NCHRP

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

REPORT 765

Analytical Travel Forecasting Approaches for Project-Level Planning and Design

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 765

Analytical Travel Forecasting Approaches for Project-Level Planning and Design

CDM Smith
Cambridge, MA

Alan Horowitz
Milwaukee, WI

Tom Creasey
Lexington, KY

Ram Pendyala
Phoenix, AZ

Mei Chen
Lexington, KY

Subscriber Categories
Highways • Planning and Forecasting • Operations and Traffic Management

Research sponsored by the American Association of State Highway and Transportation Officials
in cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2014
www.TRB.org

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Academies was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP REPORT 765

Project 08-83
ISSN 0077-5614
ISBN 978-0-309-28404-2
Library of Congress Control Number 2014940220

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at:

http://www.national-academies.org/trb/bookstore

Printed in the United States of America

C O O P E R A T I V E   R E S E A R C H   P R O G R A M S

CRP STAFF FOR NCHRP REPORT 765

Christopher W. Jenks, *Director, Cooperative Research Programs*
Christopher Hedges, *Manager, National Cooperative Highway Research Program*
Nanda Srinivasan, *Senior Program Officer*
Charlotte Thomas, *Senior Program Assistant*
Eileen P. Delaney, *Director of Publications*
Ellen M. Chafee, *Editor*

NCHRP PROJECT 08-83 PANEL
Field of Transportation Planning—Area of Forecasting

Michael S. Bruff, *North Carolina DOT, Raleigh, NC* (Chair)
Subrat Mahapatra, *Maryland State Highway Administration, Baltimore, MD*
Philip Ben Cox, *California DOT, Oakland, CA*
Dan Lamers, *North Central Texas Council of Governments, Arlington, TX*
Derek Miura, *FHWA, Lakewood, CO*
Eric Pihl, *FHWA, Lakewood, CO*
Jeffrey A. Shelton, *Texas A & M University, El Paso, TX*
Kermit Wies, *Chicago Metropolitan Agency for Planning, Chicago, IL*
Robert M. Winick, *Motion Maps LLC, Rockville, MD*
Sarah Sun, *FHWA Liaison*
Matthew Hardy, *AASHTO Liaison*
Kimberly Fisher, *TRB Liaison*

FOREWORD

By Nanda Srinivasan
Staff Officer
Transportation Research Board

This report is an update to *NCHRP Report 255: Highway Traffic Data for Urbanized Area Project Planning and Design* and describes methods, data sources, and procedures for producing travel forecasts for highway project-level analyses. The report provides an evaluation of currently used methods and tools. The report also includes appropriate information sources and system-level methods (ranging from readily available practices to advanced practices) to address a variety of project development purposes, needs, and impacts. The report is intended to be used by transportation planning, operations, and project development staff to better support planning, design, and operations recommendations. The report is accompanied by a CD-ROM providing spreadsheet tools developed for project-level analyses as well as appendices from the contractor's final report.

In 1982, TRB published *NCHRP Report 255: Highway Traffic Data for Urbanized Area Project Planning and Design*. This report compiled techniques used in urban areas to bridge the gap between system-level and project-level analyses. In 1982, there was an emphasis on new and expanded highway facilities, but today the focus has broadened to include travel demand management strategies and operational efficiency strategies. Spatial and temporal aspects of congestion are difficult to capture at the precision necessary for project-level decision-making with conventional traffic forecasting techniques. For heavily congested urban study areas and corridors, it is important to capture the effects of residual demand and peak spreading at a project level. Since 1982, there have been many improvements in travel models; however, relatively few efforts have been made to meet post-processing needs for project-level analysis. There was a need to evaluate currently used post-processors and refinement methods and to determine how to best communicate the results so that stakeholders have a sufficient degree of understanding and acceptance. Improvements in methods were needed to provide plausible and defensible forecasts to support planning and highway project development.

The objective of this research was to evaluate and describe currently used methods, data sources, and procedures for producing travel forecasts for highway project-level analysis. The research was performed by CDM Smith in association with Alan Horowitz of the University of Wisconsin at Milwaukee, Tom Creasey of Stantec, Ram Pendyala of Arizona State University, and Mei Chen of the University of Kentucky. Information was gathered via literature review, a national survey, interviews with practitioners, focus groups, and case studies collected from metropolitan planning organizations and state departments of transportation.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

PART 1

Background

CHAPTER 1

Introduction

The project-level traffic forecasting guidelines presented herein are intended to

- Help standardize the traffic forecasting process for highway projects,
- Give practical guidance to practitioners,
- Give a high-level understanding to forecast users, and
- Help define the current state of traffic forecasting practice.

These guidelines are important since highway projects constitute a large portion of the U.S. transportation system's infrastructure and, indeed, affect the entire U.S. economy. Experience has shown that traffic forecasting is a fundamental part of planning for, and developing, highway projects.

This report may be thought of as a revision of *NCHRP Report 255: Highway Traffic Data for Urbanized Area Project Planning and Design* (*1*). A tool box of techniques for directly creating project-level forecasts or for post-processing travel demand model results for use in the planning and design of highway projects was originally published in *NCHRP Report 255.*

This introduction will help define what a "project" is within the context of *NCHRP Report 255* and these new guidelines and provide an overview of the organization of the guidelines.

1.1 What Are Projects?

The guidelines presented herein are intended to be used for the planning, design, and operation of highway system elements. Examples of highway projects include the following:

- Traffic impact studies of new or modified land use activities.
- Improvements to increase reliability and reduce travel time variability in support of state or regional operational goals and objectives, such as reversible lanes, hard shoulder running, ramp metering, signal timing modifications, and variable speed limits.
- Operational studies of highway facilities, such as lane closure analyses, traffic control plans, signing plans, work zone traffic plans, and traffic incident management plans.
- The planning of new highway facilities such as corridor studies, new alignments, needs studies, transportation improvement plans, air quality analysis, tolling analyses, and access management.
- Construction of new highway facilities or expansions of existing facilities; additions including lane widening, added turn lanes, facilities on new alignments or new rights-of-way; and reconstructed pavements.

NCHRP Project 08-83 includes analysis methods to support performance goals and target setting by states and metropolitan planning organizations (MPOs).

The guidelines do not apply to highway projects with non-automobile elements. While they are multimodal to the extent that transit and non-motorized modes are part of a highway's design, the guidelines do not address stand-alone transit projects.

Figure 1-1 shows that traffic forecasting occurs in the early stages of a planning study, as well as in the environmental analysis and the design stages of a project's development. Accurate and timely traffic forecasts are crucial for ensuring the success of highway projects through each stage, including construction and operations.

1.2 Context of NCHRP Report 255

Traffic forecasting has a rich history that parallels the development of the U.S. Interstate system and transportation planning. *NCHRP Report 255* was the first comprehensive practitioner's guide to traffic forecasting that incorporated the use of computerized travel demand forecasting and provided a standardized set of procedures for translating raw traffic estimates into forecasts suitable for planning and design.

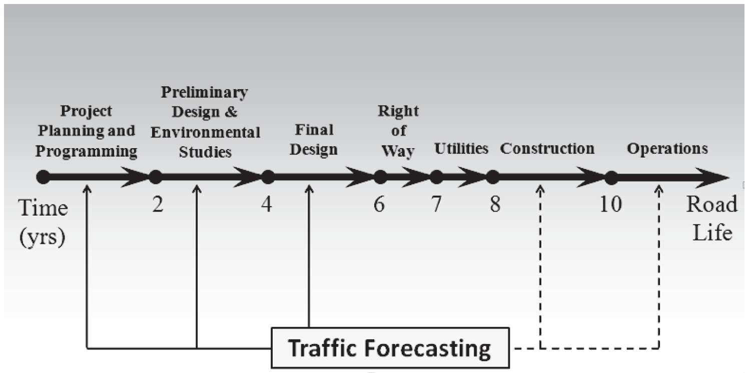


Figure 1-1. Project development process.

NCHRP Project 08-83 follows the spirit and intent of *NCHRP Report 255* in that it demonstrates how the large menu of forecasting practices that are currently available can be applied to produce reasonable forecasts for planning, design, and operations. Table 1-1 gives some perspective on how traffic forecasting has developed over time and where *NCHRP Report 255* fits within this timeline.

As can be seen, *NCHRP Report 255* came with the advent of the microcomputer. It has survived for over 30 years—a period of time that has seen the development of the Internet, much faster computers, and many innovations in travel forecasting theory and software.

New traffic forecasting guidelines are important since highway projects, piece by piece, constitute a large portion of our transportation system's infrastructure and, indeed, affect the entire U.S. economy. Experience over the past 30 years has shown that traffic forecasting is a fundamental part of developing and accessing highway projects.

1.3 Traffic Forecasting Guidelines

Project-level traffic forecasting has an underlying codification at the federal, state/MPO, and industry guideline level. In most cases, traffic forecasting procedures are the product of recommended guidelines rather than strict policy requirements. Thus, there is tremendous variation in practitioner procedures.

At the federal level, traffic forecasting is required for air quality analysis, major investment projects, and highway design projects undertaken by the federal government (Special Report 288, FHWA [*22*]). Traffic forecasting is also an integral part of several standard transportation processes, such as highway design—see the *AASHTO Policy on Geometric Design* (*121*), and the *Highway Capacity Manual* (*21*).

At the state/MPO level, traffic forecasting is also required by many states and MPOs for a variety of applications. Florida's *Project Traffic Forecasting Handbook* (*3*) guides all traffic forecasts made in Florida. Similarly Ohio, North Carolina, and several other states have manuals that guide the preparation of traffic forecasts.

NCHRP Report 255 has been an authoritative source for this required traffic forecasting in the past 30 years. Section 1.4 gives a chapter-by-chapter review.

1.4 Chapter-by-Chapter Review of NCHRP Report 255

NCHRP Report 255 was published in 1982. Despite its age, several of its sections remain relevant, and these sections have been retained in this report. Appendix A of this report presents a detailed review of *NCHRP Report 255* showing what sections remain intact in this report, which have been updated, and which were eliminated due to obsolescence (report appendices are provided on *CRP-CD-143*).

Table 1-2 summarizes the review of *NCHRP Report 255.* Turning movement procedures and directional distribution procedures are still, for the most part, valid and of current interest. Procedures that have value but are in need of major updating include the following:

- Screenline refinement,
- Interpolating between forecast years,
- Extrapolating existing forecasts,
- Time-of-day refinement, and
- Vehicle classification.

1.5 Traffic Forecasting State of the Practice

The traffic forecasting state-of-the-practice contains three sections that are contained in the appendices to this report:

- **Source documents**—a review of the literature and a review of the most important current traffic forecasting reports and sources in Appendix C. State-of-the-practice documents were reviewed as part of this research. A total of 41 source documents were reviewed and summarized.

Table 1-1. Traffic forecasting history highlights.

Year	Key Transportation Organization (s)	Planning Milestones	Technology	Traffic Forecasting State of the Art	Forecasting Related Manuals
1930s	Bureau of Public Roads (BPR - 1915)		Traffic counters		Toll road studies
	American Association Of State Highway Officials (AASHO-1914)				AASHO Geometric design of rural highways
1940s	Federal Works Agency (1939-49)		Travel surveys	Count trends	
1950s	BPR - resumes	Housing Act of 1954	Chicago Area Transportation Study six-step planning	Analytical methods	Highway Capacity Manual (HCM - 1950)
		1956 Interstate Highway Act		20-yr forecast period	
1960s	Federal Highway Administration (FHWA - 1966)	National Environmental Protection Act 1969	First Computer Models	Modeling	HCM 1965
		Fed. Aid Highway Act (1962)			Planpac documentation
					Planning studies
1970s		National Highway Transportation Survey	Commercial software	Modeling	Ismart Validation Report
	Environmental Protection Agency (EPA - 1970)	Clean Air Act Amendment (1970)			ITE Trip Generaton Report, 1st edition (1972)
	American Association of State Highway and Transportation Officials (AASHTO - 1973)				
1980s			Microcomputers	Systematic modeling	National Cooperative Highway Research Program 255 (1982)
					NCHRP 187 (1978)
					HCM 1985
1990s		ISTEA (1991)	Faster microcomputers	Air quality modeling	NCHRP 365 (1998)
					Model Validation and Reasonableness (1997)
					Quick Response Freight (1996)
2000s		Activity based modeling		Activity based modeling	HCM 2000
		Conference			Special Report 288
		Freight Analysis Framework			
2010s			Probes/cell phone studies	Performance based	NCHRP 706 (2012)
				planning	Quick Response Freight II (2007)
					ITE TG Report, 9th Edition (2012)
					HCM 2010

Source: Urban Transportation Planning in the United States (*139*).

Table 1-2. ***NCHRP Report 255*** **review summary.**

Chapter	Procedure	Application[1]					
		System Planning	Corridor/Subarea Studies	Evaluation Studies	Traffic Operations Studies	Highway Design	Environmental Studies
4	Refinement of Computerized Traffic Volume Forecasts						
	• Screenline Refinement Procedure	◒	◒	◒	--	◒	◒
	• Select Link/Zonal Tree Analysis	○	○	○	--	○	○
5	Traffic Data for Alternative Network Assumptions						
	• Modified Screenline Procedure	◒	◒	◒	--	◒	◒
	• Modified Select Link/Zonal Tree Analysis	○	○	○	--	○	○
6	Traffic Data for More Detailed Networks						
	• Subarea Focusing/ Windowing Procedure	--	◒	◒	◒	◒	◒
7	Traffic Data for Different Forecast Years						
	• Interpolation Method	◒	◒	◒	--	◒	◒
	• Extrapolation Method	◒	◒	◒	--	◒	◒
8	Turning Movement Procedures						
	• Factoring Procedures	--	●	●	●	●	●
	• Iterative Procedures	--	●	●	●	●	●
	• "T" Intersection Procedures	--	●	●	●	●	●
9	Design Hour Volume and Time-of-day Procedures						
	• Typical Urban Facilities	◒	◒	◒	◒	◒	◒
	• Atypical Urban Facilities	◒	◒	◒	◒	◒	◒
10	Directional Distribution Procedures						
	• Modification of Base Year Data	--	●	●	●	●	●
	• Use of Anticipated Future Conditions	--	●	●	●	●	●
11	Vehicle Classification Procedures	--	--	--	◒	◒	◒
12	Speed, Delay, and Queue Length Procedures						
	• Under-Capacity Conditions	--	--	○	○	○	○
	• Over-Capacity Conditions	--	--	○	○	○	○
13	Design of Highway Pavements	--	--	--	--	●	--

[1] ○ – Obsolete, to be replaced with improved procedure

◒ – Inadequate, limited applicability, improved procedure available

● – Still valid

-- – not applicable

There are 19 national sources; 20 state, county, and state/MPO sources; and 3 other sources. The documents range from handbooks to guidelines to policy manuals to peer exchanges. The topics include travel estimation and forecasting techniques, traffic data, tools and resources, and travel demand model techniques. Additionally, several of these documents contain case studies, request forms, spreadsheets/workbooks, and transferrable parameters that could be of use to practitioners.

- **Traffic forecasting survey**—a summary of results from a survey of forecasting practitioners in Appendix D. To guide the development of NCHRP Project 08-83, a survey was developed to understand the state-of-the-practice for the following:
  - Project-level traffic forecasting methods and techniques currently employed,
  - Limitations of current methods, and
  - Needs and deficiencies in the practice that must be addressed.

  The most frequently cited uses of traffic forecasting applications in *planning* were corridor planning (80%), Long-Range Transportation Plans (LRTPs) (74%), and site impact analysis (63%). Sixty-five percent (65%) of respondents reported using at least one *NCHRP Report 255* technique for forecasting.
- **Expert panel—**the findings and conclusions from a discussion with an expert panel on the form and content of *NCHRP Report 255* can be found in Appendix E, which also summarizes the panel's comments about the survey results and suggestions about various study aspects. The overall study methodology and the survey results were presented in a webinar to the expert panel.

1.6 Report Organization

This report is arranged into two distinct parts: Part 1: Background and Part 2: Guidelines. Appendices A through I are available on *CRP-CD-143*, which is bound into the report. An .iso image of *CRP-CD-143* and instructions for burning this image onto a CD-ROM are available on the TRB website. The intent of the report is to be an easy-to-use and frequently referenced resource for transportation planning practitioners.

1.6.1 Part 1: Background

Part 1 contains the chapters described below.

Chapter 1: Introduction defines and describes project-level traffic forecasting and how it fits in with the overall project development process. This chapter is a review of the traffic forecasting state-of-the-practice. A survey of practitioners and feedback from an expert panel provided input for this section.

Chapter 2: Overview of the Fundamentals of Traffic Forecasting contains a review of the fundamental traffic forecasting parameters, introduces traffic forecasting measures of effectiveness, and describes source data/basic traffic forecasting tools. It also recommends key resources—the essential bookshelf—that all forecasters need.

Chapter 3: Overview of Traffic Forecasting Tools and Methodologies describes a proposed standard for traffic forecasting. It also summarizes the state-of-the-practice of travel forecasting models (including four-step models), traffic simulation models, advanced four-step modeling practices, advanced modeling practices, modeling inputs/outputs, and other forecasting tools.

1.6.2 Part 2: Guidelines

Part 2 contains the chapters described below.

Chapter 4: The Project-Level Forecasting Process will be the starting point for most users of the guidelines. This section covers the forecasting process from inception through development of project-level traffic forecasts and documentation/communication of results. There are example forecasts contained in this section and in the appendices, along with a tool selection matrix that helps determine the correct tool to be used for a number of forecasting applications.

Chapter 5: Working with a Travel Model provides a variety of information on the proper use of travel demand models for traffic forecasting. Topics include a model component checklist; validation methods; speed/volume data errors; input data fixes; and understanding model outputs including outliers, the role of professional judgment, and computational issues.

Chapter 6: Model Output Refinements describes refinements to travel demand model outputs. Origin-destination (OD) matrix estimation methods, turning movement refinement methods, and screenline volumes adjustments using the traditional *NCHRP Report 255* (*1*) ratio and delta spreadsheets are included, as well as information on how to refine directional splits from travel demand models.

Chapter 7: Refining the Spatial Detail of Traffic Models provides guidance on specialized tools that can be developed from travel demand models, including focusing, windowing, refining directional splits from travel demand models, and multiresolution models. The chapter also discusses refining external-external trip tables and integrating statewide, regional, and local travel demand models.

Chapter 8: Improving Temporal Accuracy of Traffic Forecasts includes information that helps the forecaster understand and develop traffic forecasts for different time periods and at different levels of temporal detail. Key topics include activity-based modeling, dynamic traffic assignment, peak spreading, pre-assignment/post-assignment factoring, day-of-the-week factors and month-of-the-year factors, and vehicle classification considerations.

Chapter 9: Traffic Forecasting Methods for Special Purpose Applications contains a host of topics: basic traffic forecasting deliverables, interpolation of traffic forecasts, vehicle mix accuracy, equivalent single axle loads, benefit/cost analysis, toll/revenue forecasts, work zone congestion, environmental justice, and traffic impact studies.

Chapter 10: Tools Other Than Travel Models acknowledges that not all traffic forecasts use a travel demand model and provides guidance on when to use travel demand models and when to use other methods. Techniques covered include time-series models, a sketch-planning technique ("manual gravity") for traffic diversion, elasticity methods, post-processing using the edition of the *Highway Capacity Manual* published in 2010 (HCM2010) (*21*), combining data from multiple models ("stitching models together"), and an overview of a simplified highway forecasting tool for low-risk traffic forecasts.

Chapter 11: Case Studies uses case studies to illustrate the application of multiple techniques simultaneously. There are case studies for a suburban arterial network, a network window, a small city, an activity-based model application for a large city, a time series on a link, and blending travel forecasting with a traffic simulation model.

1.7 CRP-CD-143

The following material is available on *CRP-CD-143*, which is bound into this report. An .iso image of *CRP-CD-143* and instructions for burning this image onto a CD-ROM are available on the *NCHRP Report 765* web page on the TRB website.

Included on *CRP-CD-143* are **Appendices A through I** from the contractor's final report for NCHRP Project 08-83. These appendices supplement this report by providing a substantial amount of companion data and information. The appendices also include the extended literature review, the detailed *NCHRP Report 255* review, supplementary tables, and glossary/acronyms.

Also included on *CRP-CD-143* are **spreadsheet demonstrations.** These spreadsheets include tools for screenline refinement, OD table estimation, time-series methods, and sketch-planning methods.

Finally, *CRP-CD-143* includes, for reference purposes, **a tool developed by the North Carolina Department of Transportation to assess annual average daily traffic.**

CHAPTER 2

Overview of the Fundamentals of Traffic Forecasting

2.1 Traffic Forecasting Data and Parameters

Traffic data are the fundamental unit of information required for traffic forecasting. This includes average annual daily traffic (AADT) counts, design hour volumes, and percent trucks. Baseline traffic data can be factored by growth rates to produce forecasts, used for validation or comparison against alternative sources of information, or used as a control total against which more detailed information is developed. Several of these data can be further referenced in the *Ohio Certified Traffic Manual* (*2*) and the 2012 Florida *Project Traffic Forecasting Handbook* (*3*).

Parameters are numeric constants and/or weights used in mathematical expressions and are integral to the generation of baseline traffic data and traffic forecasts. The parameters used in project-level traffic forecasts vary depending on the study and tools used to perform the forecast and local area objectives. Most parameters are obtained by applying statistical analysis to travel behavioral data or traffic data that are obtained locally. When statistical analysis cannot be performed, then borrowed or asserted parameters may be used in the application, if appropriate and defensible. The use of borrowed parameters rather than project-specific information is more acceptable for planning studies than for engineering or design studies, where the tolerance for error is substantially lower and the need for accuracy higher. This project-level forecasting should minimize the use of borrowed parameters.

2.1.1 Basic Traffic Forecasting Definitions

Traffic counts/classification counts are used for capacity analyses and pavement design. It is necessary to have high-quality traffic count data to estimate traffic forecasting parameters of AADTs, design hourly volumes (DHVs), design hour factors (K), directional distribution factors (D), seasonal factors, the daily truck factor (T) and turning movements. Usually the state departments of transportation (DOTs) have a monitoring system responsible for programming, collecting, analyzing, and reporting traffic volume and vehicle classification data on Interstates and highways throughout the state. Permanent traffic count information provides a statistical basis for estimating AADT, D, and T for all other traffic counts where short-term traffic counts are obtained. Short-term traffic count data are useful for capturing peak-hour intersection turning movement counts. Historical count data are useful in determining traffic growth trends.

Average daily traffic (ADT) reflects the average number of vehicles that travel through a segment of roadway over a short-term period. The ADT is the raw, non-factored count data obtained by a short-term traffic count (usually a 24- to 48-hour period) typically collected on Tuesday, Wednesday, and Thursday. The ADT is an important, basic unit of traffic monitoring and is essential for developing traffic forecasts.

Average annual daily traffic (AADT) is the estimate of typical daily traffic on a road segment for all days of the week, Sunday through Saturday, over the period of 1 year. A true AADT is developed by utilizing a full year of traffic count data, such as data generated from a permanent traffic counter; however, for the purposes of the guidelines presented herein, the term AADT is used to show a factored ADT. The AADT adjustment factors include daily factors, weekly factors, seasonal adjustment factors, and axle correction factors developed from automatic traffic recorders (ATRs) that collect data continuously throughout the year. The AADT is the best measure of the total use of a road because it includes all traffic for an entire year. **It is important to always use AADT for traffic forecasting since a simple ADT may not be representative of the average traffic at the site being measured.**

The formula for calculating AADT is

$$AADT = ADT \times Adjustment\ Factor$$

Design hourly volume (DHV) is the number of vehicles that travel through a segment of roadway during the design hour. The DHV is used for making roadway structural and capacity design decisions because traffic volume varies by hour and from day to day throughout the year. The formula for calculating the DHV is

$DHV = K \times AADT$

Design hour factor (K) is the design hour factor that represents the proportion of AADT occurring in an hour. K factors can change due to a number of factors such as peak spreading and altered traffic patterns and should be updated frequently. The *AASHTO Green Book* states that the 30th highest hour of the year is best suited for the design hour used to design highways in non-urban settings and that the K factor varies only slightly from year to year even though the ADT itself might change significantly. Frequently, states are not allowed to design to the 30th highest hour because of financial constraints or large seasonal variations. Several states use the 50th highest hour or even the 100th highest hour of the year to reflect the design hour volume. Additionally, Florida uses standard K values which define "factors within a rural, transitioning, urban or urbanized area that are based on a ratio of peak hour volume to annual ADT. Multiple standard K factors may be assigned depending on the area type and facility type and applied statewide" (*2*). The formula for calculating the K factor is

$K = DHV / AADT$

Directional design hour volume (DDHV) is the amount of traffic moving in the peak direction during the design hour. It is a critical design volume with a directional component. The formula for calculating the DDHV is

$DDHV = DHV \times D$

Directional distribution factor (D) represents the proportion of traffic moving in the peak direction during the design hour. The directional factor is derived from ATR data and estimated with short-term count data. D is a critical number that helps determine the geometric design of a road. Traffic on most roads is not evenly split (50%/50% in both directions) during the design hour; the D factor represents this asymmetry and the possibility of different geometric designs by direction. The directional distribution factor is used to determine the DDHV:

$D = DDHV / DHV$

Daily truck volume (DTV) is the volume of heavy and commercial trucks on a roadway segment. **DTV** can be calculated by multiplying the total daily volume by T:

$DTV = AADT \times T$

Daily truck factor (T) is the critical value for pavement design. It represents the percentage of ADT that is heavy and commercial trucks (Categories 4 through 13). Since trucks take up more space and are heavier vehicles than passenger cars, T is an important component in the design of pavement thickness in highway design projects. The daily truck percentage is derived from vehicle classification counts on the actual facility or functional class averages:

$T = DTV / AADT$

Design hour truck percentage (DHT) is defined as the percentage of DHV that is heavy and commercial vehicles. Typically this percentage is less than the daily truck percentage since the percentage of truck traffic is not evenly distributed throughout the day. For example, in Florida, DHT is assumed to be half of T because it is assumed that the proportion of trucks present in peak-hour traffic is half that present for ADT.

Examples of other parameters used in traffic forecasting and baseline traffic data estimates include the following:

- Percentage of local and through traffic;
- Percentage of traffic by trip purpose;
- Trucks as a percentage of total traffic;
- Vehicle occupancy;
- Values of time;
- Hourly (diurnal) distribution of traffic as a percentage of total traffic;
- Rates, including trip generation rates, traffic growth rates, emission rates, and accident rates; and
- Intersection analysis inputs, including traffic progression, signal timing, and phasing.

2.1.2 Other Traffic Forecasting Data

Data required to produce project-level traffic forecasts vary depending on the study and tools used to perform the forecast and local area objectives.

Maps/aerial photos/site data are used to gather current traffic information that is not readily available from other sources and to determine existing and future land uses that contribute traffic that would use the proposed facility. The *Manual on Uniform Traffic Control Devices* (*MUTCD*) is a good reference to follow when collecting new data: http://mutcd.fhwa.dot.gov/kno-2003r1.htm (*4*). For some projects, it may be necessary to collect additional new data via surveys, including special travel time information.

Existing travel demand models are used to estimate existing and future traffic volume on various facilities and include origin-destination (OD) and routing information. Travel demand models are data intensive and require such inputs as socioeconomic data, population, employment, network geographies and attributes, survey data, freight data, and so forth for existing and future conditions and often must be validated and adjusted accordingly.

Inventory databases/reports, housed by many states and local agencies, are useful for project-level traffic forecasting.

Such inventory databases include historical traffic counts, intersection control, roadway classification, accident history, previous traffic forecasts, and so forth. The state and local area reports are useful to reference guidelines, local parameters and traffic conditions, and spreadsheets for use in traffic forecasting analysis. Such reports include the following:

- State and MPO source documents of K and D factors, hourly percentages, and traffic counts, and "FHWA Vehicle Classification Scheme F Report" (http://www.dot.state.oh.us/Divisions/Planning/TechServ/traffic/Reports/Scheme_F_Report/SchemeF.pdf).
- State level of service manual.
- Existing forecasts from corridor, long-range planning, and thoroughfare studies.

Environmental data are used for environmental analysis of air quality, noise impact analyses, and energy consumption analyses. Environmental data are not typically captured by traffic counts or traffic models, but include cold/hot starts distributions and vehicle age distributions.

2.2 Traffic Forecasting Tools

There are several methods available to produce traffic forecasts. The most appropriate method depends on factors such as the size and complexity of the project, the desired time frame, the resources available to produce the forecasts, the availability of data, and staff resources. Tools that are routinely used include the following:

- Growth rates,
- Trend line analyses,
- Time-series analyses,
- Turning movement analyses,
- Travel demand models, and
- Traffic simulation models.

At one end of the spectrum, where forecast needs are relatively simple and where external factors (e.g., land use) remain relatively constant, tools such as growth rates, trend lines or time-series analyses, and turning movement analyses are relatively simple to apply and yield reasonable results. These tools were documented in *NCHRP Report 255* and have been successfully applied for many years. They have been updated in this report.

Forecasting needs have become more complex, however, resulting in a need for more sophisticated tools and techniques. This has occurred for numerous reasons:

- Changing land use patterns have intensified travel demand in suburban and developing areas;
- Increasing traffic congestion has resulted in the need to address peak-period spreading and oversaturated roadways;
- Traditional infrastructure funding mechanisms are no longer sufficient to keep pace with growing travel demand, and user-funded alternatives must be considered in traffic forecasting;
- Applications of traffic forecasting have expanded with the increasing availability of complex tools like microscopic traffic simulation;
- Increasing policy regulations related to the environment, fuel economy, and safety have introduced new needs for traffic forecasts; and
- Travel choice and accessibility policies have resulted in the need to address transit and non-motorized forms of travel.

The result is that the set of available tools has become both more robust and more complex. Correspondingly, the required understanding of these tools and skill with their application is greater than ever.

2.3 Measures of Effectiveness

Analysts and planners produce traffic forecasts to assess transportation performance under different assumptions about transportation supply and demand. The forecasts provide information that describes the condition and performance of the transportation system and guides policy and investment decision-making. The vast quantities of data that traffic forecasts often produce need to be synthesized into credible, digestible information for a variety of audiences, including non-technical decision-makers, stakeholders, peer analysts, and individuals and groups seeking to understand how a particular decision was reached at some point in the past. There are a number of industry-standard measures of effectiveness (MOEs) that provide this information. The context of the study or analysis and the audience for the MOEs should guide the analyst toward the appropriate MOE, level of required detail, and particular style of presentation.

MOEs describe the condition and performance of the transportation system, but do not address the adequacy of the tool or the methodology employed to forecast future conditions. Understanding the validity, sensitivity, and accuracy of a forecasting procedure or tool is the province of calibration and validation.

By the time MOEs are extracted or developed from a forecasting process, the forecasting process should have been properly configured and accepted as appropriate for the purpose for which it is being applied.

Analysts should be cognizant of the context in which the information they produce will be used and come to an understanding about the MOEs to be published and presented at the outset of a study. Often, highly detailed information about a traffic forecast will be published in technical appendices, far from the executive summary most consumers will read. Or, the work of several months will be crystallized into a few short presentation slides. Anticipating how information will be used early on will help avoid misunderstandings and miscommunications. Analysts should also try to describe any underlying factors or assumptions to which the measures are most sensitive. In many instances, traffic forecasts are heavily influenced by assumptions about population or employment growth. Lastly, and within the purview of traffic forecasting, analysts should describe any trade-offs that may result from alternative courses of action beyond those that can be reliably described by MOEs, including environmental, financial, and social impacts. There are a number of industry-standard MOEs that provide this information, as shown in Table 2-1.

Table 2-1. Typical MOEs by forecasting application.

