considered **acceptable practice**. Exceptions to sequential numbering, if necessary, should be documented. It is **recommended practice** that all model regions adopt a numbering scheme for their TAZs that are sequentially nested within jurisdictions, with external stations being numbered at the end. Gaps should be left in the numbering between jurisdictions so that additional TAZs can be added without disrupting the overall numbering system. Table 4.1 shows an example of recommended and not acceptable TAZ numbering systems.

- **External zones** (also known as external stations) represent significant roadways that cross the model area boundary. Whether or not to include a roadway as an external station should depend on the roadway's regional significance and traffic volume. For a roadway to be regionally significant as an external station, its inclusion must have a significant impact on a model's forecast volumes over a substantial part of the model area. It is both **acceptable practice** and **recommended practice** for all model regions that external stations be regionally significant and have an annual average weekday daily traffic (AAWDT) volume of at least 500 for small urban areas and 1,000 for large urban areas.

The policies and procedures for practice in Virginia for definition of TAZs are summarized in Table 4.2.

Table 4.1 TAZ Numbering Recommended Versus Unacceptable Practice

Jurisdiction Number	TAZ Numbering	
	Recommended Practice	Unacceptable Practice
033	1-75	1-33, 111, 124, 167-179, 197, 318-326, 333, 411-412, 462-475
038	100-159	34-56, 104-110, 112-123, 180-196
043	200-254	57-93, 125-128, 327-332, 334, 346-351
046	300-402	94-96, 129, 211-224, 234-248, 267-279, 404-410, 413-461
051	450-535	99, 101, 197-210, 370-403, 467-501
Externals	575-598	465-466, 502-523

Table 4.2 TAZ Practice for Virginia Travel Demand Models

Component	Acceptable		Recommended	
	Small	**Large**	**Small**	**Large**
TAZ boundaries	Compatible with Census 2010	Compatible with Census 2010	Compatible with Census 2010	Compatible with Census 2010
TAZ numbering	Sequentially nested within jurisdiction to the greatest extent possible	Sequentially nested within jurisdiction to the greatest extent possible	Sequentially nested within jurisdiction	Sequentially nested within jurisdiction
TAZ population	N/A	N/A	One per 1,200 to 3,000 population	One per 1,200 to 3,000 population
TAZ trip generation	N/A	N/A	<15,000 Trips/ TAZ	<15,000 Trips/ TAZ
TAZ area	N/A	N/A	>0.25 to <1.00 square miles	>0.25 to <1.00 square miles
Inclusion of a roadway as an external station	Regionally significant and has an AAWDT of at least 500	Regionally significant and has an AAWDT of at least 1,000	Regionally significant and has an AAWDT of at least 500	Regionally significant and has an AAWDT of at least 1,000

4.1.2 Land Use/Socioeconomic Data

Local agencies are responsible for the base-year and forecast land use data necessary for travel demand forecasting. Population and employment estimates shall be based on official estimates of either the Weldon Cooper Center for Public Service of the University of Virginia, the Virginia Employment Commission (VEC), the United States Census Bureau, or other official government projections required for Federal transportation planning purposes.

A typical Virginia travel demand model input land use data file includes the following attributes: number of households, total population, population in households, population in group quarters, number of households, school enrollment by type of school (e.g., K-12 versus university), autos per household, and employment by type (e.g., retail and non-retail). These data are aggregated at TAZ level. Figure 4.1 shows land use file format used by Richmond/Tri-Cities (RTC) model, Base 2008 Version 1.0. The types of land use/ socioeconomic data used in Virginia's travel models are discussed in the subsections that follow.

Figure 4.1 RTC Model Land Use Input Data Format, Base 2008 Version 1.0

ZONE	JUR	TOT_POP	POP_HH	POP_GQ	HH	K12_ENROLL	U_ENROLL	AUTO	TOT_EMP	RET_EMP	NON_EMP	NAICS_11	NAICS_21	NAICS_22	NAICS_23
1	Petersburg	64	1	63	1	0	0	4	139	33	106	0	0	0	6
2	Petersburg	0	0	0	0	0	0	0	165	0	165	0	0	0	0
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1042	Powhatan	1758	1758	0	686	0	0	2045	715	79	636	5	22	0	244
1043	Powhatan	1190	1190	0	453	0	0	1421	55	12	43	0	0	0	23
1053	External	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1055	External	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Population and Household Data

This subsection addresses in turn four types of population and household data included in models and the common methods used to assemble them as inputs: total population and households for each TAZ, household size, automobile ownership, and cross-classification by multiple variables.

Total Population and Households for Each TAZ

Population is defined by the Code of Virginia in Section 15.2-4202:

> *"Unless a different census is clearly set forth, means the number of inhabitants according to the United States census latest preceding the time at which any provision dependent upon population is being applied, or the time as of which it is being construed, unless there is available an annual estimate of population prepared by the Weldon Cooper Center for Public Service of the University of Virginia, which has been filed with the Department of Housing and Community Development, in which event the estimate shall govern."*

The Weldon Cooper Center, contracting with VEC, is the official agency of Commonwealth of Virginia for producing population annual estimates and projections. These estimates, including the official estimates of total population for localities, are used throughout the Commonwealth for decision-making and fund allocation. The population estimates are produced annually for each non-decennial-census year for each locality. When developing TAZ population and household data for travel demand model use, it is required that local agencies use the population estimates from Weldon Cooper Center as the control totals for each jurisdiction. For a model year in the past (e.g., developing a model with 2010 base year in 2013), the jurisdiction control totals should always be the same as the decennial census data (or VEC annual estimates). The aggregate totals of TAZ population should be consistent with jurisdiction control totals. For future year population projections, it is allowed to have ±10 percent deviation from the projections Weldon Cooper Center published at the regional level. It is recommended that PDC/MPO/localities pre-coordinate with Weldon Cooper Center Demographics Research Group for any deviation that exceeds the indicated requirement.

Population totals for each TAZ should be segmented into population in households and population in group quarters, using the U.S. Census definitions. Population in group quarters includes residents of military barracks, college dormitories, prisons, long-term-care hospitals, boarding houses, and nursing homes. The decennial U.S. Census provides estimates for these segments; data from the Census Bureau's American Community Survey (ACS) may be used for years falling between decennial census years.

Further segmentation of population and household data is usually necessary. For trip production models (see Chapter 5, Trip Generation), households are often cross-classified by two variables, for example, number of persons by number of vehicles. Trip distribution and mode choice models are often applied to various segments defined by vehicle availability or income level. Acceptable and recommended practice for segmentation are discussed in later chapters on these model components.

Household Size

Trip production models, and sometimes other model components, often use as inputs the number of households segmented by the number of persons (household size) – for example 1-person, 2-person, 3-person, and 4+-person households. If the number of households in each household size category is not estimated directly (the Weldon Cooper Center produces estimates of population by jurisdiction, but not the number of households by household size category), then a segmentation procedure is used. For example, in the RTC Forecasting Model (Base 2008 Version 1.0) [7], the following procedure was used:

1. Curves were estimated from data from the National Household Travel Survey (NHTS) to estimate the percentages of households of 1, 2, 3, and 4+ persons in a TAZ based on the average number of persons per household in the TAZ. Table 4.3 displays a portion of this table.
2. For each TAZ, the average household size is defined as the household population divided by the number of households. The number of households of 1, 2, 3, and 4+ persons in each TAZ is obtained by applying the corresponding percentages for the average household size, from the complete table (of which Table 4.3 is a part).

Table 4.3 Percent Household Distribution by Household Size

Household Size	1-person (%)	2-person (%)	3-person (%)	4+-person (%)
1.0	100.0	0.0	0.0	0.0
1.1	95.4	4.0	0.6	0.0
1.2	89.2	8.0	1.8	1.0
1.3	82.9	10.6	5.5	1.0
…	…	…	…	…
4.3	1.0	3.0	4.0	92.0
4.4	0.5	1.5	2.0	96.0

Automobile Ownership

Many trip generation and mode choice models are applied to segments of households defined by automobile ownership, or vehicle availability, levels (for example, 0-vehicle, 1-vehicle, 2-vehicle, and 3+-vehicle households). There are various ways to estimate the number of households by number of vehicles. If estimates of the number of vehicles owned by TAZ are available (perhaps from motor vehicle registration or census data), an aggregate segmentation procedure similar to the procedure described above for household size segmentation can be employed. Another method is a disaggregate vehicle availability model, usually a logit model, that estimates the probabilities of a household owning zero, one, two, etc., vehicles based on demographic, location, and accessibility characteristics.

Cross-Classification by Multiple Variables

If a cross-classification of households is used as input into the trip production model and estimates of the percentage of households in segments or in cross-classification cells are not available, aggregate segmentation procedures are often employed. In the case of cross-classification, these may be two-step procedures where segments are defined for each variable (as described above for household size and automobile ownership) and the percentages in each cell estimated based on the marginal totals. For example, in the RTC model, Base 2008 Version 1.0, after the households are segmented by number of persons and number of autos as described above, an iterative proportional fitting (IPF)[8] process is used to determine the cross-classification of households by persons and autos for each TAZ. The "seed" distribution for the IPF process was derived from NHTS data and is shown in Table 4.4.

Table 4.4 Seed Table for Household Stratification in RTC Model, Base 2008 Version 1.0

Persons/HH	Auto/HH			
	0	1	2	3+
1	0.056	0.217	0.034	0.014
2	0.015	0.053	0.153	0.100
3	0.002	0.027	0.064	0.075
4	0.011	0.006	0.078	0.094

Employment Data

Employment data should be classified in terms of a known industrial classification system. It is both **acceptable practice** and **recommended practice** for all model regions to use employment data and forecasts based on the North American Industry Classification

8 The specific IPF process used is also sometimes referred to as the Fratar method.

System – United States (NAICS). The NAICS definitions for the various employment types, e.g., retail, nonretail, industrial, etc., should follow accepted practice for land use forecasting.

In Virginia, MPOs and other agencies can obtain employment by county/city from VEC at no cost. VEC also provides employment by employer, with address information for geocoding, to agencies with restrictions on use. The NAICS code for each employer also is provided. Agencies requesting employment data from VEC must sign a data sharing agreement with VEC and pay a flat fee.[9]

Area Type

An area type classification scheme for TAZs can be used as a simplified mechanism to introduce additional information about land use into regional transportation models. Often, the area type classification is constructed to reflect information about land use development characteristics, including employment and population density.[10] Area type may be used as an input variable to models, e.g., trip generation and mode choice, and/or, can be used as an input in determining highway network attributes such as free-flow speeds and capacities. For use in determining network attributes, lookup tables are typically used to determine the specific input values, with area type often cross-classified with roadway facility type.

While it is **acceptable practice** for model regions not to use an area type classification scheme in their travel demand models, it is **recommended practice** that all model regions adopt an area type classification scheme system that contains at least three classifications: Central Business District (CBD), Suburban, and Rural. Large model regions should consider additional classifications. It should be noted that functions based on discrete area types can have the potential to introduce "cliffs" between otherwise similar TAZs that fall between two classifications (or sudden changes in roadway speeds or capacities as roadways pass from one area type to another).

As an example, the RTC model [7] uses a set of five standard area type definitions: CBD, urban, dense suburban, suburban, and rural, described in Table 4.5. The area type on the network links is computed through an automated procedure described below:

1. Each link is assigned the TAZ number of the nearest TAZ.
2. A floating population and employment density is calculated for each TAZ by summing population and employment for all TAZs within one mile of the centroid and dividing it by the total area.

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9 At the time of this writing, data requests should be sent to VEC at veclmi@vec.virginia.gov.

10 In Virginia, some models use the term "LUD" for "Land Use Density" in referring to their specific area type classification scheme.

3. Stratification values for population and employment density are computed using the total mean and standard deviations (abbreviated "meanpop," "stdevpop," "meanemp," and "stdevemp."

   Population:
   - p1=mean pop – (mean pop / stdevpop)*0.5
   - p2=meanpop + (meanpop / stdevpop)*0
   - p3=meanpop + (meanpop / stdevpop)*1
   - …
   - p7=meanpop + (meanpop / stdevpop)*5

   Employment:
   - e1=meanemp – (meanemp / stdevemp)*0.5
   - e2=meanemp + (meanemp / stdevemp)*0
   - e3=meanemp + (meanemp / stdevemp)*1
   - …
   - e7=meanemp + (meanemp / stdevemp)*5

4. A predefined "area type cross-classification" lookup table (shown in Table 4.6) is read with an area type value defined for each combination of the above population and employment stratification values.
5. Area type for the TAZ is defined based on its population and employment density using the above lookup table.

(Note: The above automated procedure does not define the CBD area type, which is defined manually by VDOT through an override attribute in the input network. The area types for freeways also were defined using the override attribute.)

Table 4.5 Example Area Type System for RTC Model, Base 2008 Version 1.0

Area Type (LUD)	Description	General Parking Situation	Richmond Area Example
1	Central Business District (CBD) = Most Dense	Scarce and sometimes costly	Downtown Richmond and Petersburg
2	Urban	Limited	Fan and Church Hill
3	Exurban (Dense Suburban)	Adequate	Munford and Near West End
4	Suburban	Abundant	Glen Allen and Midlothian
5	Rural = Least Dense	Abundant	Goochland and Hanover counties

Table 4.6 Area Type (LUD) Lookup Table for RTC Model, Base 2008 Version 1.0

Population Density Level	Employment Density Level						
	1	2	3	4	5	6	7
1	5	5	4	3	3	3	2
2	5	5	4	3	3	3	2
3	4	4	4	3	3	3	2
4	4	4	4	3	3	3	2
5	3	3	3	3	3	3	2
6	3	3	3	3	3	3	2
7	2	2	2	2	2	2	2

Summary of Procedures for Developing Socioeconomic Data

The policies and procedures for practice in Virginia for land use/socioeconomic data are summarized in Table 4.7.

Table 4.7 Land Use/Socioeconomic Data Practice for Virginia Travel Demand Models

Component	Acceptable		Recommended	
	Small	Large	Small	Large
Data sources	Estimates from local agencies, VEC, Weldon Cooper Center for Public Service of the University of Virginia	Estimates from local agencies, VEC, Weldon Cooper Center for Public Service of the University of Virginia	Estimates from VEC, Weldon Cooper Center for Public Service of the University of Virginia	Estimates from VEC, Weldon Cooper Center for Public Service of the University of Virginia
Employment classification system	NAICS	NAICS	NAICS	NAICS
Area type methodology	N/A	N/A	Yes, at least three classifications	Yes, at least five classifications

Note: The Bristol, Kingsport, and Washington, D.C. MPO (TPB) regions are exempt from this guideline.

Validation Checks for Socioeconomic Data

TMPD developed a series of checks for socioeconomic data for MPOs along several dimensions (jurisdiction, jurisdiction and TAZ, and TAZ) as part of the RTC model development effort. These checks are seen as useful to other MPOs or PDCs and are presented for reference in Figure 4.2.

Figure 4.2 RTC Socioeconomic Data Checklist

Jurisdiction Level Checks

1. Population matches base year Weldon Cooper/VEC population control totals.
2. Population is consistent with Weldon Cooper/VEC population projections within established state guidelines.
3. Population/household ratio > 1.75.
4. Population/auto ratio > 0.75.

Jurisdiction and Transportation Analysis Zone (TAZ) Level Checks

1. Total population equals sum of population in households and group quarters population.
2. Total Employment equals sum of different employment categories.

Transportation Analysis Zone (TAZ) Level Checks

1. All TAZ socioeconomic data totals should be integers.
2. Household population/household ratio ≥ 1.0 and ≤ 4.0.
3. Auto/household ratio ≤ 5.0 and ≥ 0.10 (2009 NHTS average is 1.96).
4. Check that no TAZs contain zeros for all socioeconomic variables.
5. If population is zero, then check that households, autos, and other population-based variables are zero.
6. If households are zero, then check that population, autos, and other household-related variables are zero.
7. If population ≥ 1, then household population and/or group quarters should be ≥ 1.
8. If households ≥ 1, then household population should be ≥ 1.
9. Compare aerial photography with zonal land use data for reasonableness.

In addition to these rule-based checks, the FHWA Validation Manual provides details on other types of socioeconomic data checks that can be performed. These checks are summarized below.

The primary aggregate validation checks for socioeconomic data are the summation of TAZ data to different geographic areas and comparison to observed data. Summation of data such as population and households to political divisions such as cities and counties is particularly important. Comparison data is available from Weldon Cooper Center/VEC, decennial census, and the ACS. In addition to being able to check aggregate totals of data such as population and households, the ACS data provide the means to check information such as median incomes and income distributions, household size distributions, and vehicle availability distributions. The ACS also provides a means to check employment data. The check will probably be most accurate at the regional level with decreasing levels of confidence for smaller geographic areas.

Multiple independent sources of disaggregate socioeconomic data are not generally available. Five-year ACS estimates of socioeconomic data are generally available for small-level geography. In Virginia, the Weldon Cooper Center/VEC provide estimates of socioeconomic data for years between census years through incremental annual updates to the most recent census data. The five-year ACS estimates of the socioeconomic data can thus be potentially used as independent estimates of the socioeconomic data on a TAZ-by-TAZ basis.

Disaggregate checks of employment data can be performed if independent data are available. For example, detailed checks of the input data might be made using files purchased from a commercial vendor.

On an aggregate level, regional rates can be calculated and compared to historical data for the modeled region. For example, trends in persons per household or vehicles per household could be examined. Reasonableness also can be checked using GIS plots of district-level or TAZ-level data, such as average household size, proportions of households by socioeconomic stratum (e.g., income level or automobile ownership), employment by category, and residential or employment density.

Sensitivity checks for socioeconomic data can be performed once the entire model is operational. These are done by adding or subtracting an appropriate type of activity (for example, number of households, retail employment) to a TAZ and evaluating the results for reasonableness. It would be expected that increases in activity would cause increases in the amount of travel (for example, traffic volumes), with larger increases nearer the TAZ where the amount of activity is increased, and decreases in activity would have the opposite effect. While it is impractical to do this for every TAZ, a small sample of TAZs, representing different types of development (commercial, residential, etc.), area types (urban, rural, etc.), and amount of activity, can be chosen.

4.1.3 Transportation Networks

Model networks have several components, including highway network links and nodes, TAZ centroids and centroid connectors, and, if transit is modeled, transit networks consisting of routes (lines) and stops. A centroid is a node that represents the center for activity for a TAZ and is the point from which trips to and from the TAZ are loaded during trip assignment. Centroid connectors are links that connect the centroids to the highway and transit networks and represent the local streets within a TAZ.

Transportation networks are important inputs to the travel demand forecasting process. Their development must be coordinated with MPOs/PDCs and their member jurisdictions, who are responsible for reviewing transportation networks for their areas and submitting written comments to VDOT listing recommended changes. VDOT's Roadway Network System (RNS) is a good source for highway network data. Regional transit agencies, for example the Greater Richmond Transit Corporation (GRTC), should be contacted for transit network data.

When developing travel demand models in all regions, transportation networks must be created for the following scenarios:

1. Base Year; and
2. Constrained Long-Range Plan (CLRP).

Additionally, for model regions requiring air quality conformity analysis, additional interim transportation networks may be required. Networks for other scenarios, such as Vision Long-Range Plan (VLRP) and interim years other than those prepared for by air quality conformity, may be prepared but are not required.

Highway Networks

It is suggested that the VDOT Roadway Network System (RNS)/Linear Referencing System (LRS) roadway centerline and database system be used as a data source for highway networks. This system, which can be obtained from VDOT, provides the means of tracking and managing Virginia's road inventory and associated assets and attributes in a tabular, linear, and geospatial context. Using the RNS assures the accuracy of roadway representation and easier integration with other VDOT datasets.

Roadway Representation

The highway networks in travel models include a subset of all roads in the model region. Roads that carry small amounts of traffic or mainly local traffic are generally not included in the highway network. It is **acceptable practice** for all model regions to include major collectors and all higher functional classes in their transportation networks. Selected minor collector and local roads also may be included as needed to provide feasible paths between TAZs. It is **recommended practice** that all model regions include all nonlocal roadways, e.g., minor collectors and all higher functional classes, in their transportation networks. Selected local roadways also should be included as needed.

It is **acceptable practice** for all model regions to represent divided highways and their ramps and interchanges without roadway dualization (pairs of one-way links). It is, however, **recommended practice** that all model regions include roadway dualization in their networks to the greatest extent feasible. Dualization should generally be restricted to controlled access facilities such as freeways and major roadways with interchanges.

Centroid Connector Placement

For all model regions, GIS should be used to assist in the process of placing centroid and centroid connectors on the transportation network. Aerial photography and other land use GIS layers should be used as needed to identify logical access points for centroid connectors. While TAZs typically have at least two (and often more) centroid connectors to provide adequate access to the highway network, there are some situations where only one centroid connector is appropriate (for example, a development with only one entry/exit).

Highway Link Variables

It is **recommended practice** for all model regions to use the list of link variables shown in Table 4.8 for their next major model revision. Some commonsense rules for the values of link variables should be followed.

Table 4.8 Recommended Link Attributes for Virginia Travel Demand Models

No.	Link Variable	Description	Type	Need
1	ANODE	Beginning node of model network link	Numeric	Model uses
2	BNODE	Ending node of model network link	Numeric	Model uses
3	DISTANCE	Highway Link distance in miles	Numeric	Model uses
4	LANES	Number of DIRECTIONAL through lanes	Numeric	Model uses
5	FACTYPE	Facility Type used for Modeling Only	Character	Model uses
6	TWLTL	Two Way Left Turn Lane	Character	Model uses
7	ONEWAY	Directionality Indicator	Numeric	Model uses
8	TRK_PHB	Truck Prohibition Identifier	Character	Model uses
9	POST_SPD	Posted Speed Limit in miles per hour (mph)	Numeric	Model uses
10	SPDCLASS	Speed class code from speed lookup table for the region	Numeric	Model uses
11	LINK_CAP	Link Capacity in vehicles/lane/hour if known	Numeric	Model uses
12	CAPCLASS	Capacity class code from capacity lookup table for the region	Numeric	Model uses
13	AAWDT	Annual average weekday count for Base Year	Numeric	Model uses
14	RTE_NAME	Local street name (911)	Character	Network Coding

Table 4.8 Recommended Link Attributes for Virginia Travel Demand Models (Continued)

No.	Link Variable	Description	Type	Need
15	RTE_NM	Route number	Character	Network Coding
16	PROJ_ID	Project ID used by VDOT and/or MPO	Character	Network Coding
17	YR_OPEN	Estimated year highway project open for traffic	Character	Network Coding
18	YR_CLOSE	Estimated year highway project closed to traffic	Character	Network Coding
19	JURIS_NO	VDOT's city/county jurisdiction code	Character	Reporting
20	FEDFUNC	Federal functional class	Character	Reporting
21	AREATYPE	Land use ID: Five types	Character	Reporting
22	FEDAT	Federal Area Type: Urban or Rural	Numeric	Reporting
23	MPO_ID	Identifier for which MPO region link belongs to.	Character	Reporting
24	SCRLN_ID	Screenline Identifier	Character	Reporting
25	CORD_ID	Cordon Line Identifier	Character	Reporting
26	CUTLN_ID	Cutline Identifier	Character	Reporting
27	TMS_ID	TMS Count Station ID	Character	State Database Connection
28	BEGIN_MP	Beginning Milepoint of a link	Numeric	State Database Connection
29	END_MP	Ending Milepoint of a link	Numeric	State Database Connection
30	HOVTYPE	HOV Type Identifier	Character	Model uses
31	TOLL_GRP	Toll Group	Numeric	Model uses
32	TOLLGATE	Toll Gate Group representing delay at toll barrier	Numeric	Model uses
33	R_AREATYPE	Area Type defined by User	Character	Network Coding
34	R_FFLOWSPEED	Free Flow Speed defined by User	Numeric	Network Coding
35	R_LINK_CAP	Link Capacity defined by User	Numeric	Network Coding

- If a variable is not applicable for a link or data are not available, a null value should be used, not a zero, since zero could be a valid value for the variable.
- Link attributes usually have specific formats as shown in the description and data type columns of Table 4.8.

A data dictionary should be produced indicating the units or meanings of the values for all variables, especially those with "codes" (such as facility types or jurisdiction IDs). The values for the FACTYPE variable are shown in Table 4.9. Model developers should contact the VDOT designated modeler to obtain the values to use for these link attributes.

Table 4.9 Required FACTYPE Link Attribute Values for Virginia Travel Demand Models

FACTYPE	Brief Description	Additional Description	Example
1	Interstate/Principal Freeway	Controlled Access	• I-95, I-81, VA 76: Powhite Parkway (Richmond)
2	Minor Freeway	Controlled Access; Not necessarily built to Interstate standards	• Chippenham Parkway (Richmond) • U.S. 29 Bypass (Danville) • George Washington Parkway (NOVA)
3	Principal Arterial/ Highway	Limited Access, Multilane Divided	• U.S. 301 North of Bowling Green, U.S. 360
4	Major Arterial/ Highway	Highway with Posted Speed >50 mph or a Multilane Arterial	• U.S. 33, Monument Avenue (Richmond)
5	Minor Arterial/ Highway	Highway with Posted Speed <50 mph or a Single-Lane Arterial	• Huguenot Road Bridge, Three Chopt Road (Richmond)

Table 4.9 Required FACTYPE Link Attribute Values for Virginia Travel Demand Models (Continued)

FACTYPE	Brief Description	Additional Description	Example
6	Major Collector	Posted Speed >35 mph; Some through traffic	• VA 655: Beach Road Pump Road (Richmond)
7	Minor Collector	Posted Speed <35 mph; Little through traffic	• Most Smaller City/ Suburban/Rural Streets
8	Local	Only serves local traffic	• Local City/Subdivision Streets
9	High-Speed Ramp	Posted Speed >45 mph	• Interstate to Interstate Ramps
10	Low-Speed Ramp	Posted Speed <45 mph	• Most Interstate to Non-Interstate Ramps
11	Centroid Connector		
12	External Station Connector		

Some of the key variables are discussed in more detail below.

Link distances – For all model regions, it is **acceptable practice** to use existing "previously coded" distances in modeling. It is **recommended practice**, however, that all model regions use GIS tools to more accurately determine link distances.

Input Speeds – For all model regions, it is **acceptable practice** to use free-flow speeds as the basis for the input speeds used by the modeling process. Acceptable data sources for input speeds are speed limits (although they are generally lower than free-flow speeds) and speed studies. It is **recommended practice** that all model regions use speed lookup tables as the basis for input speeds. An example of a speed lookup table is shown in Table 4.10.

Table 4.10 Example Lookup Table for Free-Flow Speeds (in mph)

Facility Type	Area Type (Land Use Density) Category				
	CBD	Urban	Exurban	Suburban	Rural
Interstate/Principal Freeway	55	58	62	65	68
Minor Freeways	50	55	58	60	62

Table 4.10 Example Lookup Table for Free-Flow Speeds (in mph) (Continued)

Facility Type	Area Type (Land Use Density) Category				
	CBD	**Urban**	**Exurban**	**Suburban**	**Rural**
Principal Arterial/Highway	25	28	35	43	50
Major Arterial/Highway	25	28	33	40	45
Minor Arterial/Highway	25	28	30	35	40
Major Collector	25	25	28	32	35
Minor Collector	25	25	28	30	30
Local	25	25	25	30	30
High-Speed Ramp	50	55	58	60	62
Low-Speed Ramp	20	20	25	25	25
Centroid Connectors	15	15	20	25	25
External Station Connector	25	25	25	25	25

Roadway Capacity – For all model regions, it is **acceptable practice** and **recommended practice** to use the most recent version Highway Capacity Manual (HCM) as the basis for roadway capacities. It is not acceptable to use older versions of the HCM or arbitrary figures for roadway capacities. Roadway capacities should be assigned to each facility type in the network using the established capacity lookup table for that particular region. It is both **acceptable practice** and **recommended practice** that all capacities represent Level of Service (LOS) E. An example of a fictitious capacity lookup table is shown in Table 4.11.

Table 4.11 Example Capacity Lookup Table (vehicles per lane per hour)

Facility Type	Area Type (Land Use Density) Category				
	CBD	**Urban**	**Exurban**	**Suburban**	**Rural**
Interstate/Principal Freeway	1,600	1,800	2,000	2,100	2,200
Minor Freeways	1,600	1,700	1,800	1,900	2,000
Principal Arterial/Highway	1,200	1,300	1,400	1,500	1,600
Major Arterial/Highway	1,100	1,150	1,200	1,300	1,400
Minor Arterial/Highway	1,000	1,050	1,100	1,150	1,200
Major Collector	800	850	900	950	1,000
Minor Collector	700	750	800	850	900

Table 4.11 Example Capacity Lookup Table (vehicles per lane per hour) (Continued)

Facility Type	Area Type (Land Use Density) Category				
	CBD	**Urban**	**Exurban**	**Suburban**	**Rural**
Local	600	650	700	750	800
High-Speed Ramp	1,600	1,700	1,800	1,900	2,000
Low-Speed Ramp	1,400	1,500	1,600	1,700	1,800
Centroid Connectors	10,000	10,000	10,000	10,000	10,000
External Station Connector	100,000	100,000	100,000	100,000	100,000

SCREEN_ID – The purpose of this variable is to serve as a flag for links that are part of a screenline, cutline, or cordon line. This attribute is not intended to identify individual screenlines, cutlines, or cordon lines. VDOT maintains a separate database file which lists the Link A and B nodes for all screenline, cutline, and cordon line links for every model region.

Additional link variables may be included as needed or desired. All additional link variables must be reviewed and approved by the appropriate VDOT designated modeler prior to being used in any model.

Turning Penalties

For small model regions, it is **acceptable practice** not to use turning penalties in the highway network. It is **recommended practice** for all model regions that turning penalties be included in the model as appropriate.

Summary of Highway Network Practice

Acceptable and recommended practice for highway networks is summarized in Table 4.12.

Table 4.12 Highway Network Practice for Virginia Travel Demand Models

Component	Acceptable		Recommended	
	Small	Large	Small	Large
Extent of roadway representation	Major Collector and above	Major Collector and above	Minor Collector and above	Minor Collector and above
Representation of roadway dualization, ramps, and interchanges	None	None	Yes	Yes
Centroid connector placement	Represent majority of traffic movement from each TAZ to adjacent network	Represent majority of traffic movement from each TAZ to adjacent network	Represent majority of traffic movement from each TAZ to adjacent network.	Represent majority of traffic movement from each TAZ to adjacent network.
Turning penalties	None	Where applicable	Where applicable	Where applicable
Link distances	N/A	N/A	State database	State database
Input speeds	Free-flow speed		Free-flow speed based on lookup table	
Roadway capacities	Current HCM LOS E based on lookup table		Current HCM LOS E based on lookup table	
Link variables	N/A	N/A	See network attribute list	See network attribute list

Transit Networks

The primary source for transit network data is route maps and schedules provided by the transit operators. This information may be used for both transit network coding and network validation. Transit schedules and route maps are typically used to develop route itineraries and headways input to the travel models. They also may be used to help develop relationships between bus speeds and roadway speeds for buses operating in mixed flow or transit travel times for transit vehicles operating on exclusive guideways.