Traffic Forecasting Application	Typical Volume-based MOEs	Typical Time-based MOEs	Accessibility MOEs
Air quality conformity analysis	Area-wide Vehicle Miles of Travel	Speeds	
Asset management, including bridge and pavement needs	Link-specific volumes		
Capital Improvement Program, prioritization	Benefit/cost, Level of Service		
Congestion management process	Corridor volumes	Speeds	
Corridor mobility studies	Intersection Level of Service, intersection turning movements, traffic volumes	Segment travel times	
Demand management plans	Number of peak-hour trips, Level of Service	Vehicle Hours of Delay	
Environmental impact statements	Vehicle Miles of Travel, emissions, accidents	Vehicle Hours of Travel	
Evacuation plans	Hourly traffic volumes, throughput	Travel times	
Facility design and operations	Design hour traffic volumes		
Highway feasibility studies	Benefit/cost, screenline volumes, Level of Service	Vehicle Hours of travel	Access to labor market and jobs
Interchange justification requests	Traffic volumes, Level of Service		
Roadway (general and freight) long-range planning	Vehicle Miles of Travel, Level of Service	Vehicle Hours of Travel	Access to labor market and jobs
Traffic impact studies	Intersection turning movements, Level of Service, delay per vehicle		

There are three categories of MOEs covered in this section: volume-based measures, travel-time-based measures, and accessibility measures.

2.3.1 Volume-Based Measures

The definition of volume-based measures, their strengths and weaknesses, and their application and purpose are given in the following:

- **Definition—**Volume-based measures deal with the quantity of use of transportation facilities at a point on a transportation network, along several points on a screenline (an imaginary line that cuts across several roadways), or between origins and destinations. Demand is associated with a specific time frame, typically ranging from 15 minutes to a 365-day annual period.
- **Strengths/Weaknesses—**Traffic volumes are the most basic, readily understood, readily accepted, and thus most important output of the traffic forecasting process. However, traffic volumes do not convey the traveler's experience of congestion or delay, per se.
- **Application/Purpose—**Traffic volumes describe the number of vehicles at a point on a roadway. Traffic forecasts are often developed for specific travel markets, such as passenger vehicles and trucks. Special-purpose studies may focus on additional vehicle classes, such as buses or combination and single unit trucks.

Volumes can describe how the distribution and magnitude of demand change across different supply/demand scenarios. Volumes can describe throughput—a measure of the quantity of transportation activity that can be accommodated at a single point or multiple points on a transportation network. Volumes are also a critical input to assessments of congestion and economic and environmental impact.

There are several ways to quantify demand at multiple locations. One is to quantify demand crossing boundaries such as screenlines or cutlines or to show demand between regions using OD tables. Another is to sum the total vehicle miles traveled (vehicles × segment length, summed over all segments in the area of interest). With the exception of VMT, each vehicle (or person) should be counted only once (to calculate the total distance a vehicle travels, it must be counted multiple times).

Level of service (LOS) can be considered a traffic-volume-based measure. In transportation planning and preliminary engineering applications, LOS is a widely used and instantly recognizable qualitative measure of roadway and, in particular, vehicular congestion (this discussion does not address bicycle, pedestrian, or transit quality/LOSs). LOS distills the calculation of the quality of roadway service—which is the product of dozens of input variables and parameters—into a simple letter grade, from A to F.

The intuitive appeal of the measure is evident in Figure 2-1. Stop and go conditions are indicative of LOS F, for example.

The Highway Capacity Manual (HCM) is the definitive source for calculating LOS for operational and planning applications. The HCM and the HCM software provide separate methodologies for different roadway types, including freeways, multi-lane highways, two-lane highways, and signalized and non-signalized intersections. LOS calculation methodologies are provided for interchanges, freeway weaving sections, roundabouts, and multimodal applications as well.

LOS is a measure of the congestion produced by the interaction of supply and demand. To calculate LOS, the analyst supplies information about geometric conditions (e.g., number or lanes), traffic characteristics (e.g., free flow speed), and traffic demand (e.g., vehicles in peak 15-minute period). LOS and volume-to-capacity ranges are shown Table 2-2.

See Section 10.4 of this report for more details on the use of the HCM for project-level traffic forecasting.

LOS A/B LOS C/D LOS E/F

Source: 2009 FDOT *Quality/Level of Service Handbook (78)*.

Figure 2-1. Traffic conditions described by LOS.

Table 2-2. LOS and volume-to-capacity ranges.

LOS	Volume-to-Capacity Ratio Range	Percent of Free Flow Speed (Peak Hour)
A	0.50 and below	90% or greater
B	0.60 to 0.69	70% to 90%
C	0.70 to 0.79	50%
D	0.80 to 0.89	40%
E	0.90 to 0.99	33%
F	1.00 and above	25% or less

Source: http://www.kitsapgov.com/pw/translos.htm.

2.3.2 Travel-Time-Based Measures

The definition of travel-time-based measures, their strengths and weaknesses, and their application and purpose are given in the following:

- **Definition.** Travel-time measures describe the trip duration of travel by a vehicle between two points or the total effort incurred in travel by a group of travelers between or within regions.
- **Strengths/Weaknesses.** Travel-time-based measures more closely describe a traveler's experience than do volume-based measures. However, most forecasting applications estimate travel time less accurately than travel demand volumes.
- **Application/Purpose.** Travel-time information is often compared to some norm or standard to describe performance. The standard or baseline against which travel-time performance is being measured should be realistic and clear. When comparing travel times between two points, often the point of comparison is a no-build scenario. A related measure, travel-time delay, is expressed as the increment of time incurred in travel, over and above some expected level. Often the expected level is defined as travel in uncongested conditions (free flow times). However, uncongested conditions may be an unrealistic standard in some urbanized areas and during peak periods of travel. This is less of an issue when delay is used as a relative measure, as a way to compare alternatives.

Travel-time contours have been used to illustrate the effects of congestion on access to destinations. Travel-time contour maps are similar to topographical maps, with lines encircling a destination that radiate outward and do not touch. The spacing between the lines corresponds to the travel times needed to traverse them for a given distance. Thus, closely spaced lines correspond to slower speeds than do widely spaced lines.

Tools and forecasting techniques that include stop delay (at intersections) and queuing delay (at bottlenecks) are more accurate than those that do not. Highway capacity techniques and microsimulation models account for these travel-time components, and microsimulation does so for individual vehicles, over small time slices and at a high level of geographic detail. Regional travel demand models measure travel times for peak-hour conditions at best, and their speed models estimate times for all vehicles on a link, regardless of vehicle type or the lane of travel.

Vehicle hours of travel describe the level of activity in a region. When applied to travelers' values of time, they are the most significant component of a benefit/cost analysis. Lastly, reliability measures use the variability of travel times between two points to describe traveler inconvenience or the additional time needed as a cushion to ensure an on-time arrival.

2.3.3 Accessibility Measures

The definition of accessibility measures, their strengths and weaknesses, and their application and purpose are given in the following:

- **Definition.** Accessibility measures the proximity of people to places. Regions that offer more transportation supply to areas with more and denser land use activity score more highly on accessibility measures, other factors being equal. Since accessibility combines elements of land use and transportation supply conditions, it is used in a variety of analyses, from economic impact studies to social impact studies.
- **Application/Purpose.** Accessibility measures can be used to assess how environmental justice populations are affected by transportation investments and development and to estimate the proximity of facilities such as ports, airports, warehouses, and distribution facilities to shippers and site retail and other commercial developments, using measures such as the population within a reasonable distance of a development site.
- **Strengths/Weaknesses.** Higher levels of accessibility correspond to increased destination choices and modal choices and thus better economic and social outcomes. Basic measures of accessibility are readily understandable when the choices or opportunities available are simply counted. When used at large geographic scales, the measure can be relatively insensitive to small to moderate changes in transportation capacity. Aggregate measures of accessibility that produce unitless results (such as change in utility) can be difficult to explain and understand.
- **Application/Purpose.** Typical applications include the relationship between a smaller area and a larger region:
  - Number of households (larger region) within 30/45/60 minutes of an employment or activity center (smaller area), as a measure of access to labor.
  - Number of jobs (larger region) within 30/45/60 minutes of a residential area (smaller area), as a measure of access to jobs.

This type of accessibility measure can be averaged over several zones comprising a region as:

$$A = \frac{\sum_{i=1}^{n} A_i W_i}{\sum_{i=1}^{n} W_i}$$

Where W is the weighting factor, such as households or jobs (*5*), i is the origin traffic analysis zone (TAZ), j is the destination TAZ, and n is the number of zones.

Researchers and planners have developed more generalized measures of accessibility, suitable for application at a regional level. Such measures rely on formulations similar to the gravity model, or the logsum of a mode choice or destination choice model. A gravity-type formulation is the following:

$$A_i = \ln \sum_{j=1}^{n} O_j e^{-\beta T_{ij}}$$

where

A_i = the accessibility from region or origin i,
O = opportunities (such as jobs) at destination j,
T_{ij} = travel time between origin i and destination j, and
β = friction factor parameter for exponential function (values can range from 0.05 to 0.15).

The denominator of a destination or mode choice model, the logsum, can also be used as a measure of accessibility across all modes represented. A typical formulation is the following:

$$A_i = lne\left(\sum_{k=1}^{m} e^{V_k}\right)$$

Where V_k is a linear combination of utilities corresponding to different trip components (e.g., parking, in-vehicle time, out-of-vehicle time) for mode k.

2.4 Essential Bookshelf

The essential bookshelf is an accumulation of documents fundamental for project-level traffic forecasting. The documents include federal guidance documents, NCHRP publications, and state DOT resources. These documents are summarized and reviewed for their usefulness related to traffic forecasting. The techniques, parameters, and applications described in these reports are identified as they relate to project-level traffic forecasting.

2.4.1 NCHRP Report 716: Travel Demand Forecasting: Parameters and Techniques

The objectives of *NCHRP Report 716* (*6*) were to revise and update *NCHRP Report 365* (*7*) with current travel characteristics and guidance on forecasting procedures and applications. *NCHRP Report 716* was developed to address a broad range of planning issues and to be a user-friendly guidebook with a range of approaches and references to more sophisticated techniques. Data sources include the 2001 National Household Travel Survey (NHTS), the 2009 NHTS, and an analysis of MPO documentation. The MPO information was gleaned from 70 MPOs (ranging from small to large) through direct contact or using publicly available reports. Information includes model parameters (trip attraction rates, friction factor parameters, mode choice parameters, and volume-delay parameters) and model methods used. Variables were selected based on ease of transferability. Trip purposes include home-based work, home-based school, home-based other, and non-home-based.

The key empirical findings reported in *NCHRP Report 716* are largely contained in Chapter 4, "Model Components," which contains all the recommended parameters by model component. The components of the four-step modeling paradigm are described in chapter sections and include the following:

- **Time of day.** This section provides factors for post-distribution factoring and for post-mode-split factoring. The factors are provided for both "from" and "to" trips for each trip purpose.
- **Vehicle availability.** This section provides four different formulations of the multinomial logit model utility equation, with each formulation having many independent variables.
- **Trip productions.** This section provides options as to the independent variables for the cross-classification model and parameters stratified by city size for some trip purposes.
- **Trip attractions.** Parameters are given for linear relationships of trip attraction as a function of activity levels (employment in various industrial sectors, households, and school enrollments).
- **Trip distribution with the gravity model.** This section gives sample friction-factor parameter values and mean trip lengths for cities of various sizes, which could be used to calibrate a single-parameter friction-factor function.
- **External trips.** This section recommends against transferring external-to-external (E-E) models from other locales and for synthesizing an E-E table from traffic counts.
- **Mode choice.** The section presents several mode-split models, some multinomial logit and some nested logit, that have been developed for cities throughout the United States.
- **Automobile occupancy.** This section recommends fixed automobile occupancy factors.
- **Highway traffic assignment.** The report gives parameters for a volume-delay function (VDF) based on the Bureau of Public Roads (BPR) curve as well as a few values of time for converting tolls to impedance.

- **Transit assignment.** Rather than give specific values for an impedance function, the report gives historical ranges of ratios of out-of-vehicle time values to in-vehicle time values.
- **Freight.** This section outlines the steps of a commodity-based freight model and gives sample parameters for these steps.

Advanced modeling practices and model validation are also discussed in *NCHRP Report 716.* Additionally, case studies are provided illustrating the application of parameters for conventional travel forecasting. However, the report does not focus on the concept of transferable parameters but rather on the variability in parameters used by MPOs throughout the United States. Because of the way the parameters are presented, they mostly should be used only as guidelines to ensure that locally developed parameters fall within a reasonable range.

2.4.2 NCHRP Report 365: Travel Estimation Techniques for Urban Planning

NCHRP Report 365 (*7*) is an update to *NCHRP Report 187* (*8*) and has been superseded by *NCHRP Report 716* (*6*). *NCHRP Report 365*, for the most part, provides default parameters for three- and four-step travel forecasting models for urban areas in the United States. The philosophy of *NCHRP Report 365* was similar to that of *NCHRP Report 187*—travel forecasting parameters are transferable between urban areas, and parameters established through national data sources can be applied to specific urban areas. *NCHRP Report 365* retained few methodologies from *NCHRP Report 187*, but did retain the North Carolina E-E model and a highway spacing methodology. There is no mention of freight in *NCHRP Report 365. NCHRP Report 365* makes key recommendations in the following areas:

- Many parameters differ by urban area size. Four urban area sizes are defined.
- There are three standard trip purposes: home-based work, home-based-other, and non-home-based.
- The trip attraction equation is linear and has five independent variables: dwelling units, central business district (CBD) retail employees, non-CBD retail employees, service employees, and non-retail/non-service employees. Parameters differ by trip purpose, but not by urban area size.
- Trip productions for all trip purposes are done using cross-classification in terms of persons per household and number of automobiles (or perhaps income). The split to different trip purposes is based on income.
- Gravity model-friction factors are given in terms of a "gamma" function. Parameters vary by trip purpose.
- A logit model, with coefficients, is provided for mode split.
- Parameters are provided for the relationship between volume and travel time in the form of a BPR curve.

The availability of transferable parameters means that a generic travel model can be assembled rather quickly, as the need arises, without the need for a local travel survey. In addition, transferable parameters can help provide a seed OD table for synthetic OD table estimation from ground counts.

2.4.3 Highway Capacity Manual 2010 (HCM2010)

The HCM contains concepts, guidelines, and computational procedures for computing the capacity and quality of service of various types of highway facilities, including freeways, signalized and unsignalized intersections, and rural highways, as well as the effects of transit, pedestrians, and bicycles on the performance of these systems. HCM2010, TRB's fifth edition of the *Highway Capacity Manual* (*21*), incorporates results from more than $5 million of research completed since the publication of the 2000 edition of the HCM. It provides more in-depth analysis of signalized roadway segments and introduces a multimodal LOS methodology that considers the needs of all users of urban streets at the intersection, link, segment, and facility levels. The companion software suite contains all of the HCM methodologies and vastly facilitates capacity and LOS calculations.

The HCM provides service volume tables with which the capacity of any type of roadway can be calculated. The service volume tables enable an analyst to quickly determine the number of lanes needed to achieve a target LOS according to the demand and supply characteristics of the planned facility (e.g., free flow speed, AADT, the demand peaking factor, and the directional demand factor). The document provides guidance on the appropriate use of defaults and the construction of agency-specific service volume tables. For planning applications, the HCM estimates LOS based on look-up tables of traffic density (vehicles/lane/hour), which in turn relate to speed.

The HCM also provides methods for evaluating isolated intersection volume/capacity ratios. It provides recommended performance measures for the evaluation of systems of facilities. It identifies six dimensions of system performance: quality of service, intensity of congestion, duration of congestion, extent of congestion, variability, and accessibility. In HCM2010, for the first time, guidance is provided on adapting its capacity and free flow estimation methods for improved travel demand model traffic assignment applications. The HCM also provides case studies, examples, and guidance on the capacity and LOS analysis, and covers additional, related topics such as speed and volume data collection to quantify traffic demand and performance measures such as saturation flow and stopped delay.

The HCM is a tool for estimating roadway and traffic performance and uses project-level traffic forecasts as an input. HCM2010 has the ability to integrate easily with Freeval and Transyt7f to simulate the operational impacts of alternatives. Lastly, HCM2010 recognizes variability in traffic demand (seasonal, monthly, and daily; recreational versus commuter; and hourly [peak versus non-peak, peak hour versus analysis hour]) but offers no methods for quantifying it.

2.4.4 Travel Model Validation and Reasonableness Checking Manual, Second Edition

The *Travel Model Validation and Reasonableness Checking Manual* (*9*) provides a framework for testing and updating travel demand models to achieve an acceptable level of performance in terms of accuracy and sensitivity. The manual consists of many simple techniques that have been found useful for performing travel model validation or for understanding when a model is behaving realistically. The manual provides a unified structure of validation techniques that can be applied to a fairly broad range of travel model designs (from three- or four-step models to activity-based models, regardless of platform).

Validation refers to a set of adjustments to model parameters and corrections when errors in coding are encountered that produce an improved system-wide statistical fit to a set of observed data. Ideally these data are separate and distinct from the data used to estimate a model in the first place. Both model inputs and outputs can be validated. Each step in the model has its own comprehensive set of validation checks:

- Amount of travel (trip generation),
- Trip distribution or location choice,
- Mode choice,
- Vehicle occupancy,
- Time of day, and
- Traffic assignment.

It is noted that the validation and reasonableness checking processes did not have a process for validating traffic speeds.

The manual lists troubleshooting strategies for improving model performance when a model is quantitatively or intuitively incorrect. The manual encapsulates considerable practical knowledge on how to build and execute a travel model and reflects an understanding of how to build confidence in technical analyses.

The manual makes specific mention of *NCHRP Report 255* in a section called "Acceptable Methods for Achieving Validation Thresholds." The manual cautions that

> [*NCHRP Report 255*] procedures have been used frequently and have helped improve traffic forecasts for project planning and design. The techniques, however, are applied for a specific planning context and are not generally acceptable for all planning studies. In general, the following guidelines should be used to determine acceptable methods for achieving an improved match between modeled and observed travel characteristics:
>
> - Model adjustments or refinements are frequently made at a small-area or link level because many regional models do not have the requisite accuracy needed for detailed link level traffic forecasts.
> - The adjustments should reflect transportation supply or traveler behavior rather than simple arithmetic,
> - The adjustments should be reproducible, and
> - The reasons for adjustments should be clearly documented.

2.4.5 Quick Response Freight Manual II (QRFM II)

The *Quick Response Freight Manual II* (QRFM II), published by FHWA in September 2007 (*10*), provides information and guidance for developing freight vehicle trip tables and general information about freight. As a resource for estimating freight vehicle trips at the project level, QRFM II is potentially useful in that it

- Provides a framework for employing simple techniques to analyze and forecast freight vehicle trips,
- Identifies the available data sources and methods of data collection and validation, and
- Provides information on many case studies covering methodological and data issues.

There are five different methods of forecasting freight vehicle trips discussed in QRFM II:

- Simple growth factor methods,
- Incorporating freight into "four-step" travel forecast,
- Commodity models,
- Hybrid approaches, and
- An economic activity model.

QRFM II has abundant information on freight generation rates, techniques, and parameters for freight distribution, mode split, and assignment. While the techniques are mostly useful to develop freight forecast models, these techniques could be applicable to forecasting freight vehicle trips with an existing model and site-specific freight forecast.

Validation techniques are also available for trip generation, trip distribution, mode split, and assignment. Case studies provided in QRFM II include the Los Angeles freight forecast model, Portland metro truck model, Florida state freight model, and Texas state analysis model.

2.4.6 Institute of Transportation Engineers Trip Generation Manual and Trip Generation Handbook

The Institute of Transportation Engineers (ITE) *Trip Generation Manual* (*11*) provides trip generation rates for more than 170 land use types and building types. Users can customize the standard tables of rates by adding local adjustment factors and mixing uses and rates. Ongoing work adds to the database of site-specific traffic and land use information; over 4,000 traffic studies are aggregated for the current edition.

ITE procedures estimate the number of trips entering or exiting a site at a given time. The basic relationship is described by mathematical relationships between a dependent variable (either daily or peak-hour trip ends) and independent variables such as gross leasable square footage; number of employees; or land-use-specific variables such as restaurant seats, hotel rooms, hospital beds, and so forth. These mathematical relationships have been developed through numerous studies from which data have been collected and submitted to ITE. Mathematical relationships typically assume the form of either an average trip rate or a regression equation. No guidance is given on future growth of trip generation estimates.

This manual helps in conducting site impact studies, determining on-site circulation patterns, forecasting travel demand, performing access management studies, determining traffic signal timing, and conducting environmental assessments. Few travel demand models use ITE rates for trip generation since they treat each site, rather than the vehicle or traveler, as an independent trip generator and typically produce far higher numbers of trips than rates estimated from household surveys. Also, in most cases, ITE rates are not specific to a trip purpose.

2.4.7 NCHRP Synthesis 406: Advanced Practices in Travel Forecasting

NCHRP Synthesis 406 (*12*) describes advanced practices in travel forecasting, including some of the basic elements of tour-based models, activity-based models, land use microsimulation models, and freight and statewide travel demand models. This publication includes an overview of dynamic traffic assignment (DTA) procedures and the advantages that they offer over traditional static assignment methods. A review of advanced practices in a number of metropolitan areas around the country and interviews of more than 30 practitioners who work with, or plan to use, newer methods for travel modeling are the most important elements of this report.

The description of linking microsimulation-based activity model systems with DTA and traffic simulation models in *NCHRP Synthesis 406* is quite relevant to the practice of project-level traffic forecasting. In addition, the report alludes to the feedback between transportation and land use and notes the importance of considering the effects of project-level improvements on land use and, consequently, traffic patterns. Compared to traditional models, the outputs of activity-based travel models can be more effectively fed into traffic simulation models, thus allowing a greater level of fidelity in analyzing traffic patterns at the level of individual projects, facilities, or locations.

NCHRP Synthesis 406 details the advantages of advanced models for answering policy and modal questions, compared to traditional models. The report also notes that there are several project-level policies (such as high-occupancy toll [HOT] lanes and traffic operations improvements) and land use contexts where the advanced models offer capabilities that the traditional methods do not. Case studies are provided in Chapter 6 of *NCHRP Synthesis 406.*

2.4.8 Dynamic Traffic Assignment—Dynamic Traffic Assignment: A Primer

A number of publications describe the application of DTA, a technique for producing a sequence of time-specific (such as hourly) traffic forecasts. *Dynamic Traffic Assignment: A Primer* (*13*) is useful for project-level traffic forecasting. *Dynamic Traffic Assignment* helps practitioners determine the appropriateness of DTA for project analysis and provides guidance on how to implement DTA and interpret DTA results.

Since DTA is described as being "mesoscopic," that is, combining elements of the macroscopic techniques of regional transportation planning and the microscopic techniques of traffic operational analysis, DTA is suitable for many project-level traffic forecasts. The primary areas useful for project-level traffic forecasting are operational planning and real-time operational control. Operational planning is for making planning decisions on major operations, construction, or demand management actions that are likely to shift transportation patterns on facilities, as well as capacity-increasing strategies. Real-time operational control is for large-scale, real-time traffic management and/or information provision problems such as traffic incidents and intelligent transportation systems (ITS). The primary topics of specific interest to project-level traffic forecasting in the reports are the following:

- Advantages of DTA over static traffic assignment,
- Assignment convergence (achieving full equilibrium assignment) issues,

- Data requirements and preparation (e.g., OD trip table estimation from ground counts),
- Calibration targets and performance measures,
- Error and model validity checking, and
- Frequently encountered issues and suggestions for resolving them.

2.4.9 Dynamic Traffic Assignment—Utilization of Dynamic Traffic Assignment in Modeling

Utilization of Dynamic Traffic Assignment in Modeling (*14*) is useful for project-level traffic forecasting. This guidebook describes how to apply DTA within a modeling framework. The first part of the report provides background on DTA modeling principles and software capabilities, and the second part provides guidance on how to apply DTA using traffic models. The second section describes data requirements and techniques for developing, calibrating, validating, and applying a DTA model.

2.4.10 FHWA's Traffic Analysis Toolbox

FHWA has sponsored the development of several analytical tools relevant to traffic forecasting, which are described in *Traffic Analysis Tools* (*15*):

- **STEAM** (Surface Transportation Efficiency Analysis Model) is a benefit/cost tool suitable for project or program evaluation. Using economic principles, this tool estimates the transportation efficiency benefits of a transportation investment and considers capital costs, travel time, operating cost, safety, noise, and emissions costs. STEAM takes input directly from the traditional four-step model, and can post-process traffic assignment outputs for more accurate estimation of congested speeds.
- **SPASM** (Sketch Planning Analysis Spreadsheet Model) is a sketch-planning tool for multimodal corridor analysis and evaluation. As a spreadsheet-based version of STEAM, this tool is only useful for corridor-level analysis, and it is based on economic efficiency analysis of cross-modal and demand management strategies.
- **SMITE** (Spreadsheet Model for Induced Travel Estimation) is a spreadsheet application that evaluates the effect of urban highway capacity expansion projects, especially considering induced demand. It is used when the four-step model is unavailable or unable to forecast the full effect of the induced demand. SMITE-ML (Spreadsheet Model for Induced Travel Estimation-Managed Lanes) is a specially modified version of SMITE to evaluate the effects of pricing alternatives with managed lanes such as HOT lanes and express toll lanes in urban areas. It has been used as a quick-response sketch-planning tool for pricing policy evaluation.
- **Intelligent Transportation System Deployment Analysis System (IDAS)** is a sketch-planning analysis software tool developed by FHWA to estimate the benefits and costs of ITS investments. It is designed to help public agencies and consultants integrate ITS into the transportation planning process. IDAS evaluates various impacts including changes in user mobility, travel time/speed, travel time reliability, fuel costs, operating costs, accident costs, emissions, and noise as well as benefits (value of time saved, value of accident reductions, and so forth) and benefit-cost ratio. The ITS benefits module reflects values that have been averaged from past studies.

2.4.11 Other Forecasting Guidelines

Various traffic analysis tools and methods are reported for multiple project types. The resources include focusing tools, sketch-planning tools (many of them spreadsheet based), OD estimation methodology, and guidebooks for tolling projects and the National Environmental Policy Act (NEPA) process. These resources are discussed below.

Network Focusing—A Tool for Quick Response Subarea Analysis (*16*) describes the practice of introducing greater network and zonal detail into a project area of interest and reducing detail elsewhere. When done properly, this practice speeds model execution time without an unacceptable loss in accuracy. Subarea focusing is useful when the regional model is seriously deficient for project-level work, such as failing to contain traffic-controlled intersections or failing to be dynamic.

TCRP Synthesis 66: Fixed-Route Transit Ridership Forecasting and Service Planning Methods (*134*) examines the state of the practice in fixed-route transit ridership forecasting and service planning. This report also explores forecasting methodologies, resource requirements, data inputs, and organizational issues. In addition, the report analyzes the impacts of service changes and reviews overall effectiveness of forecasting methods based on an extensive survey of transit service agencies and operators.

Estimation of Origin-Destination Matrices Using Traffic Counts (*17*) provides a more recent update of various methods for estimating an OD matrix using traffic counts on links in a transportation network. The paper provides a survey of generic approaches as well as an annotated bibliography of some individual contributions. The author notes that the treatment of congestion effects is an important distinguishing property among the various methods used for OD estimation. There have been three primary approaches to estimating OD matrices:

- Traffic-modeling-based approaches,
- Statistical inference approaches, and
- Gradient-based solutions.

Toll Road Traffic & Revenue Forecasts: An Interpreter's Guide (*18*) provides practical information that could be used to help interpret toll and revenue projections. Topics of specific interest to project-level traffic forecasting are the following:

- Traffic modeling and forecasting,
- Traffic risk empirical evidence,
- What to look for in a traffic and revenue study,
- Often-seen issues and suggestions on how they may be resolved, and
- Appendices on traffic risk indices.

Other sections of interest in this guide for project-level traffic forecasting are the 20 tips on how to inflate traffic forecasts, tools to aid the "keep it simple" philosophy, and common sources of forecasting error (e.g., unrealized land use growth assumptions, time savings less than anticipated, unanticipated improvements to toll-free routes, less off-peak traffic, and many others).

Travel Forecasting Resource (*19*) is a website in wiki format intended to provide comprehensive coverage of topics related to travel forecasting. The committee has worked on populating topics such as conformity, data, networks, transit, pricing, and climate change. While the resource is under development, various reports are available now, including an assessment of various methods and tools covering both four-step travel demand models as well as a variety of sketch-planning tools. (http://tfresource.org/Travel_Forecasting_Resource_-_Home)

Interim Guidance on the Application of Travel and Land Use Forecasting in NEPA (*20*) describes project-level forecasting in the context of the NEPA process. The guidance does not address the need to improve the actual technical methods used to forecast land use and travel behavior as applied to NEPA processes, but tries to fill the gap between the technical guidance for producing forecasts and application of forecasts in the NEPA process.

2.4.12 State-Specific Forecasting Guidelines

Over the years, many states have published forecasting guidelines that set standards for forecasting and serve as resources of tools, methodologies, and data for those states. Due to the comprehensiveness of these sources, they can provide insight and guidelines for other areas. Several of these guides contain case studies, request forms, spreadsheets/workbooks, and transferrable parameters that could be of use to practitioners. Table 2-3 lists 20 published guideline documents that are described in

Table 2-3. State and MPO forecasting guidelines.

Organization	Author	Document
Florida DOT	Florida DOT	Florida Project Traffic Forecasting Handbook 2012
Minnesota DOT	Minnesota DOT	Minnesota Procedure Manual for Forecasting Traffic 2010
Ohio DOT	Ohio DOT/	Ohio Certified Traffic Manual 2007
Texas DOT	Texas DOT	Traffic Data and Analysis Manual 2001
Florida DOT	Florida DOT	Traffic Impact Handbook 2010
Kentucky Transportation Cabinet	Kentucky Transportation Cabinet	Traffic Forecasting Report 2008
North Carolina DOT (NCDOT)	Stone, Saur & Letchworth	Guidelines for NCDOT Project-Level Traffic Forecasting Procedures 2002
North Carolina DOT	North Carolina DOT	Project-Level Traffic Forecasting: Administrative Procedures Handbook
Oregon DOT	Oregon DOT	Oregon Analysis Procedure Model 2006
Wisconsin DOT	Wisconsin DOT	Facilities Development Manual
CALTRANS (California DOT)	California Transportation Commission	California Regional Transportation Plan Guidelines
Delaware Valley Regional Planning Commission (DVRPC)	Delaware Valley Regional Planning Commission	2000 and 2005 Validation of the DVRPC Regional Simulation Models
Georgia DOT	Georgia DOT	Design Policy Manual
Parsons Brinckerhoff	Parsons Brinckerhoff	New York Best Practice Model for Regional Travel Demand Forecasting
Utah DOT	Utah DOT	Utah Project Specific Modeling Info
Arizona DOT	Arizona DOT	Website Contents
Ohio DOT	Ohio DOT	Website Contents
Kentucky Transportation Cabinet (KYTC)	Kentucky Transportation Cabinet	KYTC Permit Guidance Manual—Traffic Impact Study Requirements
Kentucky Transportation Cabinet	Kentucky Transportation Cabinet	KYTC Design memorandum No. 03-11, Traffic Engineering Analysis
Montgomery County (MD) Planning Department	Montgomery County (MD) Planning Department	Local Area Transportation Review and Transportation Policy Area Review Guidelines, 2013

detail in Appendix C. The notable elements of the guidelines published by a selected number of states are described below:

- Florida provides guidelines and techniques to forecast traffic and assess the impacts of land use on the transportation system.
- Minnesota provides a comprehensive, step-by-step procedural manual for traffic forecasting, while the Kentucky Transportation Cabinet provides trip generation rates and data resources to forecast traffic.
- North Carolina and Georgia provide procedures for requesting project-level traffic forecasts as well as guidelines for traffic forecasting.
- Oregon provides procedures for conducting long-term analyses of plans and projects.
- Wisconsin provides policies and requirements regarding the facilities development process.
- California addresses the air quality and land use components of the planning process.
- Delaware and New York provide model development strategies, suggested validation targets, and model implementation.
- Utah provides traffic forecasting requirements and publishes standards for the tools and procedures used in the traffic forecasting projects.