Generally, the information needed for transit networks is organized by routes, or lines. Stop locations are explicitly coded although this may be somewhat loose in areas with "flag stop" operations. Route-level information includes the stop locations, headways (by time period if applicable), and travel-time information for routes that operate on exclusive rights-of-way. Stop locations should be matched to nodes in the highway network. Fare coding should accurately reflect the fare system, including fixed-fare operation, zone fares, origin-destination-specific fares (such as in the Washington Metropolitan Area Transit Authority (WMATA) rail system), and transfer fares.

Recently, the General Transit Feed Specification (GTFS),[11] developed by Google, has been used to provide data for model transit networks. GTFS provides a common format for public transportation schedules and associated geographic information. Currently in Virginia, Blacksburg Transit, Charlottesville Area Transit, and Hampton Roads Transit provide public information through GTFS, as well as WMATA, Arlington Transit, and Fairfax County in the metropolitan Washington region.[12] (It should be noted that other transit operators in Virginia, such as GRTC, provide trip planner services on their web sites using Google Maps.)

Representation of Transit Routes and Services

It is **acceptable practice** and **recommended practice** for small model regions not to have transit represented in their models through transit networks as long as transit use does not account for a significant amount of regional travel and analysis of transit-related projects and planning is not a required use of the model. For large model regions, where such transit analysis is necessary, it is both **acceptable practice** and **recommended practice** to include transit networks in their models.

Mode Definition

For large model regions, it is **acceptable practice** to include all major bus routes and intraregional fixed guideway, including commuter rail services. It is **recommended practice** to include additional modes, e.g., special bus, ferry, etc., if they are regionally significant, defined as meeting one of the following conditions:

- Comprises at least 1 percent of regional trips;
- Comprises at least 1 percent of home-based work trips;
- Comprises at least 10 percent of transit trips; or
- Accounts for at least 10,000 daily trips.

Travel Times and Speeds

For large model regions, it is both **acceptable practice** and **recommended practice** to estimate network travel speeds from operator schedules for fixed guideway facilities. For transit services that operate in mixed traffic (mainly buses, but in some cases trolleys and light rail), it is both **acceptable practice** and **recommended practice** to estimate network travel speeds based on the speeds from the highway network. This is usually done by creating lookup tables or other relationships (for example, linear or piecewise linear formulas) relating the transit speeds to the highway network speeds, based on observed transit speed

11 https://developers.google.com/transit/gtfs/, accessed June 25, 2013.

12 https://code.google.com/p/googletransitdatafeed/wiki/PublicFeeds, accessed June 25, 2013.

data. The relationships may consider the type of transit service (local versus limited stop), highway type, and area type.

Representation of Walk and Drive Access to Transit

For large model regions, it is **acceptable practice** to use distinct transit access links to represent walk and auto access and egress between TAZ centroids and transit stops. Typically, rules are developed to determine which stops may be connected to each TAZ. It is **recommended practice** to determine access and egress times through the highway network. Auto access and egress times can be estimated through the highway paths between centroids and stop nodes. Walk access times can be estimated through the same process by getting the distance and assuming an average walk speed; however, caution must be used in places where walk paths do not necessarily follow the model highway network.

For large model regions, it is **acceptable practice** not to explicitly represent park-and-ride lots in the transportation network; however, it is **recommended practice** to explicitly represent those lots served by transit in the model. Major park-and-ride lots used by travelers may be included if they are regionally significant (for example, facilities used by commuters in northern Virginia near HOV facilities). Small park-and-ride lot facilities used exclusively for carpooling are generally not worth including in the modeling process. If park-and-ride trips are explicitly estimated in the mode choice model, they should comprise a separate trip table and be assigned to the highway and transit network.

Summary of Transit Network Practice

Acceptable and recommended practice for transit networks are summarized in Table 4.13.

Table 4.13 Transit Network Practice for Virginia Travel Demand Models

	Acceptable		Recommended	
Component	**Small**	**Large**	**Small**	**Large**
Representation in the Model	No	Yes	No	Yes
Modes included	N/A	All intraregional fixed guideway and major bus routes	N/A	All intraregional fixed guideway and major bus routes; other modes if regionally significant
Network travel speeds and times	N/A	• From schedule for fixed guideway • From highway network for modes in mixed traffic	N/A	• From schedule for fixed guideway • From highway network for modes in mixed traffic

Table 4.13 Transit Network Practice for Virginia Travel Demand Models (Continued)

Component	Acceptable		Recommended	
	Small	Large	Small	Large
Representation of walk and auto access/egress to transit	N/A	Access links	N/A	Use highway network to estimate access/ egress times
Representation of park-and-ride lots	N/A	No	N/A	Yes, for facilities served by transit included in the model.

Validation Checks of Transportation Networks

Roadway and transit networks should be subjected to validation checks. The primary validation checks for input transportation network data are the aggregation of coded network data by various strata for comparison to independently summarized data for the same strata. For example, the coded lane-miles of roadway could be summed by facility type, by speed limit, or by geographic area and compared to similar summaries from available GIS data. Disaggregate transportation network checks may rely on spot checks of the data. A random sample of coded network links could be selected and certain characteristics verified using aerial photographs. Links may be checked for "exceptional" characteristics; for example, a color coded plot of all coded one-way links in the modeled region with directional arrows shown could be produced since there should be a limited number of one-way links in the region. It also is possible to perform checks comparing detailed coding to reasonable ranges. For example, coded link lengths can easily be compared to straight line distances calculated from the coordinates of end nodes of the links. Any links with differences outside of a reasonable tolerance accounting for curves could be flagged and checked for reasonableness.

On the transit side, matching of transit line coding and transit schedule information may be performed on a spot check basis. As noted above, GTFS data is available from many transit providers. It can be especially useful for checking base year networks through mapping comparisons. Although simplifications are often required to represent transit lines in models, being able to displaying the actual route information in a spatially accurate depiction, versus simply looking at printed timetables, can be invaluable in accomplishing coding checks.

It is worthwhile to build and check selected paths through the transportation network. For the roadway network, both shortest free-flow time paths and shortest distance paths can be built and checked for reasonableness by planners familiar with the area. Path checks also can be performed by adding or removing links to see whether the resulting revised paths are reasonable. Similarly, for the transit network, paths can be built and zone-to-zone travel times can be reviewed, especially for selected destinations. For example, zone-level plots of travel time to an important destination can be created and reviewed visually for reasonableness.

After the model development is complete, additional network checks can be performed by running the model. These checks may involve adding or deleting links or changing link attributes such as speed or capacity to verify whether the model results are reasonable. Similarly, transit network connections can be varied to see the impact on transit ridership.

4.2 Data for Model Development and Validation

The subsections that follow provide a discussion of different types of data used in model development and validation processes, including survey data, traffic counts, and transit ridership counts.

4.2.1 Survey Data

Survey data can be useful in the model development and validation processes. Surveys are a valuable source of information on how travelers in various markets of interest behave and make decisions. The data from surveys can be used to estimate model parameters and to check model results for reasonableness. The travel markets of interest, and the corresponding surveys, may include the following:

- Residents of the model region (household activity/travel survey);
- Transit users (transit rider/on-board survey);
- Travelers entering, leaving, or traveling through the region (external travel survey);
- Visitors to the region (visitor/hotel survey);
- Travelers to specific travel generators (special generator survey); and
- Trucks and commercial vehicles (commercial vehicle survey).

Model parameters are estimated from local or other data sources or are transferred from other sources. Local data sources can include the types of surveys listed above. The household travel survey is the main data source for estimating parameters for trip generation, trip distribution, and mode choice models as well as other components that may be included in the model such as time of day or vehicle availability models. Transit surveys may be used to estimate parameters for the mode choice model (along with household survey data) and for transit assignment. External survey data may be used for estimating external travel components; visitor survey data for visitor models; special generator survey data for estimating travel to and from generators such as airports; and truck/commercial vehicle survey for models of truck and commercial vehicle travel.

With the exception of the NHTS, which is discussed below, it is unusual to use survey data collected outside the model region directly to estimate parameters for the region. The model parameters from other regions, though, are sometimes transferred from other regions without new analysis of the survey data from those regions.

Whether or not the model parameters have been estimated from local data or have been transferred or asserted, local survey data can be useful in model validation. Model results can be compared to statistics compiled from the survey data. These types of tests are discussed in the sections of later chapters dealing with model validation.

Household Activity/Travel Survey

It is **acceptable practice** for all model regions for model parameters to be asserted, and so it is therefore acceptable for regions not to have conducted a recent household activity/ travel survey. This practice is considered acceptable in Virginia in part because of the expense of conducting such surveys and in part due to the presence of an alternative data source in the form of the NHTS "add-on" data for the State, which was collected as part of the 2009 NHTS. While the sample size of the NHTS add-on for each region is smaller than what would have been collected in a typical household survey, the sample size is substantially greater than what would have been available only from the "national sample" of the NHTS. It is also considered **acceptable practice** to use the NHTS add-on sample as the de facto household travel survey in a region in Virginia.

It is **recommended practice** for all model regions to conduct a household activity/travel survey about every 10 years, coinciding as closely as possible with the base year for a model update. Even though usable model parameters can be obtained through transferal or assertion, local survey data can be a unique and valuable resource in model validation.

Transit Rider Survey

Transit rider surveys (sometimes referred to as "on-board surveys" although they need not be conducted on transit vehicles) are important data sources for model regions where transit usage is regionally significant. It is both **acceptable practice** and **recommended practice** for models where transit is not modeled explicitly not to have a local transit rider survey. However, where transit is explicitly included in the model, it is both **acceptable practice** and **recommended practice** to conduct a transit rider survey every five years. The Federal Transit Administration recommends this practice and strongly encourages applicants for Section 5309 New Starts funding to have conducted such a survey within the last five years, especially in areas of high growth where travel patterns rapidly change.

External Travel Survey

It is **acceptable practice** for all model regions not to have a current external travel survey, especially in regions where external and through travel do not constitute a significant portion of regional travel. It is **recommended practice** for large model regions to conduct an external travel survey about every 10 years, preferably in coordination with a model update (and other survey efforts such as household activity/travel surveys). External surveys should be conducted for external stations serving major roadways: interstates, freeways, and major arterials, with perhaps a small sample of lower volume external stations to provide data that can be used for all smaller external stations. For small model regions, while data from an external survey can be valuable since the proportion of travel that crosses the regional boundary is generally higher than in larger areas, conducting such a survey is not considered **recommended practice** because of the relatively high expense of conducting such surveys in smaller regions.

Visitor Survey

It is **acceptable practice** for all model regions not to conduct a visitor travel survey. For model regions where visitors account for a significant portion of regional travel, it is **recommended practice** to conduct such a survey about every 10 years. Such regions may be characterized as having:

- At least one major international airport;
- At least one major tourist attraction that attracts over 100,000 visitors per year;
- A high percentage of the perceived tourist travel comes from outside the model region; and
- Significant year-round visitor travel.

For all other model regions, it is **recommended practice** not to conduct visitor surveys, due to their expense and the relatively low level of information that would be obtained relative to other types of data collection efforts.

Special Generator Survey

Special generators are defined as attractions that generate substantial numbers of travelers whose behavior is not captured well in the standard trip generation, trip distribution, and mode choice models. Major airports are usually best modeled as special generators, as are major tourist attractions and some military facilities. University student travel can also be the subject of a special generator model.

Special generator surveys can be relatively expensive to conduct because they focus on a small segment of travelers and they may require special permission (for example, due to security considerations in airports or due to privacy concerns in privately owned attractions). It is therefore both **acceptable practice** and **recommended practice** for small model regions to not conduct any special generator surveys although if resources are available, such surveys can be very valuable.

As part of the 2009 NHTS, VDOT commissioned a university student supplement survey. This survey was conducted among students at four major Virginia state universities under the reasoning that the random-digit dialing (RDD) method used by the main NHTS add-on undersampled these populations. These data are available for use in Virginia model development efforts.

Truck Survey

Because of the difficulty and high cost associated with conducting truck surveys, it is both **acceptable practice** and **recommended practice** not to conduct truck surveys in all model regions. Methods for developing truck and commercial vehicle model components that rely on other data sources are discussed in Chapter 8, Truck and Freight Modeling.

Summary of Survey Data Practice

Acceptable and recommended practice for travel surveys in Virginia models are summarized in Table 4.14.

Table 4.14 Survey Practice for Virginia Travel Demand Models

Component	Acceptable		Recommended	
	Small	Large	Small	Large
Household travel survey data	No	No	Yes, every 10 years	Yes, every 10 years
Transit on-board survey data	No	Yes, every 5 years	No	Yes, every 5 years
External origin-destination survey	No	No	No	Yes, every 10 years
Visitor survey	No	No	No	Yes, every 10 years if regionally significant
Special generator survey	No	No	On a limited basis as needed	On a limited basis as needed
Truck survey	No	No	No	No

4.2.2 Traffic Counts

Traffic counts are primarily used for the validation of highway assignment. Count data are used in link-level comparisons of modeled and observed volumes, for comparisons of volumes for selected groups of links (such as screenlines and cutlines), and in comparisons of modeled and observed vehicle-miles traveled (VMT).

Virginia Traffic Count Data

VDOT's Traffic Monitoring System (TMS) is VDOT's official traffic count system, or system of record for summary traffic data, and should be used as the primary traffic count data source in all model regions for all model development and application. Requests for special counts for model development or application are discouraged and must have their need clearly documented to be considered for approval by the VDOT designated modeler. The VDOT Traffic Engineering Division would ultimately address requests for special counts.

VDOT conducts a regular program where traffic count data are gathered from sensors along streets and highways and other sources. From these data, estimates of the average number of vehicles that traveled each segment of road are calculated and VDOT periodically publishes these estimates. The publication, "Average Daily Traffic Volumes with Vehicle Classification Data on Interstate, Arterial, and Primary Routes," includes a list of each Interstate and Primary highway segment with the estimated Annual Average Daily Traffic (AADT) for that segment. AADT is the total annual traffic estimate divided by the number of days in the year. This publication also includes information such as the following:

- Estimates of the percentage of the AADT made up by six different vehicle types, ranging from cars to double trailer trucks;
- Estimated Annual Average Weekday Traffic (AAWDT), which is the number of vehicles estimated to have traveled the segment of highway during a 24 hour weekday averaged over the year; and
- Peak hour and peak direction factors used by planners to formulate design criteria.

In addition to the Primary and Interstate publication, more than two hundred publications are published periodically, one for each of the counties, cities, and towns across Virginia. These publications are titled "Daily Traffic Volumes Including Vehicle Classification Estimates," where available; Jurisdiction Report numbers 000 through 340." Also available are a number of reports summarizing average VMT in selected jurisdictions and other categories of highways.

Data from TMS are used by VDOT staff and also are incorporated in many applications (Statewide Planning System, DOT Dashboard, VDOT GIS Integrator, Pavement Management System, Pavement Material Scheduling System, Highway Safety Improvement Program, Safety Analyst, and the Roadway Network System (Highway Performance Monitoring System and Railroad Crossings). Traffic data from TMS are also used by other transportation agencies (local, regional, and federal), private vendors, and institutions of higher education. TMS publications are available via the external website: http://www.virginiadot.org/info/ct-trafficcounts.asp or by requesting the data through the Traffic Engineering Division.

Adjustments to Traffic Count Data

Adjusting raw count data for daily, weekly, and seasonal variation for the model base year is necessary to process count data for use in model validation. For all model regions, it is both **acceptable practice** and **recommended practice** to adjust any raw counts collected for model development and application for daily, weekly, and seasonal variation in accordance with acceptable VDOT TMS count practice.

Traffic Count Coverage

Having adequate count coverage is important for model validation. Modeling efforts should make extensive use of VDOT TMS and other available data sources and tools to maximize count coverage and quality. Noncentroid links are defined as links that are part of the model region transportation network that are not centroid connectors or external station links. It is **recommended practice** to have a count coverage of 20 percent of noncentroid links for small model regions and 10 percent for large model regions. It should be noted, however, that more important than the total number of counts is the distribution of counts among geographic subareas, facility types, volume levels, and individual roadways (i.e., having counts on several different roadways is superior to having multiple counts on the same roadway). As discussed below, adequate count coverage on screenlines and cutlines is also important.

Cordon Line, Screenline, and Cutline Count Coverage

It is valuable in model validation to examine the amount of traffic across various lines that cross several roads in the highway network.

- A cordon line is a line that encloses a subregion of the model, often a CBD, city, or major activity center. The trips crossing the cordon line therefore include all trips to and from the subregion although they also may include trips that pass through the subregion (these trips cross the cordon line twice). The number and locations of cordon lines will vary depending on the geography of the model region; for example, a multicity region may have cordon lines around each city or CBD.
- A screenline is a line that crosses the entire model region, effectively splitting the model region into two parts, meaning that a trip from one part of the region to the other must cross the screenline. Ideally, a screenline will have a minimal number of trips where a logical path would cross the screenline twice. Depending on the geography of the region, it is useful to have at least one north-south screenline and one east-west screenline. Geographic or other barriers to transportation, particularly if they have limited crossing opportunities, often make good screenlines, especially rivers.
- A cutline is a line that crosses part of the model region, meaning that it is possible to build paths from one side of the cutline to the other that go around the cutline. They are often used in locations where a logical screenline cannot be created due to geographic, network coverage, or data sufficiency reasons.

These types of analysis lines should usually intersect a minimum of three links or link-pairs representing separate roadway facilities, but typically they will intersect many more. They should not include external stations since base-year external trip estimates are based directly on the traffic counts that would be used for validation. It is likely that there will be some overlaps among the various analysis lines, but lines that overlap substantially with one another should be avoided.

It is **recommended practice** that small model regions include at least 10 percent of their noncentroid links in their cordon line, screenline, and cutline coverage. For large model regions, it is **recommended practice** that at least 5 percent of their noncentroid links be included in their coverage.

Systematic Count Program

Having a systematic count program for collecting and assembling the necessary count data for model development and validation is vital to the modeling process. For all model regions, it is both **acceptable practice** and **recommended practice** to have a database of count locations and data which is regularly maintained and reviewed during the model improvement process.

Summary of Traffic Count Practice

Acceptable and recommended practice for traffic counts in Virginia models are summarized in Table 4.15.

Table 4.15 Traffic Count Practice for Virginia Travel Demand Models

Component	Acceptable		Recommended	
	Small	Large	Small	Large
Primary count data source	VDOT TMS	VDOT TMS	VDOT TMS	VDOT TMS
Count adjustment (seasonal, day of week, etc.)	Yes	Yes	Yes	Yes
Traffic count coverage[a]	N/A	N/A	20% of Links	10% of Links
Cordon line, screenline, and cutline count coverage	N/A	N/A	10% of Links	5% of Links
Systematic count program	Yes	Yes	Yes	Yes

[a]Counts coded on noncentroid links.

4.2.3 Transit Ridership Counts

Transit ridership counts are primarily used for the validation of transit assignment. Mode choice validation is closely related to transit assignment validation, and so transit ridership counts also are used in the validation of mode choice models, primarily to provide information that is used in estimating transit mode shares.

Ridership data are measures of "unlinked" transit trips as they count the number of times a transit vehicle is boarded. These are distinguished from "linked" trips, which are the outputs of mode choice models. A transit trip with transfers is considered one linked trip, but multiple unlinked trips.

The main source for transit ridership data is from transit operators. These are generally provided at the route (line) level. For longer transit routes, it may be useful to have ridership provided by route segment. It is desirable for high-volume stations/stops/route termini to have boarding counts at the stop level. If there are high-demand park-and-ride locations, information on the number of park-and-ride trips is useful.

For models with time-of-day components, ridership data by time period are needed to validate the mode choice and transit assignment results by time of day.

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CHAPTER 5. TRIP GENERATION

Trip generation is the first step in the four-step modeling process. In this step, the number of trips of each type begin or end in each location is estimated. It is standard practice to aggregate trips to a specific unit of geography (e.g., a TAZ). The estimated numbers of trips will be in the unit of travel that is used by the model, which is usually one of the following:

- Vehicle trips;
- Person trips by motorized modes (auto and transit); or
- Person trips by all modes, including both motorized and nonmotorized (walking, bicycling) modes.

Trip generation models require explanatory variables that are related to trip-making behavior and functions that estimate the number of trips based on these explanatory variables. These functions are usually assumed to be linear equations (often expressed as cross-classification formulations), and the coefficients associated with these variables are commonly called trip rates. These functions should always estimate zero trips when the values of the explanatory variables are all zero.

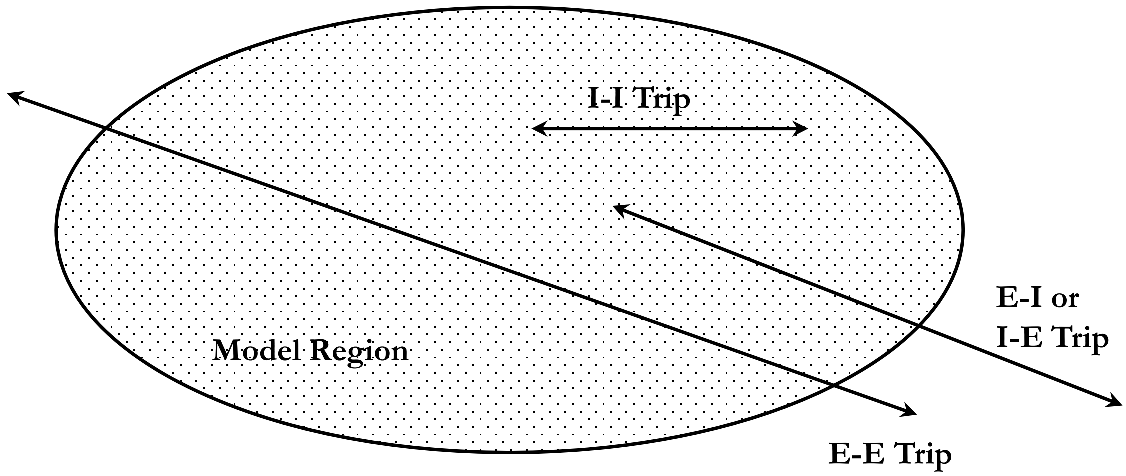
In four-step models, trip ends are classified as *productions* or *attractions.* The production end of a home-based trip is defined as the home end of the trip; the other end is the attraction end. There are advantages to the use of this convention in later model steps. For nonhome-based trips, the convention is to define the trip origin as the production end and the destination as the attraction end.

The inputs to trip generation models are socioeconomic and land use data, summarized at the TAZ unit of geography. The set of variables for trip production or attraction models depends on the trip purpose. For trip production models, the inputs are the number of households, classified by one to three variables that help explain trip making behavior. The input variables for trip attraction models are measures of TAZ activity such as employment by type, number of households or persons, and school enrollment.

The outputs of trip generation models are the number of trips produced in and attracted to each TAZ, by trip purpose. Sometimes trip outputs are segmented by a variable used in later model steps, such as income levels.

In most models, especially those for larger areas, the majority of trips are internal-internal (I-I) trips, which are both produced in and attracted to internal TAZs, that is, those TAZs within the modeling area. The trip generation process described in this chapter focuses mainly on these I-I trips; however, internal trip productions also include internal-external (I-E) trips, which are produced inside the model region (i.e., made by residents of the region) but are attracted to locations outside the region, and internal trip attractions also include external-internal (E-I) trips, which are produced outside the model region (i.e., made by nonresidents of the region) but are attracted to locations inside the region. Figure 5.1 depicts these types of trips. Chapter 7 discusses the modeling of external travel in greater detail.

Figure 5.1 Examples of Internal and External Trip Types



The remainder of this chapter describes the policies and procedures for developing, validating, and calibrating trip generation models in Virginia.

5.1 Trip Generation Practice

The policies and procedures for trip generation practice in Virginia are summarized in Table 5.1.

Table 5.1 Trip Generation Practice for Virginia Travel Demand Models

	Acceptable		Recommended[a]	
Component	**Small**	**Large**	**Small**	**Large**
Trip purposes (see text below for explanation of abbreviations)	HBW HBNW NHB	HBW HBNW NHB	HBW HBO NHB Others as appropriate (e.g., HBU)	HBW HBSc HBU HBSh HBO NHB Others as appropriate
Unit of travel	Vehicle trips	Person trips	Person trips	Person trips
Inclusion of nonmotorized modes	No	No	Yes, if nonmotorized travel is regionally significant	

Table 5.1 Trip Generation Practice for Virginia Travel Demand Models (Continued)

Component	Acceptable		Recommended[a]	
	Small	Large	Small	Large
Trip production model form	Cross classification or regression	Cross classification	Cross classification	Cross classification
Trip attraction model form	Regression	Regression	Regression	Regression
Sensitivity to land use/accessibility	No	No	Yes	Yes
Special generators	As needed		As needed	
Balancing trip productions and attractions	Home-based trip purposes balanced to productions and nonhome-based purposes to attractions		Home-based trip purposes balanced to productions and nonhome-based purposes to attractions	

[a] Note: Recommended characteristics are subject to resource constraints such as data availability and budget.

5.1.1 Trip Purposes

Travel behavior varies depending on the purpose of the activities being performed. Therefore, model accuracy is enhanced when trip purposes are distinguished in models. In conventional trip-based models, each stop to perform an activity constitutes the end of a trip. Typically, trips with one end at the traveler's home are distinguished from *nonhome-based* (NHB) trips, and sometimes trip purposes are further disaggregated among nonhome-based trips (for example, nonhome-based work and nonhome-based other). Nonhome based trips occur as part of trip chains or tours that generally begin and end at home.

Among home-based trips, *home-based work* (HBW) is always distinguished as a trip purpose since commuters to and from work exhibit different sensitivities to travel and environmental factors that travelers for nonwork purposes. *Home-based school* (HBSc) travel also is unique in terms of travel modes (since most students are too young to drive and some are so young that they require escorting), but data limitations sometimes prevent school travel from being modeled as a separate trip purpose. *Home-based university* (or college) (HBU) is another unique travel market, but usually it is only in areas with large colleges/universities that there is enough information to model such travel separately. *Home-based shopping* (HBSh) is another commonly modeled trip purpose. Other purposes such as *home-based social/recreation*, *home-based personal business*, and *home-based escorting* are sometimes used.

Unless there is an exhaustive set of home-based trip purposes, it is necessary to have a *home-based other* (HBO) trip purpose to account for home-based trip purposes that are not explicitly modeled. For example, if a model has HBW, HBSc, and HBSh purposes, there also will be a HBO purpose that would include trips made for other purposes such as personal business, recreation, etc. If a model has only a single home-based trip purpose other than HBW, this other purpose is usually referred to as *home-based nonwork* (HBNW).

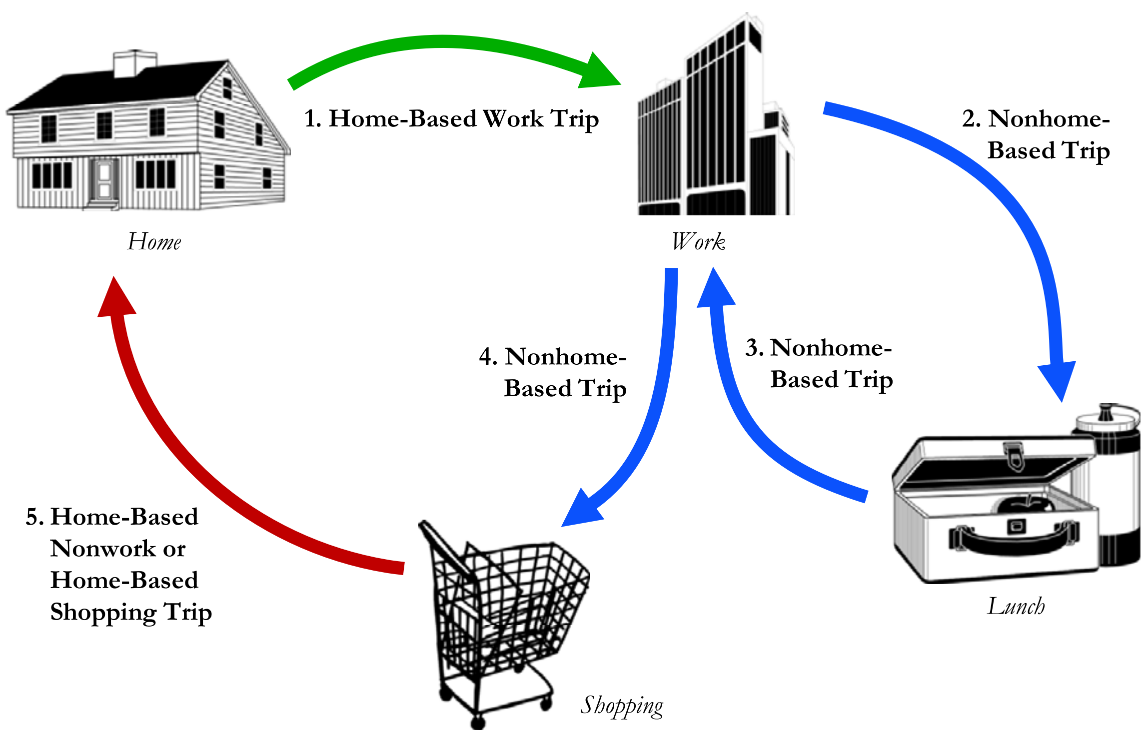
Figure 5.2 shows examples of the trip purpose definitions. From the definitions of production and attraction above, the production and attraction end of each trip is defined as follows:

- Trip 1 – Production is at home, attraction is at work.
- Trip 2 – Production is at work, attraction is at lunch.
- Trip 3 – Production is at lunch, attraction is at work.
- Trip 4 – Production is at work, attraction is at shopping.
- Trip 5 – Production is at home, attraction is at shopping.

In the illustrated example, the production end is the origin for trips 1 through 4; it is the destination for trip 5. So, trip 1 is a HBW trip, but the journey home (trips 4 and 5) does not include a HBW trip because of the intermediate stop for shopping. Trip 5 is a HBSh trip. (Note that the trip purpose does not depend on which end of the trip is the origin—any trip where either end is at home is a home based trip.)

The example has three NHB trips. Trips 2 and 3 are part of a round trip made from the workplace. Trip 4 is part of the journey home from work, but since neither end is at home, it is a NHB trip.

Figure 5.2 Examples of Trip Purposes



It is **acceptable practice** for all areas to use three trip purposes: HBW, HBNW, and NHB. For smaller areas, it is **recommended practice** to consider the use of additional trip purposes, especially HBU if there is at least one major university in the region. For larger areas, it is **recommended practice** to consider the use of several home-based trip purposes as described above, depending on regional characteristics and data availability.

Note that truck and commercial vehicle travel is treated separately from the trip purposes for personal travel (although terms such as "truck trip generation" are used). Truck and commercial vehicle travel is discussed in Chapter 8.

5.1.2 Unit of Travel

As discussed in Section 2.2, the modeling approach may be a conventional four-step approach or a "three-step" approach, omitting the mode choice component. If a four-step approach is used, the unit of travel is the *person trip* so that travel by nonauto modes may be considered. In three-step models, the unit of travel may be either the *vehicle trip* or the *person trip*. It is **acceptable practice** for smaller areas to use the vehicle trip as the unit of travel; it is **acceptable practice** for larger areas to use the person trip. It is **recommended practice** for all areas to use the person trip as the unit of travel.

When person trips are modeled, they may include either only motorized trips or both motorized and nonmotorized trips. It is **acceptable practice** for all areas to model only motorized travel. It is **recommended practice** for all areas where nonmotorized travel is regionally significant to include both motorized and nonmotorized travel. Nonmotorized travel is defined as being regionally significant in urban areas if one of the following criteria is met:

- Urban area includes universities and colleges with combined student enrollment of over 20,000; and
- A grouping of at least 20 contiguous TAZs having the two highest area type classifications, CBD and Urban, exists in the model region.

5.1.3 Trip Production and Attraction Model Forms

Productions

The best practice for the form of the trip production model is considered to be a cross-classification model. The households in each TAZ are classified by two (occasionally three) variables that affect the amount of travel generated. The household variables used may include:

- Number of persons;
- Number of workers;
- Number of vehicles (autos);

- Number of children (for HBSc); and
- Income level.

(Methods for classifying households for model input are discussed in Section 4.1.2.)

The choice of variables depends on the significance in explaining travel by the trip purpose and the availability of data for model estimation and application. *NCHRP Report 716, Travel Demand Forecasting: Parameters and Techniques*, provides the following cross-classifications based on NHTS data:

- HBW – Workers by vehicles; persons by vehicles; persons by income level;
- HBSc – Persons by children; persons by vehicles; persons by income level;
- HBNW – Persons by workers; persons by vehicles; persons by income level; and
- NHB – Persons by workers; persons by vehicles; persons by income level.

The cross-classification table for each trip purpose provides the number of trips per household of each category. The values in each cell (sometimes called "trip rates") in the table may be estimated from local household surveys or transferred from a similar region or using national sources such as *NCHRP Report 716*. Table 5.2 presents an example of a cross-classification table for HBW productions from the RTC model, Base 2008 Version 1.0.

Table 5.2 HBW Trip Production Model from Richmond/Tri-Cities (Base 2008 Version 1.0)

Number of Persons	Number of Vehicles			
	0	1	2	3+
1	0.24	0.62	1.25	1.48
2	0.50	0.62	1.25	1.49
3	1.00	1.20	1.82	2.49
4+	1.00	1.24	1.83	2.79

The trip rates increase as the values of the input variables (persons and vehicles in the example in Table 5.2) increase. However, as is the case in Table 5.2, the rate of increase may not be linear. This nonlinear trend is one reason why cross-classification models are generally considered superior to linear regression models of trip productions. While regression is still considered **acceptable practice** for smaller regions for trip production models, cross-classification is considered **acceptable practice** for larger regions, and cross-classification is considered **recommended practice** for all regions.

It should be noted that NHB productions are estimated at the household level but represent trips that by definition do not begin or end at the home and therefore likely are generated in a TAZ other than the home TAZ. This issue is typically handled by using the cross-classification model to estimate total regional NHB productions and allocating the trips to origin TAZ using a function of TAZ activity (often the estimated NHB attractions).

Attractions

Trip attraction models are estimated at a more aggregate level than trip production models, due to two main factors. First, survey data for model estimation are usually collected at the production end of home-based trip, i.e., the household. Second, the categorization of establishments is not as clear cut as it is for households since even within a particular classification (say, retail establishments), there are many potential subcategories. As a result, attraction models are often estimated from household survey data at an aggregate level such as districts.

The result of the necessary aggregation of data for model estimation is that the easiest type of attraction model to estimate is the linear regression model. Attraction models are therefore usually linear equations where the independent variables are employment by type and the number of households or population. For some trip purposes, other variables may be used – for example, school enrollment for HBSc trips.

The following are sample trip attraction equations from the RTC model, Base 2008 Version 1.0:

- HBW attractions = 0.637*Total Employment;
- HBSh attractions = 2.568*Retail Employment + 0.284*Households;
- HBO attractions = 0.345*Total Employment + 0.599*Population; and
- NHB attractions = 2.280*Retail Employment + 0.614*Nonretail Employment + 0.368*Households.

Note that these rates are adjusted using both an area type factor and a zonal accessibility factor.

It is both **<u>acceptable practice</u>** and **<u>recommended practice</u>** for all areas to use linear regression as the form for trip attraction models.

5.1.4 Sensitivity to Land Use/Accessibility Variables

As described in Section 5.1.3, production and attraction models can include a variety of socioeconomic input variables. It is **<u>acceptable practice</u>** for all regions to include only these types of variables. However, it is **<u>recommended practice</u>** to consider including additional variables to reflect land use development or transportation accessibility characteristics. For example, the RTC model, Base 2008 Version 1.0, uses an accessibility variable of the form:

$$A_i = \sum_j \frac{E_j}{t_{ij}^2} \quad (5\text{-}1)$$

Where:

A_i = Accessibility for TAZ *i*

E_j = Employment for TAZ *j*

T_{ij} = Travel time between TAZ *i* and TAZ *j*

A factor that is a function of this accessibility variable is used to adjust trip attraction totals.

5.1.5 Special Generators

There are often large activity centers in a model region that have unique characteristics that make it difficult for the trip generation models to accurately estimate the amount of travel. These locations, known as *special generators*, often include airports, military facilities, and large aggregations of certain activities such as regional medical facilities. (Major ports and intermodal facilities also fall into this category, but the additional travel activity is usually related to trucks rather than personal travel, and so they are discussed in Chapter 8 on truck and commercial vehicle modeling.) The number of productions and attractions for each special generator is estimated outside the trip generation models and is entered directly into model input files.

Because of their unique features, the only way to accurately estimate travel to and from special generators is through data collected specifically for these facilities, including special generator surveys (see Section 4.2.1) and person and vehicle counts. It is recognized that it may be difficult to obtain data for some facilities due to security and privacy concerns. Therefore, it may be necessary to approximate the trips generated through counts on nearby roadways. It may be possible in some cases to transfer trip rates from estimates for other facilities inside or outside the region, but given the unique nature of each facility, this practice can result in substantial inaccuracy and should be only a last resort.

5.1.6 Balancing Trip Productions and Attractions

Because each trip has a production end and an attraction end, the number of regional productions should equal the number of regional attractions. (This equality is true for the sum of trips in all internal TAZs, meaning the sum of I-I, I-E, and E-I trips.) However, the sum of the modeled estimates of productions and attractions, which come from separate models based on different variables that are estimated from different sources, may not be equal. A process of "balancing" productions and attractions by trip purpose is undertaken to equalize the totals prior to trip distribution.

Since the TAZ productions for home-based trips are based on models estimated from survey data at the household level, and population and household data are generally of high-quality (from census data) compared to employment data, it is generally felt that home-based production estimates are more accurate than home-based attraction estimates. It is therefore both **acceptable practice** and **recommended practice** to balance regional trip attractions to equal productions for all home-based trip purposes. For NHB trips, as discussed in Section 5.1.3, the regional attractions may be balanced to match total regional productions, but the TAZ estimates of NHB trips are usually set to match the TAZ allocation of estimated NHB trip attractions.

5.2 Trip Generation Validation

5.2.1 Data Sources for Validation

The main validation checks for trip generation models involve comparisons of model parameters to trip rates from other regions and model results to observed trip making (based on survey data). The main data source for validation is therefore a household survey data set, if available. If establishment surveys are available, they may serve as validation data sources for trip attraction models.

When recent survey data that could be used for model estimation are not available, model parameters such as trip rates may be transferred from another model or from other data sources. A common source is the National Household Travel Survey (NHTS), described in Section 4.2.1. Some other national data sources include *NCHRP Report 716* and other documents (e.g., *TCRP Report 73, Characteristics of Urban Travel Demand*). These reports summarize information from the NHTS and from travel models for various types of urban areas and planning contexts.

5.2.2 Validation Checks

Table 5.3 summarizes the model validation checks for trip generation models.

Table 5.3 Trip Generation Validation Procedures for Virginia Travel Demand Models

Type of Check	Model Region Size	
	Small	Large
Compare trip production results to expanded survey data or NHTS	Reasonableness check only	Reasonableness check only
HBW attractions per employee	Reasonableness check only	Reasonableness check only
Unbalanced production/attraction ratio[a]	0.90-1.10	0.90-1.10
Area to area trip flows by jurisdiction	Reasonableness check only	Reasonableness check only

[a] Because of the interactions with the Washington metropolitan area, Fredericksburg may be considered an exception to this guideline.

Productions

The main checks of trip generation models are comparisons of aggregate model results, usually trips per household by purpose by various other market segments, to observed data from the local household survey (if available). Market segments may be defined by demographic or geographic characteristics, or any other variables by which model results and the comparison data sources are reported. The percentage of trips by trip purpose also may be checked for reasonableness.

If a model has been estimated using local household survey data, the model results can be compared to the results from the expanded household survey data. This is particularly useful if the comparisons are made using different stratifications of the data. For example, for a cross-classification trip production model using number of persons and income level, comparing the results of an application using the base-year socioeconomic data to the expanded survey results by area type could produce important insights regarding the validity of the model. Such a comparison could help identify errors in the model estimation and errors in the survey expansion (or differences to be checked between the household characteristics during the survey period compared to the model base year). However, problems with the survey data set itself, outside the expansion, might not be identified since they would exist in both the survey data and the models estimated from the data.

If a local household survey data set is not available, the best sources for checking trip production models are the national data sources. This is a good idea even if local survey data are available because the same data set will have been used for model estimation and validation. The most up to date summaries for the 2009 NHTS data can be found in *NCHRP Report 716* (in Tables C.5 through C.9 in that document). A summary of the information in these tables is provided in Table 5.4.

Table 5.4 Summary of Trip Production Information from 2009 NHTS [2]

	HBW	HBNW	NHB	Total
Person Trips per Household (including nonmotorized)				
Population <500,000	1.4	5.1	3.0	9.5
Population >500,000	1.4	5.6	3.0	10.0
Percent of Person Trips per Household (including nonmotorized)				
Population <500,000	15%	54%	32%	100%
Population >500,000	14%	56%	30%	100%

Another reasonableness check for cross-classification models is to ensure that the rates for individual cells are consistent with one another. This includes checking that the direction (increase/decrease) between trip rates in adjacent cells along both dimensions is correct. For example, for home-based work trips, the trip rate should be higher for a greater number of workers, holding the other variable constant. However, caution should be exercised since it may not always be correct that a higher value for a variable will result in an increase in the trip rate. As an example, a two person, one worker household might make more nonwork trips than a two person two worker household. The incremental differences between trip rates in adjacent cells also should be checked for reasonableness. For example, if household size is one of the variables, the increments between one and two person households, two and three person households, etc., should be reasonable in terms of the additional trips adding a household member would produce.

Attractions

The types of checks described above are relevant for trip productions since data sources such as the NHTS and local household activity/travel surveys use households as the sampling unit. There are few data sources for checks of trip attractions that collect information at the attraction ends of trips. *NCHRP Report 716* (Table 4.4 in that document, seen as Table 5.5 below) summarizes trip attraction model parameters from several urban areas around the U.S. While the attraction models summarized in that report vary widely in terms of the variable definitions and parameter values, the HBW models cited use total employment as the only input variable, with an average parameter of 1.2. The FHWA Validation Manual cites earlier sources that indicate a range of 1.2 to 1.6 for this parameter.

Table 5.5 Sample Trip Generation Model Parameters

Station Type	A	B
Freeway/Expressway	0.071	-0.599
Arterial Near Expressway	0.118	-1.285
Arterial Not Near Expressway	0.435	-1.517
Collector/Local	0.153	-1.482

Source: NCHRP Report 716 (Table 4.4), Cambridge Systematics, Inc., 2002.

Balancing Productions and Attractions

As discussed in Section 5.1.6, the estimated total trip productions and attractions are balanced for each trip purpose. The balancing process should not require major changes to the original model outputs. Therefore, prior to balancing, these totals should be compared by trip purpose.

Before checking the balance between productions and attractions, the effects of external travel must be considered. If significantly more people from outside the modeled region work, shop, and perform other activities within the region than residents perform these activities outside, there should be more internal attractions than productions, offset by a corresponding surplus of external trip productions over attractions. This imbalance must be carefully computed since many models use vehicle trips for external travel and person trips for residential travel. (External travel is discussed in Chapter 7.) The effects of special generators (see Section 5.1.5) also must be considered.

Once these effects have been considered, the balance between productions and attractions can be checked for each trip purpose. The ratio of regionwide productions to attractions by purpose should fall in the range of 0.90 to 1.10 prior to balancing. For the base year, the balance between productions and attractions is, in effect, a validation measure. If there is not a close match, the reasons for the lack of match should be investigated.

5.2.3 Model Calibration and Troubleshooting

Issues discovered during the model checks described above may imply errors in trip generation model parameters or input data (household and employment data at the TAZ level). Some of the typical problems that may be evident from these tests and possible calibration strategies are as follows:

- Total trips from base-year model results inconsistent with expanded survey data: Check survey expansion factors for consistency with model application data, check for differences in socioeconomic data between survey and base years, and/or recheck estimated model parameters.
- Trip rates inconsistent across variables in cross-classification model: Recheck inconsistent rates, check error levels for estimated rates, and/or "smooth" trip rates by combining cells in cross-classification.
- Model results inconsistent with national sources: Recheck estimated model parameters, check for ways in which local travel characteristics differ than national, and/or adjust parameters if they seem erroneous.
- Imbalance between modeled productions and attractions by trip purpose: Check consistency of survey data with model application data, or check to ensure that external and special generator trips have been correctly considered.

CHAPTER 6. TRIP DISTRIBUTION

Trip distribution is the second step in the four-step modeling process. In this step, the number of trips generated in the trip generation step that travel between TAZs by purpose is estimated. These trips are in the same units used by the trip generation step (e.g., vehicle trips, person trips in motorized modes, or person trips by all modes, including both motorized and nonmotorized modes). Trip distribution requires explanatory variables which are related to the impedance (generally a function of travel time and/or cost) of travel between TAZs, as well as the amount of trip-making activity in the origin and destination TAZs.

The inputs to trip distribution models include the trip generation outputs – the productions and attractions by trip purpose for each TAZ – and measures of travel impedance between each pair of TAZs, obtained from the transportation networks. Socioeconomic and area characteristics are sometimes also used as inputs. The outputs are trip tables, production TAZ to attraction TAZ, for each trip purpose. Because trips of different purposes have different levels of sensitivity to travel time and cost, trip distribution is applied separately for each trip purpose, with different model parameters.

This chapter describes the policies and procedures for developing, validating, and calibrating trip distribution models in Virginia.

6.1 Trip Distribution Practice

The policies and procedures for trip distribution practice in Virginia are summarized in Table 6.1.

Table 6.1 Trip Distribution Practice for Virginia Travel Demand Models

Component	Acceptable		Recommended[a]	
	Small	Large	Small	Large
Model form	Gravity model	Gravity model	Gravity model	Destination choice model
Impedance measure	Highway travel time	Highway travel time	Highway travel time	Composite impedance that includes transit (if market is large) and any other significant modes
Income segmentation	No	No	No	Yes for HBW
Singly versus doubly constrained	Singly or doubly constrained		HBW: Doubly or singly constrained. Other purposes: Singly constrained	

[a] Note: Recommended characteristics are subject to resource constraints such as data availability and budget.

6.1.1 Model Form

The **gravity model** is the most common type of trip distribution model used in four-step models. In Equation 6-1, the denominator is a summation which is needed to normalize the gravity distribution to one destination pair to those over all possible destinations. This is called a **doubly constrained** model since it requires that the output trip table be balanced to attractions, while the numerator already ensures that it is balanced to productions.

$$T_{ij}^{p} = P_{j}^{p} * \frac{A_j^p * f(t_{ij}) * K_{ij}}{\sum_{j' \in Zones} A_{j'}^{p} * f(t_{ij'}) * K_{ij'}} \qquad (6\text{-}1)$$

where:

T^p_{ij} = Trips produced in TAZ *i* and attracted to TAZ *j*;

P^p_i = Production of trip ends for purpose *p* in TAZ *i;*

A^p_j = Attraction of trip ends for purpose *p* in TAZ *j*; and

$f(t_{ij})$ = Friction factor, a function of the travel impedance between TAZ *i* and TAZ *j*, often a specific function of impedance variables (represented compositely as t_{ij}) obtained from the model networks.

K_{ij} = Optional adjustment factor, or "K-factor," used to account for the effects of variables other than travel impedance on trip distribution.

Alternately, in a **destination choice** formulation, trip distribution can be treated as a multinomial logit choice model or similar formulation of the attraction location, in a manner consistent with the mode choice model formulation. In the logit model, the probability of choosing a particular alternative *i* is given by the following formula:

$$P_i = \frac{\exp(V_i)}{\sum_j \exp(V_j)} \qquad (6\text{-}2)$$

where:

P_i = Probability of choosing alternative *i*

V_i = Utility (deterministic) of alternative *i*

The probabilistic nature of the choice reflects that the true nature of the complete utility function is unknown; the true utility includes variables not included in the deterministic component of utility V_i. The form of the utility functions is shown in Equation 6-3.

$$V_i = \sum_k B_{ik} x_k \qquad (6\text{-}3)$$

where:

B_{ik} = The coefficient indicating the relative importance of variable *k* on choice *i*

x_k = The value of decision variable *k*

In such a formulation, the alternatives are the attraction TAZs, and the choice probabilities are applied to the trip productions for each TAZ. The utility functions include variables related to travel impedance and the number of attractions (the "size variable"), but other variables might include demographic or area type characteristics. A logit destination choice model is **singly constrained** since while the trip production totals are retained, the number of attractions is only an input variable, not a constraint or target. Sometimes, such a model is artificially constrained at the attraction end using TAZ-specific constants or post processing of model results.

While *best practice* for trip distribution models is considered to be a logit destination choice model, the gravity model is far more commonly used, primarily because the gravity model is far easier to estimate, with only one or two parameters in the friction factor formulas to calibrate (or none, in the case of factors fitted directly to observed trip length frequency distributions), and because of the ease of application and calibration using travel modeling software. Therefore, use of the gravity model for trip distribution is considered **acceptable practice** in all regions. In small regions, the gravity model for trip distribution also is considered **recommended practice**. In large regions, the destination choice model formulation is considered **recommended practice**.

6.1.2 Impedance Measure

One of the major inputs to trip distribution is the TAZ to TAZ travel impedance matrices. The term "impedance" refers to the generalized cost of travel between two TAZs. In most cases, the primary component of generalized cost is travel time, and so impedance is often expressed in time units such as minutes. The travel impedance variable may include several components. The simplest impedance variable is the highway (in-vehicle) travel time, which is an adequate measure in areas without a significant level of monetary auto operating cost beyond typical per mile costs – for example, relatively high parking costs or toll roads – or extensive transit service. In some areas, however, other components of travel impedance should be considered, creating a composite impedance measure. These may include distance, parking costs, tolls, and measures of the transit level of service. These measures, and the relative weights of each component, are often computed as part of utility functions in mode choice (see Chapter 9).

The individual components of travel impedance are computed as TAZ to TAZ matrices through "skimming" the highway and transit networks using modeling software. The components may be combined through a simple weighting procedure, which might be appropriate if all components are highway-related, or through the use of a logsum variable, which can combine highway and transit-related variables. In this case, the logsum represents the expected maximum utility of a set of mode choice alternatives and is computed as the logarithm of the denominator of the logit mode choice probability function.

It is considered *best practice* to use a composite impedance measure in areas with substantial transit use. Therefore, the use of highway travel time as the impedance measure for trip distribution is considered **acceptable practice** in all regions. In small regions, the use of highway travel time as the impedance measure also is considered **recommended practice**. In large regions, the use of a composite impedance measure is considered **recommended practice**.

6.1.3 Income/Vehicle Availability Segmentation

Besides segmentation by trip purpose, it is considered *best practice* to consider further segmentation of trip distribution using household characteristics such as vehicle availability or income level, at least for home-based work trips. This provides a better opportunity for the model to match observed travel patterns, especially for work trips. For example, if the home-based work trip distribution model is segmented by income level, work trips made by households of a particular income level can be distributed to destinations with jobs corresponding to that income level.

However, it may require substantial effort to segment attractions by income or vehicle availability level since the employment variables used in trip attraction models are not usually segmented by traveler household characteristics. Often, regional percentages of trips by income level, estimated from the trip production models, are used to segment attractions for every TAZ, especially for nonwork travel, but this method clearly is inaccurate where there are areas of lower and higher income residents within the region. *NCHRP Report 716* (see Section 4.5.2 of that report) has a discussion of segmentation processes and alternatives.

For Virginia models, it is considered **acceptable practice** in all regions to have nonsegmented trip distribution models. In small regions, the use of highway nonsegmented models also is considered **recommended practice**. In large regions, the use of trip distribution models segmented by income level for the home-based work trip purpose is considered **recommended practice**. At least three stratifications of income segmentation, if the observed dataset can support it, are recommended, with the thresholds for each range dependent on the income characteristics of the model region.

6.1.4 Singly versus Doubly Constrained Models

Most gravity models used in U.S. urban areas are doubly constrained. There is no consensus on *best practice* concerning whether it is always better to have a singly constrained or doubly constrained trip distribution model. For home-based work trips, some type of attraction end constraint or target seems desirable so that the number of work trip attractions is consistent with the number of people working in each TAZ. For discretionary travel, however, the number of trip attractions can vary significantly between two TAZs with similar amounts of activity, as measured by the trip attraction model variables. For example, two shopping centers with a similar number of retail employees could attract different numbers of trips, due to differences in accessibility, types of stores, etc. A doubly constrained model would have the same number of shopping attractions for both shopping centers, and a doubly constrained trip distribution model would attempt to match this number for both centers. So it might be reasonable to consider singly constrained models for discretionary (nonwork, nonschool) trip purposes although implied TAZ attraction totals from the outputs of such distribution models should be checked for reasonableness.

It is considered **acceptable practice** for all model regions to use either singly or doubly constrained trip distribution models. It is **recommended practice** for all model regions that the home-based work trip distribution model be doubly constrained while the models for other trip purposes be singly constrained.

6.2 Trip Distribution Validation

6.2.1 Data Sources for Validation

The main validation checks for trip distribution models involve comparisons of model results to observed travel patterns. The main data source for validation is therefore a household survey data set, if available.

For home-based work trips, an additional source is the Census Transportation Planning Products (CTPP), derived from the American Community Survey (ACS). It is important to note that work travel is treated differently in the ACS compared to travel models. The ACS asks about "typical" work travel behavior (where the person worked "most last week," how the person "usually" traveled to work, the "usual" departure time from home, etc.). The responses to these questions differ from the way that work travel is usually treated in household surveys and models, where travel to work on the specific travel day is considered. Furthermore, the ACS considers only travel to work, not from work. Additionally, stops on the way to and from work are ignored in the ACS, leading to a different definition of work travel from that of the home-based work trip in models. This implies that CTPP data, despite a larger sample size than household surveys, should be considered a secondary source for validation of home-based work trip distribution, compared to the primary source of household survey data.

6.2.2 Validation Checks

Table 6.2 summarizes the model validation checks for trip distribution models.

Table 6.2 Trip Distribution Validation Procedures for Virginia Travel Demand Models

Type of Check	Model Region Size	
	Small	Large
Intrazonal trips	Within three percentage points	Within three percentage points
Average trip length by purpose	Within five percent	Within five percent

Table 6.2 Trip Distribution Validation Procedures for Virginia Travel Demand Models (Continued)

Type of Check	Model Region Size	
	Small	Large
Trip length (time and/or distance) frequency distribution – coincidence ratio	>0.70	>0.70
Area to area trip flows by jurisdiction	Reasonableness check only	Reasonableness check only

Note: Observed data from household survey or from CTPP for HBW trips.

Intrazonal Trips

Intrazonal trips are produced by and attracted to the same TAZ. Intrazonal trips are not assigned to the transportation network, and so having too many or too few intrazonal trips can result in a significant underestimate or overestimate of travel in a model region. The number of intrazonal trips depends on the TAZ size, but it is undesirable to have a large number of intrazonal trips so that the travel represented by the assignment process is as accurate as possible. However, it is impractical to model trip distribution at a level that includes very little intrazonal travel since the number of TAZs required would cause enormous model run times and file sizes.

The modeled percentage of regional trips that are intrazonal can be compared to the observed percentage, if observed data from household surveys – or from the CTPP in the case of home-based work trips – are available. The FHWA Validation Manual suggests that the modeled percentage for each trip purpose be within three percentage points of the observed value. For example, if a trip purpose had an observed intrazonal trip percentage of seven percent, the modeled percentage should be between 4 and 10 percent.

Average Trip Length by Purpose

Trip length by purpose, in terms of both time and distance, is one measure used in the validation of trip distribution models. Both the average trip lengths and the shapes of the trip length frequency distributions from the model are compared to observed data. Because of inaccuracies in reported travel times from surveys, observed trip lengths are computed using the time and distance skims from the model applied to the specific origins and destinations reported in the survey. Average trip lengths and trip length frequency distributions for the observed condition are computed directly from the trip table obtained from the expanded survey data and compared to trip table information obtained from applying the model.

Generally, the modeled average trip lengths for each trip purpose should be within five percent of observed. In models with many trip purposes, some purposes may have relatively few trips, and so the five percent guideline can be relaxed in these cases. It also is desirable to check trip lengths by market segment, with segments defined however possible given the model's capabilities and the information available from the observed survey data. For example, if trips by different income levels are modeled separately for a trip purpose, it would make sense to compare average trip lengths for each income level modeled.

NCHRP Report 716 reports average trip lengths in minutes from the NHTS for urban areas of different population levels. While these averages cannot be assumed to be representative of the average trip lengths in any particular model region, they may provide useful points of reference, particularly in areas without recent household travel survey data. The relevant averages for areas like those in Virginia are:

- Home-based work: Northern Virginia – 32, Hampton Roads/Richmond – 26, smaller areas – 21;
- Home-based school: Northern Virginia – 21, other areas – 18;
- Home-based other (nonschool): All areas – 18; and
- Nonhome-based: Northern Virginia – 20, other areas – 18.

Trip Length Frequency Distribution by Purpose

It is insufficient to check only the average trip lengths; the frequency distribution of trip lengths also must be checked. Visual checks can be very useful; the observed and modeled trip length frequency distributions can be plotted on the same graph to see how closely the distributions match.

A common way of checking trip length frequency distributions is through the use of coincidence ratios. This concept is most easily understood as the area under both curves divided by the area under at least one of the curves, when the observed and modeled trip length frequency distributions are plotted. 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. Generally, the coincidence ratio measures the percent of area that "coincides" for the two curves. The coincidence ratio lies between 0 and 1.0, where a ratio of 1.0 indicates identical distributions.

The calculation of the coincidence ratio is defined in Equations 6-4 through 6-6.

$$\text{Coincidence} = \sum_{t=1}^{T} \min\left\{\frac{f^m(t)}{F^m}, \frac{f^o(t)}{F^o}\right\} \quad (6\text{-}4)$$

$$\text{Total} = \sum_{t=1}^{T} \max\left\{\frac{f^m(t)}{F^m}, \frac{f^o(t)}{F^o}\right\} \quad (6\text{-}5)$$

$$\text{Coincidence Ratio} = \frac{Coincidence}{Total} \qquad (6\text{-}6)$$

where:

$f^m(t)$ = frequency of trips at time *t* from the model;

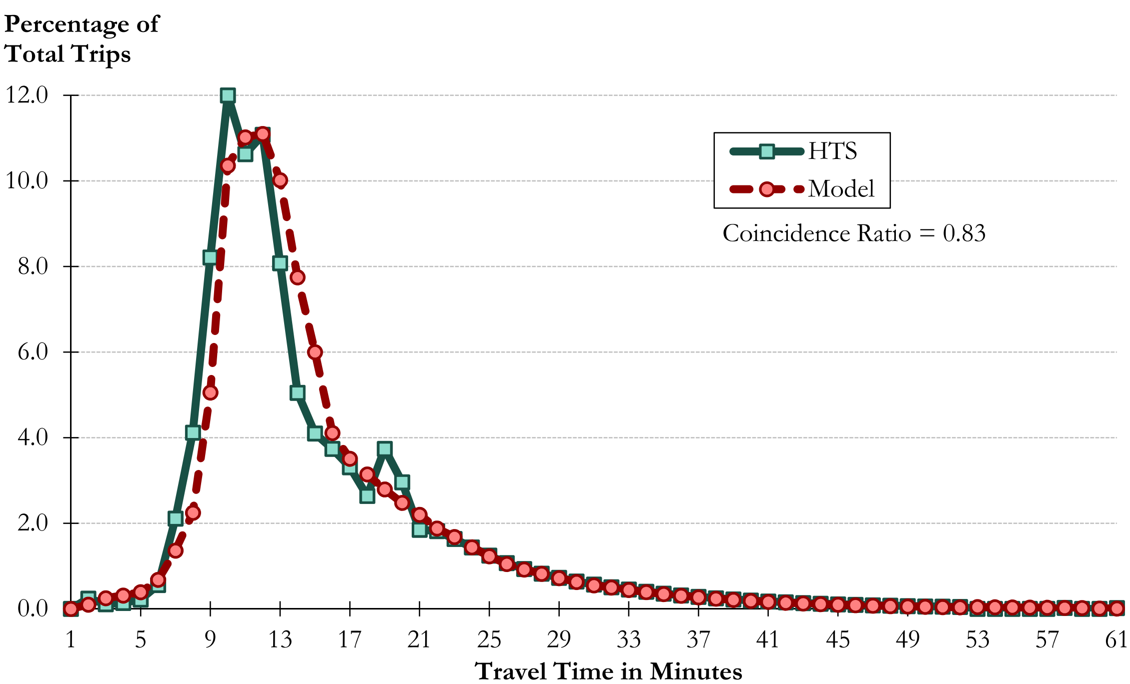
$f^o(t)$ = frequency of trips at time *t* from the observed survey data;

F^m = total trips distributed from the model; and

F^o = total trips distributed from the observed survey data.

Figure 6.1 shows an example of a coincidence ratio computation. It is preferable for the coincidence ratio for each trip purpose to be at least 70 percent. The 70 percent guideline can be relaxed in models with many trip purposes since some purposes may have relatively few trips, making a stronger statistical fit more difficult to achieve.

Figure 6.1 Example of a Home-Based Work Trip Length Frequency Distribution Comparison



Area to Area Flows of Trips by District

It is important to understand that matching average observed trip lengths or even complete trip length frequency distributions is insufficient to deem a trip distribution model validated. The modeled **orientation** of trips must be correct, not just the trip lengths. Because of sample size limitations of household surveys, it is necessary to check origin-destination patterns at an aggregate level. Generally, this is described as a **district-level** validation. The ideal number of districts is dependent on many factors, including the size of the modeled region, the number of TAZs, the amount of travel, the existence of political boundaries and travel barriers such as rivers, and the amount of market segmentation for which district-level analysis will be performed. As with other checks, district-level geographic checks should be performed separately for each trip or activity purpose. Additional market segmentation, such as by income level, also should be performed where the observed data exist and the model supports such segmentation.