These documents include state-of-the-practice techniques, resources, and case studies for state traffic forecasting. A list of the specific state forecasting guidelines based on the source document review in the interim report for NCHRP Project 08-83 is presented in Table 2-3.

CHAPTER 3

Overview of Traffic Forecasting Tools and Methodologies

This section presents an overview of traffic forecasting tools and methodologies. Of course, the most frequently used (and perhaps the best) tool is a well-validated travel demand model. Various aspects of travel demand models are discussed in this chapter. Section 3.6 covers tools and methodologies used for traffic forecasting other than travel demand models.

The traffic forecasting tool/methodology topics include the following:

- The travel forecasting model ideal, which, although rarely achievable, is worth identifying as a "gold standard";
- State of the practice of travel forecasting models, covering the current basic travel demand modeling premises and modules, advanced modeling topics, and trend line analysis techniques;
- State of the practice of data inputs for travel forecasting models, covering socioeconomic data, network data, traffic counts, household travel surveys, origin-destination surveys, and freight/heavy vehicles;
- State of the practice of data outputs for travel forecasting models, covering volumes, speeds, turning movements, measures of effectiveness, origin-destination information, and post-processors;
- Default data versus locally specific data; and
- c parameters, which is a discussion of model parameters.

Table 3-1 summarizes the topics in a matrix format with the accompanying section number in the chapter.

3.1 The Travel Forecasting Model Ideal

The starting point for establishing an ideal standard for forecasting is to recognize the need to represent traffic flows over large areas and time slices, while representing traffic conditions over small geographic areas and in small time slices. The most feasible approach for achieving this currently is the hybrid travel demand model. A hybrid model involves two or more distinctly different traffic modeling software packages that are executed sequentially, each with its own strengths and weaknesses.

The survey conducted for this report, as described in Appendix D, shows a modest trend toward the creation of hybrid models for evaluating highway projects. A typical example of a hybrid model would be a conventional four-step travel forecasting package feeding results to a dynamic traffic assignment (DTA) package that feeds results to an operations-level traffic modeling package. Some analysts have recognized that it may be necessary also to provide a feedback loop between the last modeling platform and the first, so that delays discovered by the traffic operations model can be incorporated into the travel forecasting model. Although possible, such hybrid models are often awkward to implement because of incompatibilities among the software packages and an inability to ensure convergence to a traffic equilibrium solution. Therefore, hybrid models will likely be applied only to situations requiring highly precise speed estimates that go well beyond the current capabilities of today's travel forecasting packages.

It is possible to conceive of a travel forecasting modeling package that contains many of the elements of a hybrid model, but is completely self-contained for project-level work and satisfies all the convergence requirements of a planning model.

Such a model would resolve most of the issues that have arisen when using conventional four-step models by themselves and would obviate the need for various refinements. Some practitioners are already developing/implementing software that is close to the ideal, and therefore do not need to routinely perform refinements on their model outputs. The project-level model ideal has these properties:

- For long-term travel forecasts, the ability to estimate demands between all origins and all destinations through behavioral principles.

Table 3-1. Traffic forecasting tool/methodology topics.

Topic	Description	Location
Traffic forecasting ideal	Characteristics and performance capabilities of a hypothetical, optimal forecasting tool	3.1
State of the practice in forecasting models	Characteristics and performance capabilities of a typical, good-practice forecasting tool, described for each of the common submodels (trip generation, trip distribution, model split, traffic assignment, and reporting)	3.2–3.2.1.6
Enhancements, improvements, and alternatives to standard four-step modeling	Alternative and/or better-practice model approaches and capabilities for non-activity based models. Topics include (1) Origin-destination trip table estimation from ground counts (2) Intersection turn penalties from delay calculations (3) Travel time feedback between model steps (4) Multiclass traffic assignment (5) Commodity-based freight forecasting (truck component is included) (6) Intersection delays within standard network modeling approach (7) Car ownership and fleet mix modeling (8) Multiresolution (detail in time and geography) platforms (9) Induced travel (10) Enhancement to link impedances in tolls [FORTHCOMING] (11) Estimation of intersection and ramp delay outside of standard network modeling approach including simulation	3.2.2–3.2.2.11
	Non-highway models, including non-motorized models	3.2.3
	Advanced topics, including (1) Integrated land used models (2) Spreading of the peak-hour/period (3) Time of Day (TOD) choice (4) Tours and tour-based models (5) Activity-based models (6) Dynamic traffic assignment (DTA) (7) Travel time reliability (8) Economic modeling (9) Impacts (10) Land use modeling	3.2.4.1–3.2.4.10
	Microscopic traffic simulation, what it is, how/when to use it; Comparison of measures of effectiveness from *Highway Capacity Manual* (HCM) and microscopic traffic simulation	3.2.5–3.2.5.3
Data inputs for travel forecasting models	Types and sources of data used by travel forecasting submodels: (1) Socioeconomic data (2) Network data (3) Traffic counts (4) Household travel surveys (5) Origin-destination studies (6) Freight and heavy vehicle data	3.3–3.3.6
Travel forecasting outputs	Types of results produced by forecasting and modeling process: (1) Traffic volumes (2) Speeds (3) Intersection turning movements (4) Measures of effectiveness (5) Origin-destination information	3.4–3.4.5
	Analysis derived from model outputs: (1) Emissions (2) Economic impact (3) Benefit/cost analysis (4) Bridge and pavement deterioration analysis	3.4.6
Defaults vs. locally specific parameters	Use of data and information derived from national sources or other non-local sources	3.5
Other traffic forecasting tools and methodologies	Traffic forecasting that does not rely on full travel demand or simulation modeling and with modest data requirements: 1) Kentucky Transportation Cabinet traffic forecasting 2) *NCHRP Report 255* sketch planning 3) Origin-destination matrix growth factoring 4) Time-series modes 5) Traffic impact study tools including Institute of Transportation Engineers trip generation approaches 6) Elasticities	3.6–3.6.6

- For short-term travel forecasts, the ability to estimate an origin-destination (OD) table, either through analysis of traffic counts or through behavioral principles or both.
- For long-term forecasts, the ability to make adjustments to the OD table to reflect differences between base year traffic counts and base year forecasted volumes.
- The ability to perform dynamic equilibrium traffic assignments, with appropriate feedback to earlier steps, if necessary.
- The ability to calculate delays for through and turning movements (separately) at intersections, such as signals, stop signs, and roundabouts, in accordance with accepted traffic engineering principles, such as those found in the 2010 edition of *Highway Capacity Manual* (HCM2010) (*21*).
- The ability to incorporate delays from turning movements into traffic assignments.
- Sensitivity to traffic control operational strategies, including work zones.
- The ability to apply time-of-day (TOD) factors applied prior to traffic assignment for peak-hour assignments or to create a dynamic OD table for DTAs. TOD factors could be determined through historical data or through behavioral principles such as a departure-time choice model.

Furthermore, it is implied that an ideal project-level model would have these features, which are commonly available in today's modeling packages:

- A fine-grained zone system that eliminates lumpy traffic assignments (i.e., large changes in traffic volumes on connected links) on links that are relatively free of congestion and largely eliminates unassigned intrazonal trips.
- A high level of network detail that allows for good paths connecting zones to the arterial system and allows traffic to be assigned to streets of lower functional classes.
- Multiple vehicle classes to correctly track trucks and to correctly incorporate trucks into estimates of delay.
- Multiple driver classes to correctly represent the effects of pricing on different income groups or the effects of other policies that would have varying impacts on different population segments.

An ideal travel forecasting model would be capable of responding to a variety of planning needs, including transportation systems management (TSM), transportation demand management (TDM), multimodal infrastructure changes, pricing strategies (including tolling), and policy initiatives. The behavioral principles would be robust enough to be sensitive to policies that would encourage or discourage travel.

An assumption of this report is that the analyst does not possess an ideal project-level model.

3.2 State of the Practice of Travel Forecasting Models

The state of travel forecasting has been described in many textbooks and reports, so this discussion is intended only to establish a baseline that can be referenced later when describing supplementary techniques or enhancements. The reader is directed to *NCHRP Report 716* (*6*), *NCHRP Report 365* (*7*), *TRB Special Report 288* (*22*), and various textbooks for methodological details.

3.2.1 Basic Travel Demand Modeling (Four-Step Modeling)

There are a few common elements across travel forecasting models, but there are many differences, too. Travel forecasting models can legitimately differ because of planning requirements, availability of data for calibration and operation of the model, and the philosophy and preferences of the modeler. It is difficult to say that a model is "good" or "bad" by simply looking at an outline of the model steps. Indeed, an evaluation of a model can be quite subjective, as indicated by the many peer reviews of metropolitan planning organization (MPO) models in recent years.

The following discussion is framed in the context of key concepts and components encountered in many basic or baseline travel demand models. In each instance, a "travel forecasting model" is defined as being one that is being used at least partially for highway project-level work.

3.2.1.1 Basic Premises

Basic premises are the following:

- A travel forecasting model is capable of estimating passenger and vehicle demand between all relevant pairs of origins and destinations.
- A travel forecasting model should be able to calculate passenger and vehicle demand from behavioral principles.
- A travel forecasting model should be sensitive to those policies and project alternatives that the model is expected to help evaluate.
- A travel forecasting model should be capable of satisfying validation standards that are appropriate to the application.
- Validation standards are described in the *Travel Model Validation and Reasonableness Checking Manual, Second Edition* (*9*).
- The model should be subject to frequent recalibrations to ensure that validation standards are continuously met.

3.2.1.2 Trip Generation

The following list describes some aspects of a trip generation step:

- A travel forecasting model relying on behavioral principles should be organized by trip purpose. There may be one or many trip purposes:
  - A commonly adopted set of trip purposes, from *NCHRP Report 187* (*8*), is home-based work, home-based non-work, and non-home-based.
  - Other trip purposes can be added, as needed, by subdividing one or more of these three purposes (or travel markets) such as school trips, shopping trips, and recreational trips.
  - In some cases, project-scale travel demand models may focus only on a single trip purpose to analyze a particular kind of travel behavior such as work trips or shopping trips.
  - Trip purposes include both trips from productions to attractions ("to") and from attractions to productions ("from"). The return-to-home trip purpose has fallen into disuse.
  - In a "trip-based" model, individual trips are unlinked, but tours are inherently accounted for through the use of the non-home-based trip purposes.
  - In some models, an effort is made to differentiate trip generation rates by area type or location. This assists with capturing differences in trip generation behavior, particularly along a rural/urban divide, and with addressing unique land use activity patterns, such as mixed-use or transit-oriented-design.
- A travel forecasting model may have the ability to calculate trip productions from behavioral principles. Trip productions are trip ends at the location where the need for the trip has been established:
  - Some trip production calculations are aided by an automobile availability substep.
  - A commonly accepted method of calculating trip productions is cross-classification.
  - Trip productions may be estimated from zonal data on the number of persons per household, number of workers per household, automobile availability, or income either alone or in combination.
  - Non-home-based trip productions that may have been generated at the zone of residence should be relocated to zones where there are high levels of non-home activities.
  - It is commonly accepted that trip productions are in units of person trips over a 24-hour period of time.
- A travel forecasting model may have the ability to calculate trip attractions from behavioral principles. Trip attractions are the ends of trips at the location where the trip purpose is satisfied (completed):
  - A commonly accepted method of calculating trip attractions is a set of linear equations of levels of zonal activity. Levels of activity may include number of households at the zone of residence, number of workers by industry at the zone of employment, and school enrollments at the zone of the school.
  - It is commonly accepted that trip attractions are in units of person trips over a 24-hour period of time.
- A travel forecasting model may use "special generators" to account for unique or unconventional trip generators:
  - Special generators may include productions and/or attractions.
  - Activities covered by special generators have included universities, military bases, parks, beaches, amusement parks, airports, large shopping malls, and hospitals.
  - Occasionally, special generators are used at external stations to draw external-internal trips that are not generated by the region's households out of the model during model validation.
  - Trips generated by special generators are often static and may impact forecasting results if the forecaster is unaware of their existence.
- A travel forecasting model may have the ability to reconcile (or "balance") differences between totals of trip productions and trip attractions. A single trip must have a production end and an attraction end. Thus, the total of all productions and the total of all attractions within a trip purpose must be equal. While many practitioners prefer to balance (normalize) attractions to match productions, it is helpful when the model has the option for balancing productions to match attractions. For example, if an imbalance occurs in a small region that relies on importing workers to fill regional jobs, reducing attractions to match productions would not be appropriate. The model should be capable of excluding from balancing productions and attractions at external stations and at special generators.
- A travel forecasting model may have the ability to calculate zonal "attractiveness" values in lieu of trip attractions, in which case balancing is unnecessary. Zonal attractiveness is a measure of the size of the zone. It is preferred when either a destination choice model or a singly constrained gravity model is chosen for the trip distribution step. In a singly constrained gravity model, either the sum of the trips across all columns matches the total number of productions, or the sum of the trips across all rows matches the number of attractions for a zone. In a doubly constrained model, both conditions are met.
- Commercial vehicle demand should be incorporated within the model. A typical commercial vehicle component has

steps similar to a passenger component. Many models have commercial vehicle components similar to the truck model described in the *Quick Response Freight Manual II* (*10*). A true freight model—that is, a model based on commodity flows—is still unusual in urban locations because of the difficulty of obtaining the necessary data.

3.2.1.3 Trip Distribution

A travel forecasting model may have the ability to calculate the number of person trips between origins and destinations for each trip purpose:

- OD person trips may be obtained with a doubly constrained gravity model.
- OD person trips may be obtained with a destination choice model or a singly constrained gravity model:
  – Gravity model friction factors may be calculated with a "gamma" function, an exponential function, a power function, or an empirically derived table of numbers.
  – Gravity models primarily use impedances between origins and destinations as a measure of spatial separation. Impedances are expressions of total travel costs that incorporate the effects of travel time, travel costs, and distance. The units of impedance are theoretically unimportant, but impedances are often expressed in units of minutes.
  – Destination choice models are often formulated as multinomial logit models.
  – Through trips, that is those passing entirely through the study area, are most appropriately handled by supplying an empirically derived external-external (E-E or X-X) vehicle trip table between external stations.
- When using either a gravity model or destination choice model, it may be possible to find composite impedances across modes by taking the log-sum of highway and transit impedances (and any other available modes).
- A travel forecasting model may have the ability to apportion demands into time periods shorter than one full day. A commonly accepted method of TOD factoring is to use historical fixed percentages of trips to and from the purposeful end of trips. Factors are most conveniently applied just after trip distribution, but they can be applied after trip generation or after mode split.
- In the absence of the ability to estimate demand from behavioral principles, a travel forecasting model should be able to calculate vehicle demand from traffic counts, turning movements, or other on-the-road empirical evidence. There are many available methods for estimating vehicle trip tables from traffic counts, and there is no consensus as to which method is best. Commonly adopted methods require that the user supply an initial (or "seed") OD trip table, as well as traffic counts. There is also no consensus as to how a "seed" OD table may be built; although an historical OD table is recognized as a good starting point, when available. Experimentation and common sense are required for good results.

3.2.1.4 Mode Choice

A travel forecasting model may have the ability to split trips according to travel modes:

- Two commonly accepted methods of mode split are multinomial logit and nested logit. Nested logit models group modal choices with similar characteristics in a separate calculation step and overcome the potential of multinomial models to overestimate trips by such similar modes. Mode split within these analytical methods is often a function of travel time, travel cost, and convenience and socioeconomic factors. Trips can be split into few or many modes. Potential modes include automobile, truck, bus, rail transit, nonmotorized travel, and carpool.
- In locations where the plan does not require information on transit ridership, it is possible to use historical factors to apportion trips to the automobile mode.
- In addition to splitting between transit and automobile modes, a mode choice model can be used to subdivide automobile modes into single-occupancy vehicles (SOVs) and high-occupancy vehicles (HOVs). These can be further subdivided by willingness to pay tolls.
- A travel forecasting model may have the ability to convert person trips to automobile trips in a step referred to as automobile occupancy. A commonly accepted method of determining automobile occupancy is to apply fixed historical occupancy factors to person trips in order to obtain vehicle trips. Automobile occupancy factors can, optionally, vary by TOD.

3.2.1.5 Trip Assignment

A travel forecasting model is capable of assigning highway traffic to road segments (links):

- This process involves summing the number of vehicles between each origin and destination that traverse a road segment.
- The most common division of vehicles in traffic assignment is between automobiles and trucks; although some models further subdivide trucks into light, medium, and heavy duty. In travel demand models that explicitly count trucks during the highway assignment process, a

passenger car equivalent (PCE) factor will be used. The PCE is used to convert trucks into an equivalent number of passenger cars for the model's congestion calculations and for pavement thickness calculations for highway design.

- A basic model includes only "static" traffic assignment, which assigns all traffic within a single time period to the network in a single loading.
- If congestion is not anticipated or cannot be determined with good precision, then highway traffic volumes may be estimated with an all-or-nothing traffic assignment or a "multipath" assignment method that has the ability to split trips across many paths between any given origin and destination.
- If congestion is anticipated, then highway traffic volumes may be estimated with a method that satisfies principles of traffic equilibrium. Acceptable methods of equilibrium traffic assignment include the method of successive averages (MSA) and Frank-Wolfe decomposition.
- If congestion is moderate to severe, then delays that are found in the assignment step may be fed back to any earlier steps that use highway travel times, particularly mode split and trip distribution. It is commonly accepted that feedback processes should be run until an equilibrium state is achieved throughout the whole modeling sequence. Specifically, this includes achieving a correspondence between the input travel times used for trip distribution and the travel times output from the traffic assignment model. This feedback process might require several iterations. A well-established way of obtaining consistent highway travel times throughout the model is the MSA, although other, less-efficient iterative schemes are possible. The MSA produces an unweighted average of many all-or-nothing traffic assignment volumes. Each successive all-or-nothing traffic assignment uses delays that are computed from the previous iteration's average.
- Delays (or re-estimated travel times) may be calculated for all roads in the region. Delays may occur along road segments (links) or at intersections (nodes). Delays along road segments are commonly estimated by a "volume-delay function" (VDF), which uses the estimated volume-to-capacity (V/C) ratio. VDFs can vary by functional class. VDFs are sometimes used for delays at intersections, but more sophisticated methods that are sensitive to conflicting and opposing traffic levels are growing in popularity. For example, some models use relationships drawn from HCM2010 (*21*).
- Path building may be made sensitive to turn restrictions and turn penalties that are specified ahead of time. A commonly accepted method for properly accounting for turn restrictions and penalties is vine building.
- Person trips from a mode other than the automobile mode (e.g., transit) may be assigned to a modal network.
- Traffic from a commercial vehicle component may be added to automobile traffic when assigned to the network:
  - Heavy truck traffic is commonly weighted by PCE factors, similar to those found in HCM2010 (*21*), when calculating delays.
  - Some models track trucks separately from automobiles during the assignment step through a process known as multiclass traffic assignment.
- Traffic assignments should achieve a close approximation of equilibrium conditions. This means that at the conclusion of the traffic assignment process, travel times or impedances on alternative feasible paths between origins and destinations will be very nearly equal. Without achieving equilibrium or nearly equilibrium conditions, the results from the traffic assignment process will not be nearly as realistic in replicating real-world conditions.

3.2.1.6 Outputs/Reporting

The following output/reporting functions are desirable for travel forecasting models:

- A travel forecasting model should be capable of reporting results in a form that is sufficiently detailed, precise, and diagnostic to understand the impacts of a project on the street system and provide reliable information to understand the need for and efficacy of additional roadway capacity and to calculate measures of effectiveness, as appropriate.
- Outputs should be consistent with each other and with equilibrium conditions on the network, if an equilibrium traffic assignment technique is used.
- A travel forecasting model should be able to generate traffic volumes by link, turning movements at important intersections, and delays (or loaded travel times) by link, for any time period of interest.
- A travel forecasting model may provide diagnostic reports about the trip patterns that make up a traffic assignment. Such diagnostic reports include vehicle trips in and out of each zone, select link analysis, select zone analysis, and link-to-link flow analysis.
- A travel forecasting model may provide diagnostic reports about the calculation of system demands. Such diagnostic reports include trip productions, trip attractions, average trip lengths, and trip length distributions.

3.2.2 Four-Step Modeling Enhancements

The following modeling topics are considered to be significant enhancements to four-step travel demand modeling, but not quite in the category of advanced modeling. These topics include the following:

- OD trip table estimation from ground counts,
- Turn penalties from delay calculations,
- Feedback,
- Multiclass traffic assignment,
- Commodity-based freight component (truck component is included),
- Intersection delays,
- Car ownership modeling,
- Multiresolution platforms,
- Induced travel, and
- Estimation of node delay.

3.2.2.1 Origin-Destination Table Estimation from Traffic Counts

Research on OD table estimation from traffic counts dates from the 1970s, but a clear consensus has not been reached as to how it should be accomplished.

Because of the topic's importance, numerous software packages have introduced their own algorithms for finding synthetic OD tables. Unfortunately, different algorithms will find different solutions, so the process is not usually replicable across software packages.

The idea is simple: find a reasonable OD table that will reproduce known traffic counts. On large networks, there are many different OD tables that will reproduce traffic counts with equal quality, so there is a need for additional information to help choose an OD table. Most algorithms available today supplement the traffic counts with a "seed" OD table that is a best-guess approximation of the desired result. A seed OD table may be one that has been observed in the past, one that has been observed recently but imprecisely, or one developed from principles of driver behavior.

Most of the published methods for OD table estimation formulate the algorithm as a constrained optimization problem. That is, they find the best solution to maximize some index of quality or minimize some index of error. Inherent or explicit weighting is done as a compromise between fitting the "seed" OD table well and fitting the traffic counts well.

The most rigorous algorithms are computationally intensive and can require a very large amount of computer memory. Optimization problems require searching for a solution, and the time necessary to achieve a solution increases rapidly with the number of variables. In the worst case, there can be as many variables as the number of cells in the OD table.

OD table estimation can also be made dynamic. In this case, a dynamic OD table gives the number of trips between each origin zone and each destination zone that start at a particular time. Dynamic OD tables require dynamic traffic counts and a dynamic seed OD table.

An important consideration, often missed by practitioners, is the amount of error inherent in the traffic counts. Algorithms are fully capable of tightly fitting the measured traffic counts, even though traffic counts have their own errors, some of which are substantial.

A particular application of synthetic OD table estimation is the refinement of an OD table that has been created within a travel forecasting model. In such an application, the model's OD table is adjusted to match, or almost match, ground counts. Additive or multiplicative factors are retained so that they can be applied to any forecast done later with the model.

3.2.2.2 Turn Penalties from Delay Calculation

Mesoscopic models are able to differentiate delays by turning movements, as shown in the operational analysis procedures of HCM2010 (*21*).

It is possible to incorporate those delays in subsequent path buildings within a model, so that especially long delays, say from left turns at signals, can be accounted for in shortest paths.

3.2.2.3 Feedback to Earlier Steps

Early implementations of four-step models were often criticized for doing the steps in a particular order and never resolving inconsistencies between those steps. Most troubling were inconsistencies in the path travel times that were used for trip distribution and mode split when compared to the output travel times from the traffic assignment step. In addition, travel models with an integrated land use step had travel time inconsistencies when allocating activities to zones. Work on "combined" models from the 1970s, particularly a well-known study by Evans (*137*), showed that it was possible to neatly resolve those inconsistencies.

The idea of resolving path travel time inconsistencies has been dubbed "feedback," to suggest an iterative process where delays from traffic assignment are incorporated into earlier steps in the model. Many modelers found it difficult to implement Evans's theories directly into their software, so many modelers relied on unsophisticated heuristic algorithms until it was demonstrated that MSA could find the same solution as Evans's method. MSA is iterative and follows Evans's theories in overall structure, but replaces a complex optimization substep with an elementary averaging of traffic volumes from all previous all-or-nothing traffic assignments.

Delays, thus link and node travel times, are calculated from the averaged volumes. According to Wardrop (*24*), the equilibrium conditions for a traffic assignment are reached when no travelers can improve their origin-destination travel times by changing paths. MSA obtains a solution that satisfies the conditions of "user-optimal" equilibrium traffic assignment, as described by Wardrop (*24*), and ensures complete consistency between path travel times across all steps.

3.2.2.4 Multiclass Traffic Assignment

Multiclass traffic assignment, which separately tabulates volumes for each vehicle class, is a modest extension of standard traffic assignment algorithms. Vehicles can be classified by body type (passenger cars, trucks, buses, etc.), by occupants (SOV, carpools, etc.), or by characteristics of the driver that would suggest different path-finding behaviors. Multiclass traffic assignments are usually used only when it is suspected that path choice behavior differs significantly across classes.

Typical applications of multiclass traffic assignments are determining heavy truck volumes on roads, determining the impact of road pricing, and determining the utilization of HOV lanes.

3.2.2.5 Commodity-Based Freight Component

There are two methods of forecasting freight traffic within travel models: truck based and commodity based. Truck-based components are most often seen in urban regional models. Commodity-based components are often seen in statewide models.

The development of a commodity-based model was described succinctly in 10 steps in the *Guidebook on Statewide Travel Forecasting* (*25*).

- Obtain freight modal networks.
- Develop commodity groups.
- Relate commodity groups to industrial sectors or economic indicators.
- Find base year commodity flows.
- Forecast growth in industrial sectors.
- Factor commodity flows.
- Develop modal cost for commodities.
- Split commodities into modes. There are three categories of methods for splitting commodities into modes:
  - Mode split models.
  - Tables.
  - Expert opinion.
- Find daily vehicles from load weights and days of operation.
- Assign vehicles to modal networks.

The main hindrance to building a commodity-based model in urban regions is the absence of commodity flow data for zones smaller than counties.

3.2.2.6 Intersection Delay in Traffic Assignment

Means for calculating intersection delay in travel forecasting have been rapidly evolving. Older travel forecasting models estimated delay only on links with an elementary mathematical relationship between travel time, volume, and capacity. Such relationships are referred to as VDFs. There are several forms of VDFs, but the most prevalent VDF is the "BPR curve." ("BPR" stands for the Bureau of Public Roads, which ceased to exist in 1967 and was the predecessor agency to FHWA.) VDFs are insensitive to levels of conflicting and opposing traffic, so they do poorly at estimating delays at intersections. They are also insensitive to queuing due to congestion. Some newer travel forecasting models have moved toward implementation of sophisticated delay estimation procedures to produce more realistic estimates of travel times through intersections.

The complexity of intersection delay relationships adds to the data requirements of the model. Intersections need to be described carefully in terms of their lane geometry and signalization timing. It is possible, and often desirable, to simulate signalized intersection timing so that inputting full timing information can be avoided.

Intersection delay relationships interfere with some popular methods of finding equilibrium solutions, especially those that formulate traffic assignment as an optimization problem, such as Frank-Wolfe decomposition. None of the optimization formulations in network assignment algorithms can handle situations where delay on one link is affected by traffic on other links. Current optimization formulations require a VDF in only one variable (namely link volume), and the VDF must be presented in a form for which an integral can be conveniently and quickly found. Intersection delay relationships do not satisfy these two requirements.

A major impetus for the adoption of better methods for intersection delay was the publication of the *1985 Highway Capacity Manual* (*26*) that contained, for the first time, delay estimation procedures for signalized and one-way and two-way stop intersections.

There are other ways to calculate intersection delay, but the wide acceptance and availability of the *Highway Capacity Manual* (HCM) in the traffic engineering community has made it a particularly attractive source document for calculating delay in travel models. The variety of intersections that can be handled by HCM procedures has increased over the years.

The HCM2010 (*21*) has means for calculating delays for one-way stops, two-stops, all-way stops, signals, and roundabouts.

Delays can be calculated separately for each lane group, which allows for separate movements and phases to be analyzed.

These procedures are formulated as a variational inequality problem for which solution algorithms have been developed. A troubling matter, however, is that it is entirely possible for there to be more than one equilibrium solution. The presence of multiple solutions is considered a minor issue for most planning studies, but it can distort the comparison of almost similar alternatives that might arise within traffic operations studies.

MSA is a traffic assignment method that does not rely on optimization and can find solutions to the equilibrium traffic assignment problem when delay on one link is affected by traffic on other links.

VDFs remain popular in planning models for estimating delays on uninterrupted facilities.

3.2.2.7 Car Ownership and Vehicle Fleet Mix Modeling

Car ownership or vehicle ownership has been a key explanatory variable affecting estimates of travel demand in various model components. Car ownership is an explanatory variable that appears in numerous trip production models and mode choice models, and more recently, in several destination choice models as well. It is sometimes viewed as a surrogate for household income, a variable that is often difficult to measure accurately in travel surveys. As car ownership is itself a function of several socioeconomic and demographic variables, various types of models of car ownership have been developed and incorporated into travel demand model systems in numerous metropolitan areas. Car ownership models may take the form of the following:

- Linear regression models,
- Count models such as poissons and negative binomial models,
- Unordered discrete forms such as the multinomial logic and nested logic models, or
- Ordered discrete forms such as the ordered profit and ordered logic models (*27, 28, 29*).

These models are capable of predicting vehicle ownership distributions in zones as a function of other socioeconomic and demographic characteristics (such as household size, income, number of workers, number of children, and age).

More recently, with the recognition that car ownership has reached a point of saturation for several years now, attention has turned to modeling not only car ownership but also the fleet composition or mix (*30*).

Vehicle fleet mix has important implications for energy and air quality analysis, and with the recent interest in enhancing clean vehicle penetration in the marketplace, policies aimed at influencing vehicle purchase decisions of consumers can be analyzed using vehicle fleet composition models. (There is a distinction between fleet mix in the context of modeling for air quality analysis and truck percentages used for an actual forecast. The analyst needs to be aware of the subtle implications of the difference.)

Recent developments in the formulation, estimation, and application of the multiple discrete-continuous extreme value (MDCEV) model offer considerable promise in the ability to model and forecast vehicle fleet composition (defined by mix of vehicle body types, fuel types, and vintage) for transportation policy analysis (*31*). Corridor-specific strategies that aim to promote use of alternative fuel vehicles (e.g., allowing alternative fuel vehicles with a single occupant to use the HOV lane) can be analyzed with respect to their potential to influence vehicle ownership and usage patterns among the population.

3.2.2.8 Multiresolution Platforms

Practically speaking, there is little distinction between hybrid models and multiresolution platforms. Hybrid models involve two or more modeling platforms that have fundamentally different ways of obtaining their results, such as mixing a macroscopic travel forecasting model with a traffic microsimulation. Multiresolution models involve two or more modeling platforms that have different levels of precision. However, the need to achieve highly detailed network flows usually coincides with the need for highly accurate delay estimations that may only be achievable with microsimulation techniques. See the work of Shelton and colleagues (*32*) and Burghout and Wahlstedt (*33*) as examples.

The concept of multiresolution, itself, deals with the issues of spatial scale and network precision. Mulitresolution platforms are particularly attractive when highly precise results are desired, but the scale of the study area is too large for all of the software steps at the finest level of detail. Multiresolution models enable the following:

- Multiple network structures in varying levels of precision,
- Detailed spatial representation (known as spatial decomposition),
- Detailed temporal representation (known as temporal decomposition), and
- More precise forecasts than can be achieved with a coarser model.

A particular form of multiresolution platform involves spatial detail. An example of this is the interface between a statewide model and MPO/regional models, in which the statewide model has a streamlined node, link, and zone configuration that allows for the insertion of one or more local area networks with no additional network coding.

A two-way interface between those models allows the statewide model to provide external flows for the regional models and allows the regional models to provide better impedance values for the statewide model. This same concept has been used experimentally for purely local models, where the urban area has been decomposed into many small networks and care is taken to ensure consistency of flows across all the subnetworks (*34*). Models with spatial decomposition can make efficient use of multicore computers.

3.2.2.9 Induced Travel

The notion of induced travel is often a key consideration in developing project-level forecasts. Induced travel refers broadly to the additional traffic that a facility will experience following the implementation of a project or policy that improves travel time or reduces generalized travel costs. Induced travel may arise from a number of sources that have been identified in the literature (*35, 36, 37*).

When a particular facility is improved, thus reducing travel time or cost on the facility, some travelers may divert from other routes to the improved route, thus increasing traffic volumes on the improved facility. Changes in destination choice may also result from a project-level roadway improvement as travelers may be able to visit more preferred destinations farther away without experiencing longer travel times following the improvement to a facility. Yet other travelers may shift mode choice, choosing to use the automobile mode (from transit or carpool) in light of the reduced congestion that often results from a project-level improvement. All of these shifts result in increased traffic volumes on the improved facility and constitute induced traffic. The shifts identified above are often well captured by travel demand models. Destination choice or trip distribution models capture changes in destination choice patterns in response to changes in system capacity, mode choice models capture shifts in mode usage, and traffic assignment models account for route shifts.

One of the sources of induced travel that is not captured well by current four-step travel demand models (albeit with a few exceptions) is that of net new trips that are undertaken by travelers following the improvement of a facility.

Most trip generation models in four-step models are not sensitive to accessibility measures or other network level of service variables; as such, changes in travel time or cost do not impact trip generation estimates. More recent tour-based and activity-based models, on the other hand, have begun to incorporate approaches whereby activity and tour generation are sensitive to accessibility measures (often represented by the log-sum terms of mode choice models downstream).

While induced travel may result exclusively from changes in network level of service measures due to a project-level improvement, it is also important to consider the longer term effects arising from land use changes triggered by enhancements in network accessibility (*38*). In the longer term, new land use developments may come into existence following an improvement in highway facilities. Changes in land use development patterns will, in turn, inevitably lead to changes in activity-travel patterns across the spectrum of travel choices (activity generation, destination choice, mode choice, and route choice).

Integrated land use–transport models that account for the cyclical relationship between land use and transportation are capable of accounting for such longer run effects as long as the land use forecasting models are sensitive to measures of network performance. According to Kuzmyak and colleagues (*38*), individual studies have generally reported elasticities of vehicle miles traveled (VMT) with respect to roadway capacity of +0.1 to +0.9. There continues to be considerable debate surrounding the magnitude of induced travel effects as evidenced by the split opinion reported in *TRB Special Report 245* (*39*). There do not appear to be standard methods or tools to account for possible induced travel effects in project-level forecasting efforts.

The application of elasticity values reported in the literature may provide a basis on which to apply adjustments to project-level forecasts to account for such effects (for example, the forecast from a model may be amplified by 10 or 20% to account for possible induced travel effects). As activity-based microsimulation travel models continue to gain ground in a variety of project-level analysis contexts, it is envisioned that standard methods or tools to quantify induced travel demand will evolve to meet local needs.

3.2.2.10 Estimates of Node Delay

Model Application. In a model network, a node joins two or more links. Nodes represent the physical intersection of streets or roads. In a highway system, traffic control is used to assign right-of-way at these junctions, and characteristically there is delay associated with traffic control devices.

Most travel demand model software platforms have the capability to compute and/or assign node delay. The delay can be calculated internally within the modeling software or computed/estimated externally using other tools and methods and applied as part of the trip distribution and traffic assignment steps. Whether computed internally or externally, node delay can be applied as travel time penalties of separate values assigned to individual intersection movements—left turns, through movements, right turns, and so forth.

Demand models typically aggregate total delay on a link basis, where the total delay equals the mid-block delay along the link plus the control delay associated with the node at the downstream end of the link.

Control delay can have a significant effect on travel time and route choice, but it is often ignored at the node level in travel demand models. As delay is a component of total travel time and a key parameter in route choice, node delay should be considered in the traffic forecasting process.

Types of Node Delay. Node (intersection) delay occurs in one of two ways:

- Control delay, a result of traffic control devices; and
- Geometric delay, in association with the physical characteristics of an intersection or junction.

Traffic control devices causing node delay include signals, STOP signs, and YIELD signs. In addition to being located at street intersections, traffic signals can be placed on freeway entrance ramps to meter flow, thus resulting in an associated delay.

Geometric delay is delay caused by the geometric features of a facility that cause drivers to reduce their speed in negotiating the facility. Geometric delay is relatively small when compared to control delay and is typically ignored.

3.2.2.11 Tools for Estimating Node Delay

The tools most commonly used to estimate control delay are the HCM [an updated version was published in 2010 (*21*)] and microscopic traffic simulation; however, sometimes there are special cases where conventional tools or methods don't apply. The HCM, microscopic traffic simulation, and special cases are discussed below.

3.2.2.12 HCM

The HCM provides procedures to estimate node delay for

- Signalized intersections,
- Unsignalized intersections (two-way STOP-control [TWSC], all-way STOP-control [AWSC], and roundabouts), and
- Interchange ramp terminals.

The HCM defines control delay as the increase in travel time due to a traffic control device. On an approach link, it includes delay associated with initial deceleration, queue move-up time, stopped time, and final acceleration.

HCM methods estimate control delay for individual approach lane groups at an intersection, and these can be applied to model traffic assignments. For each approach leg and the intersection as a whole, an aggregate node delay can be computed as the volume-weighted average of control delays for approach links to the node.

3.2.2.13 Signalized Intersections

The HCM method for signalized intersections represents average control delay for all vehicles during an analysis period, including those vehicles still in a queue when the analysis period ends. For an approach lane group, control delay is expressed as follows:

$$d = d_1 + d_2 + d_3$$

where

d = control delay (s/veh),
d_1 = uniform delay (s/veh),
d_2 = incremental delay (s/veh), and
d_3 = initial queue delay (s/veh).

The uniform delay term, d_1, is based on the original model developed by Webster (*40*) to represent delay under uniform arrivals and departures. As an alternative to the Webster method, the "incremental queue accumulation" procedure is offered to compute a more accurate uniform delay term where traffic moves in platoons, where movements occur over multiple green periods, and where there are movements with multiple saturation flow rates (e.g., protected-permitted left turns).

The incremental delay term, d_2, accounts for (1) delay due to the effect of random cycle-by-cycle fluctuations in demand that occasionally exceed capacity and (2) delay due to sustained oversaturation during the analysis period.

The initial queue delay term, d_3, accounts for additional delay incurred due to an initial queue at the beginning of the analysis period that is caused by unmet demand in the previous period.

All three terms incorporate the ratio of demand traffic volume to capacity for intersection approach lane groups. As the demand V/C ratio increases, approach delay increases modestly in a linear form until the V/C ratio approaches 1.0, then increases rapidly beyond that point.

Intersection delay also is a function of traffic signal timing parameters such as cycle length, phase duration and sequencing, treatment of left turns (protected, permitted, or protected-permitted phasing), and coordination with other signals. Variations in these parameters can have significant effects on intersection delay.

Requiring a complete signal timing plan can be onerous, especially for a planning application where timing parameters are unknown or must be assumed.

The HCM provides a quick estimation technique that can be used to develop reasonable timing plans for estimation of node delay. A detailed documentation of the method for an operational analysis is located in Volume 3, Chapter 18 of HCM2010.

3.2.2.14 Unsignalized Intersections

There are three types of unsignalized intersections: TWSC, AWSC, and roundabouts.

The HCM TWSC method is based on gap-acceptance theory and includes the following basic elements:

- Size and distribution (availability) of gaps on the major street,
- Usefulness of these gaps to minor street drivers and their willingness to accept them, and
- Relative priority of various movements at the intersection.

Capacity for STOP-controlled approaches is computed as a function of the conflicting flow rate, the major movement critical headway (i.e., the minimum headway or gap that drivers are willing to accept), and follow-up headway for the minor movement. Control delay is computed as a function of the demand flow rate and capacity.

The TWSC method also can be applied at two-stage crossings, where the major street is divided by a median or two-way, left-turn lane (TWLTL) that allows minor street drivers to cross or enter the major street in separate, staged movements.

The HCM does not include a detailed method for estimating delay on YIELD-controlled approaches, but the TWSC method can be applied at YIELD-controlled intersections with appropriate changes to key parameters (e.g., critical headway and follow-up headway).

The HCM AWSC method recognizes that every driver approaching the intersection must stop before proceeding and that the decision to proceed is a function of traffic conditions on the other approaches. Node delay is computed as a function of the service time (difference between the departure headway and move-up time) and the degree of utilization, which is the product of the arrival rate and mean departure headway. The method also recognizes that giving right-of-way to the driver on the right doesn't always occur, and it includes a probability of conflict model in its computation of capacity and delay.

The HCM roundabouts procedure applies to roundabouts containing one or two circulating lanes. The methodology incorporates a combination of lane-based empirical regression models and analytical gap-acceptance models for single-lane and double-lane roundabouts. Roundabout control delay is computed similarly to TWSC control delay, with a modification to account for YIELD-control on the approach leg, which does not require drivers to come to a complete stop when there is not conflicting traffic.

3.2.2.15 Interchange Ramp Terminals

Interchange ramp terminals represent a special case of at-grade (service) interchanges of freeways with surface streets. The HCM contains a methodology that addresses interchanges with signalized intersections, interchanges with roundabouts, and impacts of interchange ramp terminals on closely spaced downstream intersections. It does not address oversaturated conditions, nor does it specifically address alternative configurations like diverging diamond (double crossover) or continuous flow interchanges.

The HCM method recognizes that interchanges operate as a system and that there are operational effects associated with the close spacing of ramp terminal intersections with the surface street. Example interchange configurations include diamond interchanges and two-quadrant partial cloverleaf interchanges.

The distance separating the two intersections and/or the proximity of adjacent downstream intersections can have a significant effect on queuing and delay, especially under congested conditions.

For signalized interchanges, average control delay for each lane group and movement is estimated using the HCM signalized intersection methodology. Average control delay for each movement through the interchange is estimated as the total delay experienced by the OD combination that defines the movement. If the OD passes through both intersections, its average control delay is the sum of delays experienced along its path.

3.2.2.16 Microscopic Traffic Simulation

Microscopic traffic simulation basics are discussed in more detail in Section 3.2.5. Whereas HCM methods for estimating node delay are deterministic (i.e., they involve no randomness and always produce the same result for a given set of inputs), microscopic simulation is stochastic and accounts for inherent randomness in driver decisions and actions such as car following, lane changing, and gap acceptance. To account for this randomness, multiple simulation runs are made and average delays are computed to produce a "typical" estimate.

On an approach link, delay is generally defined as the excess travel time spent on a roadway segment compared with free-flowing travel time on a link representing zero-delay conditions. Node delay from microscopic simulation models includes control delay and geometric delay. Total delay on the link includes the excess travel time plus node delay at the downstream end of the link.

Some simulation models employ HCM methods for estimating control delay at intersections. Where this is the case, model documentation should be reviewed and/or model developers should be consulted to identify any possible departures from the HCM methods that may be incorporated into the simulation.

3.2.2.17 Special Cases

Special cases sometimes exist where conventional tools or methods like the HCM don't easily apply. While the HCM TWSC method can be applied to estimate node delay under YIELD-control, it may be more appropriate to use simulation for cases like a merge from an entrance ramp to a congested freeway.

While there might be no delay at this junction under low-flow conditions, there would be associated delay with this merge when the freeway is congested that might play a part in driver route choice (and thus in forecasted traffic). For this example, the simulation model would be run for (1) low flow and (2) congested flow conditions on the freeway. The delay difference between the scenarios could be assigned as node delay (under congested freeway conditions only) at the freeway ramp/mainline junction.

Ramp metering represents another special case where delay is intentionally introduced under specific traffic flow conditions. For this case, the ramp (link) capacity is set to the meter rate in vehicles per hour. Alternatively, the HCM chapter on advanced traffic management provides guidance for estimating capacity for single-lane and two-lane metered ramps.

For this application, two possible scenarios exist with respect to the ramp demand volume-to-capacity ratio:

1. When the ramp demand volume is less than capacity ($V/C < 1$), queues occasionally form due to randomness of vehicle arrivals, or
2. When the ramp demand volume is greater than capacity ($V/C > 1$), queue storage occurs over an extended period of time.

Deterministic queuing analysis can be performed to estimate node delay for these scenarios. Requirements for queuing analysis include the following elements:

- Mean arrival rate,
- Arrival distribution,
- Mean service rate,
- Service distribution, and
- Queue discipline.

There are several published sources that document procedures for queuing analysis and estimating delay, including those that apply to toll plazas. The analyst is advised to select the one that most directly applies to the case at hand.

Alternatively, microscopic traffic simulation can be used to estimate delay associated with ramp metering. When using simulation, estimation of delay should include the entire trip (within the analysis area) for all affected origins and destinations and not just the localized delay, as the objective of ramp metering is to achieve a smoother flow (and faster travel speeds) along the freeway.

3.2.3 Non-Highway Models

Increasing demands to forecast demand for a broader spectrum of the transportation system have contributed to a growing interest in modeling non-automobile modes of transport, including bicycle and pedestrian modes, high-speed rail, light rail, and airplane.

Traditional travel demand models have been used to forecast travel demand by various modes of transportation. Mode choice models that have been estimated using revealed preference travel survey data, or stated preference data (if revealed preference data are not available and cannot be collected), may be applied to determine the total demand for non-highway modes of travel. High-speed rail and air transportation markets comprise long distance travel demand; statewide models and special studies may be conducted to estimate long distance travel demand, and mode choice models may be used to estimate the demand for these modes of transportation. In the urban context, light rail is a non-highway mode for which considerable attention has been paid to forecasting demand due to the scrutiny that light rail projects receive through the New Starts and Small Starts processes at the federal level (*41*).

It is important to collect appropriate data that can form the basis for estimating mode choice models, and specific attention should be paid to the relative magnitude of the alternative specific constants in the utility functions for various modes. If there are competing bus- or express-bus-lines that serve the same OD pairs as the light rail mode, then the use of light rail for a particular trip may constitute as much a path choice as it does a mode choice.

The treatment of non-motorized modes of transport (bicycle and pedestrian) generally differs from that for other mechanized means of transportation due to natural and physical constraints that prevent the use of non-motorized modes for all types of travel. Bicycle and pedestrian trips tend to be shorter in length, and although they are often lumped together into a single non-motorized category, there are important differences between bicycle and pedestrian trips that should be recognized when evaluating bicycle- and pedestrian-oriented projects.

The estimation of non-motorized mode travel demand may be accomplished using a variety of approaches. A good overview of various approaches is provided in the *Guidebook on Methods to Estimate Non-Motorized Travel* published by FHWA in 1999 (*42*).

On the demand estimation side, several possible approaches are adopted to estimate non-motorized mode usage. Comparison studies allow the estimation of demand for a new pedestrian or bicycle facility by examining usage patterns at similar peer facilities with socioeconomic and land use contexts that compare well with the proposed new facility. Sketch-planning or simple spreadsheet models can be used to implement comparison studies or other approaches that are not data intensive—such as elasticity-based methods or use of descriptive characteristics from large travel surveys similar to the National Household Travel Survey (NHTS) that provide trip lengths, rates, TOD distributions, and trip purpose distributions for non-motorized trips. Full-scale travel models often include a mode choice step capable of providing estimates of non-motorized travel. These models tend to be elaborate and potentially data intensive as the estimation of a mode choice model that includes non-motorized modes as explicit choice alternatives requires that adequate non-motorized trip samples exist in the travel survey used for model development.

Non-motorized travel demand may also be estimated using off-model approaches; a separate model that is specific to non-motorized mode usage may be developed and applied outside of the regional travel demand model. Such a model would estimate non-motorized trip generation and perform trip distribution specific to non-motorized trips. Microsimulation models are beginning to incorporate the ability to simulate pedestrian movements such as in downtown environments.

An important issue associated with non-motorized and transit travel demand estimation is that there is substantial potential for induced demand. When a new light rail line or non-motorized mode facility (sidewalk or bicycle path) is built, people may be induced to make new transit or non-motorized trips that they did not make previously. One potential way to estimate the induced demand is to introduce the change in accessibility created by the new facility into a land use model that will estimate the change in development quantity and mix. The increased development can be imported into the model and will produce additional person trips.

3.2.4 Advanced Travel Demand Modeling Topics

This section covers the most frequently cited and used areas of advanced travel demand modeling topics:

- Integrated land use,
- Peak spreading,
- TOD choice,
- Tours and tour-based models,
- Activity-based models,
- DTA,
- Travel time reliability,
- Economic modeling, and
- Land use modeling.

3.2.4.1 Integrated Land Use—Transport Models

Integrated land use—transport models are used to represent the interactions between land use changes and travel demand (*43, 44*). Generally, land use characteristics serve as inputs to transport models with demand estimates influenced by variables representing the built environment. It is now well recognized that land use and transportation interact in a cyclic manner with changes in transport system attributes affecting land development patterns over time (*45*). Land use models generally involve some of the following elements:

- Models of housing development, residential location choice, and associated building stock;
- Models of business or commercial development, business location choice models, and associated non-residential building stock; and
- Models of land values and building stock prices that help establish market prices and bid rents.

Most disaggregate microsimulation-based land use models incorporate a series of choice models capable of simulating the location choices of individual households, businesses, and other agents in the urban system (*46, 47*). These models attempt to replicate the market mechanisms that exist in the real world.

Land use models are generally responsive to changes in transport accessibility measures. Changes in modal level of service attributes contribute to the growth or decline in land use development and influence the mix of land uses that will occur.

Thus, integrated land use—transport models incorporate feedback loops where travel time and accessibility measures feed back into land use models to reflect the effects of transportation supply attributes on land use dynamics (*47, 48*).

While some suggest that this iterative, cyclical process should be executed until "equilibrium" is reached, others argue that the urban system is in a constant state of flux and that feedback processes between transport and land use models actually capture the longitudinal dynamics in urban system evolution over time. In any event, integrated land use—transport models are increasingly finding their way into mainstream practice and are used for forecasting traffic associated with individual projects (*49*).

3.2.4.2 Peak Spreading

Peak spreading, an adjustment in the temporal characteristics of travel in response to worsening traffic congestion, is a phenomenon that is observed in major metropolitan areas around the world (*50*). As peak-period traffic congestion worsens, travelers tend to shift their time of departure to the shoulders of the peak period in order to experience shorter and/or more reliable travel times (less variance on experienced travel times). As a result, and especially in congested areas, the peaks in diurnal distributions of travel tend to widen and flatten over time (*51*).

Increasing flexibility with work schedules and the ability to work anytime or anywhere are further contributing to peak spreading. Peak spreading may be accounted for in several ways in the context of travel modeling (*52*):

- The use of post-processing techniques where simple peak-spreading factors obtained from traffic observations or household surveys are applied to determine the amount of traffic that remains within the peak period versus the amount of traffic that shifts to the shoulders.
- The use of peak-spreading factors within the four-step travel demand model (prior to the assignment step) to determine the travel demand associated with the peak period and the peak-period shoulders separately. Separate assignments are carried out for these different periods to reflect traffic volumes that result from the peak-spreading phenomenon.
- The use of more stand-alone-type, peak-spreading models that often take the form of TOD choice models (discrete choice models). These TOD models are sensitive to changes in system attributes and the socioeconomic characteristics of travelers in a region. They may be introduced as a separate step in the four-step travel modeling process (*53*).

3.2.4.3 Time-of-Day Choice

As concerns about alleviating peak-period traffic congestion increasingly dominate the attention of policymakers, there is a growing interest in the deployment of TOD choice modeling techniques capable of accurately representing and capturing the diurnal distributions of travel demand.

Many travel demand management strategies and pricing measures are specifically targeted at reducing peak-period traffic and alleviating congestion. The measures aim to influence the temporal patterns of travel demand and the choices people make with respect to the scheduling of their activities and trips.

TOD choice modeling techniques may be of two basic types:

- TOD factors can be derived from observations of traffic volumes or from household travel survey data. These factors can then be applied at various stages of the four-step travel modeling process to determine travel demand by TOD. These factors are based on observed data and are not sensitive to any explanatory variables.
- TOD choice models may be estimated using household travel survey data. These choice models may take the form of discrete choice models (multinomial logit models) where the number of alternatives is equal to the number of choice periods of interest.

Each of the above methods has certain advantages and disadvantages, and caution is to be exercised in deploying TOD choice models, particularly in the context of transit modeling, as transit service tends to vary by the time of day. Currently, most TOD models split trips after trip distribution.

TOD choice models have generally focused on predicting trip departure times. More recent work in modeling TOD choice has focused on modeling departure time based on preferred arrival time, expected and experienced travel time, and the notion of schedule arrival delay penalty (disutility). Tour-based models that jointly model arrival time and departure time from a tour primary stop are also being implemented.

3.2.4.4 Tours and Tour-Based Models

Tours are a series of interlinked trips that are chained together. Depending on the definition used to describe tours, they may (or may not) be considered synonymous with trip chains. For example, one may consider a journey from home to work with an intermediate stop to drop off a child at school or pick up a cup of coffee as a tour. On the other hand, one may argue that a tour should be a closed chain, in which the origin of the first trip of the tour and the destination of the last trip of the tour are the same. Regardless of the definition that one adopts, the important aspect to note is that the concept of "tours" involves a recognition that trips are not independent entities; rather, there are spatial, temporal, and modal interdependencies across trips in a tour.

Due to the importance of this interdependency in modeling travel demand and the increasing prevalence of complex trip chaining patterns in the real world, there has been a move toward the development of tour-based models. In tour-based models, the tour is the unit of analysis (as opposed to a trip), and many choice processes are modeled at the tour level. Some of the key model components in a tour-based model include (but are not necessarily limited to) the following:

- Tour generation models (frequency of tours by type—such as work tours and non-work tours);
- Subtour generation models that capture smaller tours that take place within the context of a larger tour (for example, a tour from work to eat lunch);
- Primary activity and intermediate stop destination choice models;
- Tour mode choice, subtour mode choice, and, where applicable, stop-level mode choice;
- TOD choice model for tours, subtours, and intermediate stops; and
- Tour accompaniment models to capture joint trip making versus solo trip making.

The idea behind these models is that one will be able to capture constraints and interdependencies across travel choices for trips that belong to a tour, thus providing the ability to better estimate behavioral response to a wide range of policy measures.

3.2.4.5 Activity-Based Models

Activity-based models are often considered synonymous with tour-based models. These two terms are often used interchangeably. Activity- and tour-based models are generally implemented via a microsimulation framework.

In a microsimulation framework, a synthetic population of the entire model region is generated using statistical procedures that employ census data sets. The activity- and tour-based models are then applied to the entire synthetic population to simulate activity-travel patterns of each and every person in the synthetic population, effectively returning individual activity-travel records that are similar to household travel survey records. These activity-travel records can then be aggregated into trip tables for traditional static network assignment procedures or they can be fed into DTA procedures.

Activity-based models are sometimes distinguished from tour-based models on the basis of the focus on the continuous time representation of activity engagement patterns of individuals in activity-based models. These models consider time to be an all-encompassing entity in that activity durations are explicitly modeled. In contrast, the TOD choice of activity engagement and travel episodes in activity-based models is determined by modeling the activity and travel durations along the continuous time axis.

Activity-based models start the simulation of a daily activity-travel pattern for an individual at the beginning of the day and then sequentially simulate activity after activity and travel episode after travel episode, to build an entire activity-travel pattern for the day in an "emergent" manner. The activity-travel episodes that come later in the day are influenced by activity-travel episodes that took place earlier in the day, thus capturing daily history dependency in activity-travel engagement.

Activity-based models often include the following components:

- Activity type choice models (activity generation models),
- Activity duration models,
- Constrained destination choice models,
- Constrained mode choice models,
- Activity accompaniment models, and
- Work and school activity schedule models.

Some activity-based models also introduce a greater level of heuristics and rule-based behavioral principles to bring about consistency in activity-travel patterns, simulate certain choices in a more qualitative way, and account for interdependencies in activity-travel choices across household members.

In contrast, tour-based models—although also incorporating heuristics and rules to some extent—tend to be deeply nested logit model systems with a series of log-sum terms feeding up the chain to account for interdependency across choice processes.

3.2.4.6 Dynamic Traffic Assignment

DTA refers to a class of mesoscopic traffic simulation methods in which travel demand between origins and destinations is routed through a network in a time-dependent way, and movements of individual vehicles are simulated to capture various traffic phenomena, such as delays, queues, and bottlenecks. DTA procedures need time-varying or time-dependent travel demand estimates.

These estimates may be in the form of TOD trip tables or in the form of trip lists with time stamps. One benefit of DTA is that it allows one to measure delays, queues, and other traffic phenomena as they change over time.

DTA models involve two major elements. The first is a routing element in which trips are routed from each origin to each destination along time-dependent, shortest paths. As traffic builds on a network, the shortest path between an OD pair may change, and there may be multiple shortest paths that are chosen by different travelers to execute their trips.

The time-dependent shortest path algorithms built into DTA models accomplish two tasks. First, shortest paths are constantly updated as the day evolves and traffic volumes build on the various links in the network. As traffic volumes build up, the travel times on links are updated based on macroscopic speed-flow relationships (and not based on microscopic simulations). Second, the shortest paths are computed in a time-dependent way. In other words, the shortest path reflects the fact that the travel time on a link downstream in the path may be different by the time the traveler reaches that link as opposed to when the traveler actually started the trip at the origin.

DTA can be used to refine OD travel demand using feedback. Updated skim trees from a DTA model can be fed back into the demand steps to re-estimate OD demand, and this iterative process can be continued through feedback loops until convergence is achieved.

3.2.4.7 Travel Time Reliability

Travel time reliability is a newer enhancement to travel models that takes into consideration the uncertainty of reaching a destination in a predetermined amount of time. Research has shown that drivers perceive uncertainty as a separate component of trip disutility (or impedance). The more common formulations within disutility expressions use the standard deviation of trip time as the indicator of the amount of uncertainty. Uncertainty can theoretically affect destination choice, mode choice, or route choice.

Adding an uncertainty term to the destination and mode choice steps is reasonably straightforward, but adding uncertainty to route choice has presented some challenges to modelers.

The issue with route choice is that standard algorithms for finding shortest paths do not perform well when there is uncertainty in link travel times because the standard deviation of path travel time is not the simple sum of the standard deviations of all the component (link and node) travel times. Suggested methods of overcoming this limitation have been finding the k-shortest paths, even though only one path is being selected, or iterating to improve the fidelity of the path over several trials.

3.2.4.8 Economic Modeling

Transportation Application of Economic Impact Analysis. Economic impact analysis is a special application of macroeconomic analysis, in which the benefits and costs associated with transportation investments are stated in terms such as jobs, income, and gross regional product (GRP). The principal role of traffic forecasting in estimating the long-term economic benefits of transportation investments is to estimate changes in VMT, vehicle hours traveled, and changes in accessibility. Often, economic impact analyses require specialized transportation analyses or adaptations of existing transportation methods.

Economic impact analysis extends and reinterprets user benefit analysis in terms of private-sector efficiency benefits and, more broadly, in terms of regional and national economic competitiveness. Economic impact analyses may consider consequences such as relocation, hiring, and increased or decreased household spending. These types of consequences transcend the monetary value of changing travel time and vehicle operating and safety costs at the level of directly impacted origin and destinations.

Long-term economic impacts are distinguished from short-term construction impacts. Construction impacts include the additional jobs created in building new roads or creating other new transportation services. This type of economic impact creates additional spending that cycles through the regional economy through direct wages, the spending of wages, and the additional jobs that this spending may create. In contrast, effective transportation investments reduce travel costs and increase accessibility, and the ripple effects of these impacts are long-lasting. It is these latter impacts that economic impact analysis tries to capture.

A common application of an economic impact analysis is to communicate the value of large public expenditures in terms that are readily understandable to decision-makers and the public. Because of the cost and complexity of economic impact analyses, their application is mostly limited to evaluations of proposed new highway corridor alignments, large transit systems, or communicating the value of existing programs or systems. The jobs-created-per-dollar investment figure sometimes heard around discussions of proposed programs or infrastructure improvements are often derived from the types of economic impact analyses discussed here.

There is no industry standard or broadly accepted approach to conducting an economic impact analysis of transportation projects and programs. This lack of consistency and, in some cases, rigor, creates challenges for assessing the merits of different project assessments conducted by different teams. The FHWA has produced some guidance on economic impact analysis for its Transportation Investment Generating Economic Recovery grant program and for general applications (*54*). Prior NCHRP publications have provided a framework for transportation economic impact analyses as well (*55*).

Foundation. Over the years, a number of studies have attempted to isolate the relationship between infrastructure spending—and more specifically, transportation spending—and economic outputs. In 1994, Nadiri and Mamuneas published a widely cited paper on the positive relationship between publically financed infrastructure investment and manufacturing productivity and performance (*56*). The paper also found a significant variation in the impact by industry. A 2004 paper found a positive, though diminishing, rate of return for highway capital investment for consumers and producers (*57*). A 2011 Rand Corporation meta-analysis of 35 papers describing the relationship between public infrastructure expenditures (including highway investment) and economic outcomes also found a positive relationship. These and other studies have cited a number of factors that may contribute to an apparent variability in outcomes, especially at the subnational level. Such factors include the regional economic and geographic composition of private industry and households, the maturity and coverage of the existing transportation system, and the existing level of demand in the region (*58*).

Analysis Framework. Transportation investments can create competitive advantages for a region by decreasing travel costs, increasing travel reliability, and increasing travel choices. This means that households can enjoy free time not spent in travel or use time and cost savings to consume goods and services of greater benefit to the regional economy. It also means that they may have access to more opportunities for work, as well as health care, shopping, and recreation. Businesses may be able to produce goods and services more cheaply. Businesses may also be able to reach a more desirable market, have access to a greater variety of inputs for the goods and services they produce, and enjoy lower cost shipping opportunities. Regions with these advantages can retain and attract business and household growth more readily. These consequences, which are highly dependent on the economic and geographic context within which the investment is made, lead to increased business activity and job creation.

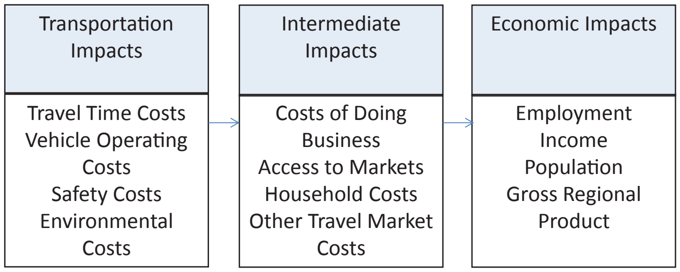


Figure 3-1. Illustrative impact framework.

A typical economic impact analysis captures one or more of these effects, in terms of economic outcomes, as shown in Figure 3-1.

Transportation investments create economic impacts whose magnitude can be estimated using a combination of tools and conversions that capture the linkage among transportation service and infrastructure spending and long-term economic growth. In broad terms, three steps in this estimation can be identified: (1) developing transportation impacts, (2) developing intermediate impacts, and (3) developing economic impacts.

3.2.4.9 Developing Transportation Impacts

Estimating Vehicle Miles Traveled and Vehicle Hours of Travel Impacts. The primary outcome of the transportation impact analysis is an estimate of the change in mobility created by a transportation investment (i.e., a project). Properly specified travel demand models or analytical approaches will capture many of the immediate effects of capacity and mobility enhancements.