District-to-district travel comparisons are reasonableness checks, and there are no specific guidelines for what constitutes a satisfactory match between modeled and observed data. This is because there is wide variation among models in terms of district definition and size, survey data sample sizes, and the number of trips by purpose.

6.2.3 Model Calibration and Troubleshooting

Issues discovered during the model checks described above may imply errors in trip distribution model parameters or input data (networks/skims or trip ends). Some of the typical problems that may be evident from these tests and possible calibration strategies are as follows:

- Average trip lengths too long or short: Recheck skim data and trip end inputs, recalibrate friction factors or adjust parameters of friction factor formula or logit utility equations, and/or check distribution patterns (see below).
- Coincidence ratio too low: Recalibrate friction factors or adjust parameters of friction factor formula or logit utility equations.
- District-level origin-destination patterns inaccurate for some interchanges: Check trip lengths (see above), check travel impedances between affected districts, introduce or adjust K-factors, and/or introduce impedance penalties on network links (e.g., bridge crossings).
- Too many or few intrazonal trips: Adjust intrazonal travel times for types of TAZs with this issue.
- Model too sensitive or insensitive to changes in level of service: Adjust parameters for appropriate level of service variables in impedance/utility functions or friction factors.

The ability to calibrate the origin-destination patterns using friction factors is limited, and other methods, including socioeconomic segmentation and K-factors, often must be considered. K-factors may correct for major discrepancies in trip interchanges, usually at the district level. They are typically justified as representing socioeconomic or other characteristics that affect trip making but are not otherwise represented in the model. Physical barriers, such as a river crossing, also may result in differences between observed and modeled trip patterns.

In a sense, K-factors are analogous to the alternative specific constants in logit models; they are intended to account for the choice factors that are not able to be included in the models. Since trip distribution models have relatively few input variables, it is reasonable to believe that other factors that affect location choice are not included in the models. In many cases they cannot be measured, quantified, or forecasted. K-factors provide a means for accounting for these factors, although they are then assumed to remain fixed over time and across all scenarios.

For this reason, K-factors must be used very cautiously. Because they can be used to provide nearly perfect matches between modeled and observed district-level origin-destination flows, it can be very tempting to apply K-factors to resolve differences in origin-destination flows without determining whether they are the best method to solve the problem at hand. The use of K-factors, therefore, should be considered "a last resort" after all other possible causes for error and calibration adjustments have been considered. Even when K-factors are introduced, they should be relatively small in magnitude – the closer to 1.0, the better. Complete documentation of the justification for the use of K-factors is required.

CHAPTER 7. MODELING EXTERNAL TRAVEL

The objective of the external modeling process is to develop origin-destination vehicle trip tables for trips with at least one end outside the model region. In most models, especially those for larger areas, the majority of trips are internal-internal (I-I) trips, which are both produced in and attracted to internal TAZs, that is, those TAZs within the modeling area. The trip generation process described in Chapter 5 focuses mainly on these I-I trips although care must be taken to avoid double counting of trips with only one end in the model region.

Models also include trips with one or both ends outside the region, known collectively as "external trips." These trips include:

- Internal-external (I-E) trips, which are produced inside the model region (i.e., made by residents of the region) but are attracted to locations outside the region;
- External-internal (E-I) trips, which are produced outside the model region (i.e., made by nonresidents of the region) but are attracted to locations inside the region; and
- External-external (E-E) trips, which pass through the model region but have both ends outside the region.

There are two basic steps in modeling I-E and E-I travel: trip generation and trip distribution. E-I and I-E trip generation must be performed for both the internal TAZs and external stations. For internal TAZs, the generated trips are estimated as fractions of total trips. E-E trip tables are usually estimated directly from the external travel survey data for the base year. External vehicle trips are assigned along with I-I vehicle trips in the trip assignment step, discussed in Chapter 10.

This chapter describes the policies and procedures for developing, validating, and calibrating external travel modeling components in Virginia. These are summarized in Table 7.1.

Table 7.1 External Travel Modeling Practice for Virginia Travel Demand Models

Component	Acceptable		Recommended[a]	
	Small	Large	Small	Large
Inclusion of transit trips	No	No	No	No (if significant transit travel across regional boundary, extending model area is preferred)
Total external trips generated	From external station counts	From external station counts	From external station counts	From external station counts

Table 7.1 External Travel Modeling Practice for Virginia Travel Demand Models (Continued)

Component	Acceptable		Recommended[a]	
	Small	Large	Small	Large
External vehicle trip types	Autos, trucks	Autos, trucks	Autos, trucks	Autos by occupancy level, trucks by type
E-E trips	Based on external survey	Based on external survey	Based on external survey or statewide model	Based on external survey or statewide model
Trip generation for internal TAZs	Fixed fraction of total trips	Based on distance from regional boundary	Based on distance from regional boundary	Based on distance from regional boundary
Trip distribution model form for I-E and E-I trips	Gravity model	Gravity model	Gravity model	Gravity model

[a] Recommended characteristics are subject to resource constraints such as data availability and budget

7.1 Inclusion of Transit or Nonmotorized Travel

As discussed in Chapter 1, many models reflect only auto travel (trucks and passenger vehicles). It follows that in areas where it is unnecessary to model internal nonauto (transit and nonmotorized) travel, it also is unnecessary to model external nonauto travel. It also is apparent that there is little benefit to considering external nonmotorized travel in any model due to the short lengths of such trips. It is therefore both **acceptable practice** and **recommended practice** to exclude nonauto external travel from the model.

In models where internal transit travel is considered explicitly, the decision whether to model external transit travel depends on whether there is a significant number of transit trips that travel across the model boundary. In nearly all areas, the number of external transit trips is very small (or zero), and so modeling external transit travel is not worthwhile. It is relatively rare for a transit operator's service area to extend beyond the model region's boundary, even in regions with multiple transit operators. If this does occur, it is preferable to extend the model region to incorporate areas where transit service is (or is expected to be) provided. In cases where this is not feasible, the best approach would be to obtain estimates of interregional transit demand from other sources (for example, transit operator projections) and to subtract the estimated external transit demand from the total demand, rather than attempt to directly model external transit travel.

7.2 Modeling of Vehicle Trips

Since modeled external travel will include only auto trips (trucks and passenger vehicles) in nearly every case, it makes sense to model these trips as vehicle trips rather than person trips. While vehicle occupancy can vary for different external travel corridors, the information to model vehicle occupancy would have to include information on areas outside the model region which is generally unavailable. It is therefore both **acceptable practice** and **recommended practice** to model external travel as vehicle trips.

Modeling external travel as vehicle trips has the advantage of being consistent with traffic count data used to estimate the total amount of external travel. Generally, the total number of external vehicle trips is equal to the sum of traffic counts for all external stations (in forecast years, with growth factors applied), noting that E-E trips are counted twice in this sum. This is discussed further below.

7.3 General Process for Modeling External Travel

The general process for modeling external travel is summarized as follows:

1. Determine total number of external vehicle trips using traffic counts at external stations (in forecast years, with growth factors applied).
2. Separate the vehicle trips by external station into truck trips (by truck type) and auto trips. If internal auto trips are segmented by vehicle occupancy level, then external auto trips should be segmented the same way.
3. Determine the percentages of external truck trips by type and external auto trips that are E-E, E-I, and I-E trips (by external station if survey data are available).
4. Create E-E auto and truck vehicle trip tables.
5. For each internal TAZ, estimate the number of E-I and I-E truck trips by type and auto trips by occupancy level so that the regional totals are maintained.
6. Distribute E-I and I-E trips between external stations and internal TAZs and create E-I and I-E vehicle trip tables.
7. Segment all external trip tables by time-of-day period (consistent with the highway assignment process).

These steps are discussed in the subsections that follow.

7.3.1 Determining External Vehicle Trips by External Station

For the base year, the number of daily vehicle trips for each external station is equal to the annual average weekday daily traffic (AAWDT) count for that station. The total number of external vehicle trips for the region is therefore equal to the sum of the traffic counts for all external stations. If traffic counts are available for every external station, these counts should be used; if counts are unavailable for some stations, vehicle trips must be estimated for those stations. For forecast years, growth factors are typically applied to the base-year vehicle trips. These growth factors, which can vary by external station, should consider the expected growth in the model region as well as the areas served by the roadways comprising the external stations. It is important to note that E-E trips are counted twice in this total of external vehicle trips while E-I and I-E trips are counted only once.

7.3.2 Segment External Vehicle Trips by Classification and Occupancy

As discussed in Chapter 8, truck trips are considered separately in travel models, typically by truck type (e.g., small, medium, and large). This segmentation applies to external trips and the external trip generation and distribution processes as well. This requires that the external vehicle trips by external station be segmented into trucks by type and autos. This segmentation is most often achieved using vehicle classification counts at the external stations. For those external stations where classification counts are unavailable, vehicle trips may be segmented using classification information from other similar roadways.

If the highway assignment process segments auto trips by vehicle occupancy level (e.g., SOV, HOV2, etc.), then external auto trips must be segmented the same way for assignment. This requires that the external auto trips by external station be segmented by occupancy level. This segmentation is most often achieved using data from the external travel survey at the external stations. For those external stations where survey data are unavailable, auto trips may be segmented using occupancy information from other similar roadways or regional averages.

7.3.3 Segment External Station Trips by Type of External Travel

The total trips by vehicle type for each external station are segmented to represent the number of E-E, E-I, and I-E trips. External travel survey data are the best source to develop segmentation percentages. When survey data are not available, segmentation will involve some estimation and judgment on the part of the model developer. Often, these percentages are estimated using experience from other areas. For example, in the Richmond/Tri-Cities model region, the percentages shown in Table 7.2 are applied to external stations by roadway facility type.

Table 7.2 External-External Trip Percentages by Roadway Type [7]

Facility Type	Passenger Car Percentage	Heavy Truck Percentage
Interstate	23	23
Minor Freeway	17	13
Principal Arterial	14	9
Major Arterial	9	5
Minor Arterial	7	1
Major Collector	0	0
Minor Collector	0	0
Local	0	0

Segmentation for E-E, E-I, and I-E trips can differ by vehicle type (as shown in Table 7.2), with survey data (if available) again being the best data source for such segmentation.

7.3.4 Creating External-External Trip Tables

The methods for generating external-external travel can be classified into three general types:

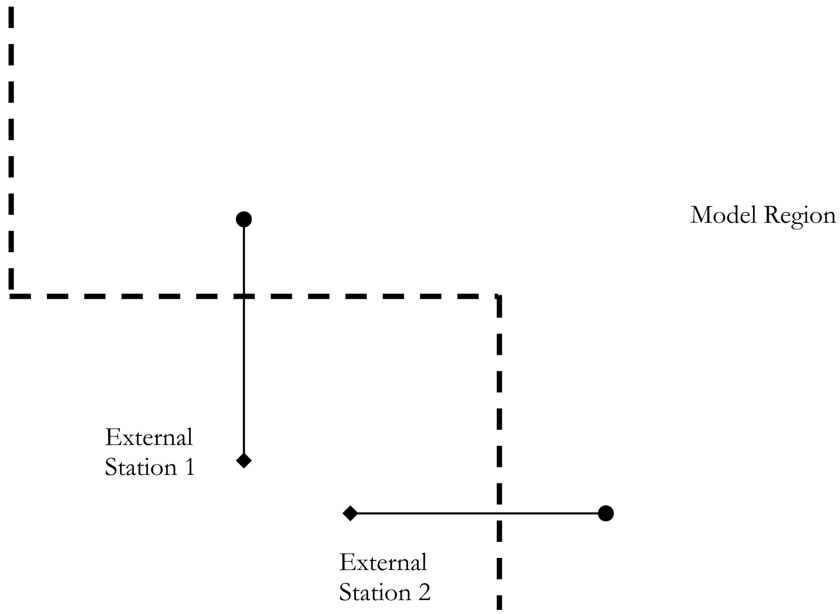
- Iterative proportional fitting (IPF) of E-E trip tables;
- Developing origin-destination factors from external travel survey data; and
- Obtaining information from a model of a larger area, such as a statewide model that includes the model area.

Iterative Proportional Fitting (IPF) of E-E Trip Tables

The IPF process uses a "seed" distribution and iteratively adjusts the cell values until a good match between the target row and column totals is achieved. For E-E trip tables, the row and column total targets represent the portions of the external station productions and attractions described in Section 7.1.3 that are through trips.

To produce optimal results, the seed for the IPF process should reflect the expected distribution of E-E trips between external stations. However, in the absence of an external travel survey, developing the seed matrix again will involve some judgment on the part of the model developer. A seed table with the same value in each cell of the table would be valid, but different values can usually be used to improve the process. First, a value of zero should be used for any external station pairs between which travel is unlikely to occur. A hypothetical example of such a case is shown in Figure 7.1, where no trips should be permitted between External Stations 1 and 2. Next, relatively higher values should be used in the seed matrix for external station pairs between which a high volume is expected, such as stations representing the points at which the same interstate highway enters and leaves the region.

Figure 7.1 Example of External Stations with No Travel Between Them



When the seed table and the targets have been established, the IPF process can be performed using modeling software or a spreadsheet.

Developing Origin-Destination Factors from External Travel Survey Data

If data from a local external travel survey are available, and the survey's sample size is sufficient, an E-E trip table can be estimated from the expanded survey data. Alternately, the percentage of trips produced by each external station that are attracted to each other station can be obtained and applied to the external station trip productions to create an E-E trip table. These percentages should be applied separately by vehicle type (auto and each truck type). Because the survey data represent the base year (or a recent year), this process is used only for base-year E-E trip tables. In this case, forecast year tables are generally created through an IPF process, using the base year trip table as the "seed."

Obtaining Information from a Model of a Larger Area

The Virginia Statewide Model (VSM) can be used to produce E-E trip tables for any models whose regions lie entirely within Virginia. This can be done using the process commonly used for creating subarea trip tables in a regional model. As is typical for subarea models, the level of zonal resolution is usually finer for regional models than for the VSM, and so a disaggregation process for the VSM trip tables is required. Because subarea trip tables are dependent on the highway assignment results for the larger model, adjustments to ensure consistency with the target external station volumes are performed, often done using an IPF process.

The process for creating E-E trip tables from the VSM can be summarized as follows:

1. Define a subarea of the VSM corresponding to the regional model's analysis region, with the links defining the subarea cordon corresponding to the regional model's external stations.
2. For each vehicle type (auto and truck), create a trip table for this subarea using the modeling software.
3. Adjust the trip table for each vehicle type using an IPF process where the row and column targets are the external station target volumes for the vehicle type, and the seed trip table is the table from the subarea extraction process.
4. Create a correspondence between the VSM TAZs and the regional model TAZs.
5. For each regional model TAZ, determine the percentage of travel in the VSM TAZ by vehicle type for the regional model TAZ. This fraction is the percentage of trips in that TAZ in the regional model trip table of the trips for all TAZs lying within the VSM TAZ in which the regional model TAZ is located.
6. Apply these percentages to the trip table created in Step 3 to create the E-E trip table for the regional model.

7.3.5 Determining E-I and I-E Trips for Internal TAZs

The trip generation process described in Chapter 5 estimates the total number of person trips generated in each internal TAZ. Experience and logic dictate that that the closer a TAZ is to the model region's boundary, the higher the percentage of travel that is external to the region. It is therefore both **acceptable practice** and **recommended practice** to relate the I-E/E-I share of total trips to the TAZ's distance from the regional boundary. Often, the highway distance to the nearest external station is used. As an example, the Richmond/Tri-Cities model Base 2008 Version 1.0 uses Equations 7-1 and 7-2 to estimate the shares of I-E trips for internal TAZs [7]:

$$\text{I-E share for work trips} = 0.152 * (\text{Distance} \wedge -0.643) * 0.892 \tag{7-1}$$

$$\text{I-E share for non-work} = 0.069 * (\text{Distance} \wedge -1.197) * 0.892 \tag{7-2}$$

Where "distance" refers to the highway distance from the TAZ to the nearest external station in miles.

The parameters of these types of equations can be estimated from external travel survey data if available. Otherwise, parameters can be transferred from other models and calibrated. It should be noted that separate functions can be used for I-E and E-I trips although when no local survey data are available, the same equation may be used for both E-I and I-E trips (as is done in Richmond/Tri-Cities). It also should be noted that while it is possible to segment external trips by work and nonwork purposes, it is not necessary to do so. Even if external trips are not segmented by purpose, separate equations by trip purpose, such as

Equations 7-1 and 7-2, may be used for the purposes of determining the total E-I and I-E trips for internal TAZs from the trip generation results.

Two other steps are necessary to complete the process of determining E-I and I-E trips for internal TAZs. First, since the trips estimated in the trip generation process are person trips, they must be converted to vehicle trips for use in E-I and I-E trip distribution models. This process is straightforward and uses vehicle occupancy rates derived from external travel surveys, household travel surveys, or other data sources such as NHTS. Second, a normalization process is needed to ensure that the total numbers of I-E and E-I trips generated in internal TAZs equal the total trips generated at external stations, as determined by the process discussed in Section 7.1.3. This may involve adjusting the parameters of formulas such as Equations 7-1 and 7-2 or by adjusting the outputs for I-E trips to match the totals for the external stations.

7.3.6 E-I and I-E Trip Distribution

The processes described in Sections 7.1.3 and 7.1.5 produce E-I and I-E vehicle trip ends for each external station and each internal TAZ. A trip distribution process uses these as inputs to create the E-I and I-E vehicle trip tables. It is both **acceptable practice** and **recommended practice** for all model areas to use the gravity model (see Section 6.1.1) for E-I and I-E trip distribution. Highway travel time is used as the impedance measure for E-I and I-E trip distribution. The friction factors may be fitted to the observed trip length frequency distributions (if external travel survey data are available), transferred from another region or a previous model version, or fitted to functions such as the exponential gamma functions.

7.3.7 Segmenting external trip tables by time of day

Because the E-E, E-I, and I-E vehicle trips are assigned along with the internal auto and truck vehicle trips, the time-of-day segmentation for external trips must be consistent with that for internal trips. It is both **acceptable practice** and **recommended practice** to factor external vehicle trip tables using fixed factors derived from traffic counts at external stations.

7.4 External Travel Validation

7.4.1 Data Sources for Validation

The main validation checks for external travel models involve comparisons of model results to observed travel patterns. The main data source for validation is therefore the external travel survey data set, if available. The household travel survey provides information on I-E trips, but not E-E or E-I travel.

7.4.2 Validation Checks

It should be noted that external travel models are designed to match the trip inputs at the external stations, and so checks of these volumes are unnecessary. It is not possible to estimate the actual number of E-I and I-E trips generated in internal TAZs due to the low incidence of such trips in most cases and the small sample sizes of external travel surveys.

Table 7.3 summarizes the model validation checks for trip distribution models.

Table 7.3 External Travel Validation Procedures for Virginia Travel Demand Models

Type of Check	Model Region Size	
	Small	Large
Average trip length by vehicle type	Within 10%	Within 10%
Trip length (time and/or distance) frequency distribution – coincidence ratio	>0.60	>0.60
External-to-district/district-to-external trip flows	Reasonableness check only	Reasonableness check only

Average Trip Length by Vehicle Type

As discussed in Section 6.2.2, similar to the checks for internal travel models, the average trip lengths and the shapes of the trip length frequency distributions from the model are compared to observed data if available. Average trip lengths and trip length frequency distributions for the observed condition are computed directly from the trip tables obtained from the expanded survey data and compared to trip table information obtained from applying the model.

Because of the smaller number of trips associated with external travel, error ranges are higher than those associated with internal travel, and the guidelines for comparisons with observed data are less strict. Generally, the modeled average trip lengths for each vehicle type should be within 10 percent of observed. Depending on the segmentation used, some vehicle types (e.g., heavy trucks) may have relatively few trips, and so the 10 percent guideline can be relaxed in these cases.

Trip Length Frequency Distribution by Purpose

As described in Section 6.2.2, visual checks of trip length frequencies can be useful; the observed and modeled trip length frequency distributions can be plotted on the same graph to see how closely the distributions match. Coincidence ratios (see Section 6.2.2) can be used. The guideline for external travel is for the coincidence ratio for each vehicle type to be at least 60 percent.

External to District/District to External Trip Flows

While the concept of "districts" is not applicable to external stations, comparisons can be made of modeled and observed travel between districts comprised of internal TAZs, which may be based on jurisdictions, and groups of adjacent external stations, or individual stations with higher volumes. These comparisons are reasonableness checks, and there are no specific guidelines for what constitutes a satisfactory match between modeled and observed data. The low sample sizes for external travel surveys make it difficult to specify such guidelines.

7.4.3 Model Calibration and Troubleshooting

Issues discovered during the model checks described above may imply errors in:

- E-I/I-E internal TAZ trip generation model parameters;
- E-I/I-E trip distribution model parameters;
- E-E trip tables; or
- Input data.

Some of the typical problems that may be evident from these tests and possible calibration strategies are as follows:

- Average trip lengths too long or short: Recheck trip end inputs, recalibrate friction factors or adjust parameters of friction factor formula, and/or check distribution patterns (see below).
- Coincidence ratio too low: Recalibrate friction factors or adjust parameters of friction factor formula.
- District-level origin-destination patterns inaccurate for some interchanges: Check trip lengths (see above); check travel impedances between affected districts.

CHAPTER 8. TRUCK AND FREIGHT MODELING

8.1 Background

The person trips generated in the trip generation step (see Chapter 5) and the external travel discussed in Chapter 7 comprise most, but not all, travel in a region. Trucks and other commercial vehicles are an important segment of the travel market. The Fredericksburg, RTC, and Hampton Roads models all have a truck module.

There is a difference between *truck models* and *freight models*. The difference is that freight models also may include nonhighway modes, such as rail and water, and that truck trips may include nonfreight-related activities. While trucks are the mode carrying most of the freight tonnage in the U.S., trucks also are used to perform services; to do maintenance; to carry construction materials and equipment; depending on the definition of freight, to deliver local (e.g., last mile) freight; and to do the repositioning of empty or partially loaded trucks that are necessary so that trucks are available to carry loads of long-distance freight. This distinction is important because, according to the Federal transportation regulations, VDOT and MPOs are required to consider freight, as distinct from trucks, in their transportation planning. But estimates of the volume and performance of all trucks may be necessary to support other planning efforts, such as infrastructure, energy, or environment planning.

Additionally, the truck counts collected by VDOT and others will include both freight and nonfreight activities. Those counts cannot classify trucks as engaged in carrying freight or engaging in some other purposes. Nonfreight activities are highly correlated with population. So, as the size of an urban area increases, the share of all truck travel for nonfreight activities increases. Conversely in rural areas between metropolitan urban areas, freight activities may represent the majority of the travel by trucks.

The FHWA Freight Analysis Framework Version 3 (FAF3) loaded highway network [8] can be used to make an estimate of the vehicle-miles traveled (VMT) that is attributed to all vehicles, to what the FAF considers to be freight in trucks, and all travel by trucks, for the entire U.S., for all of Virginia, and for the FAF regions in Virginia. The FAF3 metropolitan regions are similar to MPOs, but do not share precise boundaries. Also, the FAF includes only the higher functionally classified roads. The results are shown in Table 8.1.

The figures in Table 8.1 are not intended to serve as model validation targets. The roads included in the FAF network are not the same as those included in models used in Virginia; the boundaries of the FAF regions are not the same as the model regions; and the trucks in FAF are not necessarily the same as the trucks in travel demand models. Table 8.1 is intended to show that all trucks do not carry freight, at least freight as defined by the FAF, and that the percentage of a region's truck travel that is freight depends on the size of the region (e.g., regions with larger populations have more nonfreight trucks and thus a lower share of freight trucks) and the location of the region (e.g., Hampton Roads is not on a major through traffic corridor, and thus has a lower share of FAF freight trucks than does Richmond, which is on the I-95 Corridor).

Table 8.1 FAF All and Truck VMT by FAF Regions

	Total Daily VMT (thousands)	Total Daily Truck VMT (thousands)	Truck Percentage of Daily VMT	Total Daily FAF Truck VMT (thousands)	FAF Trucks as Percentage of All Trucks
U.S.	5,536,940	758,197	14%	330,831	44%
Virginia	166,938	19,046	11%	8,552	45%
Washington, D.C.-Maryland-Virginia	95,733	8,232	9%	2,090	25%
Virginia portion of Washington, D.C.	48,155	4,183	9%	1,410	34%
Richmond area	33,253	3,795	11%	1,348	36%
Hampton Roads area	29,009	2,076	7%	371	18%
Virginia non-metropolitan	56,521	8,991	16%	5,424	60%

Source: Cambridge Systematics analysis of the FAF3 Highway Network.

The remainder of this chapter discusses truck and freight modeling practices relevant to Virginia.

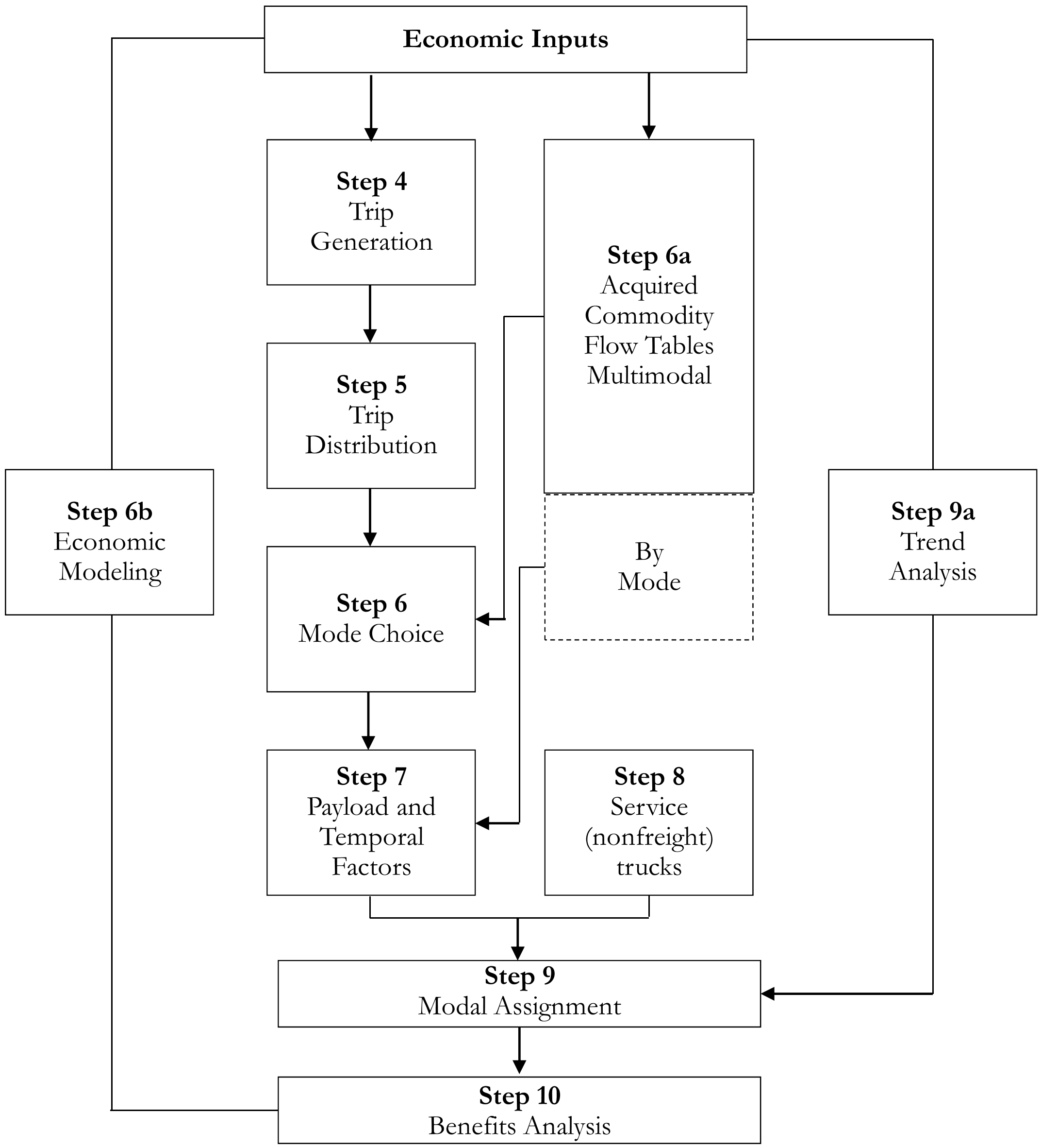
8.2 Truck and Freight Modeling Practice

8.2.1 Statewide Freight Models

This section discusses statewide freight models, which often provide inputs to MPO truck models.

All travel demand models, including truck models, require trip tables between TAZs and networks that connects these TAZs. Freight models include tables of freight shipments between TAZs, and the modal networks that connect those TAZs. In multimodal freight models, the flow unit in the tables may be annual tons, but when assigned as trucks on a highway network, these flows are typically converted to daily truck vehicle trips between TAZs. *NCFRP Report 8* [9] presents a framework for freight models as shown in Figure 8.1. (The numbered steps in Figure 8.1 refer to the steps in *NCFRP Report 8*, Chapter 4.)

Figure 8.1 Freight Model Framework



The two paths in the middle of Figure 8.1 (the path beginning with Step 4 and the path beginning with Step 6a) differ only in how the freight trip table is developed. That table may be developed through the direct acquisition of a commodity flow table (Step 6a), or the table may be developed through a "four-step" trip process similar to what is used in passenger modeling (Steps 4, 5, and 6). If the freight model only deals with flows by truck, then the freight model involves only a single mode, and the mode choice step is not necessary. As shown in Step 7 of Figure 8.1, if the commodity flow or multimodal table is expressed as annual tonnage, flows are converted from annual tons by truck to average daily trucks using an annual to daily conversion factor and a factor of payload (tons) per truck by commodity.

NCFRP Report 8 suggests the use of 295 to 300 as the annual to average weekday factor. The Quick Response Freight Manual (QRFM) [10] suggests a range of payload factors, with the factors to be used dependent on both the local economy and the commodities included in a freight model. In addition to the QRFM source, FHWA also issued a report, Development of Truck Payload Equivalent Factor [11], which provides state-specific factor estimates which may be for converting measures of tons into numbers of trucks. Step 8 in Figure 8.1 reinforces that truck models should include both freight and other trucks.

While freight truck volumes and their performance can be observed locally, the behaviors creating freight truck tables are national (or international). The factors that cause the production (origins) of freight shipments and the attraction (destinations) of freight shipments and the networks used to travel between these TAZs are therefore national in scope. While it might be appropriate for statewide models to consider these factors, it is not practical for an MPO model to forecast behaviors far beyond its own region. Additionally, while freight behavior (including that by trucks) may be national, the travel by nonfreight/service/other trucks is influenced by local behavior. For that reason, it is not typically necessary for service trucks to be shown as traveling from large TAZs outside of the principal model region. Those service trucks that begin or end outside of the region can be loaded at external stations on the boundary of the model region.

Direct Commodity Tables

The Virginia Statewide Model (VSM) is a typical example of an acquired (direct) commodity database used as a freight truck trip table. According to the report for NCHRP Project 8-36B Task 91 [11], Virginia is one of eight states that use a direct commodity flow trip table as part of their freight truck trip table. According to the documentation for the VSM [12] [13], the freight truck trip table is directly taken from the proprietary TRANSEARCH commodity database. It uses the TAZ system in that database for its external zones beyond the Virginia border. In the VSM, the freight truck table also is called its long distance truck table.[13] The service truck table, by contrast, has internal TAZs that are TAZs in Virginia, but whose external trip ends may be through external stations representing highways at the Virginia State line. The annual to daily factor used in the VSM is given as 1/365. The payload factors are as shown in Table 8.2.

[13] Also called a "Reebie" truck table after Reebie Associates, the developer of TRANSEARCH at that time. Reebie Associates has since been acquired, and is doing business as IHS/Global Insight.

Table 8.2 VSM Truck Load Factors by STCC2[14] Commodity [13]

STCC	Commodity Type	Movement Type		
		Intrastate	Interstate	Through
01	Farm Products	16.1	16.1	16.1
09	Fresh Fish or Marine Products	12.6	12.6	12.6
10	Metallic Ores	11.5	11.5	11.5
11	Coals	16.1	16.1	16.1
14	Nonmetallic Ores	16.1	16.1	16.1
19	Ordinance or Accessories	3.1	3.1	3.1
20	Food Products	17.9	17.9	17.9
21	Tobacco Products	9.7	16.4	16.8
22	Textile Mill Products	15.2	16.1	16.5
23	Apparel or Related Products	12.4	12.4	12.5
24	Lumber or Wood Products	21.1	21.0	21.1
25	Furniture or Fixtures	11.3	11.3	11.4
26	Pulp, Paper, Allied Products	18.6	18.5	18.6
27	Printed Matter	13.8	13.6	13.9
28	Chemicals or Allied Products	16.9	16.9	16.9
29	Petroleum or Coal Products	21.6	21.6	21.6
30	Rubber or Miscellaneous Plastics	9.1	9.2	9.3
31	Leather or Leather Products	10.8	11.0	11.3
32	Clay, Concrete, Glass, or Stone	14.4	14.3	14.4
33	Primary Metal Products	19.9	19.9	20.0
34	Fabricated Metal Products	14.3	14.3	14.3
35	Machinery	10.8	10.8	10.9
36	Electrical Equipment	12.7	12.8	12.9
37	Transportation Equipment	11.3	11.3	11.3

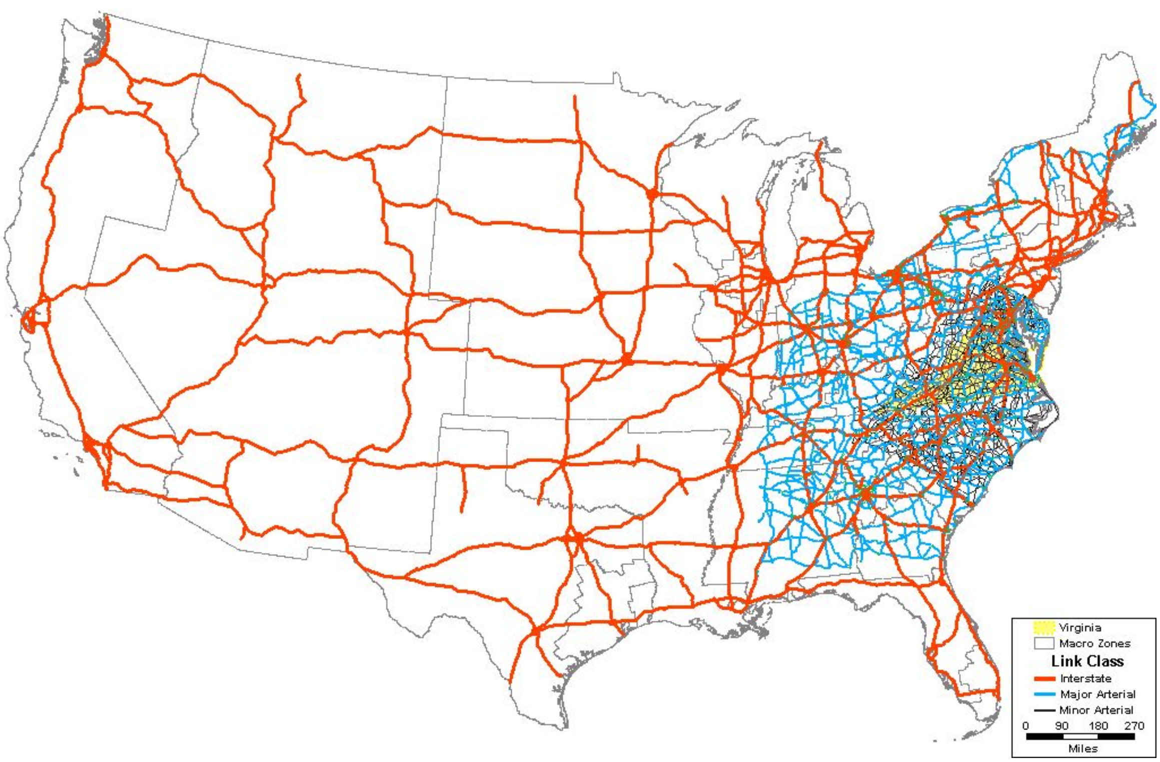
[14] STCC is the Standard Transportation Commodity Classification, which is a hierarchical system. In the VSM it is used at the two-digit level of classification. The "STCC 50" code shown is not part of the formal STCC codes, but is unique to TRANSEARCH.

Table 8.2 VSM Truck Load Factors by STCC2[15] Commodity [13] (Continued)

STCC	Commodity Type	Movement Type		
		Intrastate	Interstate	Through
38	Instruments, Photo and Optical Equipment	9.4	9.4	9.7
39	Miscellaneous Manufacturing Products	14.2	14.4	14.8
40	Waste or Scrap Metals	16.0	16.0	16.0
50	Secondary Traffic	16.1	16.1	16.1

The external highway network and external macro zones in the VSM are shown in Figure 8.2. Not shown in that figure are the external stations (border nodes) at the Virginia Border. Also not shown are the smaller TAZs within Virginia (micro zones).

Figure 8.2 VSM Highway Network of Continental U.S. [12]



[15] STCC is the Standard Transportation Commodity Classification, which is a hierarchical system. In the VSM it is used at the two-digit level of classification. The "STCC 50" code shown is not part of the formal STCC codes, but is unique to TRANSEARCH.

"Four-Step" Freight Models

As noted above, the VSM uses a direct commodity truck trip table. Alternately, a commodity table could have been used as an estimation data set to develop the trip table produced in the first three steps of traditional four-step trip model. According to the NCHRP Project 8-36B Task 91 report, this process is used in seven statewide freight models in the U.S. In these models, the number of commodities is reduced to a more manageable number (typically approximately a dozen) that are consistent with the state's economy.

Freight Trip Generation

The forecast variables for the trip generation for internal state TAZs reflect the detailed industry employment (typically NAICS employment) for those state TAZs. An example from *NCHRP Report 606* [14] is shown in Table 8.3.

Table 8.3 Production Equations by Commodity Group in the Florida Statewide Model [14]

Commodities		Coefficient (Annual Tons per Employee)	Variable Name (SICXX Employment)
Code	Name		
1	Agricultural	45.597	SIC07
2	Nonmetallic Minerals	6,977.771	SUM(SIC10-14)
3	Coal	*No Production Employment*	
4	Food	245.464	SIC20
5	Nondurable Manufacturing	90.120	SUM(SIC21, 22, 23, 25, 27)
6	Lumber	241.464	SIC24
7	Chemicals	678.583	SIC28
8	Paper	190.814	SIC26
9	Petroleum Products	795.117	SIC29
10	Other Durable Manufacturing	212.202	SUM(SIC30, 31, 33-39)
11	Clay, Concrete, Glass	1498.501	SIC32
12	Waste	0.500	Total Employment
13	Miscellaneous Freight	0.599	Total Employment
14	Warehousing	314.852	SIC50 + SIC51

Note: SIC is the Standard Industrial Classification hierarchical system industries that was commonly used before development of the NAICS.

Freight Trip Distribution

Freight trip distribution follows the same concepts discussed in Chapter 6, Trip Distribution. Productions are distributed to attractions using the gravity model where the friction factors use a negative exponential function of distance. Distance is assumed to be a good explanatory variable because freight shipment cost is highly correlated with it. The coefficient of the negative exponential friction factor is equal to the average trip length, which can be measured separately for each commodity being transported.

Freight Mode Choice

As discussed in Chapter 9, Mode Choice, the percentage of trips between TAZs choosing each mode is typically forecast using a logit formulation. The utility equations include constant terms which account for all impacts not considered by the utility variables. The most important variables in freight mode choice have been found to be travel time, travel cost, and the reliability of travel. The problem in freight forecasting is that the utility constants are large compared to the variable portion of utility. The constants account for such considerations as existing business practices and relationships. The difficulty of estimating the constants is eliminated by using an incremental or pivot point logit equation. In this application the changes in utility are applied to the existing mode shares. Since the existing mode shares already include the considerations of the unknown utility constants, by taking the differences in utilities between existing and an alternative conditions, the constant terms cancel out. Thus forecasts can be made using changes in the utility variables, assuming that all other conditions remain the same.

The incremental logit model takes the form shown in Equation 8-1.

$$\mathrm{S}'_{\mathrm{ijm}} = \frac{S_{ijm} * \exp\left(\Delta U_{\mathrm{ijm}}\right)}{\sum_{m}^{M} S_{ijm} * \exp\left(\Delta U_{\mathrm{ijm}}\right)} \tag{8-1}$$

where,

S'_{ijm} = New share of the flows carried by mode *m* between TAZ *i* and TAZ *j*,
S_{ijm} = Existing share of the flows carried by mode *m* between TAZ *i* and TAZ *j*,
U_{ijm} = Utility from *i* to *j* of mode *m* among all modes *M*, which also is stated as
= Modal Constant $_m$ + b^v * $\mathrm{ExplVar}^v_{ijm}$;

where

b^v = Coefficient for ExplVar *v* (e.g., travel time); and
$\mathrm{ExplVar}^v_{\mathrm{ijm}}$ = Explanatory Variable *v* (e.g., travel time) for mode *m* between TAZ *i* and TAZ *j*;

Freight Assignment

The highway assignment step, which is described in Chapter 10, is where the modal vehicle trip tables are loaded to their respective networks. However, the assignment of freight trucks on highway networks does not necessarily follow the rules of passenger vehicle assignments. As a result, freight trucks are often preloaded to minimum distance routes before autos and other vehicles are assigned in a user equilibrium.

While the interaction of trucks and autos sharing highways does determine the speed and performance for all vehicles, freight trucks operate to maximize profit, and not necessarily to minimize travel time. The simplifying assumption in equilibrium highway assignment of perfect knowledge of the highway system may be more problematic for long distance freight trucks, whose drivers may not have the local knowledge of alternative routes. Additionally, some routes may have height, width, or turning radius restrictions that do not allow for the passage of large freight trucks. Trucks can (and should) be restricted from certain highway links, such as auto-only parkways.

For many freight operators, truck revenue is restricted to a distance between an origin and a destination as agreed by the carrier and the shipper/receiver, and time costs are relatively small. Thus, freight trucks may have little incentive to use longer, faster routes, especially considering that trucks use more fuel than autos. Similarly, if those longer, faster routes are tolled, there may be little usage incentive.

Subarea Extraction from the Statewide Model for MPO Regions

For MPOs whose model regions are geographically within Virginia, the VSM may be used to produce better estimates of truck volumes at the external stations of the MPO model region. If the VSM includes more truck segments than the MPO model, applying information from the more detailed segmentation to the more limited truck segments in the MPO model may be considered. This may be done using the standard techniques of subarea extraction available in modeling software.

Typically the TAZs of the MPO model will nest within the TAZ structure of the VSM. The productions and attractions for each truck table can thus be computed for each MPO model TAZ. The percentage shares for productions and attractions for each MPO model TAZ in the corresponding VSM TAZ can be used to expand the windowed truck tables. These truck trips can be used directly and validated in the MPO model truck trip tables. Alternately, the windowed and expanded truck trips can be used to calculate the percentages for each VSM truck travel segment in the MPO model, and the percentages can be applied to the MPO model truck trip tables.

8.2.2 MPO Models

Truck Models (Including Service Trucks)

The policies and procedures for trip distribution practice in Virginia are summarized in Table 8.4.

Table 8.4 Truck Modeling Practice for Virginia MPO Travel Demand Models

Component	Acceptable		Recommended[a]	
	Small	Large	Small	Large
Truck trip generation	Transferred truck trip generation parameters	Transferred truck trip generation parameters	Transferred truck trip generation parameters	Parameters estimated from commercial vehicle survey
Treatment of ports and terminals	Special generators	Special generators	Special generators	Special generators
Truck trip distribution	Gravity model	Gravity model	Gravity model	Gravity model
Truck trip assignment	Multiclass assignment with separate truck trip tables and appropriate passenger car equivalent (PCE) values	Multiclass assignment with separate truck trip tables and appropriate PCE values	Multiclass assignment with separate truck trip tables and appropriate PCE values	Multiclass assignment with separate truck trip tables and appropriate PCE values

[a] Recommended characteristics are subject to resource constraints such as data availability and budget.

Truck trip tables in MPO models include mainly service trucks. When freight trucks are included, most are internal-external (I-E), external-internal (E-I), and external-external (E-E) truck trips. E-E truck traffic is affected more by an MPO's location relative to major national freight highway corridors than by conditions on the roads in the region. Service (nonfreight) trucks that operate within the region may be the focus to truck models of MPOs.

Since MPO models generally deal only with the truck mode, there is no mode choice function. MPO models therefore deal only with truck trip generation and distribution, with trucks being assigned along with autos during highway assignment.

Some modeling practitioners create a truck trip table by factoring the auto vehicle trip table so that the total truck VMT would meet an aggregate target, say 7 to 10 percent of regional VMT. However, the origins, destinations, and routes chosen by trucks are different than the travel patterns of auto trips. Merely factoring the auto tables may produce the correct cumulative VMT for trucks, but the travel patterns will probably be erroneous. Factoring auto trip tables is therefore **unacceptable practice**.

Trip Generation

The first edition of the QRFM [15] based the estimation of truck productions and attractions on certain socioeconomic data categories:

- Agriculture, Mining and Construction;
- Manufacturing, Transportation, Communications, Utilities, and Wholesale Trade;
- Retail Trade;
- Office and Services; and
- Households.

Table 8.5 presents some examples of truck trip generation equations from *NCHRP Report 606* as well as that from the 1996 QRFM. In this process, the estimated productions and attractions for truck are summed before proceeding to the trip distribution step. However, there is value in retaining the information associated with the purposes represented by these categories. As an example, the Los Angeles MPO developed a truck model [16] that retained truck "purposes" through additional model steps.

Table 8.5 Combination Internal Truck Trip Rates [14] [15]

Variable	Phoenix (1991)[a]	Washington	Vancouver[b]	San Francisco (1993)[c]	New Jersey Truck Model	Richmond[d]	QRFM (1996)
Retail Employment	0.0615	0.0300		0.0001	0.0590	0.140	1.206
Industrial Employment	0.0833	0.0300	0.0665	0.0293	0.0800	0.25	1.284
Public Employment	0.0400	0.0200		0.0220	0.0384		
Office Employment	0.0053	0.0200	0.1640	0.0220	0.1207	0.029	0.514
Total Employment				0.0112			
Agricultural Employment							1.573
Households	0.0210				0.0202	0.068	0.038

[a] Trucks over 28,000 pounds – attraction rates only.

[b] Trucks over 44,000 pounds.

[c] Assumed three- and four-axle truck rates are "heavy truck"– production rates only.

[d] Base 2008 Version 1.0

Commercial vehicle trip diary surveys are a useful method of data collection, particularly for understanding internal-internal (local) truck trip activity in an urban area. The basic approach of data collection involves selecting a representative sample of trucks operating in the region, and obtaining travel diaries from truck drivers for a certain time duration. A more recent approach is the use of Geographic Positioning Systems (GPS) receivers, which are used to trace individual truck trip activity. However, GPS-based data collection in itself cannot provide key truck trip characteristics pertaining to commodity hauled, shipment size, and activity at trip end.

The basis for estimating the parameters of the truck trip generation equations is a truck or commercial vehicle survey, or perhaps an establishment survey. However, in many cases a local survey is not available. Transferring truck trip generation parameters from other sources is not an ideal practice; as shown in Table 8.5, even when the same variables are used in truck trip generation for combination trucks, there is considerable variation among different areas in the coefficients of these variables. The amount of truck travel depends on the makeup of the region's economy among service, heavy manufacturing, high-value manufacturing industries, resource extraction, and other industries. Since regional economies differ, it should be expected that the amount of truck travel supporting these economies differ. For that reason, the use of local surveys to establish truck generation rates is preferred. However, it is recognized that in the absence of such surveys, transferred parameters may be required. In such cases, it is essential that the amount of truck travel be validated during the highway assignment validation, using vehicle classification counts and adjusting transferred rates as necessary.

It is therefore **acceptable practice** for all regions to transfer truck trip generation parameters and validate them to match the amount of truck travel indicated by vehicle classification counts. It is **recommended practice** in large areas to develop truck trip generation parameters from local survey data.

Some regions may have facilities such as ports, truck terminals, and intermodal facilities, that generate truck traffic that may not be consistent with the trips generated using the employment-based trip rates. If such facilities exist, it is both **acceptable practice** and **recommended practice** to treat these facilities as special generators (see Section 5.1.5). If data for these facilities, including special generator surveys (see Section 4.2.1) and person and vehicle counts are available, they should be used to estimate truck trips.

Trip Distribution

The 1996 edition of the QRFM presents the use of exponential friction factors in a gravity model to distribute truck trips. The recommended formulations use travel time in minutes as the impedance measure and are as follows:

For all light trucks:

$$F_{ij} = e^{-0.08} * t_{ij}$$ (coefficient corresponds to 12.5-minute average trip length)

For all medium trucks:

$$F_{ij} = e^{-0.10} * t_{ij}$$ (coefficient corresponds to 10-minute average trip length)

For all heavy trucks:

$$F_{ij} = e^{-0.03} * t_{ij}$$ (coefficient corresponds to 33.3-minute average trip length)

Where:
F_{ij} = friction factor for O-D pair *ij*, and
t_{ij} = congested travel time for O-D pair *ij*.

The gravity model as formulated may connect purposes that have little reason to be connected (for example, mining truck productions connected to household truck attractions). This may be addressed by modifying the truck trip generation equations so that the propensity to make trips between purposes also is considered. As an example, the Phoenix MPO determined the percentage of trips that were made between TAZs using a GPS survey of trucks, and included that information in a modified trip distribution process, as shown in Equation 8-2.

$$T_{ilu_m jlu_n} = PctP_{lu_m lu_n} * P_{ilum} * \frac{PctA_{lu_m lu_n} * A_{jlu_n} * FF_{ij}}{\sum_j PctA_{lu_m lu_n} * A_{jlu_n} * FF_{ij}} \qquad (8\text{-}2)$$

Where, as in the gravity model:

$T_{ilu_m lju_n}$ = The number of trips, *T*, between land use activity *m* in TAZ *i* and land use activity *n* in TAZ *j;*

P_{ilu_n} = The productions, *P*, of land use activity *m* in TAZ *i;*

A_{jlu_n} = The attractions, *A*, of land use activity *n* in TAZ *j;*

FF_{ij} = The friction factor of travel between TAZs *i* and *j.*

The nonstandard terms limit the interchanges, which are computed between TAZs, to those that are most likely to occur:

$PctP_{lu_m lu_n}$ = the Percent of Productions, *PctP*, of land use activity *m* that are made to land use activity *n;*

$PctA_{lu_m lu_n}$ = the Percent of Attractions, *PctA*, in land use activity *m* that are made to land use activity *n.*

These percentages between land use activities might be obtained from a commercial vehicle survey or from a GPS survey of trucks.

If local data for estimating a truck model are unavailable, an origin-destination matrix estimation (ODME) process may be used to create truck trip tables. If a truck model distinguishes trucks by type and sufficient truck counts are available, the development of a truck table from an ODME process can serve as the estimation database for the development of truck trip generation equations, the identification of special generators including external stations, and trip distribution equations.

It is **acceptable practice** and **recommended practice** for all regions to use a gravity model formulation for truck trip distribution. It also is **acceptable practice** and **recommended**

practice for all areas to develop truck trip generation and distribution parameters from an ODME process.

Assignment

Trucks should be assigned together with autos and other vehicles in order to account for the interaction of these vehicles on performance. As noted in the discussion of freight assignment, truck restrictions or preferences on links should be considered in the assignment rules. Additionally, if capacity is stated in passenger cars per hour, a passenger car equivalent (PCE) should be used to factor the truck trip table. A combination truck on the relatively flat terrain associated with most MPO models is typically equivalent to 1.5 to 2.0 autos. It should be noted that this PCE includes not only a comparison of the physical lengths of the vehicles, but the effective lengths of the vehicles, including their safe stopping distance. As an example, the Indiana DOT has studied PCEs for trucks and recommend PCE values for single-unit and combination truck for basic urban freeways (level terrain) of 1.35 and 1.60, respectively [17].

It is **acceptable practice** and **recommended practice** for all regions to use a multiclass assignment with separate truck trip tables and appropriate PCE values for truck trip assignment.

8.3 Truck Model Validation

8.3.1 Data Sources for Validation

A variety of data sources can be obtained to validate truck/freight models. These are discussed in the subsections that follow.

Vehicle Registration Data

Truck registration data multiplied by average trips per day per truck can provide a total regional control total of truck trips, potentially by purpose. State vehicle registration databases often indicate whether registered vehicles are used for commercial purposes. It should be recognized, however, that motor carriers and private fleet operators may register their trucks in states based not on operations but on consideration of state taxes and regulations and adjustments. State truck registrations may therefore underestimate or overestimate the actual size of a state's active truck fleet. Vehicle data also may be purchased from R.L. Polk & Co., a privately-owned consumer marketing information company.

Commercial Vehicle Surveys

Commercial vehicle surveys can serve as a data source not only for estimating truck trip generation and distribution model parameters, but also for validating model results. If a commercial vehicle survey is used to develop a service truck model, and the service truck model will be used together with a freight model (even if only for external trips), an effort should be made to remove the freight trucks from the estimation database to avoid "double counting" of these trucks.

Vehicle Classification Counts

Section 4.2.2 discusses traffic count data. Vehicle classification count data, which classifies vehicles according to the 13 axle-based classes defined by FHWA, are generally available from VDOT for sampled highways. For the 13 classes, the information includes counts by location, hour of the day, and date. In summary format, this information generally presents truck volumes (defined as FHWA Classes 5 through 13, six tires and above) and occasionally includes buses (FHWA Class 4). Four-tire pickup trucks, vans, and sport utility vehicles (FHWA Class 3), are almost always included with passenger cars.

Commodity Flow Data

There are several public and private sources for freight origin-destination data in the United States. The most commonly used sources include the following:

- Global Insight TRANSEARCH (annual freight tons by STCC commodity and mode between user-defined zones). TRANSEARCH is a privately maintained comprehensive market research database for intercity freight flows complied by Global Insight (formerly Reebie Associates).
- FHWA Freight Analysis Framework (annual freight tons by STCG2 commodity and mode between 123 FHWA-defined zones). The FAF is based entirely on public data sources and transparent methods and has been expanded to cover all modes and significant sources of shipments.
- U.S. Census Bureau and Bureau of Transportation Statistics (BTS) Commodity Flow Survey (CFS) (annual freight tons by STCG2 commodity and mode for origin and destination Metropolitan Statistical Areas). The CFS is developed through a partnership between the Research and Innovative Technology Administration (RITA), Bureau of Transportation Statistics (BTS), and the U.S. Census Bureau, U.S. Department of Commerce. This survey provides data on the movement of goods in the U.S., including information on commodities shipped, value, weight, and mode of transportation as well as origins and destinations of shipments of manufacturing, mining, wholesale, and selected retail establishments.
- Surface Transportation Board's Carload Waybill Sample (annual freight tons by STCC commodity by rail between U.S. Bureau of Economic Analysis (BEA) Economic Areas (public release) and U.S. Counties (restricted release) and intermediate rail junctions). The Waybill Sample is a stratified sample of carload waybills for terminated shipments by rail carriers. A waybill is a document issued by a carrier giving details and instructions relating to the shipment of a consignment of goods. Typically, it will show the names of the consignor and consignee, point of origin of the consignment, destination, route, method of shipment, and amount charged for carriage.

- U.S. Army Corps of Engineers' Waterborne Commerce Statistics Database (annual freight tons by Harmonized Series (HS) commodity by water for U.S. ports and waterways). The Waterborne Commerce Statistics Database presents detailed data on the movements of vessels and commodities at the ports and harbors and on the waterways and canals of the United States and its territories. Statistics are aggregated by region, state, port, and waterway for comparative purposes. Data on foreign commerce are supplied to the USACE by the U.S. Bureau of the Census, U.S. Customs, and purchased from the Journal of Commerce, Port Import Export Reporting Service.
- U.S. Census Bureau's Vehicle Inventory and Use Survey (VIUS) (truck miles and ton-miles, by VIUS commodity groups, by truck type). The VIUS provides data on the physical and operational characteristics of the nation's truck population. Its primary goal is to produce national- and state-level estimates of the total number of trucks. The first survey was conducted in 1963. It was then conducted every five years beginning in 1967 and continuing to 2002. Prior to 1997, the survey was known as the Truck Inventory and Use Survey (TIUS). VIUS has not been collected as part of the Economic Census since 2002.

8.3.2 Validation Checks

The validation checks for truck models include checks of truck trip generation, trip distribution, and assignment, and are similar to the checks for the corresponding passenger model components.

Trip Generation

As discussed in Section 5.2.2, aggregate trip generation checks focus on comparisons of modeled trip ends to observed data. In the case of truck models, the observed data would be from a commercial vehicle survey (or perhaps an establishment survey) if such a survey data set is available. There are no specific guidelines for how close the match should be since these survey data sets generally have a lot of variation in trip rates, and a better check of the amount of truck travel comes from the comparison of assigned truck volumes to truck counts (see below).

Truck Trip Distribution

As discussed in Section 6.2.2, trip distribution checks focus on comparisons of modeled trip lengths and origin-destination patterns to observed data, again from a commercial vehicle or establishment survey if available. The same types of checks (comparisons of average trip lengths by truck type, coincidence ratio, etc.) used for person trip distribution model checks can be performed. As with truck trip generation checks, there are no specific guidelines for how close the match should be.

Assignment

After assignments of vehicles by type (automobile and truck at a minimum), the vehicle classification counts can be used to compare the observed automobile and truck counts (and shares by vehicle type) with the estimated automobile and truck volumes (and shares) produced by the travel demand model. These vehicle assignments will include both personal and commercial vehicles, derived from both personal and commercial models, and so calibration adjustments deemed necessary from these comparisons may be required for either the personal or commercial models or both. The validation summaries also are usually summarized by functional class, area type, and screenlines. Chapter 10 provides more information on traffic assignment validation.

Highway assignment validation must consider all trucks. The link flows of trucks includes both freight truck and service trucks. If a model estimates these flows separately, each of their volumes should always be less than the total observed flows. There are several classification systems for trucks used within the U.S. DOT. The BTS in the (now discontinued) VIUS uses a system of eight weight-based classification for trucks, which was adopted by the EPA and other agencies. FHWA uses a system of 13 axle and body types that is used by state DOTs and others for vehicle classification counts. Additionally, very light trucks – those with only four tires, such as pick-up trucks – also are widely used for personal travel while their volumes are reported as combined. If a truck model is based on one classification system and the validation data uses another classification system, adjustments should be made before using the validation data.

When trucks are assigned with autos using multiclass assignment, parameters should be checked to ensure that they have been modified as necessary to accommodate trucks. These parameters include equilibrium convergence criteria (number of iterations, relative gap, etc.), volume-delay function parameters, time-of-day factors, and PCE factors.

8.3.3 Model Calibration and Troubleshooting

Since truck trip assignment is performed as part of the overall highway assignment process that includes passenger cars, the validation and calibration process is not completely separable from the process for highway assignment described in Section 10.5. The assigned truck volumes by type should be compared to the corresponding vehicle classification counts (e.g., modeled heavy truck volumes should be compared to heavy truck counts). Since changes to network and assignment parameters affect both auto and truck assignment results, changes should not be made only to address truck model validation concerns.

If truck volumes are generally too high or too low while auto volumes are not, this is likely a reflection of issues with the truck trip tables and therefore the truck trip generation and distribution processes. This is especially true if those model components used transferred parameters rather than locally estimated parameters. It therefore makes sense to consider adjusting the parameters of these models to address general overassignment or underassignment. For example, if truck volumes are generally too high, truck trip rates can be reduced, or friction factors in the trip distribution model adjusted to reduce the average truck trip length. These types of revisions can be made for specific truck types as indicated by the comparison of modeled volumes to counts by truck type.

If modeled truck volumes (but not auto volumes) are substantially different than counts in localized areas, it may make sense to check, in the vicinity of the issue, the network parameters related to trucks (for example, roadways with truck restrictions) and/or volumes for large generators of truck trips in the vicinity.

CHAPTER 9. MODE CHOICE

This chapter pertains to those regions in Virginia where transit is modeled, and therefore mode choice must be considered. As discussed in Section 1.4, Virginia includes large model regions where it is required that transit travel be explicitly modeled, smaller regions where transit needs to be modeled (for use in planning of transit operations or improvements or to test the potential mode shifting effects of policies and projects being considered), and smaller regions where it is not necessary or efficient to model transit.

Mode choice is the third step in the four-step modeling process and is performed only in models where transit travel is considered. In this step, the person trip tables created in the trip distribution step are split into trip tables by travel mode. The travel mode definitions vary by region and are discussed further in Section 9.1.2.

The main inputs to mode choice models include the trip distribution outputs – the production TAZ to attraction TAZ person trip tables by trip purpose – and measures of travel time, cost, and other level of service variables between each pair of TAZs, obtained (skimmed) from the transportation networks. Socioeconomic and area characteristics are sometimes also used as inputs. The outputs of mode choice are production TAZ to attraction TAZ trip tables by mode for each trip purpose. Because trips of different purposes have different levels of sensitivity to travel time and cost, mode choice is applied separately for each trip purpose, with different model parameters.

This chapter describes the policies and procedures for developing, validating, and calibrating mode choice models in Virginia.

9.1 Mode Choice Practice

The policies and procedures for mode choice practice in Virginia are summarized in Table 9.1.

Table 9.1 Mode Choice Modeling Practice for Virginia Travel Demand Models

Component	Acceptable		Recommended	
	Small[a]	Large	Small[a]	Large
Model form	Nested or multinomial logit	Nested or multinomial logit	Nested or multinomial logit	Nested logit
Modes	Auto, transit	Auto, transit	Auto, transit	Auto: SOV, HOV[b] Transit: Walk access, auto access
Level of service variables	In-vehicle travel time (IVTT), out-of-vehicle travel time (OVTT), cost	IVTT, OVTT, cost	IVTT, OVTT, cost	IVTT, OVTT, cost, transfers if determined to be significant
Other variables	As needed		As needed	

[a] Only if nonauto modes are included in the model (see Chapter 5).