These effects include, in descending order of likelihood: (1) changing routes (trip assignment), (2) changing departure times (departure time choice), (3) changing mode of travel (mode choice), and (4) changing origin or destination (trip distribution/destination choice). These impacts can be captured by travel demand models, extra-model estimation methods, or some combination of the two. The result of these effects is a difference in VMT and vehicle hours of travel (VHT) in comparison to baseline (i.e., without the investment) conditions.

Estimating Intermediate Impacts. Often, a substantial amount of post-processing is required to convert changes in VMT and VHT into a form usable by a macroeconomic model. These conversions produce transportation cost changes specific to industry types and other sectors of the economy.

Value of Time and Disaggregating Travel Markets. Travel between each origin and destination represents a variety of economic values of time. For economic impact modeling, it is useful to understand the types of travelers that use the roadway system in sufficient detail to assign values that correspond to the economic use of travel.

Travel markets can include personal travel, commuter travel, on-the-clock automobile travel (travel on the way to conduct business), on-the-clock truck travel, tourism travel, and other leisure travel. If a travel demand model does not include all the passenger travel markets needed for the analysis, data from local household interview surveys and national surveys, such as the NHTS, may supplement the analysis. Freight travel may be separated from truck travel and further disaggregated by commodity and/or industry, using sources such as the Transearch database and the Vehicle Inventory and Use Survey (VIUS).

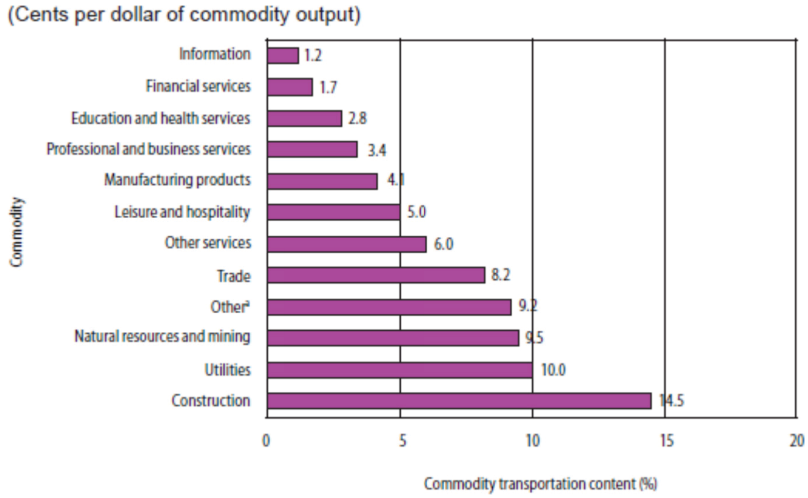
Estimating Changes in Other Transportation Costs. Total maintenance, operating, and accident costs require unit costs that are applied to miles traveled and do not require disaggregation into travel markets. Generally, unit values for vehicle types such as automobile and single and combination unit truck suffice. There are numerous academic and practitioner-level data sources offering suggested values for these unit values; one of the most widely used sources is the AASHTO Red Book.

Improvements to transportation networks and modal options can also lead to an increase in lower cost shipping, warehousing, and delivery configurations, for a given good. Logistics models can analyze these options, although they are highly complex and are not commonly used in regional analyses.

Industry-Specific Costs and Input/Output Models. Input/output models provide information that an analyst can use to translate transportation costs into industry-specific costs. Transportation is one of many inputs that industries use to produce their goods and services. What types of inputs and how much of each input a particular industry uses to produce a dollar of output are expressed in an input/output table. The U.S. Bureau of Transportation Statistics (BTS) has developed a special type of input/output table, the Transportation Satellite Accounts (TSA), which describes how much transportation is used as an input by industries. The TSA includes transportation needs that are met by a private industry's own transportation fleets as well those provided by other private carriers (see Figure 3-2).

Accessibility Impacts. The reach of business services is influenced by the transportation supply and demand characteristics of each region. Geographic information system (GIS) techniques can be used to calculate the size of the labor market or customer market that falls within a normal delivery or trip time, which affects the ability of businesses to attract business activity.

Access plays a role in productivity as well, and these effects are sometimes captured in production function models.



Source: BTS, RITA.

Figure 3-2. Transportation cost as a share of output.

Industries that rely on specialized inputs that are not readily substituted are more sensitive to changes in access than are businesses and industries that can readily substitute the inputs they use to produce their goods and services. This idea has been explored in *NCHRP Report 463: Economic Implications of Congestion* (*59*). Estimating these cost and productivity effects by industry requires information about travel flows and the inputs various industries use to produce their goods and services.

Estimating Economic Impacts. At the intermediate evaluation stage, transportation costs are translated into industry and household costs in a way that is consistent with the economic structure of a region. The economic impact analysis inputs these changes in industry and household cost structures to estimate the broader benefits to the regional economy.

Regional Macroeconomic Models. Economic models estimate the advantage gained or lost by an economic region from a change in costs, compared to other regions. Some of these models estimate the impact of changes in business and household costs on factors that influence each other, such as the price of goods, the demand for goods and services, the demand for and cost of labor, and business activity in a region. The outcome of these model estimates are GRP, income, and employment. These models may be dynamic, in that they show how changes in one factor influence the others over time.

An example of this is how increased economic activity might cause wages and prices to increase. Other models focus on the economic relationships between industries and consumers in a static way, using input/output tables or regression-like functions that show the relationship between costs and productivity.

3.2.4.10 Land Use Modeling

Travel demand in a region or along a corridor is strongly influenced by the changes in land development patterns that occur over time. A host of land use variables serve as inputs for travel demand models, and the accuracy of project-level traffic forecasts is inextricably tied to the accuracy with which land use variables are predicted into the future. Land use measures may include housing and population by dwelling unit type, firms and employees by industry sector, parks and recreational spaces, and economic indicators such as prices and rents for residential or commercial space. It is generally believed that land use defines the five "Ds" that are important determinants of human travel behavior and activity choices:

- **Density**, which is generally measured in terms of units (or employees or inhabitants) per unit area; higher density of development is generally associated with greater levels of non-motorized and transit mode usage.
- **Diversity**, which represents the mix of land uses that are present in a zone or spatial unit; a greater mix of land uses is considered conducive to transit use, non-motorized mode use, and shorter trips.
- **Destination accessibility**, which focuses on the ease with which alternative destinations may be reached by various modes of transportation; this aspect also incorporates network design aspects because grid networks are considered to provide greater accessibility than cul-de-sac type designs.
- **Design**, which focuses on the design of the built environment and the provision of green space; for example, wide sidewalks, bicycle pathways, and designs in which storefronts and building facades are close to the street are considered conducive to promoting bicycling and walking.

- **Distance to transit**, which measures the ease with which transit stops, terminals, and stations can be reached from anywhere in space.

By developing forecasts of the housing and employment markets, land use models provide the critical inputs and built environment descriptors needed for accurately modeling travel demand. Using accurate measures of land use is a necessary condition for producing realistic travel demand forecasts.

Land use forecasting processes come in a variety of forms. There is increasing use of land use models in the profession, largely motivated by the increasing availability of accurate land use data (in electronic databases), particularly at the parcel level. Since land use is highly dependent on local zoning policies and regulations, building permits, and economic cycles, there is a continued use of Delphi methods in the development of future land use projections. However, these methods are being increasingly informed by computational models that use a series of economic and socio-demographic projections, existing land use development patterns, data on developable/vacant land, and bid-rent price equations to determine the likely patterns of land use change that will occur over time.

A review of land use models is provided by Wegener (*45*). Early land use models, such as the Lowry model (*60*), took the form of aggregate spatial distribution models and used gravity-based approaches to allocate housing and employment to various sectors across space. Another well-known aggregate land use model system is that comprising the DRAM (disaggregate residential allocation model) and EMPAL (employment allocation model) models (*61*); this model system and variants of it continue to be used in a number of jurisdictions.

MEPLAN is another extension of the aggregate land use model series, where housing location is modeled with greater rigor and behavioral validity by recognizing the trade-off between housing prices and transportation costs. More recently, there has been considerable work in the development of disaggregate land use models that simulate the dynamics of housing and employment markets in a detailed fashion; examples include, but are not limited to, UrbanSim (*46*) PECA (*62*), TRANUS (*63*), RELU (*64*), ILUTE (*48*), and LEAM (*65*). Many of these models use discrete choice modeling methods to simulate choice processes, hedonic bid-rent functions to predict market prices, and market clearing mechanisms to forecast land use change over time. There are a growing number of case studies in which these land use models have been integrated with transport models (both four-step travel demand models and activity-based microsimulation models) such that land use changes are sensitive to changes in network conditions and accessibility measures over time (*64*).

3.2.5 Microscopic Traffic Simulation

Some forecasts require information about the detailed interactions of traffic in small time increments over short distances (such as at driveways and intersections) and so require the use of tools more detailed than travel demand models. Complex tools like microscopic traffic simulation models have emerged to fill this need. Microscopic traffic simulation is the simulation of individual vehicles moving through a roadway system. This kind of simulation incorporates mathematical models for basic relationships that simulate driver behavior related to:

- Car following,
- Lane changing, and
- Traffic stream entry gap acceptance.

Vehicles typically enter a roadway network based on a statistical arrival distribution and are tracked through the network over intervals of time (these are usually small; e.g., 1 second). At each point of origin into the network, vehicles are assigned a destination, a vehicle type, and driver type.

By their nature, traffic microsimulation models are stochastic—they incorporate the randomness reflective of real-world uncertainty and variability into the modeling process.

Mathematical models typically use probability distributions and random number generators to initiate network entry and other events. Vehicles then "obey" the rules for car following, lane changing, gap acceptance, and right-of-way as they are defined in the models. Model variability increases when operational parameters like actuated signal control also vary.

Because they are stochastic, traffic microsimulation models require multiple runs to define the likely range of results within which performance measures (delay, travel speed, etc.) may fall. The number of required model runs (i.e., sample size) varies, depending on the level of congestion in the network and the desired error or level of confidence about the mean value for the performance measure in question.

Statistical analyses to derive the mean, standard deviation, and desired confidence intervals are needed to estimate the likely range of results, due to variability. The required number of runs for model calibration may be different than for model application, depending on the desired error for each.

3.2.5.1 Guidelines on the Use of Microscopic Traffic Simulation Tools

There are several widely used, commercially available microsimulation programs in use. They differ in the ways that they apply models to simulate driver behavior. There is also a considerable amount of published literature on the various aspects of microsimulation. One notable source is the FHWA *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software* (*66*). Guidance on data collection, model development, error checking, calibration, application, and evaluation of results from this source is summarized below.

Data Collection. The specific data required by a microsimulation model will vary, depending on the software being used and the model application. Required data typically include geometric data (number of lanes, lane use, turn bay lengths, posted speed limit, grade, etc.), traffic control data (signal timing plans, for example), demand data (traffic entry volumes or counts, turning movements, and OD tables), and vehicle classification information. In addition to basic input data, microsimulation models require data on vehicle and driver characteristics. These data often are difficult to measure in the field and default values typically are provided in the software. Additional data typically are collected for calibrating the model. These data include travel times, turning movement counts, observed queues, and saturation flow rates.

Model Development. The blueprint for constructing a microsimulation model is the link-node diagram. The diagram identifies which streets and highways will be included in the model and how they will be represented. Nodes represent the intersection of two or more links and typically are located using x-y (and sometimes z) coordinates. They represent an intersection/junction or a change in link geometry. Physical and operational link characteristics input into the model include number of lanes, lane width, link length, grade, and curvature.

Other link-based parameters that may be entered include pavement condition, sight distance, and locations of bus stops, crosswalks, or other pedestrian facilities. Traffic control data are entered at the node level and include type of control (no control, YIELD signs, STOP signs, traffic signals, and ramp meters). Other model development elements include traffic operations and management data, traffic demand data, driver behavior data, event and scenario information, and simulation run controls.

Error Checking. Error checking a simulation model is essential so that the calibration process does not result in distorting model parameters to compensate for coding errors. Error checking should be performed in three sequential stages: (1) software error checking, (2) input coding error checking, and (3) animation review. Software error checking should be performed to identify the latest known "bugs" and workarounds. Input coding should be checked for the link and node network, demand input, and traveler behavior and vehicle characteristics. The animation then should be reviewed to ensure that vehicle behavior is as expected and that the network has been coded correctly. Analysts' expectations also should be field verified. It is possible that some residual errors may exist after error checking steps have been performed. These may be due to software limitations or an error in the software itself. The error checking step should be performed prior to calibration.

Calibration. Calibration is the adjustment of model parameters to improve the model's ability to reproduce driver behavior and traffic performance characteristics. It is necessary because no single model can accurately account for all possible traffic conditions and because models must be adapted to local conditions. Calibration is a process that involves adjusting model parameters so that local traffic conditions are reasonably reproduced. Calibration involves the adjustment first of global parameters, then local (link-specific) parameters. A three-step strategy is recommended:

1. Calibrate capacity parameters,
2. Calibrate route choice parameters, and
3. Calibrate overall model performance.

A calibration objective function (mean square error or MSE, for example) should be chosen and the analyst should seek to minimize the error between model output and field measurement.

Application and Evaluation. Alternatives analysis includes several steps:

1. Development of baseline demand forecasts,
2. Generation of project alternatives,
3. Selection of measures of effectiveness,
4. Model application (runs),
5. Tabulation of results, and
6. Evaluation of alternatives.

Microscopic traffic simulation models, like travel demand models, include traffic distribution and assignment steps typically associated with travel demand models. Different software platforms perform these in different ways with varying levels of complexity. At one end of the spectrum, vehicles enter the network and are assigned as they approach each node, based on user-input turning volumes or percentages.

This occurs at each successive node, where the vehicle assignment is repeated as a stochastic process of the predetermined turning movement proportions. For this approach, the "distribution" is the accumulation of vehicles at the network exit nodes.

At the other end of the spectrum, several simulation programs perform a trip distribution–traffic assignment process similar to that employed in travel demand models. These processes may include the capability to perform equilibrium-based traffic assignments that model flow under near-saturated or oversaturated conditions. Advanced microsimulation models may include DTA functionality, where paths between OD pairs vary in real time as a function of congestion and traffic control.

3.2.5.2 Microsimulation and Highway Capacity Manual Measures of Effectiveness

Microsimulation and the HCM employ significantly different computational procedures to estimate delay, congestion, and other measures. Therefore, when using either methodology, analysts should carefully document and cite the source of the method used to estimate a measure of effectiveness.

Generally, HCM-based performance measures are the result of macroscopic, deterministic methods. Vehicular demand is quantified in terms of an average or maximum flow rate (in vehicles per hour) and measures such as speed and density are representative for all vehicles traversing a facility during the analysis period. Microsimulation uses a trajectory analysis of individual vehicles to define and estimate performance measures.

The current logic is that any comparison of results between the two approaches is possible only through analysis of vehicle trajectories as the "lowest common denominator." The HCM advises that trajectory-based performance measures can be made consistent with HCM definitions through field measurement and calibration.

Operational performance measures fall into five basic groups:

- Speed-related measures,
- Queue-related measures,
- Stop-related measures,
- Delay-related measures, and
- Density-related measures.

Table 3-2 provides a comparison of the five groups of performance measures and the basic computational differences between the macroscopic deterministic methods and microsimulation trajectory-based methods. These are for uninterrupted-flow facilities like freeways and rural highways and for interrupted-flow facilities like urban streets and signalized intersections.

In addition to similar performance measures computed by HCM-based methods, some microsimulation tools also estimate additional environmentally related performance measures such as fuel consumption and emissions.

For more information on the differences between HCM-based performance measures and those computed by microsimulation tools, the user is advised to consult the FHWA *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer* (*67*).

In Section 11.6 of this report, Case Study #6—Blending a Regional Travel Forecasting Model with a Traffic Microsimulation illustrates the use of a microscopic traffic simulation model for developing traffic forecasts.

3.3 State of the Practice of Data Inputs for Travel Forecasting Models

Four-step travel demand models make use of a variety of input data sources. These data inform the model development process and establish the descriptive characteristics of the region being modeled. This section discusses the state of the practice with regard to model input data.

3.3.1 Socioeconomic Data

Socioeconomic data describe the population and economic activity occurring in an area and are correlated with the magnitude, location, and mode of travel demand. These data are placed into a database organized by traffic analysis zones (TAZs), small units of geography that subdivide the model area. Each record in a TAZ database represents a unique TAZ in the model and contains the socioeconomic data required by the model. TAZs are significant in the modeling process since all trip ends are generated at the TAZ level, and all trips travel from one TAZ to another.

3.3.1.1 Demographics

Demographic data are the key independent variables in trip generation models. Socioeconomic and demographic information is relatively easy to obtain through sources such as the decennial Census and the American Community Survey (ACS). Similarly, a significant portion of the behavioral data that are used to define trip-making characteristics can be obtained through household travel surveys. This connection between trip-making behavior and socioeconomic and demographic characteristics is widely regarded as being one of the most documented and robust aspects of travel demand models.

Typical variables include households, dwelling unit type, occupancy and vacancy rates, automobile ownership, income, and population. These variables are described below.

- **Household.** The household typically serves as the base unit upon which all other demographic characteristics are built. Attributes such as population and automobile ownership are often expressed as persons per household or vehicles per household. The typical cross-classification trip generation model used in many conventional travel demand models will stratify households according to some combination of variables, such as population in the household, income, automobile ownership, and/or dwelling unit type.
- **Dwelling unit type.** This variable is used in some areas with high seasonal variability in dwelling unit occupancy or with a mix of residential building types as the basic unit of socioeconomic information in trip generation. Dwelling

Table 3-2. Comparison of measures of effectiveness from microsimulation and HCM methods.

	Deterministic Methods (e.g., HCM)	Vehicle Trajectory-Based Methods (e.g., Microsimulation)
Speed-Related Measures	Average speeds are computed on the basis of free flow speed and determinants such as demand volumes, weaving speeds, proportion of heavy vehicles, grades and link delay (where applicable). For some facility types, there are different procedural methods for undersaturated and oversaturated conditions.	Speed- and travel-time-related measures are treated together because they are closely related. The average speed of an individual vehicle is computed by dividing the segment (link) length by the travel time. Space mean speed for all vehicles traveling on a segment is estimated by dividing the number of vehicle miles of travel for the segment by the number of vehicle hours of travel time.
Queue-Related Measures	Measures are defined for both interrupted and uninterrupted flow facilities. Queues may be defined in terms of the number of vehicles in a queue or the distance of the last vehicle in the queue from the end of the segment (i.e., back of queue). The probability of the back of queue reaching a specified point where it will cause operational problems (e.g., turn lane spillback) is of particular interest.	Microsimulation tools have the ability to produce queuing measures more robust than those produced using HCM-based methods, but these measures are difficult to compare to the HCM. Of particular importance is what defines a queued state and this definition typically varies across various microsimulation tools. Vehicles generally are considered to have left the queue when they have left the link on which they entered the queue; thus, the link definition is an important parameter. Microsimulation models are able to establish an instantaneous back-of-queue at each point in time, so the question of how to process these instantaneous values in a meaningful manner is particularly important. Queue length analyses are treated differently for (1) undersaturated noncyclical operation; (2) undersaturated cyclical operation; and (3) oversaturated operation, either cyclical or noncyclical.
Stop-Related Measures	Measures include an estimated number of stops on an approach or stop rate (in stops per mile), computed using deterministic procedures.	Most microsimulation tools provide their own definition for what constitutes a stopped state, including when a stop begins and when it ends. It is important for the analyst to understand how the stopped state is defined for the tool at hand and to what extent the parameters can be adjusted to be consistent with the HCM. Estimating the number of stops can be problematic, depending on the microsimulation tool, in that it generally relies on varying arbitrary thresholds. The accumulation of multiple stops (i.e., subsequent stops after the first one) poses problems with microsimulation models, and it is difficult to compare values produced by various microsimulation tools and the HCM.
Delay-Related Measures	There are multiple definitions and thresholds for delay across the various computational methods. For uninterrupted flow facilities, delay is computed as the difference between free flow speed and calculated operational space mean speed for undersaturated conditions. For oversaturated conditions, the space mean speed is estimated from the prevailing density on a segment. For interrupted flow facilities, control delay is defined as the delay that results from a traffic control device (compared with an uncontrolled condition).	In microsimulation models, delay is generally defined as the excess time spent on a roadway segment (link) when compared with a time at an ideal speed representing zero-delay conditions. Various simulation models have different definitions of this ideal or target speed. Delay may be aggregated (usually expressed in vehicle hours) or unit delay (usually expressed in seconds per vehicle). With respect to vehicle trajectories, delay elements include stopped delay (time a vehicle is actually stopped), queue delay (which reflects the time spent in a queue), control delay (delay resulting from a traffic control device), and segment delay (delay experienced by each vehicle upon leaving the upstream node).
Density-Related Measures	Density is expressed in terms of vehicles per mile per lane. For undersaturated uninterrupted flow conditions, it is computed by dividing the adjusted flow rate by the estimated speed. For oversaturated conditions, it is determined by queue-tracking procedures defined in the HCM. Density is not reported for interrupted flow facilities.	Density is simply the sum of vehicles on a roadway section at a specific time. The question, therefore, is how to apply the definition of density to the proper roadway section at the proper time. If the microsimulation tool reports an average vehicle spacing, then an equivalent density can be computed as the segment length divided by the average vehicle spacing.

For more information, please consult Chapter 7 of the HCM 2010 *(21)*.

units may either be given as a total number or may be further stratified. The most common stratification of dwelling unit types is to distinguish between single-family and multi-family dwelling units. There tends to be a correlation between dwelling unit types and access to an automobile, a strong predictor of trip-making activities. In general, residents of single-family homes tend to have more access to automobiles than residents of multi-family homes (e.g., apartment buildings). Even when factors such as income and household size are corrected for, the fact that many apartment complexes and condominiums place a restriction on the number of parking spaces available to residents will tend to limit the number of automobiles available to each household. Furthermore, given the aggregate nature of data at the TAZ level, some models make use of a population disaggregation technique to divide the households in a TAZ into distinct cohorts composed of specific household sizes. Further disaggregation of households into dwelling unit types provides for a much more precise application of a cross-classification trip generation model.

- **Occupancy and vacancy rates.** These are used to determine what percentage of dwelling units are occupied, and therefore make up the number of households in the data set. Occupancy rates describe the percentage of dwelling units that are occupied at the time that the population data were collected. Typically, this reflects the conditions experienced in April once every 10 years, when the census is conducted. Often, models will make use of vacancy rates instead. Vacancy rates describe the percentage of dwelling units that remain vacant at a given time. When vacancy rates are used, it is common to see two separate rates given: permanently vacant units and seasonally vacant units. Permanent vacancies describe units which remain unoccupied throughout the year and may be due to foreclosures, evictions, abandonment of property, or a weak housing and rental market. Permanent vacancies as a percentage of total dwelling units can also describe average vacancies resulting from normal turnover in the housing market. Seasonal vacancies describe dwelling units that are occupied for only a portion of the year. These may include second homes and vacation homes. Beach houses and mountain cottages represent common types of seasonal vacancies.
- **Automobile ownership.** This describes the number of vehicles owned by a given household. The higher the number of vehicles owned by a given household, the greater the access the residents of the household have to an automobile and the higher the likelihood that trips will originate from that household. It is common to see automobile ownership categorized, with a certain percentage of households in the TAZ falling within each of the categories. Common categories include 0 autos, 1 auto, and 2+ autos; although one may encounter greater disaggregation such as a separate 2 autos category with an additional 3+ autos category. Larger numbers of categories are used if the analysis of household travel surveys supports greater segmentation in automobile ownership. Typically, households owning four or more functional automobiles have historically been a small enough segment of the population to not justify greater segmentation. This may change if the number of multi-generational households increases in the future.
- **Income.** Income is used by some models instead of automobile ownership as a predictor of trip making. Households are typically divided into income categories. While specific categories vary from model to model, a typical stratification will include income ranges that describe low income, medium income, and high income. It is also possible to encounter a five-tier system that includes very low income and very high income. As with automobile ownership, the key determining factor of the number of categories used should depend on the results of a local household travel survey. While there is generally a correlation between income and automobile ownership, the relationship between automobile ownership and trip making is not as clear.
- **Population.** Population data describe the number of individuals living in an area. While it is possible to associate population with a wide variety of attributes, most models tend to restrict themselves to those attributes directly related to the trip generation model's structure. Most travel demand models tend to identify household characteristics and then disaggregate TAZ-level population into households. The population then adopts the characteristics of the households. Typically, the key attribute most models look at with regard to the population is the number of people living in the TAZ.

  Travel demand models using more sophisticated lifestyle trip generation models will also attempt to identify additional characteristics relevant to those models. Examples include identifying school-aged population, retirees, and military personnel. At an even more sophisticated level, the emerging activity-based models being developed by some of the larger MPOs in the country require a greater level of detail in order to create data records for each individual in the model along with their relationships to each other. Typically, these relationships are described at the household level and aim at trying to identify which household members travel together on which trips. Such relationships are usually derived from household travel surveys.

Common sources of demographic data include the U.S. Census, U.S. Census Journey-to-Work data, the ACS, and mid-census estimates:

- **U.S. Census.** The U.S. Census collects data on every individual living within the United States of America every tenth year. The decennial census is by far the greatest source for demographic data. The census expends every effort in its mission to count every individual. As such, it represents the most inclusive data set on the American population in the United States. The census collects data on every individual using a form (previously referred to as the short form) that captures the most vital statistics of concern to the census. Namely, this form focuses on the number of individuals residing in each dwelling unit. In the past, a sample of the population was also taken using a supplemental long form that could be expanded to the population as a whole in order to get more detailed characteristics of each household. The long form has been discontinued and replaced by the ACS, which is now conducted on a continuous basis throughout the decade. The decennial census remains the primary source of population data for most travel demand models in the United States. During the course of a census data collection and post-processing effort, individual MPOs work with the U.S. Census Bureau to define TAZs. This makes it possible to disaggregate census data into the TAZs.

- **U.S. Census Journey-to-Work data.** These data have been a tremendously valuable census-related resource for transportation modeling and transportation planning for decades. The Journey-to-Work data are at the TAZ level and are a rich source for home-based work trips from the origin zone (home) to the destination zone (employment zone).

  Laws and policies protecting the privacy of respondents dictate the level of disaggregation that can be applied to census data before they are provided to the public. The smallest amount of data is available at the smallest level of census disaggregation, the census block. As it pertains to modeling, the only relevant data that can be obtained at the block level is number of persons and dwelling units. Higher levels of aggregation can reveal income, automobile ownership, and other characteristics. Census block groups can be used to provide most of the demographic data needed for a travel demand model.

  It is not uncommon, particularly in rural areas, that census block groups are too large to serve as TAZs; however, TAZs can be designed so as to nest within census block groups. Block group characteristics can then be applied to the individual TAZs. Even when TAZs are delineated in conjunction with the census, the resulting TAZs may need to be larger and/or more oddly shaped than desired in order to ensure that the contained population data represent observed census data and not synthesized population. These large TAZs may then be subdivided using a combination of census block data, knowledge of the area, and professional judgment.
- **The ACS.** The ACS replaces the census long form and serves the purpose of providing more detailed information on the American population than the census short form. The ACS is a continuous survey conducted on a sample of the American population and supplements data collected during the decennial census. Questions asked by the survey touch on subjects such as housing costs and rent, utilities, race, gender, and other topics. The continuous nature of the survey makes it possible to track trends in the population on an annual level.
- **Mid-census estimates.** These can be used when it is not possible to set a travel demand model base year to a census year. Many models have base years that are not defined consistently with census years. The need to validate a model to traffic ground counts often dictates the model's base year, and not all areas will have traffic counts for a census year. Even when counts are available, it may have been too long since the last census to base a current model on the data. This is very common during the second half of a given decade. Mid-census estimates of population address this issue and are typically developed through a combination of population forecasting techniques and local knowledge of regional population patterns. An analysis of area-wide growth trends serves to establish reasonable mid-census control totals and general distribution patterns of the new growth. Many areas conduct a review of occupancy permits to identify where, specifically, growth is taking place and how many new households may have settled in the region. As with any estimation techniques, mid-census estimates assume that there has not been a recent disruption to historical trends. Disruptions such as the recent economic environment result in actual growth that can diverge greatly from the established trends.

3.3.1.2 Employment

Employment data are the key input used by trip generation models to develop trip attractions. These data represent the economic activity occurring within a region. Most trip purposes rely on employment data for generating trip attractions.

For employment data to be useful, they must contain three pieces of information: location of employment, number of employees, and an industrial code for the employer describing the type of work being performed at the job site. Employment data are usually acquired for a specific moment in time.

Typical variables include location, number of employees, industrial classification codes, and employment categories:

- **Location.** Location data are typically conveyed through street address data corresponding to the job location. Depending on the data source, addresses given may be for corporate offices and not actual job sites such as individual retail stores. Care must be taken in understanding the nature of the data source and how much cleaning of the data has taken place prior to use. Addresses can be geocoded to provide latitude and longitude (lat-long) coordinates. Errors in the development of lat-long data may occur. The most common error is the inversion of coordinate signs. These errors become apparent as soon as an attempt is made to plot the locations. Another common error is the truncation of decimal places in the coordinate. This can result in a more subtle shift in location that is difficult to detect.

- **The number of employees.** The number of employees at a job site is crucial for developing travel demand model employment data. Number of employees should be given as an absolute number.
- **Industrial classification codes.** These codes identify the type of work performed by the employment center. These codes may be provided either by the older Standard Industrial Classification (SIC) system, the newer North American Industry Classification System (NAICS), or both. These codes are used to group employment by broad categories that are used by the travel demand model.
- **Employment categories.** These are broad categories into which employment data that are put into travel demand models are usually aggregated. The categories are created by grouping together employment types based on industrial codes with similar types of activities. Similar activities are assumed to have similar impacts on the number of trips attracted to a given TAZ based on the type of employment found there. Three of the most common categories are retail, service (service employment may also be called office or commercial employment), and industrial. At times, these three categories can be supplemented by additional employment categories. Common additional categories include subdividing industrial into manufacturing and non-manufacturing, dividing service into separate service and office employment, distinguishing between standard and trip-intensive retail (fueling stations, fast food restaurants, etc.), and including special categories for government, hospital, and/or military employment depending on the design and requirements of the travel demand model.

A number of sources exist for the acquisition of employment data. These data can be obtained both from private vendors and the government. Government sources of these data include Local Employment Dynamics (LED) data and the Quarterly Census of Employment and Wages (formerly known as ES-202).

3.3.2 Network Data

Transportation networks represent the physical transportation system in a travel demand model. These models are typically constructed from a set of points called nodes on a coordinate plane. The linkages between the nodes are called links.

Links typically carry information about distance, travel time, and roadway capacities, and provide curvature to the network, while nodes establish intersections or opportunities to change travel direction in the network. For traditional models, link networks describe network connectivity movements along a series of interconnected nodes, for example, from Node 101 to Node 102 to Node 103. Some modeling software packages describe network connectivity as a sequence of links instead of referencing network nodes, for example, from Link 1 to Link 2 to Link 3.