[b] If HOV facilities/policies are important in the region.

9.1.1 Model Form

The **logit model** is the most common type of mode choice model. For more information about logit models, a good summary is provided in Section 4.1 of *NCHRP Report 716*. For more detailed information, other good sources include Ben-Akiva and Lerman (1985) [18] and Koppelman and Bhat (2006) [19].

The logit model is an example of a discrete choice model. Discrete choice analysis uses the principle of utility maximization. A decision-maker is modeled as selecting the alternative with the highest utility among those available at the time a choice is made. An operational model consists of parameterized utility functions for the choice alternatives in terms of observable independent variables and unknown parameters.

The utility represents the individual's value for each choice alternative, and its numerical value depends on attributes of the available options and the individual. An analyst never knows the true utility function, because of variables that are not included in the data set, that the analyst chooses to omit from the model (e.g., because he cannot forecast them well), or that are completely unknown to the analyst. The model estimates the probability that each alternative is chosen by an individual in a particular segment of the population, defined by geography (origin-destination of trip) and personal characteristics.

The simplest function used in mode choice models is the multinomial logit formulation. In this type of model, the probability of each alternative is expressed as shown in Equation 9-1.

$$P_i = \frac{\exp(V_i)}{\sum_j \exp(V_j)} \qquad (9\text{-}1)$$

where:

P_i = Probability of choosing alternative i

V_i = Utility (deterministic) of alternative i

The probabilistic nature of the choice reflects that the true nature of the complete utility function is unknown; the true utility includes variables not included in the deterministic component of utility V_i. The form of the utility functions is shown in Equation 9-2.

$$V_i = B_{i0} + \sum_k B_{ik} x_k \qquad (9\text{-}2)$$

where:

B_{i0} = The constant associated with alternative i

B_{ik} = The coefficient indicating the relative importance of variable k on choice i

x_k = The value of decision variable k

Another logit model form that is often used for mode choice is the **nested logit model**. Under a nested structure, the model pools together choice alternatives that share similarities, and the choice is represented as a multistep decision. The probability of choosing an alternative within its nest of similar alternatives is given by the multinomial logit formula (Equation 9-1). The probability of choosing a nest of alternatives among other nests at the same level also is given by Equation 9-1, where the nest utilities are composite utilities of the alternatives in the nest, computed using a logsum variable representing the expected maximum utility of the set of alternatives in the nest. The logsum is computed as the logarithm of the denominator of the multinomial logit mode choice probability function for the alternatives within the nest. Figure 9.1 depicts the multinomial and nested logit model structures.

In models with a mode choice component, the use of either a multinomial or nested logit model is considered **acceptable practice** in all regions. If there are more than two alternatives, the use of a nested logit model is considered **recommended practice**.

Figure 9.1 Multinomial and Nested Logit Models

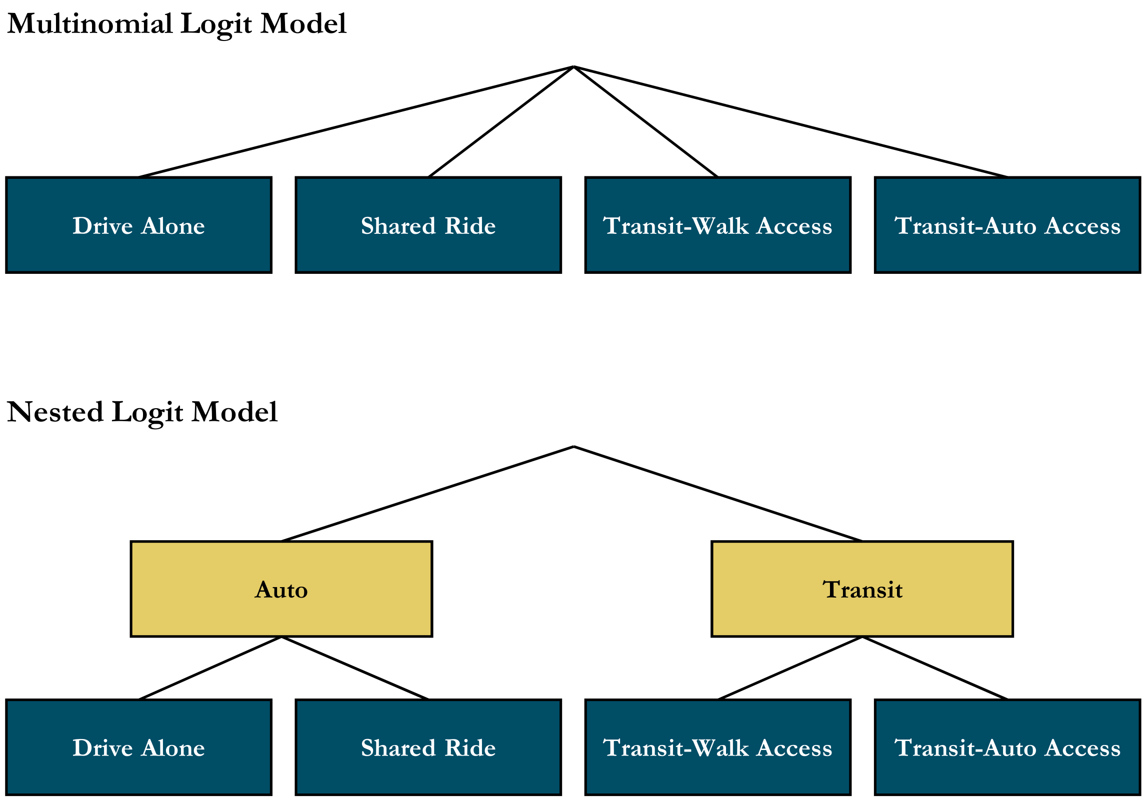
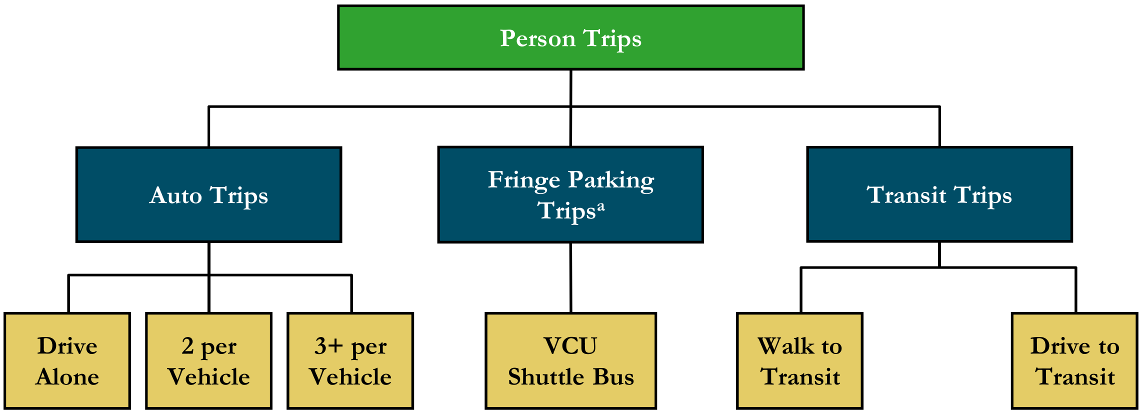


Figure 9.2 presents an example mode choice model from the RTC Model, Base 2008 Version 1.0. The model has six modes in three nests, including a separate mode for the Virginia Commonwealth University Shuttle Bus. Table 9.2 presents the coefficients (i.e., the B_{ik} from Equation 9-2) for the variables in the mode choice model.

Figure 9.2. RTC Mode Choice Model Nest Structure (Base 2008 Version 1.0)



[a] *For HBW and HBO purpose only.*

Table 9.2. RTC Mode Choice Model Coefficients (Base 2008 Version 1.0)

Parameters	Values	Equivalent IVTT
Level of Service Variables		
In-vehicle time (minutes)	-0.0250	1.00
Out-of-vehicle time (minutes)	-0.0500	2.00
Cost (cents)	-0.0015	0.06
Number of transfers	-0.1250	5.00
Nesting Coefficients		
Auto/transit	0.5	
Walk/drive/fringe to transit nest	1.0	
Other parameters		
Auto operating cost	10.5 cents per mile	
Shared-ride 2 average occupancy	2.0 passengers	
Shared-ride 3 average occupancy	3.2 passengers	
Auto parking cost	Defined at zone	
Value of time	$10.00 per hour	

Note: Mode choice model constants for the RTC model are split into three market segments based on the destination location – Downtown Richmond, Downtown Petersburg, and rest of the model region. Mode specific constants are developed for all purposes and time periods by market segment.

9.1.2 Modes

For regions using a mode choice model, it is **acceptable practice** to include only two travel modes, representing automobile and transit. It is **recommended practice** to include additional travel modes. Auto can be segmented into single-occupant vehicles (SOV) and high-occupancy vehicle (HOV), with HOV possibly being segmented into two-occupant and three (or more)-occupant vehicles if policies or investments that treat these vehicle occupancy classes separately are being considered in the region. In regions with significant travel by transit with auto access, transit should be segmented by auto access and walk access, with auto access potentially segmented by park-and-ride and kiss-and-ride (dropoff/pickup) if there is significant travel by each access mode. Transit may be further segmented by type of transit, such as local bus, express bus, commuter rail, light rail, and subway/elevated if these modes exist in the region. However, this additional segmentation should be considered only if these submodes truly compete with one another in the same geographic areas. There are costs and complexity associated with including more modes in the models.

If nonmotorized travel is carried through earlier model steps, at least a single nonmotorized mode is included in mode choice. The nonmotorized mode may be further segmented into walk and bicycle if there is significant bicycle travel in the region and sufficient data are available to estimate and validate the model for these modes.

9.1.3 Level of Service Variables

The variables in the mode choice model utility function (x_k in Equation 9-2) are primarily *level of service variables* that describe and distinguish the service experienced by travelers on each mode. Most of these variables reflect measures of travel time and cost although some (such as transit transfers) reflect other service characteristics.

The following level of service variables should be included in all models:

- **In-vehicle travel time** (IVTT) **–** The time spent traveling inside vehicles (autos or transit vehicles);
- **Out-of-vehicle travel time** (OVTT) **–** The time spent walking or bicycling to or from the main travel mode at both ends of the trip, transferring between vehicles, or waiting for transit vehicles; and
- **Cost –** The cost associated with travel, including auto operating costs, parking costs, tolls, and transit fares.

It is **acceptable practice** for all regions to include these three (aggregate) level of service variables in mode choice models. The individual variables are computed as TAZ to TAZ matrices through "skimming" the highway and transit networks using the modeling software.

It is **recommended practice** for all regions to consider additional level of service variables. These may include nontime/cost variables such as the number of transit transfers or segmentation of the three main variables. For example, OVTT may be separated into wait time, walk access/egress time, and/or transfer time. Cost may be segmented by type (auto operating, parking, tolls, and transit fares).

9.1.4 Other Variables

It is considered both **acceptable practice** and **recommended practice** for all model regions to use only level of service variables in mode choice models. However, other variables may be considered. These may include characteristics of the traveler or his household, such as income level or vehicle availability. Such variables may be used directly in the utility functions or may be used to segment the travel markets.

9.1.5 FTA Considerations in Mode Choice Model Development

Current Federal Transit Administration (FTA) guidance allows for the use of "local" travel forecasting procedures (as opposed to incremental methods or FTA Simplified Trips-On-Project Software (STOPS) model) to produce forecasts supporting Section 5309 New Starts and Small Starts applications. Thus, FTA recognizes that there are no standard or "correct" methods that are universally applicable to all regions. Mode choice models will need to reflect the fact that each metropolitan area has unique conditions and must be responsive to local decision making. If the models are used to forecast transit ridership, it is essential that they explain the current transit conditions and capture the tradeoffs between travel times and costs as well as fulfill their ultimate objective of yielding reasonable forecasts. These favorable properties are heavily dependent on the model calibration and validation procedures with rigorous quality assurance checks that are described in this chapter.

During review of forecasts that may support New Starts/Small Starts applications, FTA considers the follow aspects:

- The properties of the forecasting methods;
- The adequacy of current ridership data to support useful tests of the methods;
- The successful testing of the methods to demonstrate their grasp of current ridership;
- The reasonableness of inputs (demographics, service changes) used in the forecasts; and
- The plausibility of the forecasts for the proposed project.

As part of this review FTA looks for potential problems in mode choice models in "local" models. Some examples include: unusual coefficients in mode choice models, bizarre alternative-specific constants, and inconsistencies between path parameters (see Section 10.4 for discussion on transit path building) and mode choice coefficients. Since these problems can have a cascading effect of producing errors in trips, FTA suggests that modelers ask themselves if patterns across market segments are explainable. FTA also suggests that there be conformity between parameters used in transit path selection and mode choice utility expressions for transit choices. That is, the path building process must weigh the various travel time and cost components in a manner that is consistent with the relative values of the mode choice coefficients.

If a travel forecasting model is going to be used to produce forecasts support a New Starts or Small Starts application, FTA encourages early and regular communication with their travel forecasting staff during mode choice model development, even if it is independent of a specific transit project.

More information can be found at http://www.fta.dot.gov/grants/15681.html.

9.2 Mode Choice Validation

The mode choice model validation process is connected with the transit path building and assignment validation processes, which are described in Sections 10.4 and 10.6 respectively. Any calibration of the transit assignment process may lead to model changes that affect mode choice, whether they are network changes, revisions to path building or skimming, or other changes to the model. The mode choice models cannot be considered completely validated until the transit path building and assignment models also have been validated.

9.2.1 Data Sources for Validation

The main sources of data for validation of mode choice models include the following:

- **Transit ridership counts** have the best information on the total amount of travel by transit, usually at the route level. It is important to recognize, however, that ridership (boarding) counts represent "unlinked trips," meaning that a person is counted each time he or she boards a new transit vehicle. So a trip that involves transit transfers is counted multiple times. Mode choice models consider "linked trips," where a trip including transfers counts as only a single trip. Information on transfer rates is required to convert unlinked trips to linked trips; such information generally is obtained from transit on-board surveys.
- **Transit rider survey –** A transit rider survey (typically an on-board survey) is an invaluable source of information for validation of the transit outputs of mode choice models. A wealth of information that cannot be obtained from transit counts is available from on-board surveys, including:
  - Transit trip origin-destination patterns by trip purpose;
  - Access modes;
  - Transit paths (ideally, surveys should ask riders to list all routes used in order in the path for the linked trip);
  - Transit submodes used (e.g., bus, light rail);
  - Transit transfer activity; and
  - Characteristics of the surveyed riders and their households.
- **Household travel/activity survey –** For modeling in Virginia, the National Household Travel Survey (NHTS) Add On records are considered household surveys. The household survey is the best source for information on nontransit travel data since the number of observations for transit travel is usually small. The expanded household

survey data can be used to produce observed mode shares for nontransit travel by purpose for a number of geographic and demographic market segments.

- **Census data –** The Census Transportation Planning Products (CTPP) contain information on modes for work travel. The Census Bureau uses the American Community Survey (ACS), which is conducted continuously, to collect data on work location and travel (among other items). Section 6.2.1 discusses how work travel is treated differently in the ACS compared to travel models.
- **National sources –** National data sources include the National Household Travel Survey (NHTS), *NCHRP Report 716*, and other documents (e.g., *TCRP Report 73, Characteristics of Urban Travel Demand*).

9.2.2 Validation Checks

Table 9.3 summarizes the model validation checks for mode choice models.

Table 9.3 Mode Choice Validation Procedures for Virginia Travel Demand Models

Type of Check	Model Region Size	
	Small	**Large**
Check parameter estimates	Reasonableness check only	Reasonableness check only
Compare modeled trips by mode (mode shares) to observed data by market segment	Reasonableness check only	Reasonableness check only
Check modeled vehicle occupancy (if auto submodes are included)	Reasonableness check only	Reasonableness check only
Compare modeled transit trip lengths to observed data	Reasonableness check only	Reasonableness check only
Checks of model sensitivity to input variables	Reasonableness check only	Reasonableness check only

Check Parameter Estimates for Reasonableness

Mode choice model parameters, the coefficients and constants in the utility functions, may be estimated using local data, transferred from another model, or asserted. An important check is that all mode choice model parameters should be of reasonable sign and magnitude. Estimated parameters should be checked not only for reasonableness, but also for statistical significance. A complete set of statistical tests should be performed as part of the model estimation process.

The determination of "reasonable" requires experience and judgment. One common way of examining reasonableness is to compare the magnitude of model coefficients to those used in other models. Some of the national resources, including *NCHRP Report 716* and the FHWA Validation Manual, include examples of model parameters from areas around the U.S.

The values of model parameters, however, depend on model structure, the presence or absence of other variables, and the context of the area being modeled. It is not valid, for example, to assume that the coefficients in a model with three variables would be the same as the coefficients for the same variables in a model with those same three variables plus two others. It also would be unreasonable to assume that, for example, a cost variable coefficient in a model, which represents the sensitivity of mode choice to, say, one dollar of travel cost, would be the same in another model for an area with a significantly higher cost of living, or even in another model estimated for the same area 5 or 10 years earlier.

Level of service coefficients should always be negative in sign since higher values of the variables (time, cost) for a mode represent a worse level of service. These coefficients represent the sensitivity of mode choice to particular components of level of service. Therefore, they might be expected to have similar values for all mode choice models, at least those structured similarly, since it would seem unlikely that travelers in one urban area are far more or less sensitive to, say, wait time than they are in another area.

It is important to consider the coefficients not only individually, but also the relationships between them. In nearly all mode choice models, coefficients for variables representing out-of-vehicle time – including wait, walk access/egress, and transfer time – are greater in absolute value than in-vehicle time coefficients. This relationship implies that time spent waiting or walking is considered more onerous than time spent in a vehicle, usually sitting (see Table 9.2). Typically, the ratios of out-of-vehicle time coefficients to in-vehicle time coefficients are about 2 to 3 for home-based work trips with some higher values estimated for nonwork trips.

Another relationship that can be checked is the value of (in-vehicle) time, which is represented by the ratio of the in-vehicle time coefficient to the cost coefficient. Represented in dollars per hour, the values of time typically range from about $3 to $10 per hour for work trips, with lower values typical for nonwork trips.

If a nested logit mode choice formulation is used, a logsum variable is included in the model specification for each nest of modal alternatives. The coefficients of these variables are estimated or asserted. While there are no specific reasonableness checks of logsum variable coefficients, especially asserted coefficients, the coefficients' validity must be checked with respect to two rules:

- Logsum coefficients must be between zero and one. The coefficients should be statistically different from both zero and one (although statistical significance can be checked only for estimated coefficients, not for asserted coefficients).
- The logsum coefficient for a nest should be lower than the logsum coefficient for any higher level nest of which the nest is a component.

Mode-specific constants also are model parameters that should be checked for reasonableness. Checks of constants are discussed in Section 9.2.3.

Comparison of Modeled Trips to Observed Data

The most basic aggregate checks of mode choice model results are comparisons of modeled trips by mode, or mode shares, to observed data by market segment. Market segments include trip purposes as well as demographic segments, such as income or vehicle availability levels, and geographically defined segments.

Mode choice models are applied using person trip tables as inputs. The mode choice model's results, therefore, represent shares of the total trip table that use each of the mode choice alternatives. Validation of the model's aggregate results involves checking the shares for the model's base-year scenario results against observed mode shares.

A household survey is the only comprehensive data source covering all modes, and therefore is the only source for mode shares. However, shares for modes that are used relatively infrequently – notably transit modes – as well as mode shares for relatively small segments of the population (for example, zero-vehicle, high-income households) cannot be accurately estimated from household surveys due to small sample sizes. While it may be problematic to find an alternate source for some segments or modes (such as bicycle travel), transit trips and shares by segment may be estimated using other data sources, including ridership counts and transit rider surveys.

Transit ridership counts provide estimates of total transit trips, not mode shares. To convert these trips to shares, an estimate of the total trip table for each market segment is needed. Assuming good validation of the trip generation and distribution components, the trip table outputs from the trip distribution model can provide this information. Basically, the transit trips by submode, access mode, trip purpose, and other segmentation level, segmented using the transit rider survey data (and converted from unlinked trips to linked trips), can be subtracted from the total trips represented in the trip distribution outputs to obtain estimates of "observed" nontransit trips. The nontransit trips can be separated into trips by individual mode (auto and nonmotorized submodes) using information from the household travel survey.

Check Modeled Vehicle Occupancy

Checks of vehicle occupancy are performed when the mode choice model includes more than one auto submode (for example, SOV and HOV). In such cases, the split between the auto submodes, which represent vehicle occupancy levels, must be checked. (If only one auto mode is included in the mode choice model, vehicle occupancy factors are used to convert the auto person trips from the mode choice outputs to auto vehicle trips for use in highway assignment.)

The most basic check is to compare the modeled base-year model shares of trips made by vehicle occupancy, both by trip purpose and for all trips, to observed shares. When a sufficient household survey data set is not available, modeled occupancy levels may be compared to representative data from another data set, such as the NHTS, CTPP, or *NCHRP Report 716*. In many cases, the national observed data sources do not represent observed data for the modeled area, and so a precise match is not necessary. The comparison represents more of a reasonableness check.

Comparisons of Modeled Transit Trip Lengths to Observed Data

If observed data on transit trip lengths are available, modeled transit trip lengths should be compared to the observed data. While this is a check of both trip distribution and mode choice, the mode choice model must be run before this check can be performed.

Data on transit trip lengths is usually obtained from transit rider surveys. There are two levels at which observed transit trip length data may be available:

- For the in-vehicle portion of transit trips (stop to stop); and
- For entire trips (origin to destination).

Modeled trip lengths can be obtained for either level although the analyst should be careful to ensure that the model results are on a consistent basis with the observed data. For example, say a commuter rail survey yields data on the average length of trips on commuter rail. In this case, for modeled trips that include both commuter rail and bus segments, the length of the commuter rail segment must be considered when comparing to the observed data.

At either level, it is worthwhile for transit trip length comparisons to be segmented using available variables. If the survey data source can provide statistically significant information on trip lengths by trip purpose, traveler/household characteristics (e.g., income level), or subregional geography, it makes sense to perform the comparisons by market segment.

Sensitivity Testing

Sensitivity testing can be performed for mode choice models by varying model inputs and checking results for reasonableness. Model inputs that can be varied include level of service variables (time/speed and cost) and any demographic or TAZ level variables that are used as model inputs. Some example tests include:

- Increasing or decreasing highway or transit travel times by a fixed percentage regionwide;
- Increasing/decreasing parking costs in the CBD by a fixed percentage;
- Increasing/decreasing automobile operating costs (e.g., fuel cost in real terms) by a fixed percentage;
- Increasing/decreasing headways on selected transit routes or submodes by a fixed percentage or amount;
- Increasing/decreasing fares on selected transit submodes by a fixed percentage;
- Changing development patterns for forecast years by moving projected new activity among different parts of the modeled region (e.g., from suburbs to small urban centers or from outlying areas to infill); and
- Reallocating the number of households by income level for a forecast year.

The resultant changes in demand due to changes in a model input variable reflect the sensitivity to the variable; the sensitivity level is determined by the coefficient of the variable in the utility function. Simple "parametric" sensitivity tests can be performed by introducing small changes in the input variable or in the parameter itself and checking the results for reasonableness. It can be important to consider that for certain input parameters, the original calibration data for a regional model may include only a narrow range of experienced values (e.g., automobile operating cost per mile). For these parameters in particular, care should be taken in interpreting the outputs of sensitivity tests, particularly when large changes are specified in the input parameters.

The changes in demand for a modal alternative (or group of alternatives) with respect to a change in a particular variable can be expressed as arc elasticities. While there are some rules of thumb for what constitute reasonable elasticities, there are no specifically defined ranges of reasonable elasticities. Generally, experience has shown that elasticities of transit demand with respect to level of service variables are usually well under 1.0 in absolute value. According to work performed as part of the Traveler Response to Transportation System Changes series [20], the Simpson & Curtin formula indicates that the midpoint arc elasticity of transit demand with respect to fare is about –0.4.[16] It is important to recognize that since the logit formulation is nonlinear, the elasticities of modal demand are not constant. The elasticity calculated for one particular "point" (say, a specific market segment defined geographically, demographically, and temporally) will not be equal to the elasticities computed at other points.

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[16] The "Simpson-Curtin Rule," a commonly cited guide, is evolved from simplified use of a formula that describes a shrinkage ratio relationship, not an elasticity relationship, as is explained in TCRP Report 95.

9.2.3 Model Calibration and Troubleshooting

Issues discovered during the model checks described in Section 9.2.2 may imply errors in mode choice model parameters, input data (networks/skims or trip tables), or highway or transit path building procedures. Some of the typical problems that may be evident from these tests include the following:

- Transit demand for specific market segments is too high or low: Check trip distribution to determine if the overall travel in the market is correct, check implied transit share for the market, recheck transit skim data related to the market, consider revisions to the logit model structure, consider adding or removing indicator variables related to the market, consider revisions to mode-specific constants (see discussion below).
- Nonmotorized mode shares for specific market segments are too high or low: Check trip distribution to determine if overall travel in the market is correct, recheck skim data (usually distance skims) related to the market, consider adding or removing indicator variables related to the market or adjusting the coefficients of existing indicator variables, consider revisions to mode-specific constants (see discussion below).
- Modeled vehicle occupancy by trip purpose differs significantly from observed levels: Check observed data for errors, check sensitivity to mode choice model input variables and consider adjusting logit model parameters, consider adding or removing indicator variables related to the market or adjusting the coefficients of existing indicator variables, consider revisions to mode-specific constants (see discussion below).
- Auto submode shares for specific market segments are too high or low: Check trip distribution to determine if overall travel in the market is correct, check implied mode share for the market, recheck skim data related to the market, consider adding or removing indicator variables related to the market or adjusting the coefficients of existing indicator variables, consider revisions to mode-specific constants (see discussion below).
- Model too sensitive or insensitive to changes in level of service: Adjust parameters for appropriate level of service variables in utility functions.

Mode-Specific Constants

The interpretation of a mode-specific constant is that it represents the part of the modal utility that is not considered by the variables in the utility function. The variables represent measurable characteristics of the trip, the traveler, and the area on which the trip is made that affect the choice of mode. The constant, therefore, represents the sum of items that affect the choice that are not included in the variables. These items may include reliability, comfort, convenience, safety, and many other factors.

In model estimation, the original values of constants are estimated. The constants can easily be revised so that modeled mode shares match targets. It is evident that the "correct" values for modal constants are unknown since they represent factors affecting choice that could not be quantified sufficiently to be included in other mode variables. It would be incorrect, however, to assume that all validation issues are the result of these unknown factors. As is the case with K-factors in trip distribution (discussed in Section 6.2.3), simple adjustments to modal constants estimated using weighted samples should be considered "a last resort" after all other possible causes for error and calibration adjustments have been considered, and so this is why they are listed as the last items in each bullet above. Because constants can be revised to provide nearly perfect matches between modeled and observed mode shares, it can be very tempting to revise modal constants to resolve differences in shares without determining whether it is the best method to solve the problem at hand.

The values of mode-specific constants, whether estimated or revised during calibration, should be checked for reasonableness. One way of doing this is to compare the value of a constant relative to the constants of other modal alternatives to the values of other parameters. For example, the difference between the rail and bus constants could be divided by the in-vehicle time coefficient to express the difference in units of minutes of "equivalent" in-vehicle time. If the difference between two constants was –0.5 (with the rail constant higher), and the in-vehicle time coefficient was the same for the two modes and equal to -0.025, the difference in the constants is equivalent to –0.5/–0.025 = 20 minutes of in-vehicle time. This implies that all other things being equal, a traveler would be indifferent between a bus trip and a rail trip that is 20 minutes longer.

The interpretation of differences between constants can be muddied somewhat by modal availability issues. For example, it is common to see transit constants that are so much lower than auto constants that it is implied that a traveler would be indifferent between a transit trip and an auto trip that is several hours longer. However, many travelers may not have the auto mode available while others do not consider transit as a viable mode.

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CHAPTER 10. TRIP ASSIGNMENT

Trip assignment is the fourth and final step of the four-step modeling process. It includes:

- **Highway assignment**, in which the routes of auto and truck vehicle trips along the highway network are estimated; and
- **Transit assignment**, in which the routes of person trips along the transit network are estimated. Transit assignment is performed only in models where transit travel is considered.

This chapter describes the policies and procedures for developing, validating, and calibrating highway and transit assignment models in Virginia. It also covers the related topic of highway and transit **"network skimming."** The skimming process entails creating TAZ to TAZ matrices of level of service (time and cost) variables using the optimal paths between TAZs. These matrices are key inputs into the trip distribution and mode choice processes. The relationship between network assignment and skimming is that both involve building optimal paths between TAZs. The assignment process uses these paths to load the highway vehicle and transit person trip tables onto the network to obtain roadway volumes and transit boardings and volumes. The skimming process uses the paths to develop the matrices of level of service variables.

This chapter is organized as follows. Section 10.1 discusses highway assignment while Section 10.2 presents the procedures for transit assignment. Section 10.3 describes highway network skimming while Section 10.4 discusses transit network skimming. The process of highway assignment validation is described in Section 10.5 while Section 10.6 discusses transit assignment validation.

10.1 Highway Assignment Practice

The policies and procedures for highway assignment practice in Virginia are summarized in Table 10.1.

Table 10.1 Highway Assignment Practice for Virginia Travel Demand Models

Component	Acceptable		Recommended	
	Small	Large	Small	Large
Assignment algorithm	Any multipath method	Equilibrium assignment	Equilibrium assignment	Equilibrium assignment
Time periods modeled	Daily	Daily; AM, PM, and off-peak	Daily; AM, PM, and off-peak	Daily; AM, PM, midday, and night
Speed-volume relationship	BPR, conical, or Akcelik function		BPR, conical, or Akcelik function	

The main inputs to highway assignment include the highway network, as described within Section 4.1.3, and the vehicle trip tables. The vehicle trip tables may include:

- **Internal auto vehicle trip tables**, which are outputs of the mode choice model (see Chapter 9), or the trip distribution model (see Chapter 6) if a three-step process is used;
- **External vehicle trips** (see Chapter 7); and
- **Truck trip tables** (see Chapter 8).

The internal auto vehicle trip tables may include separate tables for single occupant vehicles (SOV) and high-occupancy vehicles (HOV) if these modes are distinguished in the mode choice model (see Section 9.1.2). It is usual practice to model SOV, HOV, and trucks as separate vehicle classes through a multiclass assignment procedure, which is readily implementable in the modeling software.

Highway assignment determines vehicle routing from origin to destination along shortest paths along the network, with consideration of the effects of congestion on travel time. This is done through **volume-delay functions**, which include parameters relating travel time to volume and capacity. All vehicle trip tables are assigned together in a process known as **equilibrium assignment**.

10.1.1 Assignment Algorithm

Although there has been considerable progress made in the development of regional dynamic traffic assignment procedures, the state of the practice for highway assignment currently is static equilibrium assignment, even in areas with activity-based travel demand models. Equilibrium assignment is a multipath procedure where vehicle trips are loaded from origin to destination through an iterative process. During each iteration, the trips for each origin-destination TAZ pair are assigned to a single shortest path along the network (each iteration is known as an "all or nothing" assignment). The loadings from the iterations are weighted in a manner that results, at convergence, in the travel times along all paths being equal. This ensures that no driver could improve his travel time by changing his or her path. This property is Wardrop's first principle of equilibrium [21].

Iterative multipath assignment procedures have been in use for decades, with various procedures used to weight the iterations. Among these methods, equilibrium assignment is defined as the procedure that satisfies Wardrop's first principle. Since equilibrium assignment procedures are readily available in modeling software, it is **recommended practice** for all areas for highway assignment. In smaller areas, other multipath methods are considered **acceptable practice**.

In practice, it requires a large number of iterations to achieve true convergence, as noted in a report, "Investigation of New Equilibrium Assignment Methods for the VDOT Travel Demand Models," prepared for VDOT by Old Dominion University (ODU) [22], as well as research done by others. The ODU report recommends that assignments run until a relative gap (a measure of the difference in results between consecutive iterations) of 1E-04 is achieved. Achieving convergence is important in having a good model since insufficient convergence can result in unexplainable differences between the results of scenarios. The number of iterations required to achieve a relative gap of 1E-04 can be high in networks for large urban areas. Model operational considerations (e.g., run times) can come into play in ultimately setting threshold values. The ODU report notes that the biconjugate Frank-Wolfe algorithm in VDOT's currently adopted modeling software is more efficient than the Frank-Wolfe algorithm in achieving convergence, and it is the **recommended practice** as of 2012.

10.1.2 Time Periods Modeled

In large areas, it is considered both **acceptable practice** to perform highway assignment separately for at least three time periods: the morning peak, evening peak, and off-peak periods. These periods comprise a 24-hour average weekday. Most large areas separate the off-peak period into midday and night periods, however, and this is **recommended practice** for these areas in Virginia.

The daily trips are divided into trips by time period prior to assignment. This may be done immediately prior to assignment (i.e., after mode choice) or earlier in the modeling process (after trip generation or trip distribution). In four-step models in Virginia, this is accomplished through the use of factors applied to daily trips by trip purpose and direction (production to attraction or attraction to production). The factors are typically derived from household survey data.

It is sometimes desirable to have traffic volume results for each peak hour (as distinguished from the peak periods which may be two or more hours long). This can be accomplished by further subdividing the time periods for assignment although this is not required practice. Peak hour volumes may be obtained by factoring peak-period volumes, with factors often derived from traffic count data.

Note that the use of fixed factors for peak period and peak hours means that peak spreading is not explicitly considered in four-step models. There are a handful of examples of time-of-day choice models associated with four-step models, which allow peak spreading to be considered. However, these are often complex and difficult to estimate and validate, and so they are not required practice in Virginia.

Smaller areas also may consider assignment by time period if there is a desire for volumes by period. It is considered **acceptable practice** in smaller areas to perform highway assignment for the entire 24-hour average weekday without respect to time periods. However, it is considered **recommended practice** in smaller areas to perform highway assignment for at least three time periods.

10.1.3 Speed-Volume Relationship

To consider the effects of traffic congestion on travel times and speeds, highway assignment processes use relationships of volume, capacity, and speed/time at the link level. These speed-volume relationships, often called "volume-delay functions," may vary by roadway type (and sometimes by time of day).

Another report, "Evaluation of Volume-Delay Functions and their Implementation in VDOT Travel Demand Models," prepared for VDOT by ODU [23] examined three volume-delay functions used in highway assignment: the BPR, Conical, and Akcelik functions.

The BPR function has the following form:

$$T=T_0*[1+\alpha*(V/C)^{\beta}] \qquad (10\text{-}1)$$

Where:

T=average link travel time

T_0=link travel time at free-flow status

V=volume (or demand)

C=capacity

α and β=parameters

The conical function has the following form:

$$T=T_0 * (2+(\alpha^2*(1-V/C)^2+\beta^2)^{1/2}-\alpha*(1-V/C)-\beta) \qquad (10\text{-}2)$$

Where:

T =average link travel time

T_0=link travel time at free-flow status

V= volume (or demand)

C =capacity

$\beta=(2\alpha-1)/(2\alpha-2)$, $\alpha>1$

The Akcelik function has the following form:

$$T = T_0+0.25*t*((V/C)-1+((V/C-1)^2+(V/C)*8*J/Q/t)^{1/2}) \qquad (10\text{-}3)$$

Where:

T=average link travel time per unit distance (hr)

T_0= free-flow travel time per unit distance (hr)

V= volume or demand (vph)

C = link capacity (vph)

Q = lane capacity (vph)

J= delay parameter

t = flow period (typically 1 hr)

Any of these functions, which are described in detail in this ODU report, are considered both **acceptable practice** and **recommended practice** for all areas. The parameters of the function that is used should be adjusted during model validation to optimize the model results. This report suggests the following acceptable ranges for the two parameters in the BPR formula:

- The value of α should be between 0 and 2; and
- The value of β should be between 1 and 10.

10.2 Transit Assignment Practice

The policies and procedures for transit assignment practice in Virginia are summarized in Table 10.2. These apply only in regions where transit is modeled explicitly.

Table 10.2 Transit Assignment Practice for Virginia Travel Demand Models

Component	Acceptable		Recommended	
	Small	**Large**	**Small**	**Large**
Assignment method	Shortest path	Shortest path	Multipath	Multipath
Time periods modeled	Daily	Peak and off-peak	Daily	Peak and off-peak

The main inputs to transit assignment include the transit network, described in Section 4.1.3, and the transit person trip tables, which are outputs of the mode choice model. As discussed in Chapter 9, typically there are separate trip tables for transit with walk access and transit with auto access; additional transit submodes also may be modeled. The transit path building process includes various parameters (described in Section 10.4).

Transit assignment determines the routing of transit passengers from origin to destination along shortest paths along the transit network, including access and egress through walking or automobile. Transit assignment procedures in Virginia generally do not consider the effects of capacity constraints on route choice since in most cases capacity of transit vehicles is not a major issue. Multipath assignment procedures are used to reflect the differences among transit riders' values of the time and cost associated with the various components of the transit trip, including time spent riding in transit vehicles, walk and auto access/egress, wait time, and transferring.

10.2.1 Assignment Method

It is considered **acceptable practice** in all areas to perform transit assignment using a single minimized generalized cost path for each origin-destination TAZ pair. This should be adequate in cases where there are few transit options. It is considered **recommended practice** in all areas to use a multipath transit assignment process. The currently adopted VDOT modeling software platform includes such an assignment procedure, the PT module.

10.2.2 Time Periods Modeled

In some areas the transit level of service may differ considerably between peak and off-peak periods. For example:

- Some express services may run only during peak periods;
- Service frequency on some routes may be substantially higher in peak periods; and
- Transit fares may vary by time of day, as is the case with the WMATA rail service.

In such cases, it is desirable to assign transit trips separately for peak and off-peak periods. The peak periods need not be defined in exactly the same way as for highway assignment.

It should be noted that in most cases, auto access or egress is at the home end of the trip, regardless of whether that represents the origin of the trips – the home end is the destination for trips made by persons returning home. The simplest way to deal with this issue is to assign transit trips with auto access from the production (home) end to the attraction (nonhome) end, regardless of whether the traveler is leaving from or returning home. This reduces the number of transit paths required for assignment and provides the opportunity to combine the morning peak and evening peak periods into a single peak period for transit assignment, further reducing computation. In a combined peak period, the same paths are used for trips leaving from and returning home. Since this process presents trips returning home as if they had boarded the transit vehicle at the transfer point between the transit and auto egress trip segments, the boardings and alightings at stations must be determined by treating half of the boardings as alightings. This simplification is not exact (since travelers may make one direction of a round trip during the combined peak period and the other direction in the off-peak period), but this approximation is usually good enough for most planning purposes.

It is considered both **acceptable practice** and **recommended practice** for small areas to perform transit assignment at the daily level. It is considered both **acceptable practice** and

recommended practice for larger areas to perform transit assignment for two periods, peak (combined) and off-peak.

10.3 Highway Network Skimming

Highway network skimming is performed using modeling software sometime prior to trip distribution, the first model component for which it is a required input. There are two variables for which highway skim matrices are produced, travel time and distance. Sometimes toll cost may be skimmed as well, if priced roadways exist in the network. Other highway-related costs are either related to distance (auto operating cost) or are related to the attraction end of the trip (parking cost) and need not be skimmed. For models involving HOV facilities, the highway network is prepared with special limit codes on HOV facilities and a separate skim table is produced including time and distance employing HOV links where applicable (the HOV links are not considered in the non-HOV skim table in such cases).

In some models, especially larger models and those for which feedback loops are used (see Chapter 11), the skims represent "congested" travel times from a loaded network. Because models will converge more quickly if the starting travel times are closer to the final times, it is efficient to create some type of loaded network to skim. Sometimes this is done by assigning a vehicle trip table developed from another source, such as the expanded household survey data.

The process of creating highway network skims in modeling software is straightforward, with the user needing to supply only the highway network to be used and to define the variables to be skimmed. The paths for which the skims are produced reflect the least generalized cost paths. If a loaded network is skimmed, and the assignment used for loading the network was a multipath assignment, there may be multiple paths used for assignment; however, the skims will reflect the shortest path found by the modeling software path building process. If the assignment was a reasonably well converged equilibrium assignment, this is not really an issue since the travel times along all used paths for each origin-destination pair are approximately the same. The distances may vary among the paths used, but usually they are not very different from the distance along the shortest travel-time path found by the modeling software.

10.4 Transit Network Skimming

Transit network skimming is somewhat more complex than highway network skimming, for two reasons:

1. Skim matrices for more variables need to be produced. These variables typically include transit in-vehicle time, wait time, transfer time, walk access and egress time, auto access time, and fare. Sometimes the number of transfers is skimmed.
2. The best paths are determined not by a single variable such as travel time but by a weighted combination of the various components of transit level of service (time and cost), often the same variables for which skim matrices are produced.

The weights used in combining the effects of the different variables should be consistent with the relative values of the coefficients of the variables in the mode choice model's utility function (i.e., the parameters B_{ik} in Equation 9-2). Since the mode choice parameters may vary by trip purpose, it is customary to use the relative weights from the home-based work mode choice model.

Multipath transit path building algorithms in modeling software allow the creation of transit skims from multiple "best" paths. If such a procedure is used, this means that the particular values for an origin-destination TAZ pair in the skim matrices may not correspond to any particular path.

Note that the FTA guidance presented in Section 9.1.5 is relevant to the path building procedures.

10.5 Highway Assignment Validation

10.5.1 Data Sources for Highway Validation

The main sources of data for validation of highway assignment include the following:

- **Traffic counts** have the best information on link-level volumes and also can be used to produce measures of vehicle-miles traveled (VMT). Traffic count data used for highway assignment validation should be directional if peak and off-peak periods are being modeled and should be segmented by these time periods. Vehicle classification counts are needed to validate truck volumes from the assignment process. The primary source for traffic count data in Virginia is the Traffic Engineering Division, Traffic Monitoring Section (see also Section 4.2.2). It must be noted that traffic counts can have substantial variation; a good discussion of this issue can be found in Section 9.1.1 of the FHWA Validation Manual.
- **Speed data –** Speed data that can be used in highway assignment model validation includes data from standardized approaches and field studies. The data collected can vary from simple point-to-point travel times to run times, cruise times and signal delay times, delay times due to incidents, and in some studies, coincident traffic counts on the facilities traversed. As with traffic count data, travel time and speed studies may be subject to substantial variation depending on the day or days the data are collected. Standardized approaches include using commercial sources (e.g., INRIX or Tom Tom), archived real time data from VDOT road sensors, and the FHWA National Performance Management Research Data Set).
- **HPMS –** The Highway Performance Monitoring System (HPMS) estimates VMT from traffic counts. Regional VMT estimates provide a basis for comparison with modeled VMT. However, prior to using the observed regional VMT based on the HPMS data, the consistency of the HPMS data and the modeled data should be verified. Consistency checks should include the HPMS area covered versus area covered by the travel model, the facilities included in HPMS (e.g., local streets) versus facilities included in model; and

whether VMT estimates are based on average annual daily traffic or average annual weekday traffic.

- **Other data sources –** Various data sources that include some bases for comparison of aggregate model outputs include the NHTS, *NCHRP Report 716*, and the FHWA Validation Manual.

10.5.2 Highway Assignment Validation Checks

Table 10.3 summarizes the model validation checks for highway assignment.

Table 10.3 Highway Assignment Validation Procedures for Virginia Travel Demand Models

Type of Check	Model Region Size	
	Small	Large
VMT by link group (facility type, geographic subregion, etc.)	See Table 10.4	See Table 10.4
R^2 between modeled volumes and counts on links	0.92	0.90
Percent root mean square error	See Table 10.5	See Table 10.5
Cordon line and screenline volume checks	< 54,000: ± 10 percent ≥ 54,000 and < 250,000: see Figure 10.2 ≥ 250,000: ± 5 percent	< 54,000: ± 10 percent ≥ 54,000 and < 250,000: see Figure 10.2 ≥ 250,000: ± 5 percent
Cutline volume checks	< 250,000: see Figure 10.2 ≥ 250,000: ± 5 percent	< 250,000: see Figure 10.2 ≥ 250,000: ± 5 percent
Speed checks	Reasonableness checks only	Reasonableness checks only

Generally, highway assignment checks consist of comparisons of base-year model outputs, based primarily on link volumes, to observed data from traffic counts. Many comparisons, such as VMT and screenline, cutline, and cordon line volumes, are based on aggregations of data from the link volumes. If observed speed data are available, output model speeds may be compared to the observed speed data for the base year.

If highway assignment is performed for peak and off-peak time periods, the validation checks described in this section should be performed for the assignment results for each period, as well as for the entire average weekday (the sum of all periods). The best way to perform these checks is to first perform the validation checks for the entire day, and when the daily assignment results have been sufficiently validated, to then check the results for each time period. So the same set of checks (e.g., VMT, R^2, percent root mean square error, screenline, etc.) would be performed multiple times, first for the entire daily results, and then for each period of interest (a.m. peak, p.m. peak, etc.). Because the daily checks will verify that the overall amount of highway travel is reasonable, the time period checks are important mainly to verify whether the split of travel among time periods is reasonable. It is important to note that because volumes for periods of a few hours are substantially lower than daily volumes, the guidelines involving percentages of differences are necessarily somewhat looser than those for daily results. For example, the guidelines for checks of percent root mean square error provide higher thresholds for differences for lower volume groups. Since the distribution of peak period link volumes will be skewed toward the lower volume groups compared to daily volumes, more links will be examined using these higher thresholds.

Checks of truck volumes should be conducted separately in addition to checks of total volumes. The vehicle classification traffic count data are used in these comparisons.

It is critical to note that the guidelines presented in Table 10.3 should **not** be treated as pass-fail tests for model validation. Matching or exceeding the guidelines is not sufficient to determine the validity of a model, nor is it a requirement for a validated model. Experience has shown that models can be overcalibrated; making too many changes to attempt to meet validation guidelines can decrease a model's predictive capability.

VMT Checks

Base-year VMT produced by the model can be compared to observed VMT estimated from the traffic count data (for links with counts) or from HPMS data. The VMT checks should be made for the region and by market segment. Markets may include facility type, area type, and geographic subdivision (e.g., county or superdistrict).

As distinguished from the tests described later in this section, VMT checks provide an overall modeling process check. Different information regarding the modeling process can be inferred from each level of the summaries:

- *Regional VMT summaries* provide an indication of the reasonableness of the overall level of travel. The results help confirm that the trip generation, trip distribution, and mode choice models, as well as the assignment process, are performing reasonably.
- *VMT summaries by facility type* provide an overall indication of the operation of the assignment procedures. These results of these summaries might indicate issues with free-flow speeds, link capacities, or volume-delay functions, any of which may vary by facility type.
- *VMT summaries by geographic area* may be useful for uncovering geographic biases in the modeling process. These biases might relate to previous steps in the modeling process.
- *VMT summaries by combinations of the above strata* may provide additional diagnostic information if one of the above summaries indicates a validation problem.

Table 10.4 lists some example guidelines used for the match between modeled and observed VMT by facility type and area type for some other states, including Ohio, Florida, and Michigan, as well as guidelines prepared by FHWA in 1990.

Table 10.4 Example VMT Guidelines by Functional Class and Area Type

Stratification	Modeled Versus Observed VMT				
	Ohio[a]	Florida[b]		Michigan[c]	FHWA[c]
		Acceptable	Preferable		
Functional Class					
Freeways/Expressways	±7%	±7%	±6%	±6%	±7%
Principal Arterials	±10%	±15%	±10%	±7%	±10%
Minor Arterials	±10%	±15%	±10%	±10%	±15%
Collectors	±15%	±25%	±20%	±20%	±20%
All Links		±5%	±2%		
Area Type					
CBD	±10%	±25%	±15%		
Fringe	±10%	±25%	±15%		
Urban	±10%	±25%	±15%		
Suburban	±10%	±25%	±15%		
Rural	±10%	±25%	±15%		

[a] Giaimo, Gregory, Travel Demand Forecasting Manual 1 – Traffic Assignment Procedures, Ohio Department of Transportation, Division of Planning, Office of Technical Services, August 2001.

[b] FSUTMS-Cube Framework Phase II, Model Calibration and Validation Standards: Model Validation Guidelines and Standards, prepared by Cambridge Systematics, Inc., for the Florida Department of Transportation Systems Planning Office, December 31, 2007, Table 3.9, page 3-16.

[c] The FHWA Travel Model Improvement Program Workshop over the Web, The Travel Model Development Series: Part I – Travel Model Estimation, prepared by Cambridge Systematics, Inc., June 9, 2009, Slide 11, http://tmip.fhwa.dot.gov/sites/default/files/presentation_8_with_notes.pdf, accessed November 29, 2009.

Link Volume Checks

Traffic volume-related checks compare modeled to observed traffic volumes at the link level. Consequently, the amount of difference between the modeled and observed traffic for each link contributes directly to the overall measure of closeness even when the results are aggregated in different ways. This is in contrast to the VMT checks described above where a positive difference on one link can cancel a negative difference on another link. The traffic volume-related checks described in this section focus on traditional measures that are scalable and easily explained: percent root mean square error (%RMSE) and coefficient of determination (R^2).

Percent Root Mean Square Error (%RMSE)

%RMSE for a set of links can be calculated using Equations 10-1 and 10-2.

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}\left[(\text{Count}_i - \text{Model}_i)^2\right]}{N}}$$

(10-1)

$$\%\text{RMSE} = \frac{\text{RMSE}}{\left(\frac{\sum_{i=1}^{N}\text{Count}_i}{N}\right)} \times 100$$

(10-2)

Where:

$Count_i$ = The observed traffic count for link i;

$Model_i$ = The modeled traffic volume for link i; and

N = The number of links in the group of links, including link i.

%RMSE is a measure of accuracy of the traffic assignment measuring the average error between the observed and modeled traffic volumes on links with traffic counts. As such, %RMSE should be summarized by facility type or by link volume group. Summarizing the measures by geography also can provide good validation information, especially if the measures continue to be stratified by facility type or volume group.

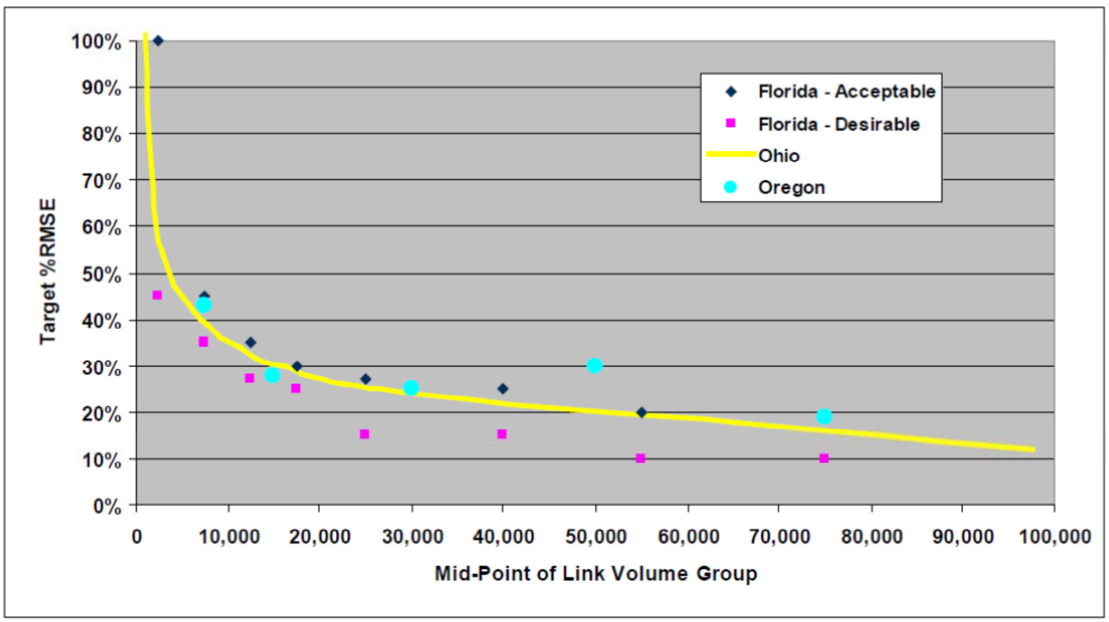
Table 10.5 provides guidelines for target %RMSE by volume group, based on guidelines used in Florida [24]. Guidelines for other segmentation plans, such as facility types and time periods, can be derived from Table 10.5 by noting the average volume for each segment. Figure 10.1 depicts graphically the %RMSE guidelines in three states (Florida, Ohio, and Oregon).

Table 10.5 Percent RMSE Guidelines [24]

Volume Range	%RMSE Guideline
Less than 5,000	100%
5,000-9,999	45%
10,000-14,999	35%
15,000-19,999	30%
20,000-29,999	27%
30,000-49,999	25%
50,000-59,999	20%
Greater than 60,000	19%
Areawide (daily)	40%

Note: The areawide daily guideline is based on VDOT practice (the FDOT areawide guideline is 45%).

Figure 10.1 Example %RMSE Guidelines



Sources: Ohio - Giaimo, G., Travel Demand Forecasting Manual 1–Traffic Assignment Procedures
Florida - FSUTMS-Cube Framework Phase II, Model Calibration and Validation Standards: Model Validation Guidelines and Standards
Oregon: FSUTMS-Cube Framework Phase II, Model Calibration and Validation Standards, Draft Technical Memorandum 1.

R-Squared (R^2)

Pearson's product-moment correlation coefficient (*R*) is a standard statistical measure available in spreadsheet programs and other readily available software packages. *R* is a dimensionless index that ranges from –1.0 to 1.0 inclusive that reflects the extent of a linear relationship between two data sets. It is calculated as shown in Equation 10-3.

$$R = \frac{N \times \left[\sum_{i=1}^{N}(\text{Count}_i \times \text{Model}_i)\right] - \left(\sum_{i=1}^{N}\text{Count}_i\right) \times \left(\sum_{i=1}^{N}\text{Model}_i\right)}{\sqrt{\left[\left(N \times \sum_{i=1}^{N}\text{Count}_i^2\right) - \left(\sum_{i=1}^{N}\text{Count}_i\right)^2\right] \times \left[\left(N \times \sum_{i=1}^{N}\text{Model}_i^2\right) - \left(\sum_{i=1}^{N}\text{Model}_i\right)^2\right]}} \tag{10-3}$$

Where $Count_i$, $Model_i$, and N are as defined as in Equations 10-1 and 10-2.

The coefficient of determination, R^2, which is simply the square of *R*, is typically interpreted as the proportion of the variance in a dependent variable that is attributable to the variance in an independent variable. This traditional interpretation does not hold for traffic assignment validation since the modeled traffic assignment is not dependent on the traffic count, or vice versa.

In effect, R^2 has been assumed to be a measure of the amount of variation in traffic counts "explained" by the model. R^2 must be used with caution. An R^2 value for all links in the region implies that links with high capacities (e.g., freeways) can, and usually do, carry more traffic than links with low capacities (e.g., local streets). As such, the value of R^2 probably says more about the coding of facility type and number of lanes than about how the model and assignment is performing.

Scatterplots of modeled traffic volumes versus the observed traffic volumes can provide useful visual validation tools. These can be used in connection with the R^2 summaries.

Cordon Line, Screenline, and Cutline Checks

Comparison of modeled volumes to observed counts for sets of critical links, especially along cordon lines, screenlines, and cutlines, are useful for assessing model quality. Cordon lines, screenlines, and cutlines are defined in Section 4.2.2. It is recommended practice that small model regions include at least 10 percent of their non-centroid links in their screenline, cordon line, and cutline coverage. For large model regions, it is recommended that at least 5 percent of their non-centroid links be included in their screenline, cordon line, and cutline coverage. Below are summarized the definitions and the relevant VDOT guidance for validation measures for each:

- A <u>cordon line</u> is a line that encloses a subregion of the model, often a CBD, city, or major activity center. For both small and large model regions, the estimated volume for highway cordon lines should be within 10 percent of observed count volumes for cordon volumes with less than 54,000 observed count volume. Higher volume cordon lines should follow the same guidelines used for highway cutlines, discussed below. For cordon lines with observed count volumes greater than 250,000, cordon line volume should be within 5 percent of observed count volumes.

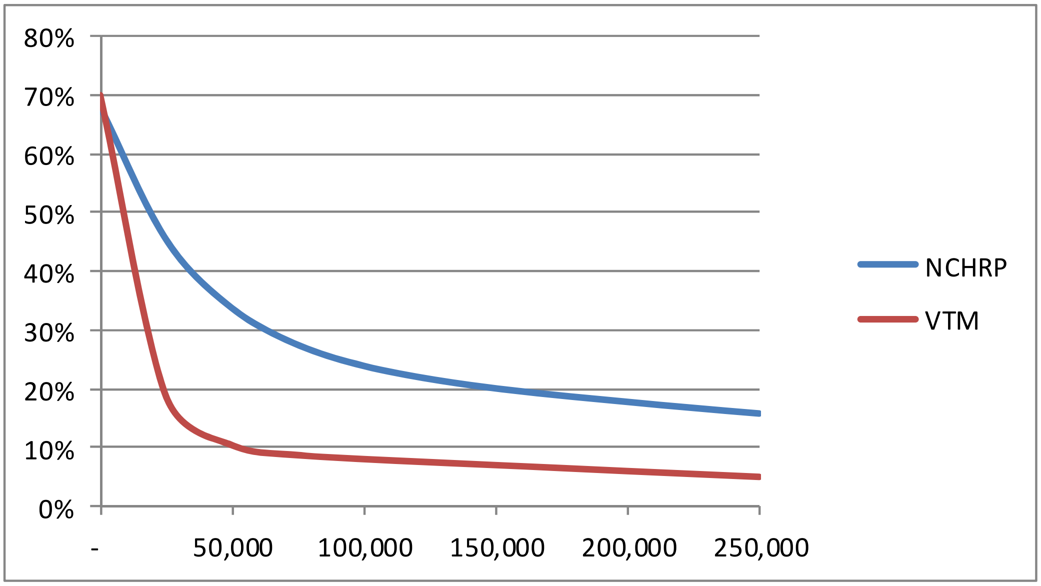
- A screenline is a line that crosses the entire model region, effectively splitting the model region into two parts. For both small and large model regions, the estimated volume for highway screenlines should be within 10 percent of observed count volumes for screenline volumes with less than 54,000 observed count volume. Higher volume screenlines should follow the same guidelines used for highway cutlines, discussed below. For screenlines with observed count volumes greater than 250,000, screenline volume should be within 5 percent of observed count volumes.
- A cutline is a line that crosses part of the model region, meaning that it is possible to build paths from one side of the cutline to the other that go around the cutline. The allowable deviation in cutlines should vary according to the total volume of the cutline. Lower volume cutlines should have higher allowable deviations while higher volume cutlines have lower allowable deviations. This is discussed further below.

NCHRP Report 255 contains a maximum desirable deviation curve that traditionally has been used by model analysts to assess allowable deviations for cutlines depending on the volumes involved. VDOT staff have developed a custom equation and curve for allowable cutline deviation for the VTM system which is shown as Equation 10-4. Both curves are illustrated in Figure 10.2. The VTM curve maintains flexibility for low volume cutlines while providing meaningful guidelines for cutline analysis. For cutlines with observed count volumes of 250,000 or greater, cutline volume should be within 5 percent of observed count volumes.

$$\textbf{Maximum Allowable Deviation} = \frac{60 * e^{(-0.075*C/1000)} + \left((-0.02)*(C/1000)\right) + 10}{100} \qquad (10\text{-}4)$$

Where C = Cutline Count Total

Figure 10.2 VDOT Maximum Desirable Deviation in Total Cutline Volumes



Source: NCHRP Report 255

Speed Checks

Speed checks compare modeled speeds to observed data from travel-time studies or, possibly, spot speed data for facilities not affected by intersection controls. The speed checks are focused on time of day or peak-period assignment results. While they can be easily calculated from VMT and vehicle-hours of travel (VHT) summaries for links, 24-hour average speeds are not very meaningful.

It is somewhat more difficult to define validation tests focused on speeds than it is to define traffic volume-related validation checks. While modeled speeds can easily be calculated for each link, the modeled speeds are directly impacted by the quality of the assignment results. Thus, errors in assigned speeds might result from errors in the estimation of speeds or from errors in assigned traffic volumes. This issue might be addressed by filtering the links included in the test to include only those links where the assigned traffic volume is relatively close to the observed traffic count.

There are no numeric guidelines for speed checks. These checks are reasonableness checks only.

Sensitivity Testing

The FHWA Validation Manual presents some sensitivity tests for highway assignment. These are shown below:

- *Regional sensitivity* – Check reasonableness of the change in VMT in response to changes in total trips. Change trips by a factor (e.g., 1.5) and check to see whether total VMT changes by a similar factor. If there is little congestion in the region, VMT should increase by a similar factor. If there is substantial congestion, VMT should increase by more than the factor.
- *Localized sensitivity* – Modify key network elements and review assignment results for changes and reaction to network elements (using a fixed trip table). For example, remove a key bridge or limited access facility and review the impact on traffic using volume difference plots between the original and modified alternatives.
- *Oversensitivity* – For congested networks, make a minor change to a network (e.g., add a lane of traffic to a minor arterial link) and reassign a fixed trip table using same number of iterations and closure criteria. Review the impact on traffic using volume difference plots between the original and modified alternatives. Traffic impacts should be very localized.

It makes sense to perform each of these tests several times, using different values or changes to the networks in different locations. Changes should be made in both directions, i.e., both adding and removing highway facilities.