All highway networks are used to define the transportation system and can be edited to ensure an accurate reflection of all possible movements along the transportation system being represented in the model. Typical variables carried by highway network links include the following:

- **Functional classification.** Functional classification describes a segment of road with regard to a hierarchy of roadway purpose which the road serves with respect to different roadway characteristics. Common functional classes include freeways, principal and minor arterials, collectors, and local streets for both urban and rural areas. The most commonly encountered functional classification system in a travel demand model is the FHWA schema used by the Highway Performance Monitoring System (HPMS). In some cases, a model may employ a local variation of the FHWA system in an attempt to capture the distinctive roadway characteristics of the area.
- **Facility type.** Similar to functional classification, facility type describes the nature of a road with regard to a hierarchical classification of roadway purpose that the road serves. Unlike functional classification, facility types are typically defined without regard to the prevailing land use surrounding a given segment of road or whether the land use abutting the road is urban or rural in character. Common facility types include collector, arterial, expressway, and freeway.
- **Area type.** Area type describes the prevailing land use surrounding a given segment of road in relatively broad categories (but more specific than merely distinguishing between urban and rural segments). Common area types include central business district (CBD), residential, suburban, and rural.
- **Number of lanes.** Number of lanes describes the number of through traffic lanes occurring on a given segment of road. Since most travel demand models handle each direction of traffic as a distinct entity, the number of lanes is most commonly expressed as the number of lanes per direction.
- **Speeds.** Speeds are expressed in travel demand model input networks as free flow speeds. Free flow speeds are the speeds at which traffic is expected to travel without regard to congestion. Some models make use of posted speeds (those speeds indicated on speed limit signs for given segments of

roads) as the basis of their free flow speeds. Other models may make use of speeds developed based on speed-delay studies conducted for an area. Typically, some attempt is made to include the impacts of signal delay and side friction into the free flow speed since most travel demand models in use today do not explicitly model these phenomena. Many models use some combination of facility types, area types, and/or functional classes to derive free flow speeds. Some models require the analyst to directly input model speeds for each link in the network.

- **Traffic counts.** Traffic counts are typically included in travel demand models to help validate the model's highway assignment. Additionally, traffic counts may serve as a benchmark for forecasting reasonableness by providing a point of comparison with future year model results. See Section 3.3.3 for a more detailed discussion of traffic counts in travel demand modeling.
- **Annual average daily traffic or average daily traffic.** Models typically use an average weekday. Annual average daily traffic (AADT) is developed from traffic counts. Traffic forecasts usually use an AADT or a specific day. See Section 3.3.3 for a more detailed discussion of AADTs in travel demand modeling and project-level forecasting.
- **Capacities.** Capacities express the number of vehicles that can be expected to travel along a given segment of road during a given segment of time. Capacities are primarily used during the highway assignment step of the travel demand model to measure congestion and the influence of traffic diversion. Capacities are typically expressed as the number of vehicles per lane per hour, but are typically converted by travel demand models into total hourly or peak-period capacities. Many models use some combination of facility type, area type, and functional classes to derive the capacities for the model network. Some models require the analyst to directly input capacities for each link in the network. In some cases, models may make use of more sophisticated equations to derive capacities using additional variables such as the presence of on-street parking and lane width.

Network geometry describes the physical shape of the transportation network. Over the past decade, great advances have been made in network geometry. The greatest impact of inaccurate network geometry is the potential for large discrepancies between modeled link distances and real-world link distances. These discrepancies can translate into significant differences in travel times. Large differences in travel time can result in less accurate highway assignments, which lead to greater error in travel demand model results.

Most new highway networks created for travel demand models today are created by importing data from established GIS or linear referencing systems (LRS) datasets. The major commercially available travel demand modeling software packages all now have features built into them that allow the user to import GIS or LRS data and translate them into a format suitable for travel demand modeling. At the very least, geographically accurate distances can be retained in the model network. The major commercially available modeling software also provides GIS environments in which users can edit and maintain highway network data as a GIS feature.

Currently, the most common method of creating a highway network from scratch is to import an already existing GIS dataset using a travel demand modeling software package and make edits to the network using a graphic user interface. It is now common to edit and maintain network data completely in a GIS/LRS environment. State departments of transportation (DOTs) typically have or have access to mapping and data resource centers that maintain a database of their roadway inventory in a GIS format. The quality of these data varies from state to state and depends on how advanced each agency's GIS practice is. U.S. Census TIGER line data can also serve as a starting point, but may contain more errors and lack the specific data desired to develop a highway network. Private vendors can also provide these data.

GIS/LRS data used to develop highway networks will need to be carefully reviewed since such data are typically developed originally for mapping purposes without regard to network connectivity or path building. Common errors include missed connections, missing pieces, and intersections occurring where they should not (such as an arterial intersecting with the mainline of a freeway instead of passing under it).

3.3.3 Traffic Counts

Traffic counts are typically included in travel demand models to serve as a basis upon which to validate the model's highway assignment. Additionally, traffic counts may serve as a benchmark for forecasting reasonableness by providing a point of comparison with future year model results. In some cases, the volume-to-count ratio from a validated highway assignment is used to develop an adjustment factor that is then applied to forecast model results to compensate for base year validation error. Traffic counts are also instrumental to establishing a model's external trips.

Traffic counts that are used in a travel demand model are consistent with the temporal scale of the model. Hourly traffic counts can be summed to any larger period to develop either daily or TOD models. However, in many cases, hourly count data are not available, just daily count data.

While many travel demand models still only assign overall vehicle or person trips, more and more models are attempting to explicitly model truck traffic. Vehicle classification counts can assist with the development and validation of truck models.

Traffic counts can usually be obtained from a state's DOT. The quality of traffic count data varies from state to state.

Most state DOTs maintain at least some permanent automatic traffic recorders (ATRs or PTRs) to collect data along the state's more crucial roadways. These usually include segments of Interstate highways and key state highways. These are then supplemented by periodic temporary counts collected around the state. Temporary counts are usually collected for a period of a few days and then post-processed using seasonal adjustment factors to develop AADT. Some states may also utilize peak season weekday average daily traffic (PSWADT) for modeling and then convert the results into AADT. Some MPOs and municipalities also conduct supplemental count programs not covered by the state program. Additional counts may sometimes be collected as part of a corridor study or in conjunction with a model development project.

3.3.4 Household Travel Surveys

Household travel surveys are conducted by contacting individuals at their place of residence and asking them to answer some questions regarding their daily trip-making activity and household characteristics. The primary purpose of collecting these data is to have enough information to estimate the non-assignment components of travel activities, possibly including trip generation and trip chaining, trip distribution, time of trip departure, and mode choice.

Travel diaries are usually sent to respondents as a follow-up to a household travel survey. Respondents are asked to take the diary with them as they travel throughout the day and make notes concerning where they are going, the mode of travel used to arrive at the destination, the departure and arrival times, reason for travel, number of passengers, and any other information that is considered desirable by the surveyor. In some cases, global positioning system (GPS) units may be loaned to respondents for more accurate data collection.

Often, respondents fail to report short distance trips, viewing such trips as being of negligible importance. This can skew travel behavior results related to short trips that could be represented in a travel demand model as either intrazonal trips or trips to neighboring zones. GPS units can be used to capture these trips.

Whenever possible, models should make use of recently collected household survey data from the local area. However, due to the expense of conducting a household travel survey, many models are using out-of-date or borrowed trip generation parameters. Those states that participated in the 2008 NHTS add-on may have a wealth of data that can be used for this purpose. Some states participating in the NHTS have focused on collecting data on undersurveyed populations, typically those falling in rural areas outside of MPO boundaries. Other states purchased more comprehensive add-ons that are intended to develop trip generation rates for all MPOs throughout the state.

3.3.5 Origin-Destination Studies

OD data are used to develop trip distribution models, external trip tables, and baseline data for corridor studies. OD studies are a common feature of traffic and revenue studies conducted as part of a toll road financing study.

Types of OD studies typically conducted include intercept surveys, license plate video capture, GPS tracking, and use of cellular phone data:

- **Intercept surveys.** These surveys involve stopping respondents in mid-travel and asking them questions concerning where they are traveling from, where they are traveling to, the reason for their travel, and how they plan to get to their destination. This technique is most frequently used when attempting to get external trip data for a subarea or a travel demand model external boundary. It is also used for corridor studies to identify which trips may be more susceptible to trip diversion. Some states have passed laws or enacted policies to prohibit intercept surveys. Intercept surveys can be disruptive to travel and need to be coordinated with the appropriate government agencies and law enforcement. In some special cases, surveyors may use natural stops in traffic flow (such as signalized intersections) to distribute mail-back survey cards to minimize the impact to traffic.
- **License plate video capture.** This is an alternative to the intercept survey. In this method, high-speed cameras are set up in strategic areas around the study area. License plates are recorded as the vehicles travel past the field of vision of the cameras. The captured data are then post processed, and matching license plates from the various cameras are noted. A distribution of trips across the cordon established by the cameras is then recorded. This method does not disrupt the flow of traffic, but limits the data that can be collected to only the observed OD pattern. Data on vehicle occupancy or trip purpose are unobtainable.
- **GPS tracking.** This method is not as common as the other methods for collecting OD data, but more work is being done to leverage the capabilities of GPS tracking. For example, in California, it has become common to incorporate GPS tracking in OD studies. Another example of this is GPS data available from the American Transportation Research Institute (ATRI) showing freight truck movements. This information can be useful in calibrating and validating truck models, but is limited to long distance truck travel. Furthermore, since the data are continuous GPS data, all movements are captured. Long distance trucks often make periodic stops that are not their final destination. The data need to be reviewed carefully to verify true origins and destinations.
- **Cellular phone data.** Use of cellular phone data is increasing in planning studies with long distance OD travel data

requirements. Since cellular phones need to be connected to the cellular phone network to send and receive calls, it is possible to track the movement of the phone as it travels around the cellular phone service provider's service network. These data, stripped of any information that could be traced to an individual, can then be post-processed to provide OD data. While this limits data collection to users of cellular phones, these phones have become very prevalent.

3.3.6 Freight and Heavy Vehicles

Data for heavy vehicle movements are typically derived from the FHWA *Freight Analysis Framework* (FAF). Although particularly suited to long distance Interstate movements, this information can be disaggregated using locally developed data to be more suitable to regional planning efforts. The availability of the FAF series of data sets along with the *Quick Response Freight Manual II* (*69*) has coincided with an increase in the development of truck and freight models.

3.4 State of the Practice of Outputs for Travel Forecasting Models

Travel demand models often supply the raw data needed for project-level decision-making. However, these data are rarely suitable for use directly and will typically need to be post-processed. This section discusses some of the common outputs of the travel demand models that are used at the project level.

3.4.1 Volumes

The simplest and most basic forms of travel demand models represent daily (24-hour) travel corresponding to an average annual weekday. Daily models are sufficient for most planning applications when the purpose is to identify relative changes in demand between alternatives. Many daily models are still used for transportation planning in medium and small urban areas and rural areas, to help identify the needed improvements for roadway facilities.

However, roadway design requires an assessment of traffic at peak conditions. Travel demand is distributed unevenly during the hours of the day, often with noticeable peaks during the morning and evening commuting hours. In many cases, congestion does not occur outside of these peak times. Because daily models do not model traffic specifically at these peak times, they are ineffective at explaining the impacts of congestion. While methods exist to post-process 24-hour volumes into peak volumes, many models in areas that experience congestion attempt to make this process more accurate by specifically modeling smaller periods of a day using a TOD approach (see Sections 3.2.4.2 and 3.2.4.3). A tripartite division of AM peak, PM peak, and off-peak or a four-part division of AM peak, mid-day, PM peak, and overnight are the most common TOD schemes encountered. Typical peak periods cover 3 hours each with the remaining periods making up the difference of the 24-hour day. Daily volumes for such models are usually generated by summing the period volumes. At a minimum, a model that estimates peak conditions is necessary to understand the effects of congestion. More recently, models that assign trips on an hourly level have been developed. This is accomplished either by subdividing some of the periods into hours (typically the peak periods) or subdividing the entire 24-hour day into 24 hourly segments.

In almost every case, some level of post-processing will be required to make forecast traffic from travel demand models suitable for project-level forecasting. Model volumes can also be used as inputs to microsimulation models. The finer the temporal resolution of the travel demand model's assignment, the easier it is to incorporate the model volumes into a traffic microsimulation.

3.4.2 Speeds

Congested speeds are produced by the model for the same temporal resolutions as the volumes developed by the model. Congested speeds are derived from the congested travel times produced by the model's traffic assignment. Congested travel times are a function of the V/C ratio and produced by the VDF.

The larger the temporal resolution of the model, the less the speeds developed by the model reflect actual travel speeds at any given time. Even at the smallest level of temporal resolution encountered in travel demand models, the hour, the congested speeds reflect at best an average speed.

Furthermore, the VDFs used in most travel demand models are only rough approximations of actual congested travel time relationships. As a result, the congested speeds and travel times are themselves only rough approximations. Model speeds are an essential component to many analyses, such as benefit/cost analyses and air quality emissions modeling.

3.4.3 Turning Movements

Most travel demand modeling software packages are capable of producing existing and forecasted turning movement volumes. These turning movements are taken directly from the model's path building subroutine during highway assignment. Most travel demand models do not incorporate intersection modeling into their process. As a result, the turning movements developed by most models are insensitive to intersection capacity and delay characteristics, which have a significant influence on real-world turning movements.

The commercially available software packages most commonly used in the United States have the ability to incorporate some level of intersection modeling as part of the travel demand model, including defining traffic control devices, cycle lengths, and the number of turn lanes. However, the incorporation of intersection modeling in regional travel demand models is relatively rare due to the data requirements and the additional complications that modeling intersection delay can produce for network assignment validation. Standard methods for developing turning movements include taking the approach volumes at an intersection from a model and calculating the turning movements using off-model tools.

3.4.4 Measures of Effectiveness

Measures of effectiveness (MOEs) provide analysts with statistics that can be used to evaluate the performance of a set of supply and demand characteristics associated with a traffic forecast. MOEs are often applied on a relative scale to compare various alternatives. These measures can also be compared to other non-model data to form a portion of a larger decision-making tool or process. More information on MOEs can be found in Section 2.3.

Typical MOEs include the following:

- **Vehicle miles traveled.** VMT is the product of the number of vehicles traveling along a given segment of road and the distance those vehicles travel on the segment. These results are then summed to the regional level. VMT is a measure of travel demand and is also used in a variety of post-processing applications to measure the intensity of travel in corridors during alternatives testing, estimating regional fuel consumption, and estimating regional pollutant emissions. It is also sometimes used as a weighting factor for calculating area-wide statistical averages over many highway segments.
- **Vehicle hours of travel.** VHT is the product of the number of vehicles traveling along a given segment of road in the transportation system and the travel time experienced by those vehicles on the segment. These results are then summed to the regional level. VHT is an additional measure of vehicular activity, but it also can be used to estimate system-wide or subsystem delay. Like VMT, VHT is easily extracted from travel demand model highway assignment results.
- **Congested speeds.** Congested speeds are derived from congested travel times produced by the model. Link-specific congested speeds are derived by dividing the link length by the congested travel times. System-wide average congested speeds are derived by dividing VMT by VHT, averaged over all roadway segments or links. While some attempt is made in most models to take into account intersection delay and side friction, the methods employed tend to be very aggregate and not well suited to operational analysis.
- **Fuel consumption.** Fuel consumption is typically a component of economic impact assessments and air quality analysis. The simplest methods of calculating fuel consumption involve applying fuel consumption rates to VMT. More sophisticated methods attempt to tie fluctuations in fuel consumption to changes in congestion. Fuel consumption rates are derived from sources such as the national CAFÉ standards and the *Transportation Energy Data Book* (*68*). The latest version of EPA's emissions model, MOVES2010a, also includes a sophisticated fuel consumption model.
- **Vehicle hours of delay.** Vehicle hours of delay measures the amount of time lost due to congestion. A common approach to developing hours of delay is to calculate VHT using both congested and free flow travel times. The difference between the two is considered to be the delay.
- **Cost of delay.** Cost of delay assigns a monetary cost to delay. This metric is often used in planning and benefit/cost analysis to provide a comparison of the relative values of transportation investments. Cost of delay can be calculated by multiplying the vehicle hours of delay by a value of time. The value of time is typically calculated for a local area as a function of the area's average wage rate, which may be specified for each of a number travel markets.

3.4.5 Origin-Destination Information

OD data are developed by all travel demand models as a normal part of the trip distribution and assignment processes. Common forms of OD data model output include the following:

- **Forecast OD tables.** Forecast population and employment data, other socioeconomic data properly representative of future conditions, and future transportation supply conditions (for models using feedback) form the basis for developing forecast OD tables. Area-to-area flows showing the change in intra- and inter-regional trips, as well as trip length frequency distributions, are ways of summarizing and comparing OD tables between a base and forecast year.
- **Select link.** Select link analyses identify the origins and destinations and the assignment path of trips traveling along particular segments of roads. Select link analyses are used in corridor studies and bridge projects to identify impacted populations and roads. These analyses are also used to determine the influence area (travel shed) of a particular link or corridor to define study areas and to build OD matrices for subarea models.
- **Select zone.** The select zone analysis identifies the volumes and the paths associated with travel to and from

a selected group of zones. This information can then be used to calculate the distribution of trips due to specific developments.

3.4.6 Model Outputs for Other Analyses

Travel demand models are outputs often used in economic and environmental impact analyses as part of a comprehensive project forecasting analysis. As travel demand modeling software has become more sophisticated, flexible, and customizable, it has become more common to see post-processors built directly into the models. Post-processors are commonly developed for the following purposes:

- **Air pollution emissions.** Air pollution emissions post-processors take model data such as VMT, VHT, and speeds and determine how much pollution is generated in an area due to transportation activity. EPA's emission model, MOVES2010a, and its predecessor, MOBILE6.2, both use travel demand model data to determine the amount of air pollution due to mobile source emissions. Additional post-processors are typically written to integrate the data from the travel demand model with the data from the emissions model. Simpler emission post-processors have also been developed for assessing the carbon footprint of the transportation system by calculating the amount of greenhouse gases emitted by vehicles along the transportation system.
- **Economic impact analysis.** There is growing interest by planning agencies in the economic development impact of transportation plans, alternatives, and policies. Post-processors address the question of the amount of business or jobs growth that might be achieved. Economic development is driven by improvements in accessibility resulting from travel time savings for commuters, customers, and commercial activity.
- **Benefit/cost analysis.** Motivated by a desire to prioritize transportation investments, benefit/cost post-processors assign monetary values to the transportation activities forecast by the travel demand model. At the most basic level, the value of travel time and vehicle operating costs are compared to the capital and operating costs of a proposed improvement or new facility to determine whether the cost is justified on transportation efficiency grounds.
- **Bridge and pavement deterioration analysis.** Bridge and pavement condition models estimate the effect of vehicle activity (and many other factors) on asset condition. Since bridge and pavement damage is a function of vehicle weight, the condition models require detailed information about vehicle types, which are commonly expressed as equivalent single axle loads (ESALs). A travel demand model's forecasts of future automobile and truck volumes can provide useful information for an agency's maintenance, rehabilitation, and reconstruction programs.

3.5 Defaults versus Locally Specific Parameters

Ideally, travel forecasting models should be statistically calibrated to conditions for the area being analyzed. However, project-level travel forecasts are often done under severe time and budget constraints that preclude a rigorous calibration. In other cases, some data that would form the basis for certain parameters do not exist. This report suggests the use of transferable parameters where appropriate and necessary, and when the analyst understands the implications of borrowing parameters from another location or from national defaults.

Parameters are an important input to the travel forecasting process and are usually obtained by applying statistical analyses to travel behavioral or traffic data that are obtained locally. The quality of an individual parameter can be assessed by certain statistics, such as a t-score, that are provided during the estimation process. These statistics give the analyst confidence that the model will provide good forecasts. When statistical analysis cannot be performed, then the analyst is forced to use borrowed or asserted parameters of unknown quality for the application.

The notion of transferable parameters has a long history, dating to the release of *NCHRP Report 187* (*8*). The authors of *NCHRP Report 187* were working mainly on professional experience because there was little scientific evidence prior to this time that the concept of transferable parameters would work adequately. The ultimate success of *NCHRP Report 187* (*8*) and its subsequent revision, *NCHRP Report 365* (*7*), demonstrated the strength of the idea through many applications throughout the United States. The draft report for *NCHRP Report 716* (*6*), which replaces *NCHRP Report 365* (*7*), contained a review of academic literature on transferability. The authors of this review concluded that transferability worked well in some situations and did not work well in others. The situations where transferability did not work well tended to involve attempts to transfer parameters well into the future or instances in which there were inconsistencies in how socioeconomic and network data were prepared. Often the performance of transferable parameters could be improved through scaling or other forms of adjustment.

The concept of transferable parameters was extended to urban truck forecasting by the *Quick Response Freight Manual* (*6*) from FHWA in 1996 and its revision, the *Quick Response Freight Manual II* (*10*), in 2007. *NCHRP Report 599: Default Values for Highway Capacity and Level of Service Analyses* (*70*) provides an extensive look at the application, sensitivity, and transferability of default values used in highway capacity analyses.

There are two classes of transferable parameters, borrowed and asserted, and their uses are somewhat different. Borrowed parameters are those prepared somewhere else and are thought to remain relatively constant when applied within a new locale. For example, *NCHRP Report 365* (*7*) contains many parameters that were obtained from the *1990 National Personal Travel Survey* (*71*), the forerunner of the NHTS. These parameters were stratified by city size to reflect assumed differences in urban geography. The analyst could reasonably expect that these parameters would be good enough in places of similar characteristics (e.g., metropolitan area size) as those for which the parameters were developed because the parameters were derived from a scientific sample of all U.S. households. It is also possible to use borrowed parameters selectively when individual parameters from a local calibration fall outside well-established norms.

Asserted parameters are also defaults, but they are imposed upon the analyst by agency policy to maintain consistency across forecasts. Asserted parameters are similar to borrowed parameters in that they are believed to be readily transferable, but they are most often created by identifying similarities in models in different locations. Asserted parameters are particularly useful for developing parity in competing applications for funding at the state and national levels. Asserted parameters have also been used to ensure that all applications for new site developments are treated equally.

Where possible, sensitivity analyses of default parameters should be conducted. This will help the analyst to determine whether the use of borrowed or asserted parameters is acceptable or whether locally determined parameters should be utilized instead. Specifically, if varying an input parameter for a particular model or method results in a wide range of results, then it may be concluded that the parameter in question is highly sensitive, and resources should be committed to data collection and accurate development of the parameter based on local conditions.

3.6 Other Traffic Forecasting Tools and Methodologies

There are many tools and methodologies other than travel demand models used by traffic forecasters. These tools are very useful to agencies in providing traffic forecasts for a variety of needs. A short list of other traffic forecasting tools and sketch-planning tools is provided:

- The Kentucky Transportation Cabinet's manual gravity tool procedure (*72*),
- *NCHRP Report 255* spreadsheet (trend line analysis, extrapolation, screenline adjustment, and model assignment adjustments),
- Turning movement tools (several versions are publicly available),
- OD matrix growth factoring,
- Time-series models,
- Traffic impact study tools, and
- Elasticity methods (see Section 10.3 of this report).

A brief overview of these tools is provided below so that practitioners can both make use of them and improve them.

3.6.1 Manual Gravity Tool Procedure—Kentucky Transportation Cabinet

This sketch-planning tool is developed for traffic forecasting on new facilities in an area not covered by a travel demand model. The tool is built around the methodologies provided in *NCHRP Report 387* and those published by Caltrans (*73*). The procedure diverts trips to the new facility based on its attractiveness, which is a function of distance and travel time advantage over alternative routes. The required input data include infrastructure characteristics, traffic and control, no-build average daily traffic (ADT) for base and future years, and ADT turning movements at major intersections. There are five major steps involved in the procedure:

- Estimate free flow speed.
- Estimate roadway capacity using HCM approaches for various facility types.
- Generate no-build traffic forecasts for base and future years (using growth factor) and turning movements at major intersections in the study area (using a program such as turns.bat).
- Compute congested speeds using a modified version of the BPR curve.
- Perform diversion analysis based on an equation developed by Caltrans that computes the percentage of diverted traffic as a function of travel time (based on congested speeds) and distance savings of the new facility for traffic volume between each OD pair.

The procedure provides a quick forecast of the traffic volume on a new facility. However, users are advised to check the reasonableness of the results of each of the above steps. The accuracy of the final forecast depends on the accuracy of the input data.

3.6.2 Sketch-Planning Tools—NCHRP Report 255

NCHRP Report 255 contains a number of sketch-planning tools, such as trend line analysis and turning movement forecast tools that can be used when modeling tools are not available or are deemed unnecessary.

Trend line analyses are based on the principle that a traffic volume trend can be established by analyzing land use patterns and/or historical traffic counts. Trend lines can be either linear, representing a constant growth rate over time, or non-linear. Non-linear growth curves fall into three basic categories:

- Increasing growth (exponential),
- Decreasing growth (logarithmic), and
- Stepped growth.

Trend line analyses use historical traffic volume data to develop a regression model. The model then is used either to interpolate growth between 2 years or to extrapolate growth from a single time frame. An important step is to determine the shape of the growth curve upon which the trend line analysis will be based. For the least sophisticated and least demanding analyses, linear growth is appropriate.

For moderately sophisticated analyses, land use trends and both local and through traffic should be considered; either linear or non-linear trends may be applicable. For high-level analyses in which land use changes form the basis for selecting the curve, stepped growth may be the most appropriate.

Trend line analyses typically require a large number of data points, and outliers should be identified and understood before being discarded. Because trend line analysis assumes a continuation of past growth patterns, the analyst should always check the reasonableness of the output, especially when there is a change in land use, future roadway capacity, or geometry. The output should also be compared against other forecasts for the adjacent facilities. *NCHRP Report 255* provides guidance on the use of trend line analyses for both interpolation and extrapolation.

NCHRP Report 255 provides methods for estimating turning movements for planning and designing highway intersections and interchanges. *NCHRP Report 255* recognized that traffic assignments rarely provide turning movement forecasts that can be used directly and that therefore these forecasts need significant refinement. The refinement procedures described in *NCHRP Report 255* can be used to develop more reliable turning movement estimates from various sources and for various uses.

NCHRP Report 255 discusses three sets of procedures: factoring procedures, iterative procedures, and "T" intersection procedures:

- **Factoring procedures.** These procedures use either the ratio method or the difference method. The primary feature of factoring procedures is that they are easy to apply but assume a constant growth rate consistent with past trends. Factoring procedures also require base year turning movement counts, which may not be available.
- **Iterative procedures.** These include separate directional volume and non-directional volume methods. The directional volume method adjusts future year turning movements to match a predetermined estimate of turning movement percentages and can be applied whether or not base year turning movements are known. The non-directional volume procedure requires more judgment on the part of the analyst as typically the turns are derived from knowledge of the non-directional approach link volumes and an estimate of the total turn percentage at the intersection. Both of these procedures (which typically use iterative proportional fitting or Fratar methods) require several iterations before an acceptable closure is reached. As these methods have been implemented in software, they are far less time consuming today than when they were applied originally by hand. These procedures are not intended to be used for design purposes.
- **"T" intersection procedures.** These are a special application of the iterative procedures. The non-directional volume method will produce a unique solution if all three approach volumes are known. The directional volume method will produce a unique solution if directional approach volumes and one turning movement are known. The method allows analysts to use approach link volumes as a substitute for base year turning movements in cases where these are not available.

3.6.3 OD Matrix Growth Factoring

This method involves a simplified application of a travel demand model. In this method, a model sketch network of a study area is developed and a base year OD matrix is created (typically using matrix estimation) from traffic counts. The base year OD matrix can be either a 24-hour matrix or a peak-period matrix. Growth factors are applied to the base year matrix to create a future year matrix or matrices. Growth factors can be based on various sources, such as trend analyses, population and/or employment projections, anticipated land use changes, and so forth. A single growth factor can be applied or separate factors can be applied to individual cell matrices (i.e., individual OD pairs). The future year matrices then are assigned to the model network.

This factoring approach can be easily misapplied. The analyst is cautioned that changes in socioeconomic variables do not transfer directly to equivalent changes in automobile trips and therefore other variables such as productions and attractions should be considered. Inherent in the method is the assumption that travel patterns external to the study area will remain constant, so determination of the extent of the study area network is important.

3.6.4 Time-Series Models

Time-series models extrapolate upon past trends to predict future conditions. Time-series models can be used for the traffic forecast itself or for forecasting the inputs to travel forecasting models. There are only a few articles in the published literature on the use of time-series methods for travel forecasting. A review of existing literature and practice is contained in the *Guidebook on Statewide Travel Forecasting* (*44*), published in 1999. At that time, practice was confined almost exclusively to the use of linear trend models and growth factor models. The survey done for NCHRP Project 08-83 also showed that many agencies are still using linear trend models and growth factor models.

The Wisconsin Department of Transportation, departing from the norm, reported on the use of Box-Cox regression analysis, which is still being actively used by that agency. The survey done for NCHRP Project 08-83 failed to find any other popular techniques.

Time-series analysis is a very active area of statistics, and methods exist that greatly expand upon elementary techniques such as linear trend models or growth factor models. Major statistical software packages contain full suites of time-series methods. There is much untapped potential for project-level traffic forecasting.

The trend analysis method adopted by the Florida Department of Transportation (FDOT) performs traffic forecast for areas without a travel demand model. It relies primarily on historical traffic counts to establish growth trends through regression analysis; data on gas sales, land use, and population are used as a supplement when traffic counts are insufficient. K30 and D30 factors can be used to forecast directional design hourly traffic, and T24 (a daily truck factor) can be used for facilities without existing truck traffic counts.

The FDOT methods cite a series of resource documents, including *NCHRP Report 255* (*1*) and *NCHRP Report 187* (*8*), the Institute of Transportation Engineers' (ITE's) *Trip Generation Handbook* (*11*), and so forth.

3.6.5 Traffic Impact Study Tools

Traffic impact studies assess the local congestion consequences of a prospective land use site development. They are unique to traffic forecasting in that they combine forecasts of background traffic with a forecast of locally generated traffic. Background or non-site traffic forecasts typically are developed using travel demand models or manual tools like trend line analyses. Forecasts for site-generated traffic are prepared using accepted land use/trip generation relationships based upon quantifiable parameters such as gross leasable area, number of employees, or number of parking spaces. Site-related trips are distributed and assigned to the area roadway network (either manually or using a travel demand model), then summed with background traffic for the total traffic forecast. Guidance for forecasting background traffic varies from little or none to very specific (FDOT, for example). Section 9.9 of this report supplements the guidance materials listed below.

3.6.5.1 Trip Generation Handbook, 2nd Edition (11)

The ITE's *Trip Generation Handbook* provides guidance on estimating site-generated traffic stratified by land use types. The basic relationship is described by mathematical relationships between the dependent variable (either daily or peak-hour trip ends) and independent variables (such as gross leasable square footage and number of employees) or land use–specific variables (such as restaurant seats, hotel rooms, hospital beds, and so forth). These mathematical relationships have been developed through numerous studies from which data have been collected and submitted to the ITE. Mathematical relationships typically assume the form of an average trip rate or a regression equation. No guidance is given on future growth of trip generation estimates.

3.6.5.2 Kentucky Transportation Cabinet Permits Manual—Traffic Impact Study Requirements (74)

The Kentucky Transportation Cabinet's procedures for traffic impact studies follow the ITE's recommendations for site trip generation, distribution, and assignment. The Cabinet has developed spreadsheets for performing trip generation and for estimating future design year non-site traffic. The Cabinet specifies an analysis or design year 10 years after the year of opening. In the event that the full build-out of the development is anticipated to extend beyond the 10-year horizon, the design year is the year of full build-out.

Future year forecasts are estimated using the weighted average annual rate provided by exponential and linear growth models. Design-year, no-build traffic volumes are determined by applying the projected growth rate to existing traffic volumes.

Final design-year total traffic volumes are determined by summing future (no-build) traffic, pass-by trips, and trips generated (entering and exiting).

3.6.5.3 Kentucky Transportation Cabinet Design Memorandum No. 03-11: Traffic Engineering Analysis (75)

The Kentucky Cabinet has published a policy manual for traffic engineering analyses in highway design. The procedures and methodologies are consistent with the most recent edition of the HCM and can be used to (1) determine the basic number of lanes on a facility and (2) determine the need for auxiliary lanes on a facility. The policy manual specifies the need for design-year as well as current or opening-year traffic volumes.

3.6.5.4 Florida Department of Transportation Traffic Impact Handbook (76)

FDOT's *Traffic Impact Handbook* was prepared to assist state and local agencies in reviewing and providing comments on local government comprehensive plan amendments and development orders as they relate to transportation impacts on state and regional multimodal facilities. The two main categories of reviews are local government plan reviews and development of regional impact (DRI) reviews.

The *Traffic Impact Handbook* advises that future conditions for impact assessments can be estimated using "manual methods," travel demand forecasting models, or a combination of the two. Manual methods are those methods of trip generation done without large-scale travel demand models. The most common examples of manual methods are the use of trip generation factors to estimate trip generation and the application of growth factors or the addition of known trips from other developments to the surrounding road system to estimate background traffic growth.

The *Traffic Impact Handbook* contains an entire section on projecting background traffic. Background (non-site) traffic is typically estimated using one of three methods based on local area needs and conditions:

1. Growth rate/trend methods relying on historic trends. These methods are typically appropriate in applications for
   - Small projects that will be built within 1–2 years.
   - Areas with at least 5 years of data showing stable growth that is expected to remain stable.
2. Build-up methods that use specific development information. These methods are typically appropriate in applications for
   - Areas experiencing moderate growth.
   - Areas where multiple projects will be developed during the same period.
   - Project horizon years of 5 years or less.
   - Locations where there is thorough documentation of development approvals.
3. Model methods that involve the use of a large-scale travel demand model. Model methods are typically appropriate in applications for
   - High growth areas.
   - Large regional projects that may have multiple build-out phases.
   - Locations where there is sufficient information available to calibrate the model to current and future conditions.

3.6.6 Elasticity Methods

In the absence of a highly sophisticated travel demand model, project planners need to rely on simple methods to determine the impacts of multimodal operational policies. A well-established method of doing so is in the application of elasticities. Elasticity is a concept from economics that describes the percentage change in travel demand resulting from a percentage change in an independent variable, such as cost or travel time. As an example, the transit industry elasticity standard known as the Simpson-Curtis rule held that a 1% increase in fare would reduce ridership by 0.33% (or that a 1% decrease in fare would increase ridership by 0.33%). The equivalent elasticity is −0.33. Often, only a single (constant) elasticity is available over the entire range of independent variables.

Elasticities are handy shortcuts for estimating changes in travel demand where there is a reasonably close similarity between the project at hand and the case study that created the elasticity. Analysts applying elasticities should take care in application not to exceed the range of experience that the elasticity is derived from. As an example, using an observed elasticity derived from a change in travel cost of 20% to forecast the change in demand from a 100% increase in travel costs is inappropriate. Chapter 15 of *TCRP Report 95: Traveler Response to Transportation System Changes Handbook (38)* provides elasticities for a very large number of transportation system changes.

PART 2

Guidelines

CHAPTER 4

The Project-Level Forecasting Process

Project-level traffic forecasting can be complex, given the amount of data and analysis required, but the process follows established and accepted methodologies. Nonetheless, many issues can arise along the way, including communication, the role of engineering judgment, and forecasting accuracy. All of these items will be covered in this chapter.

Chapter 4 will also serve as a launching point for the guidelines. Methodologies that can be used in the forecasting process will be indexed in this chapter to help the forecast developer or manager to choose the most effective approach to meet the needs of the project.

This chapter has five parts:

- **Traffic Forecasting Context—Management Perspective.** Managers of agencies who request traffic forecasts and others trying to understand traffic forecasting can gain the "big picture" with a look at high-level components such as the time frame, study area, alternatives/scenarios, and needed resources. Furthermore, an electronic tool is provided to help select the proper tool to perform traffic forecasts.
- **Traffic Forecasting Steps—Analyst Perspective.** This section breaks out the typical traffic forecasting process into discrete steps including forecast preparation, forecast analysis, forecast final product, and three mini case studies.
- **Role of Judgment.** While traffic forecasting includes many sophisticated tools based on high-level statistics and requires very specialized education and experience, it is still in some respects an "art" and requires sound judgment for many decisions.
- **Forecast Accuracy.** This section describes model error, traffic forecasting error, and corrective measures for improving forecasting. It should be mentioned that these guidelines are meant to reflect the state of the practice, and, since the use of descriptive statistics qualifying traffic forecasts is not a standard, no recommendation is made. However, forecasts are developed from limited data resources and project into a distant future, so it seems that this area is ripe for new investigation.
- **Traffic Forecasting Rules of Thumb.** These rules of thumb, developed from many decades of experience, are intended to help the forecaster develop boundaries for traffic forecasting development.

4.1 Traffic Forecasting Context—Management Perspective

This section generalizes the process of traffic forecasting as a discrete series of procedural steps, so that both the common and unique elements of forecasting can be described in a logical way.

4.1.1 Forecasting Application

Traffic forecasts are normally performed by or for an agency that has an established forecasting and decision-making process. The need for a traffic forecast can originate from many sources, including the execution of institutionalized practices such as the following:

- Traffic impact studies,
- Baseline performance assessments,
- Baseline reliability assessments,
- Operational strategy assessments,
- Benefit assessments,
- Work zone management planning,
- Roadway (passenger, commercial, and freight) long-range planning,
- Asset management including bridge and pavement needs,
- Air quality conformity analysis,
- Congestion management process,
- Facility design and operations, and
- Capital improvement program prioritization.

Alternatively, a forecast can be triggered by a decision to assess the need for, and efficacy of, a prospective large investment for a particular component of the roadway system in studies such as the following:

- Environmental impact statements,
- Highway feasibility studies,
- Interchange justification requests,
- Corridor mobility studies,
- Access management studies,
- Demand management plans, and
- Evacuation plans.

For location-specific analyses requiring an expenditure of staff resources, agencies have developed protocols for processing and prioritizing traffic forecasting requests.

There are many ways that a request for a traffic forecast is initiated. State transportation commissions, state legislative bodies, metropolitan planning organization (MPO) boards of trustees, department of transportation (DOT) executive management teams, and private developers are some examples of those who can initiate requests.

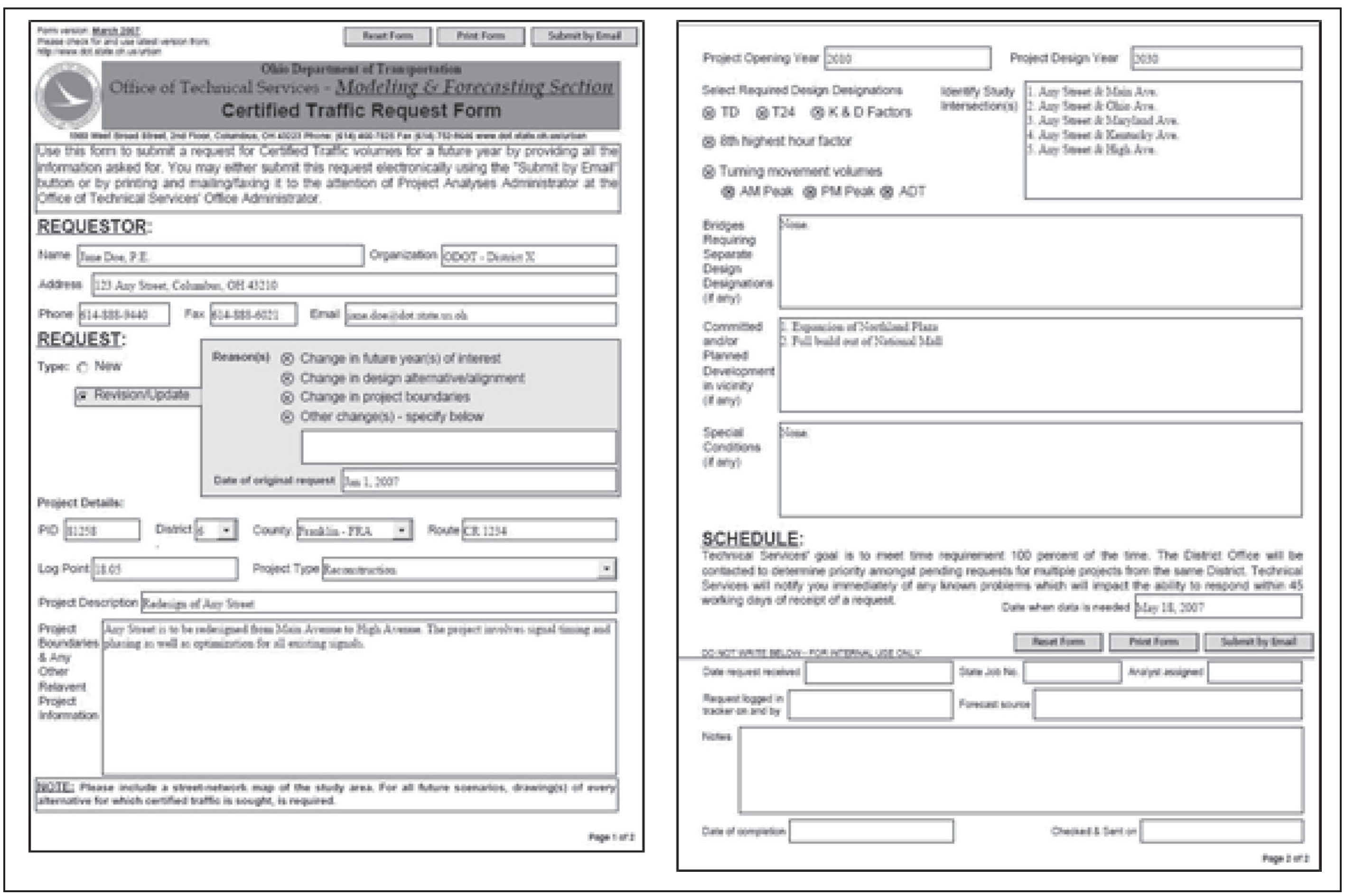
4.1.2 Scope

Before the forecast is given to the traffic forecasting analyst, the scope is set by the forecast requestor. See Figure 4-1 for an example traffic forecast request form. Typically, the scope request will cover, at a minimum, the following six items that are identified next and discussed in some detail below.

- Determine time frame,
- Determine geography/study area,
- Alternatives and scenarios (including forecasts of supply alternatives and demand alternatives),
- Identify resources, and
- Select traffic forecasting tool(s).

4.1.2.1 Determine Time Frame

Most traffic forecasts prescribe a comparison of transportation system performance under different assumptions about current and future conditions. Forecasts using shorter time horizons have more reliable data available to them and, thus,



Form version: March 2007
Please check for and use latest version from:
http://www.dot.state.oh.us/urban

Reset Form | Print Form | Submit by Email

Ohio Department of Transportation
Office of Technical Services - *Modeling & Forecasting Section*
Certified Traffic Request Form

Use this form to submit a request for Certified Traffic volumes for a future year by providing all the information asked for. You may either submit this request electronically using the "Submit by Email" button or by printing and mailing/faxing it to the attention of Project Analyses Administrator at the Office of Technical Services' Office Administrator.

REQUESTOR:

Name: Jane Doe, P.E. — Organization: ODOT - District X
Address: 123 Any Street, Columbus, OH 43210
Phone: 614-888-9440 — Fax: 614-888-6021 — Email: jane.doe@dot.state.oh.us

REQUEST:

Type: New / Revision/Update

Reason(s): Change in future year(s) of interest; Change in design alternative/alignment; Change in project boundaries; Other change(s) - specify below

Date of original request: Jan 1, 2007

Project Details:

PID: 81258 — District: 6 — County: Franklin - FRA — Route: CR 1234
Log Point: 18.05 — Project Type: Reconstruction
Project Description: Redesign of Any Street
Project Boundaries & Any Other Relavent Project Information: Any Street is to be redesigned from Main Avenue to High Avenue. The project involves signal timing and phasing as well as optimization for all existing signals.

NOTE: Please include a street-network map of the study area. For all future scenarios, drawing(s) of every alternative for which certified traffic is sought, is required.

Page 1 of 2

Project Opening Year: 2010 — Project Design Year: 2030

Select Required Design Designations: TD; T24; K & D Factors; 8th highest hour factor; Turning movement volumes: AM Peak, PM Peak, ADT

Identify Study Intersection(s):
1. Any Street & Main Ave.
2. Any Street & Ohio Ave.
3. Any Street & Maryland Ave.
4. Any Street & Kentucky Ave.
5. Any Street & High Ave.

Bridges Requiring Separate Design Designations (if any): None.

Committed and/or Planned Development in vicinity (if any):
1. Expansion of Northland Plaza
2. Full build out of National Mall

Special Conditions (if any): None.

SCHEDULE:

Technical Services' goal is to meet time requirement 100 percent of the time. The District Office will be contacted to determine priority amongst pending requests for multiple projects from the same District. Technical Services will notify you immediately of any known problems which will impact the ability to respond within 45 working days of receipt of a request.

Date when data is needed: May 18, 2007

Reset Form | Print Form | Submit by Email

DO NOT WRITE BELOW – FOR INTERNAL USE ONLY

Date request received — State Job No. — Analyst assigned
Request logged in tracker on and by — Forecast source
Notes
Date of completion — Checked & Sent on

Page 2 of 2

Figure 4-1. Example of traffic forecast request form (Ohio DOT).

forecasts can be configured to extract more detailed information, such as turning movements or speeds in small time increments, with greater confidence.

Traffic forecasting years are usually prescribed by the client and/or the FHWA, EPA, and other regulatory agencies. Typically, the forecast year is at least 20 years beyond the "opening" year. The AASHTO Policy on Geometric Design prescribes a 20-year design horizon, which has been in use for 60+ years, since the initial design of the Interstate highway system. The prevailing thinking is that 20 years is a reasonable design life for a highway, which necessitates an estimate of the future traffic volumes.

For design studies, a forecast near the current year is also always provided. Three options are used:

- Base year, the year of the model of the most recent traffic counts;
- Current year, the year when the forecast is produced; and
- Opening year, the estimated year that the new facility will be opened or become operational.

Each of these options has advantages and disadvantages. Using an opening year forecast requires information about future conditions and has accuracy-associated risks. It has the advantage of producing a 20-year forecast rather than some other period, and it is required by many states (such as North Carolina and Ohio). Using a base year forecast from a travel demand model may be appropriate if the base year is fairly current, but this practice is generally frowned upon since most agencies prefer to see a strong tie-in to actual traffic counts in the current year.

The current year seems to be most logical for decision-making purposes, unless the forecast is required to have the 20-year design period start with the current year. Therefore, one frequently sees the design period correspond to a point in time more than 20 years beyond the current year to avoid the problem of the design period going out of date.

In general, traffic impact studies, site development analyses, interchange justification studies, and capital improvement programming (prioritization) require near-term forecasts, on the order of a 2-to-10-year horizon, while design and planning studies may require time horizons up to 30 years or more.

4.1.2.2 Determine Geography/Study Area

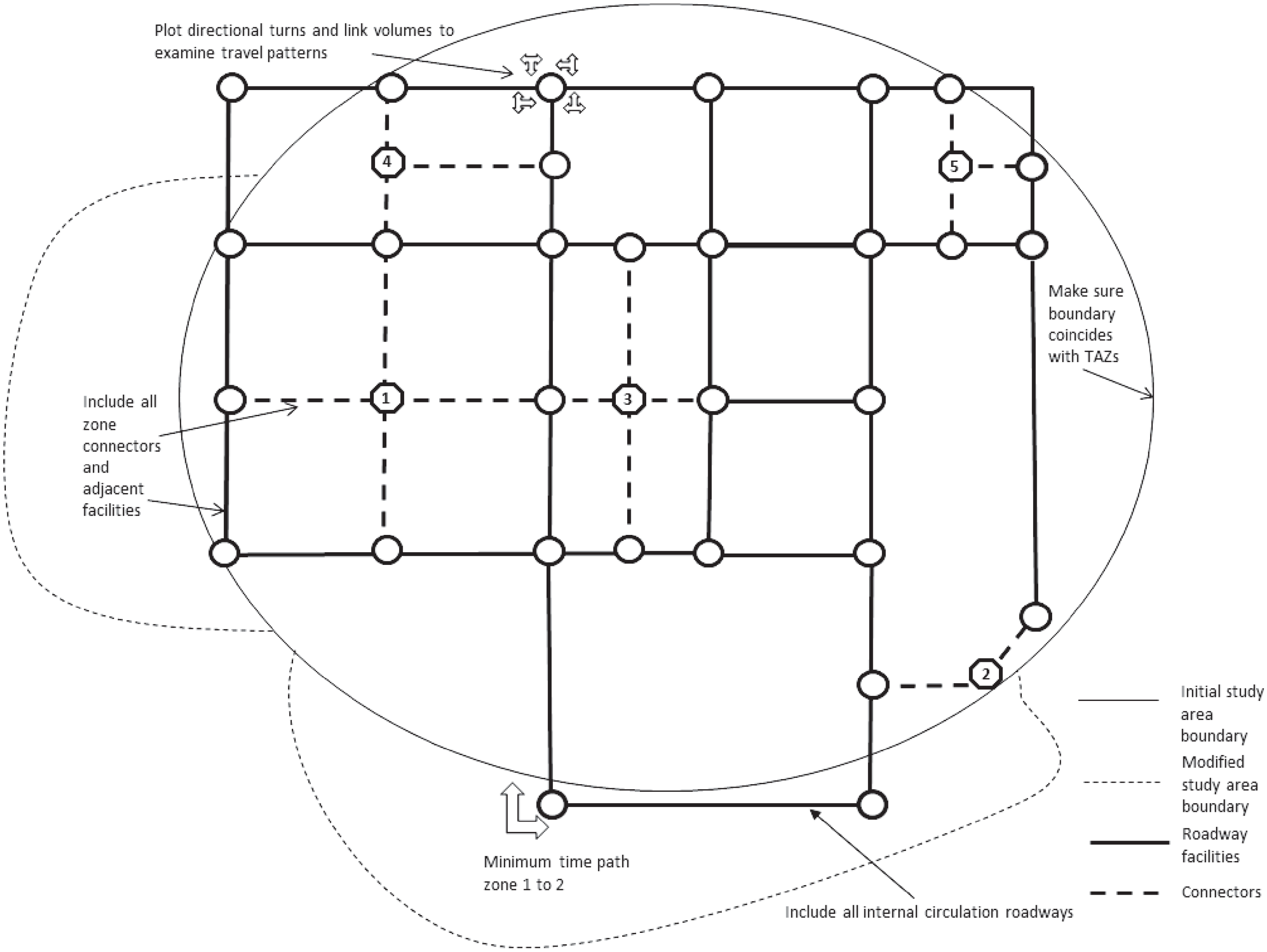
Traffic forecasts for projects of limited scope (bridges, intersections, and most traffic impact studies) use relatively small study areas, sometimes as small as the geometry of the subject project itself. Traffic forecasts for bigger facilities and developments use a larger study area since the traffic patterns may be changed by highway improvements in other locations. *NCHRP Report 255* states that for computational purposes this area should be kept to a minimum; however, it should include that portion of the network in which any link changes (e.g., addition, deletion, or upgrading) will be proposed. Table 4-1 shows various study area descriptions by project type.

The study area should be defined based on the project type and by reviewing various resources such as area maps, aerial photography, natural features, and jurisdictional boundaries. The review should identify roadways and developments to be included in the study area as well as any areas that may be influenced by the proposed project. Guidelines for selecting a study area from *NCHRP Report 255* are shown in Figure 4-2. This figure illustrates a typical project study area showing how its boundary, which defines the project impact area, may be adjusted to better match the arterial road network, critical intersections, and traffic analysis zones (TAZs).

Choose the study area to cover not only the facilities being analyzed, but also those zones that might affect the use of those facilities. Special care should be taken to include all zone

Table 4-1. Study area descriptions.

Project Type	Study Area Size	Data Needs
New Development	Buffer area beyond the building structure	Travel time and distance
Intersection	Buffer area beyond the key intersections	Hourly flows for all legs of intersection
Corridor	One intersection beyond termini and key intersections	Base year traffic counts and roadway flows
Focus Area	Buffer area beyond termini including key intersections and roads	Base year traffic counts and roadway flows
Alternative Study	Buffer area beyond termini including key intersections and roads	Base year traffic counts and roadway flows
Long-Range Transportation Plan (State)	Buffer area beyond state boundaries	Interstate flows
Long-Range Transportation Plan (MPO)	Buffer area beyond MPO boundaries	Principal arterial flows



Source: *NCHRP Report 255,* Figure A-36, p.83 (*1*).

Figure 4-2. Study area guidelines.

connectors and adjacent facilities that could serve as alternate routes to/from those zones:

1. Choose the study area boundary lines to coincide with the system-level TAZ boundaries.
2. Plot all directional turning movements and link volumes from the base year or future year assignments on an enlarged network map showing highway system, node numbers, and centroid numbers covering the local area. Examine the plotted traffic volumes closely to see which analysis zones should logically be included in the study area.
3. Include all internal circulation roadways within the study area. This means that all trips originating and terminating solely within the study area must be accommodated by facilities that are situated within the study area. Zonal tree data can be used to determine minimum time paths between zones.

For new developments such as shopping centers, office parks, and neighborhoods, a study area can be defined in terms of travel time or distance. For corridor projects, a study area can be defined by a buffer around the corridor segment and key adjacent intersections. Figure 4-3 shows a corridor study area in Kentucky in which the circled area contains the four alternatives being modeled. In this case, the study area encompassed alternative routes to or from which traffic could be diverted.

For large-scale projects, the study area often spreads beyond the boundaries of any single available forecasting tool, and adjustments or enhancements to existing tools must be made. One frequent adjustment is the blending or merging of two or more travel demand modeling areas to encompass the entire influence area of a project. The defined study area then might influence the choice of tools used (see Appendix I) and may even necessitate that a new tool be created.

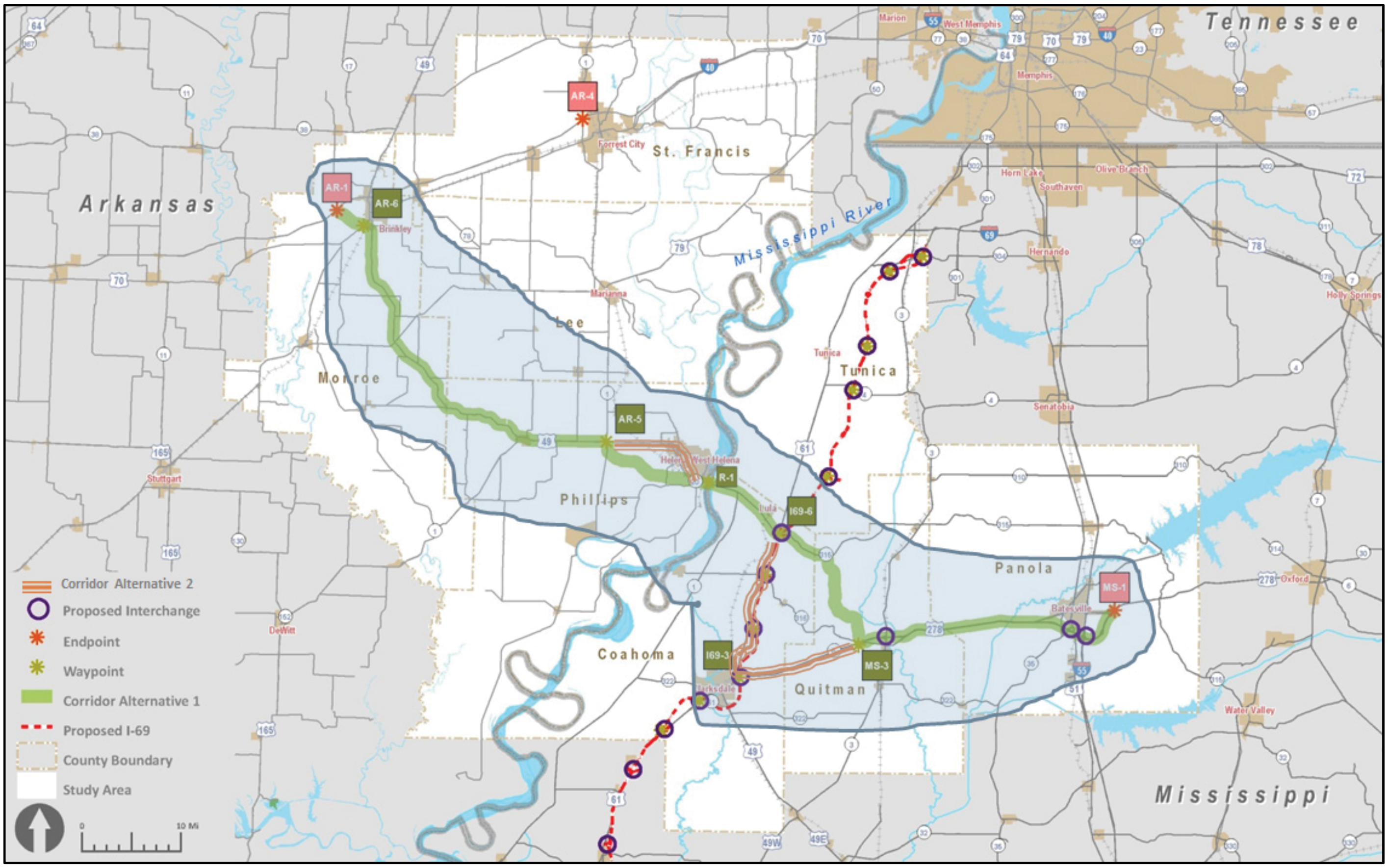


Figure 4-3. Corridor project study area.

For small-scale projects, windowing or focusing procedures may be used to define the study area based on sphere-of-influence methodology. The sphere of influence is the area surrounding the project that would be affected by the project. This area "captures" all facilities that could be expected to directly influence the traffic patterns on the facilities under study. Within the study area, the network and zonal definition is increased to include specific smaller arterials and/or collector streets and smaller zones specified by the analysis. Figure 4-4 shows an example of the sphere-of-influence areas identified for external-to-internal travel. This same methodology can be applied in determining the study area by identifying the types of roadways and land uses near the proposed project. For example, Interstate facilities and major arterials near the project would likely capture the trips from a wider range and thus have a larger sphere of influence. Similarly, a mall or major special generator land use may have the same impact, resulting in a larger sphere of influence.

4.1.2.3 Alternatives and Scenarios

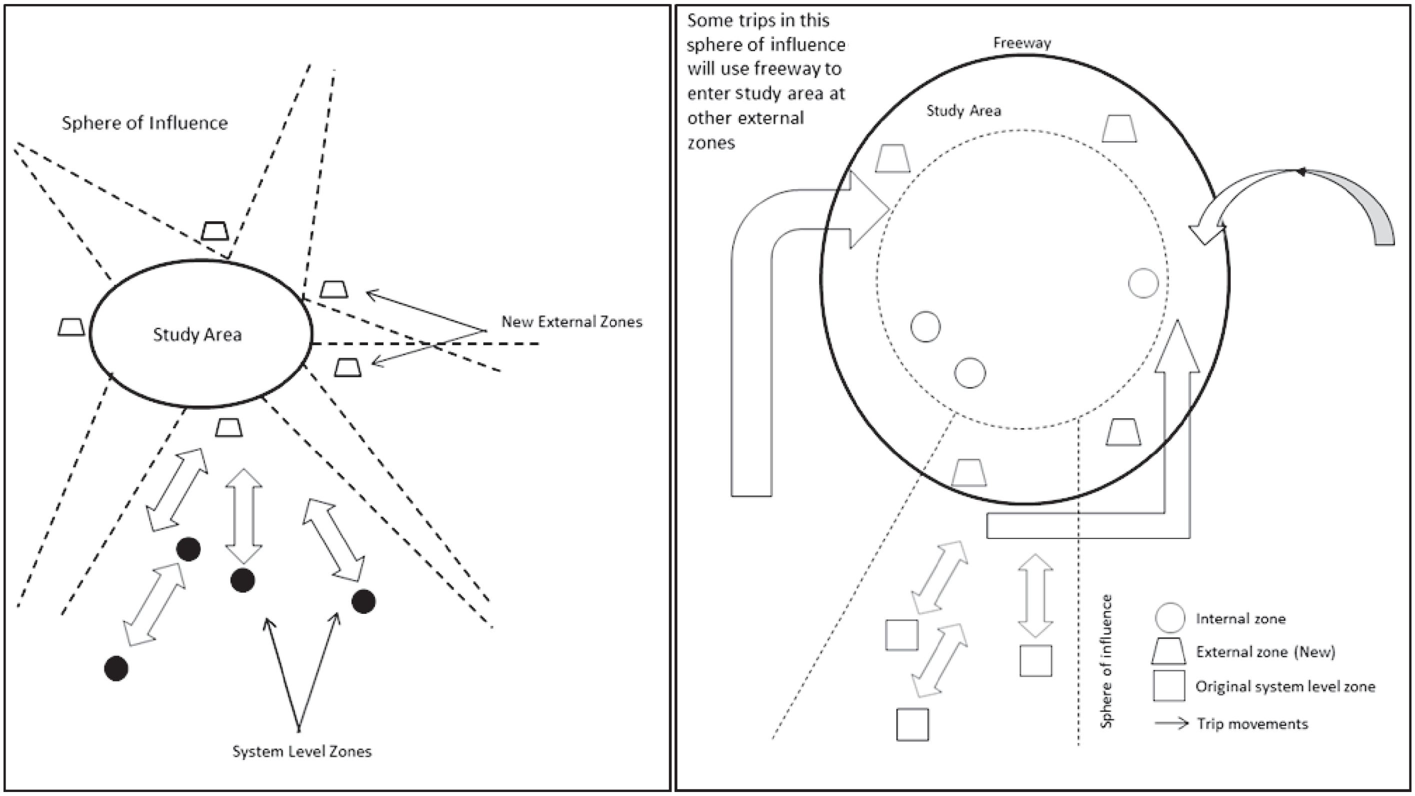
There are many complex schemes that affect project-level traffic forecasts, and usually these schemes are called alternatives and/or scenarios. For purposes of these guidelines, alternatives will involve geometric or operational changes to be forecasted while scenarios will be considered to be non-geometric, non-operational, project differences such as major changes in land use.

4.1.2.4 Forecasts of Supply Alternatives

The supply characteristics of the alternatives for which forecasts will be developed also influence the tool to be used and its data requirements. For instance, a new highway project such as a bypass or a corridor study might have a "Do Nothing" alternative along with several new alternatives. Each alternative will need to be modeled or analyzed, including producing the appropriate set of measures of effectiveness (MOEs).

Figure 4-5 is an example of traffic forecasting alternatives from the Phoenix–Tucson Bypass Study (*135*), in which the existing road (I-10) is shown along with two possible new corridor alignments.

Some more complex forecasts will have a large range of geometric alternatives. Other transportation projects might have more complex alternatives such as transportation systems management alternatives including HOV lanes, pricing,



Source: *NCHRP Report 255*, Figures A-50 and A-51 (*1*).

Figure 4-4. Sphere of influence.