The assignment results can be used to check the sensitivity of the entire model system to changes in socioeconomic data inputs. The value of a key input, such as the number of households, population, retail employment, or nonretail employment, can be increased or decreased for a specific TAZ, and the effect on total travel, as measured by VMT, can be examined. This type of check is usually repeated with various levels of change, in both directions, and is performed for TAZs of various area types within the region.

10.5.3 Highway Assignment Model Calibration and Troubleshooting

Since assignment is the last step in the modeling process, issues discovered during the model checks described in Section 10.5.2 may imply errors in almost any component of the model process, as well as assignment model parameters, input data (networks/skims or trip tables), or highway or transit path building procedures. Some of the typical problems that may be evident from these tests include the following:

- <u>Low, high, or unrealistic base-year modeled link volumes compared to traffic counts</u>: Check network coding (speeds, capacities, turn penalties, etc.) on these links, nearby/adjacent links, and links on competing paths; check TAZ connections and loading at centroids; and check traffic count data for accuracy.
- <u>Uneven facility loading on parallel competing routes</u>: Review centroid connections, review facility and area type coding and input starting speeds for assignments; review TAZ structure and number of TAZs (may need to have finer spatial resolution); and review final congested speeds and volume-delay functions.

- Modeled travel times/speeds not consistent with observed data: Review facility and area type coding and input starting speeds for assignments; review final congested speeds and volume-delay functions.
- Links with zero assigned volume: Check network coding (including nearby or competing links) for continuity, stub links, centroid connector locations, and attributes such as free-flow speeds and capacities.
- Links with very high assigned volume/capacity ratios: Check network coding (including nearby or competing links) for centroid connector locations and attributes such as free-flow speeds and capacities.

10.6 Transit Assignment Validation

10.6.1 Data Sources for Transit Assignment Validation

The main sources of data for validation of transit assignment include the following:

- **Transit ridership counts** have the best information on the total amount of travel by transit, usually at the route level, and sometimes at the stop level, especially for fixed guideway services. Since these counts represent unlinked trips, they are consistent with the boarding volumes that are the outputs of transit assignment.
- **Park-and-ride lot utilization –** Regions that have an established park-and-ride system may collect parking lot utilization data for the various lots. The data collected may range from the number of spaces used on a daily basis to the number of vehicles parking at the lot on a daily basis to license plate surveys of parking lots. Vehicle counts at park-and-ride lots are superior to counts of used parking spaces since the vehicle counts provide a clearer picture of park-and-ride lot demand.
- **Transit rider survey –** The transit rider survey (see Section 4.2.1) is a source of information for validation of the some outputs of transit assignment models, such as path checks and transfer activity.

10.6.2 Transit Assignment Validation Checks

Table 10.6 summarizes the model validation checks for transit assignment.

Table 10.6 Transit Assignment Validation Procedures for Virginia Travel Demand Models

	Model Region Size	
Type of Check	**Small**	**Large**
Boardings, by route group and type of transit	Reasonableness checks only	Reasonableness checks only
Transfer rate	Reasonableness checks only	Reasonableness checks only

Generally, transit assignment checks consist of comparisons of base-year model outputs, based primarily on route boardings, to observed data from ridership counts. Since most regions have relatively few transit lines, checks by line are typically reported for each line although the comparisons may need to be made for groups of routes to achieve sufficient ridership for comparison.

If the transit assignment is performed for peak and off-peak time periods, the validation checks described in this section should be performed for the assignment results for each period, as well as for the entire average weekday (the sum of all periods). As is the case with highway assignment checks, the best way to perform these checks is to first perform the validation checks for the entire day, and when the daily assignment results have been sufficiently validated, to then check the results for each time period.

Boarding Count Checks

Most transit assignment checks begin with the comparison of modeled to observed transit boardings. In addition to total system boardings, these comparisons may include boardings by line and by mode. Validation checks typically consist of comparing absolute and relative differences between modeled and observed boardings by line.

Comparison of modeled to observed boardings at major transfer points provides another set of validation checks. The major transfer points may include park-and-ride lots, fixed guideway transit stations (e.g., light rail stations), and bus transit centers or "pulse points."

The assignment of an "observed" transit trip table (based on expanded data from a transit rider survey) can be valuable in providing an "in-between" data point for transit assignment validation. If the modeled boardings resulting from the assignment of the "observed" transit trip table match the observed boardings reasonably well, but the modeled boardings resulting from the assignment of the transit trip table from the mode choice model do not match up well with the observed boardings, issues with the mode choice model or preceding models such as trip distribution may be indicated. If the results from assignments using both trip tables ("observed" and from the mode choice model) match each other well but not the observed boardings, there may be issues with the transit network or path building procedures (although checks of the observed data, boardings and transit survey, also should be performed).

Transit Rider Survey-Based Checks

If a transit rider survey is available, the observed regional transfer rate or boardings per linked trip can be estimated. This information also can be estimated from boarding counts if the operator provides transfers and records boardings by fare payment type. Modeled boardings per linked trip can be estimated from the transit assignment results. As with previous checks, this comparison can be made based on the assignment of either observed transit trip tables or modeled trip tables.

Sensitivity Testing

The sensitivity checks for transit assignment are very much related to those for mode choice. Changes in input variables can change modeled transit mode shares and therefore modeled transit ridership. Specific checks focusing on transit assignment might include changing key transit routes or segments and reviewing assignment results using a fixed transit trip table. For example, a route might be removed, or its headway changed, and the effects on nearby routes checked. It makes sense to perform each of these tests several times, using different values or changes to the networks in different locations.

10.6.3 Transit Assignment Model Calibration and Troubleshooting

As discussed in Section 10.5.3, since assignment is the last step in the modeling process, issues discovered during the model validation checks described in Section 10.6.2 may imply errors in almost any component of the model process. However, unlike the case of highway assignment, it might be possible to isolate transit assignment issues to the transit assignment process if an observed transit trip table from an on-board survey is available. Some of the typical problems that may be evident from these tests include the following:

- Low or high boardings/ridership compared to route/stop boardings: Check network coding (stops, etc.) on the affected routes/stops, nearby/adjacent routes, and competing routes; check transit access links; check run times, speeds, and/or dwell times for routes; check level of zonal resolution and transit walk access percentages; check trip tables for consistency between trips in corridor and observed boardings; modify path building/ assignment parameters; if using multipath assignment procedures, investigate changes in route "combination" factors; investigate changes to transfer penalties; investigate changes to relationships between wait time, out-of-vehicle time, in-vehicle time, and transit cost.
- Low or high boardings per linked trip: Review walk access/egress assumptions, investigate changes to transfer penalties, modify assignment procedures, increase market segmentation, modify path building/assignment parameters, if using multipath assignment procedures, investigate changes in route "combination" factors, investigate changes to transfer penalties, investigate changes to relationships between wait time, out-of-vehicle time, in-vehicle time, and transit cost.

Note that these actions are intertwined with those for the mode choice model validation (see Section 9.2.3).

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CHAPTER 11. FEEDBACK LOOPS

This chapter describes the process of feeding back travel times that are outputs from the highway assignment process to be used as inputs in earlier model steps. This process is needed in regions with substantial highway congestion. Generally, in small model areas, it is considered **acceptable practice** not to use feedback loops, but it is a **recommended practice**. It is considered both **acceptable practice** and **recommended practice** in larger regions to use feedback loops.

The policies and procedures for external travel modeling practice in Virginia are summarized in Table 11.1.

Table 11.1 Practice in Feedback for Virginia Travel Demand Models

Component	Acceptable		Recommended[a]	
	Small	**Large**	**Small**	**Large**
Use of feedback loops	No	Yes	Yes	Yes
Feedback process	Simple iterations	Method of Successive Averages	Method of Successive Averages	Method of Successive Averages
Convergence check (examples)	• VMT for iteration *n* within 5% of VMT for iteration *n 1* • 95% of links with volume change less than 5% between iterations • Relative gap < 0.001	• VMT for iteration *n* within 1% of VMT for iteration *n 1* • 99% of links with volume change less than 5% between iterations • Relative gap < 0.0001	• VMT for iteration *n* within 5% of VMT for iteration *n 1* • 95% of links with volume change less than 5% between iterations • Relative gap < 0.0001	• VMT for iteration *n* within 1% of VMT for iteration *n 1* • 99% of links with volume change less than 5% between iterations • Relative gap < 0.00001

11.1 Feedback Process Description

Highway travel times are among the important inputs to the trip distribution and mode choice components. Travel times are affected by traffic volumes as higher levels of congestion reduce speeds. The highway assignment process that estimates volumes, however, occurs after trip distribution and mode choice in the modeling process, and so highway travel times are therefore among the outputs of the highway assignment process. This means that the traffic volumes and their effects on speeds are unknown when these components are run initially, and the travel-time outputs from highway assignment may be inconsistent with the inputs to distribution and mode choice.

The initial travel times are estimated through the network skimming process as described in Section 10.3. These initial estimates may be "free-flow" times or may be based on approximated levels of congestion. In many regions with relatively low levels of congestion, these approximations are sufficient to produce reasonable model results and are consistent with the output speeds from highway assignment. In regions with higher levels of traffic, however, a process is needed to ensure consistency between travel-time inputs and outputs.

The process for travel-time feedback can be summarized as follows:

1. Run the entire model process from trip generation through highway assignment ("iteration 0"). Transit assignment may be omitted in this initial iteration.
2. Skim the highway network to produce TAZ to TAZ travel-time inputs for the next iteration.
3. Rerun the model from trip distribution through highway assignment, using the travel-time inputs from Step 2.
4. Perform convergence checks (see Section 11.3) on the model results.
   - If convergence has been achieved, produce the final model results using the appropriate averaging method (see Section 11.2). Transit assignment should be performed at this time, and the process is terminated.
   - If convergence has not been achieved, compute travel times for the next iteration by skimming the highway network and using the appropriate averaging method, and return to Step 3.

The averaging referred to in Step 4 is discussed in Section 11.2, and the criteria for determining convergence are discussed in Section 11.3.

11.2 Averaging of Information from Feedback Iterations

While it is possible to simply use the output travel times from one iteration as inputs to the next, an efficient means for achieving convergence is to average times from the various iterations. This section describes two basic ways to feed back travel times.

- Simple iterations, in which the levels of service predicted in one iteration are used without modification as inputs to the next iteration, and the results of the final iteration are accepted as the final estimate of both trips and travel times; and
- Averages of iterations, in which the intermediate trip predictions of the simple iteration process are averaged to provide the final estimate of trips, and/or the impedance variables for the current iteration are those which are consistent with average values of the trips predicted in all prior iterations.

11.2.1 Feedback Based on Simple Iterations (No Averaging)

The simplest way to perform feedback is to use the estimated travel times from the previous iteration as inputs to the current iteration. The estimates of the trips and travel times provided by the final iteration are taken to be the final estimates. If this strategy is successful, the travel-time inputs and outputs for the final iteration will be nearly the same. Also, the estimated trips for the last two iterations will be nearly equal.

The main potential problem with this strategy is that the process is not guaranteed to converge. This can occur because oscillations may cause a new iteration to be worse, in some sense, than any of the previous iterations. Even if the process does converge, it may happen slowly, resulting in high execution times. More generally, the number of trips in the final estimate bears no direct relationship to any of the paths computed in the intermediate iterations.

11.2.2 Feedback Based on the Average of Successive Iterations

A logical enhancement to the simple iteration strategy can provide a more stable process. Each of the iterations of the revised process is exactly the same as in the previous strategy. The final estimates, however, are different. Rather than using the final iteration without modification, a weighted average of the trip estimation results for each iteration is used. This averaging process occurs at the network link level. The final travel times are then obtained using the average link volumes as inputs to volume-time functions.

There are some potential problems with this strategy. Iterations with relatively low speeds will have low trip totals and therefore reduced influence on the final estimate. Again, the process may not converge, and even it does, it may happen slowly. Furthermore, the consistency of the final estimate is not guaranteed; it will surely be better than in the simple iteration strategy but may be far from the desired level. These problems can be mitigated by the use of "successive averages."

To address this issue, a process can be used where each iteration begins by estimating a new trip table based on the travel times output from the previous iteration. These trips are then assigned to new paths in the transportation networks. The results of this assignment, plus the prior iteration assignment, are then used to compute a fraction to be applied to the new trips and assigned volumes. This fraction, with the prior iteration trip table and assignment results and the new trips and assignment results computed in the current iteration, is then used to provide new "successive average" assigned volumes. Finally, these new assigned volumes are used to update all travel times.

The final estimates of trips and travel times are equal to the predictions in the final iteration; in this case, however, the link volumes in the final iteration represent a successive average. Successive averages of trips serve to dampen the oscillations of the simple iteration strategy. There are several ways to compute the fractions for each iteration. In the "method of successive averages" (MSA) [25], the fraction for iteration n is equal to $1/n$. Another way to compute the fractions is to use the network equilibrium assignment method, which computes optimal factors for each iteration to satisfy an objective function. This is known as the Evans algorithm [26]. Both of these methods insure that this strategy converges to a stable final estimate of trips and travel times.

The MSA procedure uses the average of the link flow variables from all previous solutions so that the output of the next solution produces convergent variables. In each solution, each of the previous solutions is weighted equally. The first solution is a standard run of trip distribution, mode choice, and traffic assignment steps. The second solution starts with the travel costs of the first solution, and then is equally averaged with the first solution. The third solution, which is based on the average of the first two solutions, is weighted one-third and the former solution is weighted two-thirds. Similarly, the *n*th solution, which is based on the result of solution (*n*-1), is weighted (1/*n*) and the former solution is weighted (*n*-1)/*n*. The link volumes resulting from this method are mathematically guaranteed to converge for any pattern of highway assignments.

In regions where feedback is employed, it is considered **acceptable practice** to use feedback based on simple iterations and **recommended practice** to use the MSA procedure for averaging results from feedback iterations.

11.3 Convergence and Checks

There is no single method of checking convergence of feedback loops that is considered best practice in travel modeling. Generally, the outputs of a feedback iteration are compared to the values of the same outputs from the previous iteration, and if the differences are lower than the values set by the convergence criteria, the feedback process ends.

There are several different types of model outputs that can serve as the basis for convergence checks. These include:

- Travel times (or skim matrices);
- Trips, or trip tables; and
- Highway volumes, perhaps using an aggregate measure such as VMT.

The comparisons may be based on a straight comparison of an aggregate statistic. For example, if the VMT in iteration *n* is within five percent of the VMT for iteration *n-1*, the model may be considered converged although VMT checks alone are considered an insufficient convergence measure. Another aggregate statistic that is sometimes used is relative gap, the same statistic used to determine whether an equilibrium assignment has converged (see Section 10.1.1). For disaggregate statistics (e.g., trip tables or skim matrices), a measure such as root mean square error (RMSE) (see Section 10.5.2) may be used. In these cases, convergence is determined when the RMSE between the results of successive iterations goes below a set value. Another measure used in some areas is the change in link volumes, where convergence is assumed when the percentage of links with volume changes above a certain threshold (say, five percent) between iterations is lower than a set amount (say, one percent). Another method proposed by Slavin [27] is the "skim matrix root mean square error." This metric measures the difference between skim matrices in adjacent feedback loops. As convergence is reached, the difference between the skim matrices should decrease, indicating increasing stability between loops. The use of both this metric and the relative gap convergence method for traffic assignment creates a fixed point solution for the travel demand forecasting problem.

If relative gap is used as the convergence criterion, recent research indicates that a very small value such as 0.00001, should be used to achieve sufficient convergence. Some areas, though, have used a larger threshold, such as 0.0001 or even 0.001. Obviously, the tighter the criteria, the longer the potential processing time to obtain. The trade-offs between greater stability in results and longer times spent running the models should be considered as model approaches are developed.

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CHAPTER 12. DOCUMENTATION AND DELIVERABLES

This chapter discusses the policies for providing documentation and deliverables for model validations and updates in Virginia. Because model documentation is produced at the end of the model update process, when resources and time might be tight, there is often pressure to produce it quickly, and perhaps not as comprehensively, and not to review it thoroughly. However, good and complete documentation is essential for proper understanding by model users and important for informing interested parties on how model processes function during model applications and reviews. Quality control for model documentation and all deliverables is therefore critical.

12.1 Model Documentation

Model documentation should provide complete information on the model development, validation, and calibration processes. The following items should be included in model documentation reports:

- Introductory/summary information, including the motivation for the model update and the specific areas in which the model was updated and a description of the report's organization;
- Data used in the model update, estimation, and validation (the types of data items discussed in Chapter 3 of this manual);
- For each model component, specifics of the model estimation, transfer, or assertion results, including details of all assumptions, model parameters, and estimation statistics (if applicable); and
- Complete documentation of the validation of the model, including the validation of all components.

The documentation report for any model updates should be presented to VDOT in hardcopy and electronic format as specified by the VDOT designated modeler.

12.2 Model Deliverables

Besides the model documentation, other model deliverables that should be provided for every updated model include the following:

- Data files used to develop the model, including survey data sets and model estimation files;
- Data files used in model validation;
- All model input data files, including highway and transit networks and socioeconomic data files;
- Other associated files such as a shape file with the TAZ boundary information;

- All files necessary to run the model in the modeling software platform;
- Source code for any programs developed to run the model;
- Model output files for the validated base-year scenario and other scenarios used in model testing and validation; and
- Any reports showing model output results for the validated base-year scenario and other scenarios used in model testing and validation.

Table 12.1 shows a checklist of the files that should be provided to VDOT at the conclusion of model improvement projects. Survey data files (Items 2 through 5 in Table 12.1) should include all applicable files (for example, household file, person file, trip file, etc.) and should include the geocoded data.

Table 12.1 Checklist of Deliverables needed for Model Improvement Projects

Item	Deliverable	Description
1	TAZ Structure	Shape file
2	Travel Survey*	In a database format as directed by the VDOT designated modeler
3	External Station Survey*	In a database format as directed by the VDOT designated modeler
4	Transit On-Board Survey*	In a database format as directed by the VDOT designated modeler
5	Other Survey Results*	In a database format as directed by the VDOT designated modeler
6	Transportation Networks (Highway, Transit*)	Network file in modeling software version currently used in Virginia
7	Land Use Data Files for All Tested Scenarios	In a database format as directed by the VDOT designated modeler
8	Traffic Count Data (including counts of external stations)	In a database format as directed by the VDOT designated modeler, with a correspondence to the transportation network.
9	Required Model Execution Files	All required files for using and enhancing further model in the modeling software format.
10	Complete Software Source Code*	For any software developed for the model
11	Model Results	Model output files (loaded network, trip tables, etc.) for the validated base-year scenario and other scenarios used in model testing and validation in a format compatible with the modeling software.
12	Model Documentation Report	In Word and PDF format

The deliverables shown in Table 12.1 are required unless specified otherwise by the VDOT designated modeler. The file format for model deliverables should be compatible and consistent with established VDOT practice. Model files should be delivered in a format compatible with the current modeling software used by VDOT. Model documentation files should be delivered to VDOT in both Microsoft Word and PDF format.

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CHAPTER 13. APPLICATION AND ANALYSIS

This chapter discusses the policies and procedures for developing model outputs for presentation and using model results for project planning applications.

13.1 Developing Model Outputs For Presentation

The main outputs of travel models that are used and presented by planners include aggregate statistics such as VMT and mode shares, and more detailed outputs such as link-level traffic volumes and boardings for transit routes. Modeling software has several standard reporting procedures available for reporting typical model outputs. It is also relatively easy to present model results graphically through maps.

13.1.1 Traffic Volumes

Traffic volumes at the link level are among the chief outputs of highway assignment and represent estimates of the volumes on specific roadway segments for the scenario being modeled. Because of the uncertainties and the assumptions involved in forecasting, it has long been recognized that modeled link volumes should not be treated as precise, accurate estimates of future traffic volumes. Before presenting modeled volume information or using it in planning analyses, it should be critically examined.

NCHRP Report 255 [28] has long been used to refine model volume outputs for project analyses. NCHRP currently is updating this report through Project 8-83, "Analytical Travel Forecasting Approaches for Project-Level Planning and Design," and a new report, *NCHRP Report 765*, is expected to be available in 2014. This report is expected to carry forward the same recommended techniques. Until this new report is ready as a reference, it is both **acceptable practice** and **recommended practice** to use the techniques in *NCHRP Report 255* to adjust model volume outputs.

An issue that should be considered when presenting model volume results is that of "false precision." The analytical techniques used in modeling provide specific estimates of traffic volumes, down to the vehicle level (or even fractions of vehicles). It is obvious, however, that there is error associated with the outputs of any model, even a well validated model. These may be forecasting errors, simulation errors, or simple reflections of the uncertainties involved in preparing forecasts. While it might be desirable to present the volume outputs as ranges, it is impossible to quantify exact error ranges – one cannot say that the volume estimate is within a certain range with, say, 95 percent confidence, and models do not output such ranges. It is therefore desirable to present results in a way that does not provide users and viewers of the results with false confidence about the precision of results. A common way of partially addressing this concern is to present volumes as rounded numbers, say to the nearest 100.

While individual link volumes can be plotted using modeling software or GIS, aggregate measures related to traffic volumes, such as VMT, are usually not displayed graphically.

These are often reported from standard modeling software outputs. For measures that are used frequently, modelers may wish to create custom reports.

13.1.2 Other Measures

There are several other measures that are used in planning and project analyses that are derived from travel model outputs. These may include:

- *Highway speeds and travel times*, either at the link level or as aggregate measures such as vehicle hours traveled;
- *Transit ridership*, as route- or station-level boardings or as link volumes; and
- *Measures of total travel* derived from trip tables, including trips from one location to another and mode shares.

While a few of these measures may be plotted using modeling software functions or GIS (for example, link speeds), most of them are generated using simple reports in the modeling software or using custom reports developed by users.

The same cautions cited in Section 13.1.1 regarding the need to examine raw model results and the "false precision" of outputs apply to all model outputs. Planners should use the same care in using and presenting these model results as is used for traffic volumes.

13.2 Using Model Results for Planning Applications

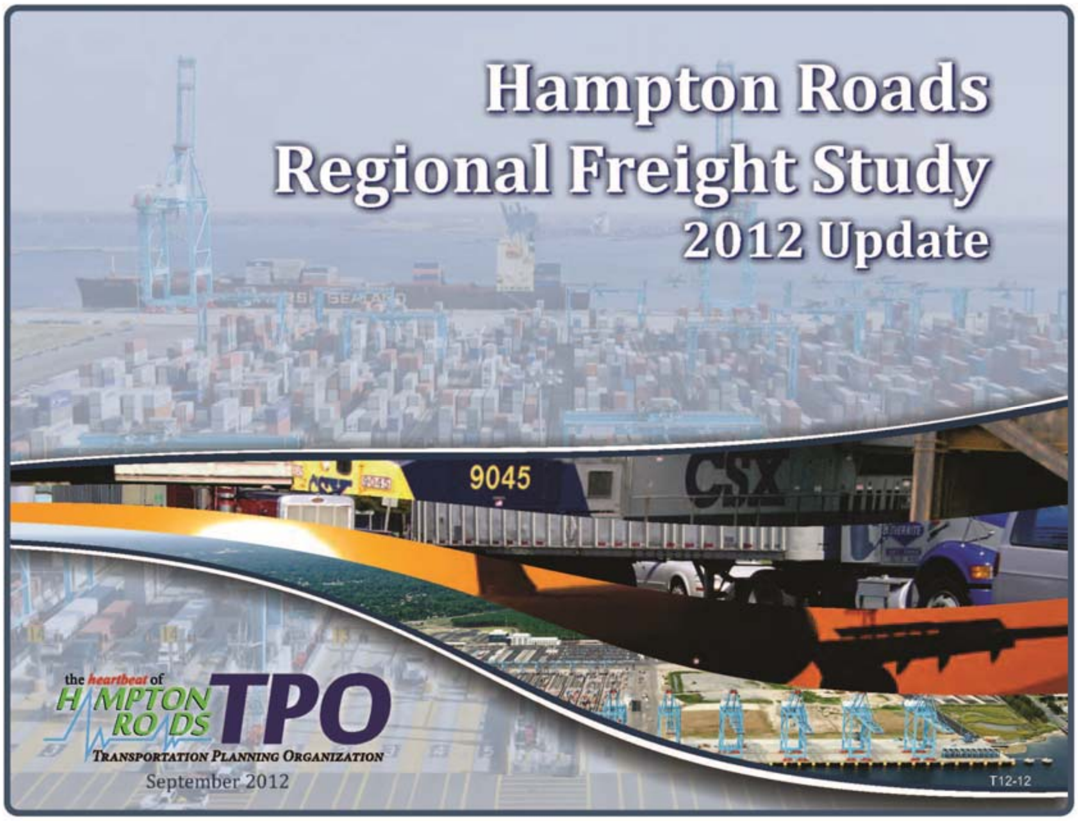
As discussed in Chapter 2, there are many uses for results from travel demand models. It is important to recognize that a travel model is just one tool among many that planners can use for their analytical needs. In some cases, it may make sense to use tools other than models. This section discusses some of the common transportation planning analyses and how (and whether) models can be used in conducting them.

13.2.1 Evaluation of Transportation System Performance

Performance measures are usually somewhat aggregate in nature although some measures may be aggregations of disaggregate data (for example, percentage of roadway miles operating under congested conditions). This means that travel demand models, which can cover the entire planning region as well as providing information at the facility level, are well suited to system performance evaluations. Planners often develop custom reporting of frequently used performance measures from model outputs.

A recent example of using travel demand model in evaluating system performance is HRTPO's Hampton Roads Regional Freight Study (September 2012) [29] (Figure 13.1), expanding the analysis of existing truck volumes and delays by location to include future truck volumes and delays in Hampton Roads. It uses the new truck component and time-of-day capability of the regional travel demand model to forecast truck volumes and congestion to be faced by trucks in the next 20 years. The report compares existing to forecasted truck delays, highlighting future roadway segments with the highest total weekday truck delays and resulting annual truck congestion costs.

Figure 13.1 Sample Evaluation of Transportation System Performance



13.2.2 Long- and Short-Range Transportation Planning

The development of long-range transportation plans involves the evaluation of sets of projects that planning agencies are considering to improve mobility and the quality of life in the region. This often involves scenario analysis, where groups of projects are analyzed together to determine their cumulative impacts over the long term. Short-term plans (for example, Transportation Improvement Programs) require similar analyses although it may be desirable to estimate the impacts of some projects over a shorter timeframe. Generally, models are well suited to this type of analysis since scenarios can be created to represent individual projects or groups of projects. However, there are some types of projects (see Section 13.2.4) for which other analysis tools are more appropriate, and such projects may be included in transportation plans. In such cases, it may be best to analyze those specific projects separately using other appropriate tools.

Most MPOs in the Commonwealth of Virginia have used their regional travel demand models to assist in the long range transportation plan preparation, such as FAMPO's 2040

Long Range Transportation Plan [30] and TJPDC's 2040 Long Range Transportation Plan [31] (Figure 13.2).

Figure 13.2 Sample Long Range Transportation Planning Efforts

13.2.3 Air Quality Conformity Analysis

Many of the inputs into air quality analysis are derived from travel model outputs. These mainly are measures of demand (e.g., VMT) and travel speed, often segmented by facility type, geographic subarea, etc. Since emissions rates vary by vehicle type, the use of separate outputs for autos and trucks, and trucks by type if modeled, can be very useful. All of these measures are available from travel model outputs although they need to be examined and possibly refined or "post processed" before being used in air quality analyses. There are several other inputs into air quality analysis that are not derived from models, including climate and vehicle fleet information; these data must be developed separately.

13.2.4 Evaluation of Transportation Improvements and Infrastructure Investments

The evaluation of individual larger scale transportation projects, including highway improvements and transit service changes, also is well suited for analysis using travel demand models. Since the impacts of these projects may go well beyond their immediate vicinity, models can be used to examine these more distant impacts.

There are some types of projects for which models may not be as well suited for analysis. These include:

- *Traffic operations analyses* – Highway networks in conventional travel demand models do not represent all aspects of roadway design; lane configurations, turning lanes, parking allowances and prohibitions, and merging/weaving sections are not explicitly specified. The static highway assignment procedures used do not account for vehicle interactions such as intersection dynamics, queuing, etc. Microscopic or mesoscopic traffic simulation models are better suited for such analyses. While regionwide traffic simulation is not yet practical in most cases, it is common to use outputs from travel demand models as inputs to traffic simulation tools. Traffic operations software also can be useful for these analyses.

- *Provision of travel information* – Projects concerning the amount of information provided to travelers and the way in which it is provided may include installation and operation of variable message signs; provision of information through on-line sources, smartphones, and similar means; and traveler information services such as 511 services. Because travel demand models do not use as inputs measures of the information that travelers have, such projects cannot be analyzed using these models. It is likely that data specific to the type of information provided and its effects on travel behavior will need to be collected although there are studies, such as FHWA's Integrated Corridor Management project, that are looking into this topic.

- *Dynamic pricing* – Some types of toll facilities and managed lanes have dynamic pricing that changes by time of day depending on traffic levels. While toll roads can be analyzed in travel models, prices that vary during the day cannot be accurately analyzed because of the lack of a time-of-day choice component. Activity-based models do have this capability, but some of the mechanisms by which dynamic prices are set have not been incorporated into the type of highway assignment procedures used by both conventional and activity-based models.

- *Transportation demand management (TDM) actions* – Many of these types of actions, such as telecommuting, compressed work weeks, and carpool matching, are not well suited to analysis by travel models. In practice, such policies have been analyzed using post-processing techniques, sketch planning analyses, or data-driven tools.

13.2.5 Evaluation of the Effects of Transportation and Planning Policies

Some types of planning policies are well suited to analysis using travel demand model outputs. Toll roads can be analyzed in terms of their effects on mode and route choice although, as noted above, dynamic pricing may be difficult to analyze. Other types of pricing policy analysis, such as parking pricing or gasoline price (or tax) changes, also can be modeled. Land use policy analysis may be difficult to perform using conventional travel models because of the limited nature of the land use-related policy variables that are used in model inputs and the relatively coarse level of spatial detail in models. Activity-based models may be better suited, especially if parcel-level land use data are used. Some transit-related policies may be able to be modeled although the way in which pricing is represented – average fares by aggregate population segment, without explicitly modeling pass usage – limits the types of policies that can be accurately analyzed.

13.2.6 Corridor and Subarea Analysis

Travel demand models are well suited for use in major corridor studies that cover several miles. Such studies examine the regional or systemwide impacts of project alternatives that would generally exceed the abilities of microscopic-level tools. When performing corridor studies, it is important to review the level of detail in the regional transportation network and TAZ structure to determine its adequacy for the corridor-level analysis. Additional TAZs and network detail are often added for this type of analysis.

Because they are designed for regional analysis, travel demand models are not always well suited for subarea analysis. When subarea analysis is undertaken, it is usually necessary to add additional zonal and network detail, which may require model revalidation and therefore entail considerable effort. In many cases, it may be desirable to use a travel demand model in connection with a more detailed type of analytical tool, such as a traffic simulation model or intersection analysis tool.

Two good examples in creating subarea models from a regional travel demand model can be found in the recent VDOT Richmond District I-95/I-64 Overlap Study (report is available by sending a request to VDOT TMPD or Richmond District).

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