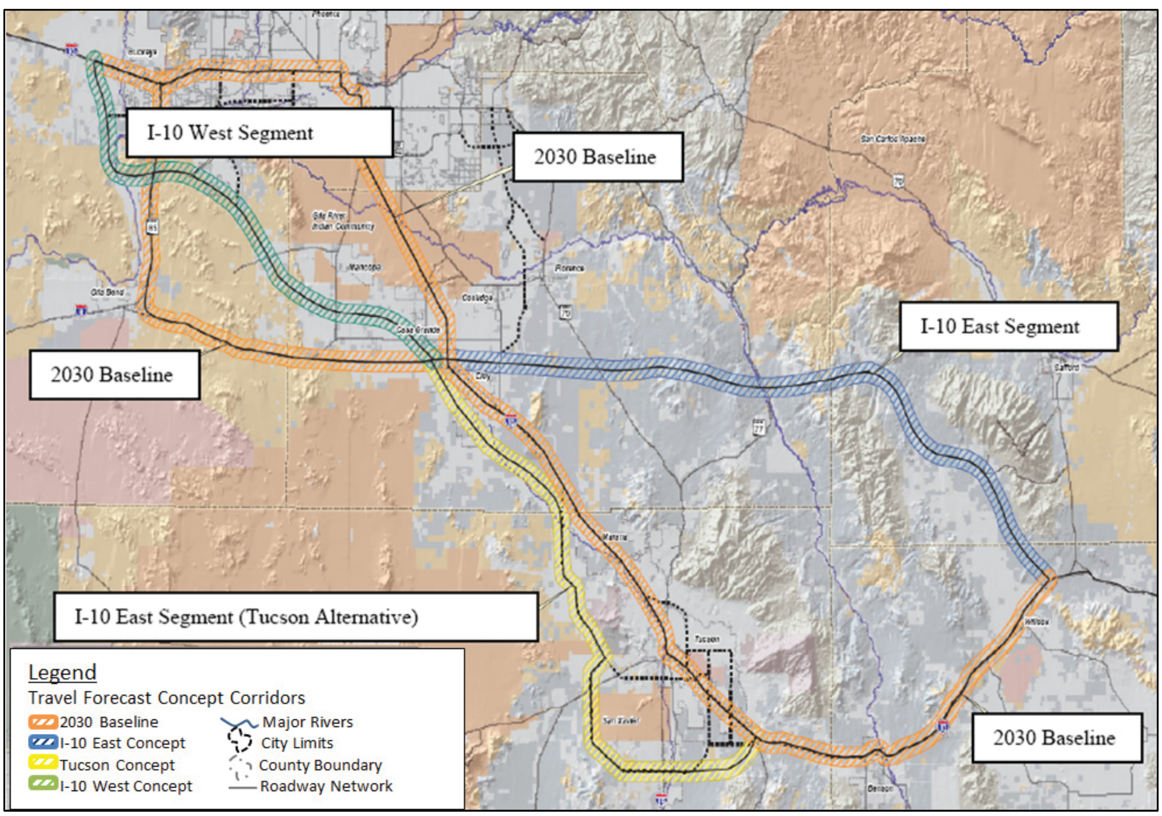


Figure 4-5. Typical forecasting alternatives.

transit alternatives, and other non-highway alternatives not covered in these guidelines.

4.1.2.5 Forecasts of Demand Alternatives (Scenarios)

Alternatives testing may also involve estimating the implications of alternative or new levels of demand. For example, a new automobile factory or a large new subdivision might be assessed for its impacts on the local transportation system. In these cases, travel demand forecasts might combine existing land uses with growth in certain TAZs.

Another use of demand alternatives is to have adjustable population and employment levels for future and/or intermediate years. For instance, Arizona might have a 2050 population of 12 million for the intermediate growth scenario and a 2050 population of 16 million for the high growth scenario. Clearly, the increase in population or employment will have a major impact on the forecasted traffic. Usually this usage of scenarios is done only during the planning stage, not during the design or operations stages.

Another usage of demand alternatives might be to combine a set of geometric or roadway improvements. This is most frequently done for planning purposes such as a long-range transportation plan or a transportation improvement program.

4.1.2.6 Identify Resources

There are often significant constraints on the time, staff, and money that can be devoted to a forecasting project. There is usually a correlation between the complexity and significance of a forecast and the resources available for it. The limits of the schedule and budget will strongly influence the choice of analysis tools and the number and kind of refinements that can be made to them.

There is a strong relationship between the time and budget requirements of a project, the level of review, and the scrutiny that the project will receive. Internal studies covering small areas can often be completed quickly and at a relatively low cost. For example, the Ohio DOT likes to see certified small project traffic forecasts completed within 2 months. However, very complex projects could span several years, for many reasons, including the following:

- The need for extensive data collection (such as origin-destination [OD] surveys, extensive traffic counts, and household surveys);
- Alternatives/scenarios being modified mid-course;
- Involvement of federal agencies requiring more detailed review;
- A particularly complex forecasting process due to project size issues (number of turning movement locations, large number of alternatives, and tolling or pricing components); and
- Professional service contracts that might be needed to augment agency staff resources and which require the development of a formal written scope in order to advertise for the necessary professional services.

As can be seen from this section on traffic forecasting scope, appropriate resources—budget, time, and staff—are critical to the success of the endeavor.

4.1.2.7 Selecting Traffic Forecasting Tool(s)

The requirements for traffic forecasting for design, planning, and operations can vary significantly. Planning applications may have many scenarios rather than a fixed design requirement. Design applications may include features such as pavement design aspects, including load spectra, or equivalent single axle loads (ESALs) and may need to be certified. Operational applications may have a much closer future year and use different MOEs.

Section 4.1 has identified the major components of traffic forecasting for a management perspective. A crucial part of this forecasting context is the need to use appropriate tools for the job at hand. Figure 4-6 shows the process where the

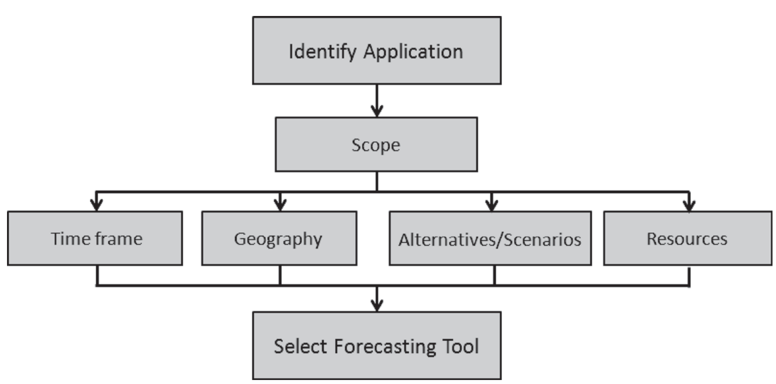


Figure 4-6. Traffic forecasting context components.

application (forecast need) results in the development of a detailed scope that then results in the need for selecting a forecasting tool.

Selecting the appropriate tool is a very complex process that is accompanied by the need to finance, develop, and maintain the forecasting tools. Forecasting tools can range from trend line analysis, sketch-planning techniques, traffic simulation models, sophisticated travel demand models at many levels of geography (MPO, regional, statewide, and multi-state), and many other tools. These guidelines discuss the use of many of these tools for project-level traffic forecasting purposes.

A tools selection matrix was developed for this project to help both managers and analysts select the appropriate tool. This tool selection matrix is described in Appendix I, and an accompanying spreadsheet can be found on *CRP-CD-143*, which is bound into this report. (An .iso image of *CRP-CD-143* and instructions for burning this image onto a CD-ROM are available on the *NCHRP Report 765* web page on the TRB website.)

4.2 Traffic Forecasting Steps—Analyst Perspective

The previous section covered various elements leading to actually developing the traffic forecast. This section covers the development of the traffic forecasts. Figure 4-7 displays the major traffic forecasting steps.

The section contains the following subsections:

- **Forecast preparation—**primarily consisting of data collection, finding archived traffic forecasts, and making needed field observations;
- **Forecast development—**consisting of travel demand model runs (or use of another forecasting tool);
- **Quality analysis/quality review—**forecasting is iterative and requires many edits/corrections;
- **Forecast product: documentation—**example of a refined final product; and
- **Communication—**good communication is critical to this process and permeates every step.

4.2.1 Forecast Preparation

Forecast preparation consists of collecting needed data to support the forecasting. Data assembled include existing data, new data gathered especially for the project, related previous traffic forecasts, and information gained through site visits.

4.2.1.1 Existing Data

Existing data fall into the following general areas:

- Traffic data—sources and types,
- Socioeconomic and demographic data,
- Data on land use and/or development activity and land use plans,
- Use of transferable trip generation rates from a source such as the Institute of Transportation (ITE) *Trip Generation Manual*, and
- Matrix of MOEs versus travel forecasting outputs.

4.2.1.2 New Data Collection

Frequently, existing data are not adequate for performing the traffic forecasts, especially for more complex projects. Therefore, additional data might be required, such as demographic surveys, special counts, and special travel time information.

4.2.1.3 Related Previous Traffic Forecasts

Traffic forecasting usually must be consistent with other studies and traffic forecasting work done in the past, especially the recent past. It is important for the traffic forecaster to gather related forecasts and sift through the information and become familiar with it. Well-organized forecasting agencies may maintain databases that track traffic forecasts.

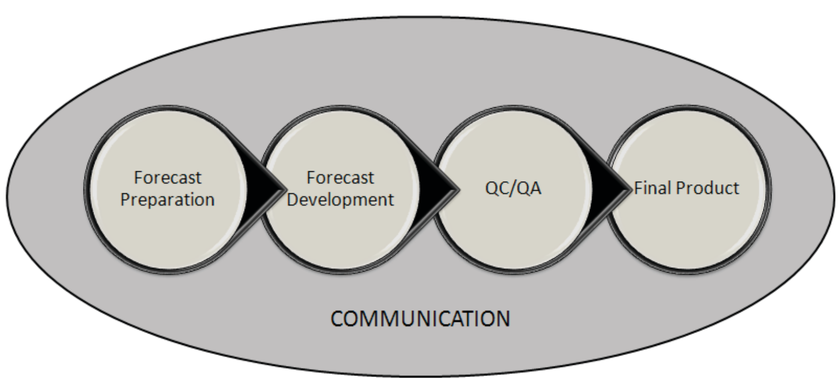


Figure 4-7. Traffic forecasting steps.

Already prepared forecasts include corridor study forecasts, long-range planning study forecasts, and thoroughfare study forecasts. The forecasts must be examined for scope, study area compatibility, forecast year, growth rates, assumptions used, adequacy of tools used to develop the forecasts, land use changes, and other factors.

4.2.1.4 Site Visits

A site visit can be especially useful for centrally located staff specialists or a consultant who may not be too familiar with the characteristics of a project study area. The North Carolina Project-Level Traffic Forecasting Technical Manual (*77*) recommends that a field visit be conducted to collect information from a site and that the visit include the following:

- Observe and characterize land use in the study area;
- Locate truck generators;
- Note factors that inhibit development;
- Observe traffic on existing roads directly impacted by the project, especially areas with traffic congestion;
- Note roads and driveways not on maps;
- Inventory locations (intersections and roads) needing additional traffic counts; and
- Conduct personal interviews with local planners or officials on the visit, especially to gauge upcoming development.

Included on *CRP-CD-143* for reference purposes is a tool that the North Carolina DOT developed to assess annual average daily traffic (AADT).

Aerial imagery or satellite imagery may also provide useful information about the physical characteristics of the area and facility being analyzed. Careful field notes should be taken so that relevant information is preserved for analysis and documentation.

4.2.2 Forecast Development through Mini Case Studies

After the forecast data preparation is complete, the forecast development begins. Two example forecasts provided by the Ohio DOT are shown in Appendix F. Those two forecasts include a simple and a complex project forecast.

This section describes good-practice forecasting and tool application for three situations: (1) turning movements at intersections, (2) small area roadway volumes using trend lines, and (3) area modeling. Each situation is described and illustrated by mini case studies that use procedures directly adapted from *NCHRP Report 255* (*1*). Other aspects of forecast development are also discussed that are related to the use of forecasts from travel demand models or spreadsheets from *NCHRP Report 255.*

4.2.2.1 Forecasting Development and Mini Case Study 1: Turning Movements Background

Traffic forecasts involving intersections generally require the calculation of peak-hour turning movements for the current (or opening year) and future design year. It is very important to have recent turning movement counts since the turning movement forecasts are used to determine whether turn lanes are needed, their storage length, and whether multiple lanes are needed. The parameters needed for turning movement calculation are current year turning movement AADTs, future year AADTs, K factors, and D factors.

A Microsoft Excel spreadsheet was developed to compute intersection turning movement volumes based on average daily traffic (ADT) and K factors. The spreadsheet is based on methodology outlined in *NCHRP Report 255* (*1*). The steps needed to compute turning movement volumes using the spreadsheet are as follows:

1. Gather existing/base year turning movement volumes. This usually requires a request for data collection, although in some cases data have already been collected (perhaps from a signal warrant analysis, a traffic impact study, or a previous traffic forecast). This information is input into the volumes tab of the spreadsheet.
2. Obtain future year AADTs and K factors. These are input into a table in the lower left-hand side of the volumes tab. The future year AADTs are normally obtained from traffic models or trend line analysis, as discussed in Chapter 3 of this report. K factors must be estimated. These two parameters are used to compute a future design hour volume (DHV) for each intersection approach.
3. Current year turning movements are derived using the manual data, and then directional factors are calculated for each approach.
4. Future year DHVs are computed using the current year D factors and the future DHV.
5. Future year directional link volumes are then automatically input into the *NCHRP Report 255* calculation tab.
6. The *NCHRP Report 255* calculation procedure iterates until a convergence is reached.
7. The final result is automatically transferred to the volumes tab. Results should be carefully inspected for anomalies, and any needed adjustments should be made.

This spreadsheet is meant for forecasting turning movements on four-legged intersections but can also be used for three-legged intersections. Separate spreadsheets are included on *CRP-CD-143* for five- and six-legged intersections.

Appendix G includes a detailed example of how this spreadsheet based on *NCHRP Report 255* is to be used. Chapter 6 gives detailed information on new turning movement tools prepared for these guidelines. The new tools are included on *CRP-CD-143*.

There are several principles worth remembering as one calculates turning movements:

- Turning movements should be balanced within a corridor. If Intersection A is the northernmost intersection and Intersection B is the intersection immediately to the south and there are no driveways, minor intersections, or other traffic sources (e.g., parking lots or garages, etc.) in between them, then the directional volumes for A's south approach must match the directional volumes for B's north approach. Judgment must be used to ensure that any difference in volumes between study intersections reflects conditions in the field accounting for traffic sources/links.
- Intersection volumes should be rounded to the nearest 10. It is easier to understand rounded values, and, more importantly, unrounded values imply accuracy that is misleading.
- All numbers used in traffic forecasts are estimates, even for AADTs that come almost directly from automatic traffic recorders. Therefore, it is necessary to use sound judgment when computing turning movements.
- Field visits are useful for assessing traffic patterns for turning movements, especially on major corridors. An acceptable substitute is an interview with someone else familiar with the area.
- The ITE *Trip Generation Manual* is a good source of directional factors for new facilities lacking existing count data.
- Commercial areas frequently have high mid-day peaks that may exceed the normal high peaks found in the AM or PM periods. If possible, consult the hourly volume distribution from a 48-hour count to assess the need for including a mid-day peak period.
- Mixed land use areas sometimes have lower K factors and flatter (close to 50/50) directional distributions.
- Schools and factories frequently produce atypical K factors and D factors. It is not unusual for D factors to exceed 0.70 on roads with much of the traffic coming from a school or factory.

4.2.2.2 Forecasting Development and Mini Case Study 2: Trend Line Analysis

Trend line analysis is used to estimate future traffic volumes and truck percentages when a travel demand model is not available. Ohio uses the *NCHRP Report 255* procedure for trend line analysis. Other procedures—such as autoregressive methods—are discussed in Section 10.1.

The parameters needed for trend line analysis calculation are current year AADTs, historical AADTs, current year volumes, and historical volumes.

An example of using the *NCHRP Report 255* (*1*) trend line analysis spreadsheet is included in Appendix G-1. The main steps in using the trend line spreadsheet are listed below:

1. Gather historical data for the subject locations from automatic traffic recorder (ATR) data reports or other sources.
2. Plot a chart with volumes on the y-axis and the year on the x-axis.
3. Use regression analyses to estimate a line with coefficients that best fits the historical traffic volumes. Linear regression is the most commonly used method for trend line analysis.
4. Repeat the analyses for truck volumes.
5. A preliminary estimate of future volumes can be computed using the trend line analyses.
6. Determine the growth rates for passenger traffic and truck volumes.

A typical trend line analysis graph is shown in Figure 4-8. The linear regression equation takes the form:

$$y = bx \pm a$$

where

y = Future ADT,
x = Future year,
a = the y-intercept, and
b = slope of the line.

Caution must be exercised with using typical trend line analysis using linear regression. There must be an adequate number of data points (at least five). Sometimes data outliers must be discarded. Reasonableness checks should be applied, such as the following:

- Review of land use and land use changes,
- Review of other forecasts in adjacent facilities, and
- Review of potential changes to future roadway capacity and geometry.

4.2.2.3 Forecasting Development and Mini Case Study 3: Area Modeling

Most traffic forecasts will involve the use of a travel demand model to determine future design volumes since the interaction of land use changes and changes to various transportation facilities is too complex to assess using simple trend line analysis techniques. *NCHRP Report 255* (*1*) included a spreadsheet for developing traffic forecasts from traffic data and model assignments using screenline analysis. A procedural explanation for using this spreadsheet is given in Appendix F-2.

This spreadsheet is based on the procedures discussed in Chapter 4 of *NCHRP Report 255's* "Users Guide" and updated

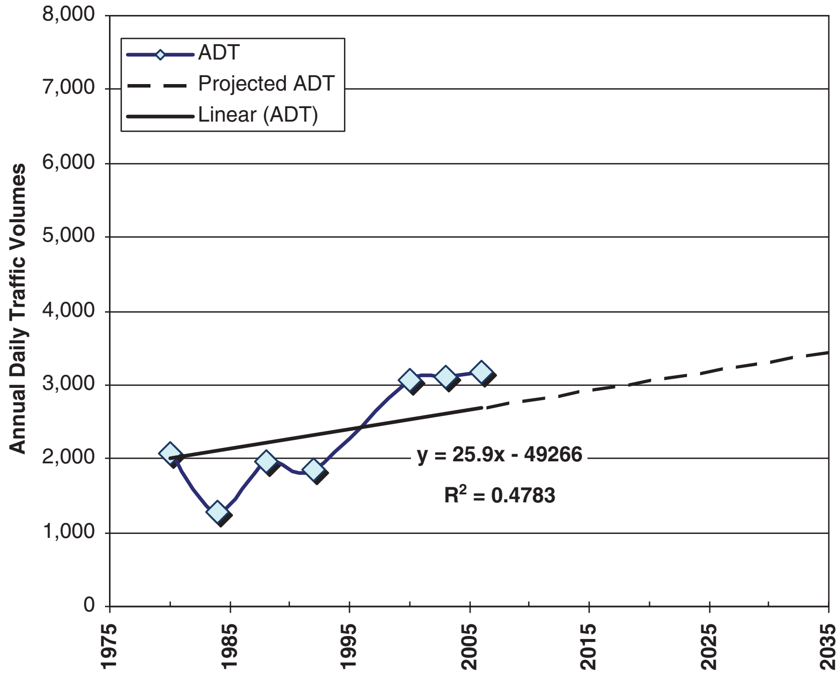


Figure 4-8. Trend line analysis using regression.

in these guidelines as discussed in Chapter 6. An excerpt from the spreadsheet is shown in Figure 4-9.

This method acknowledges that a travel demand model is a tool that produces volumes that, for design purposes, require a comparison and possible reconciliation with existing traffic counts. The method accounts for the over- or under-simulation of the model at any one location when compared to traffic counts in the base year and applies the same correction for the over- or under-simulation to the future year modeled volumes.

Two example forecasts provided by the Ohio DOT are shown in Appendix F-1, one for a simple forecast and the second for a more complex traffic forecast.

4.2.3 Quality Analysis/Quality Review

Forecasting is often an iterative process, involving assessment, corrections, or adjustments and retesting. Steps in this review range from data analysis to forecasting accuracy.

4.2.3.1 Data Analysis

The data analysis is mostly performed with spreadsheets and with travel demand models. The traffic forecaster serves as a quality control and quality assurance (QC/QA) source for the traffic monitoring program since the traffic monitoring program rarely has the opportunity to look at the data in as much depth as the forecaster.

4.2.3.2 Forecast Review and Refinement

A traffic forecast is just one piece of a massive traffic puzzle. It is incumbent upon the forecaster to understand what has been done in the past and to make use of it as a validation of the new forecasting work. Of course, there are some cases where the magnitude of a development or the examination of new facilities renders previous work irrelevant. However, in most cases, the previous analysis is important. There are some cases, for instance, where there is a record of decision on

USER INPUT
OPTIONAL INPUT
FINAL REFINED FORECAST

	COL 1	COL 2	COL 3	COL 3.5	COL 4	COL 5	COL 6	COL 7	COL 7.1	COL 7.2	COL 7.3	COL 7.4
					near base model		2008					
	Road/Link	Min Diff	Max Rat	Use SL	count year	count data	Ab	$Ab^{interpolate}$	R	D	MR	SLR
(east leg)	SR 18 (State St)	0.5	2	Enable	2011	2215	1687	2243	0.99	-28	0.41	0.99
(north leg)	Mitchell Rd	0.5	2	Enable	2011	520	416	490	1.06	30	1.73	0.99
(west leg)	SR 18 (Deshler Rd)	0.5	2	Enable	2011	2011	1861	2479	0.81	-468	0.00	0.99
(south leg)	Mitchell Rd	0.5	2	Enable	2011	592	157	184	3.22	408	6.34	0.99

Figure 4-9. Screenline spreadsheet.

a major investment study, where it is crucial for the forecast to be consistent with previous work.

Traffic forecasting results should be logical when compared with other studies and traffic forecasting work in the past, especially the recent past. It is important for the traffic forecaster to gather related forecasts and sift through the information and become familiar with it. Advanced forecasting agencies maintain databases that track traffic forecasts. Forecasts that are especially important to obtain include corridor study forecasts, long-range planning study forecasts, and thoroughfare study forecasts. The forecasts should be examined for scope, study area compatibility, forecast year, growth rates, assumptions used, quality of the tools used to develop the forecasts, and land use changes.

Resources available to the traffic forecaster can include the following:

- MPO planning studies;
- Traffic impact studies;
- Long-range transportation plans; and
- Planning studies done by other agencies, including state DOTs.

Common sense and the ability to intuitively grasp what the "right" answer should be are very useful. Knowledge of the area being forecasted, the highway corridor as well as possible development, can serve as a check on the final product. It is also always useful to keep in mind how and where the forecasts will be used to validate that the proper amount of effort has been applied to the forecast.

4.2.4 Final Product of Forecast Development

The final product will typically consist of a memo, turning movement diagrams, and summary documentation for the file.

It is important for complex traffic forecasts to be well organized, with assumptions and data sources well documented for other users to understand. Examples of a simple and complex traffic forecast are given in Appendix F. This section describes typical final product sections and their contents in more detail.

4.2.4.1 Final Product Documentation

Traffic forecasts are critical to transportation planning and design efforts, yet their importance is often overlooked or taken for granted. Traffic forecasts form the foundation for critical decisions regarding project need, design concept, and scope. Thus, good project decisions begin with good traffic forecasts.

Proper documentation of traffic forecasts—i.e., providing factual or substantial support—is essential. Documentation should provide a clear explanation of the reason for the forecast, assumptions that were made, explanation of the tools and methods that were used, and the results.

Common elements contained in a traffic forecast report include the following:

- Table of contents,
- Request for forecast,
- Project description/purpose of forecast,
- Data types and sources,
- Forecasting parameters,
- Discussion of tools and methods,
- Results,
- Supporting data/information, and
- Glossary.

These elements are explained in further detail in the following section.

4.2.4.2 Table of Contents

The table of contents is an important, yet sometimes overlooked element in traffic forecast reports. It is the "road map" to the information that follows. As the report typically includes tables, graphs, and figures, a list of tables and list of figures should be included, as well. Some technical documents refer to all tables and graphics as "exhibits," and these are indexed in a list of exhibits.

4.2.4.3 Request for Forecast

Development of a traffic forecast frequently begins with a request for the forecast by a sponsoring agency, often a different part of the organization or an outside group. Typically this request is documented through the preparation of a forecast request form, regardless of whether the forecast is performed in house or is outsourced. Forecast request forms contain supporting information such as the project name, identifier, and description; need for the project; type of forecast(s) desired; and forecast years (opening year, design year, and interim year[s]), if needed. Frequently, the forecast request form is included in the documentation.

4.2.4.4 Project Description/Purpose of Forecast

Documentation should include a description of the project and the specific purpose for which the forecasts have been developed. To the extent possible, the project description should contain the design concept and scope. For example:

> The project involves the widening of Grand Boulevard from First Avenue to Fourteenth Avenue, a distance of 1.4 miles. The project will widen Grand Boulevard from its current three-lane section to a four-lane, median-divided cross-section. Design hourly

traffic volumes, including intersection turning movements, were developed for the purpose of establishing geometric design criteria, determining intersection approach configurations, and pavement design.

The project description also should reference a project location map and a conceptual diagram of the improvement, if applicable. An example is provided in Figure 4-10.

4.2.4.5 Data Types and Sources

Traffic forecasts rely heavily on current, accurate data. It is important to document data types and sources, as the data will be used to conduct analyses upon which multimillion dollar decisions will be made. Documentation should include an Internet URL (uniform resource locator) if one exists. For electronic documents, the URL should be presented as a hyperlink that goes directly to the data. Where data are summarized within a graph or table in the forecast document, the source of the data should be included as part of the graphic.

Common data used in the development of traffic forecasts include traffic counts (24-hour directional counts, peak-hour intersection turning movement counts, and vehicle classification counts), population and employment summaries and projections, descriptions of roadway characteristics, land use and development plans, and planned/programmed projects that will influence future travel patterns and demand.

4.2.4.6 Forecasting Parameters

Parameters used in development of traffic forecasts must be presented and discussed. The most commonly used forecasting parameters are:

- Design hour factor (K);
- Directional distribution (D);
- Peak-hour factor (PHF), when used for capacity calculations or when a peak 15-minute flow rate is needed;
- Percent trucks (T), both for 24-hour and peak-hour traffic volumes;
- Forecast year(s)—opening year, design year, and interim year (if required); and
- Growth rates.

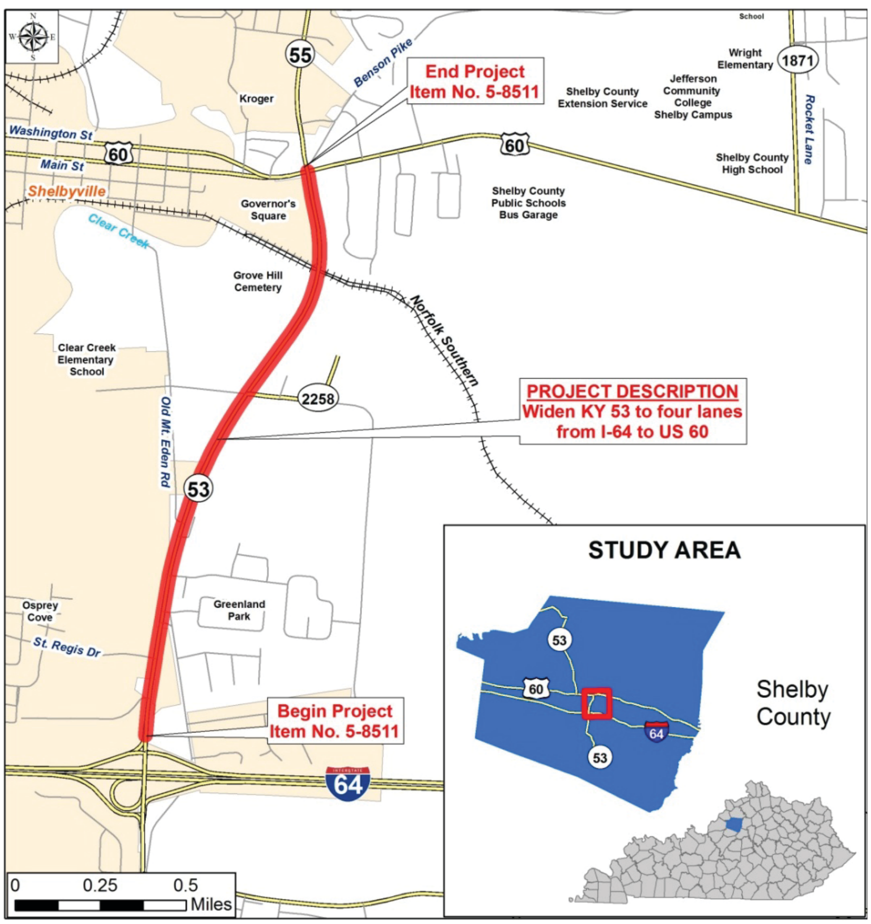


Figure 4-10. Example study area map.

It is important to explain the development and basis for selection of these parameters, as they can have a significant impact on the forecasts and resulting decisions. Where necessary, supporting data should be included. For example, historic traffic volumes and trends may be used to support the selection of a particular growth rate, or the analysis of 24-hour directional traffic counts may be used to justify the selection of specific K and D factors to be used.

In some cases, actual data to support the development of forecasting parameters may not be available, which may necessitate the use of "default" values or parameters, where a default value is defined as an average or representative value used in the absence of actual data. A number of states have developed average or default values based on statewide data, and these values typically are aggregated according to characteristics such as functional classification and area type (urban, suburban, developing, and rural). It is always preferable to use actual, specific data in the development of forecasting parameters, but default parameters may be acceptable when the data do not exist. Along with the development of the forecasting parameters, documentation should contain the explanation and justification of default values where they are used.

4.2.4.7 Discussion of Tools and Methods

A key component of a traffic forecast report is the discussion of tools and methods used. The discussion should entail the justification for specific tools and methods, their application in developing the forecasts, and their limitations.

The writer of the report must determine the appropriate level of detail to include regarding the tools and methods. Too little detail may result in unanswered questions for readers or imply a "black box" approach. Too much detail may confuse the reader or bury the important information within a myriad of details.

The writer must decide which information is primary to the discussion and which is supplemental and therefore could be included in an appendix.

4.2.4.8 Results

Within the main body of the report, the results section should present all of the pertinent information that will be used for the conduct of subsequent analyses, development of design parameters, and decision-making.

While the other sections in the main body of the report serve to support the development of the forecasts and other information to be used, the results section should be prepared as though it were going to stand on its own; that is, it should not require the reader to refer to other sections to obtain the primary forecast information.

The results section should provide maps, tables, graphs, and diagrams to accompany the text. The writing should be clear and concise, yet contain adequate detail to support forecasts as they are presented. It should be clear and simple, but not elementary. An example graphic containing traffic volume and ESAL forecasts is provided in Figure 4-11.

4.2.4.9 Supporting Data/Information

While all information and data necessary to support the development of traffic forecasts should be included in the documentation, only the information considered to be primary should be located in the main body of the report. The secondary or supporting information should be located in an appendix. For example, if a forecast is to include ESAL calculations, the forecasted ESAL values should be included in the results section, preferably as part of a map or diagram, while the individual ESAL worksheets should be located in an appendix.

Some agencies require certification or authorization of traffic forecasts before they can be used. Often this is documented by a certification letter, which acknowledges that the agency is in agreement with the tools and methods used, the assumptions incorporated, and the resulting forecasts. The certification or authorization should be included as part of the supplemental information.

4.2.4.10 Glossary

A glossary is helpful for providing an explanation of the terminology used in a traffic forecast report, especially for decision-makers and others who may not be entirely familiar with the forecasting process. The glossary should include commonly used abbreviations (such as AADT) in addition to definitions of terms.

4.2.5 Communication

A traffic forecast may be well documented, yet poorly written. Effective communication is critical to having a good traffic forecast. A good traffic forecast report should do the following:

- Be clear and concise;
- Have an appropriate level of detail to support the forecast;
- Make effective use of maps, tables, and other graphics; and
- Be well organized and easy to follow, with the primary information contained in the main body of the document and supplemental information located in the appendices.

The report should be organized according to the main elements (see Section 4.2.4.1), with headings and subheadings to effectively delineate the sections.

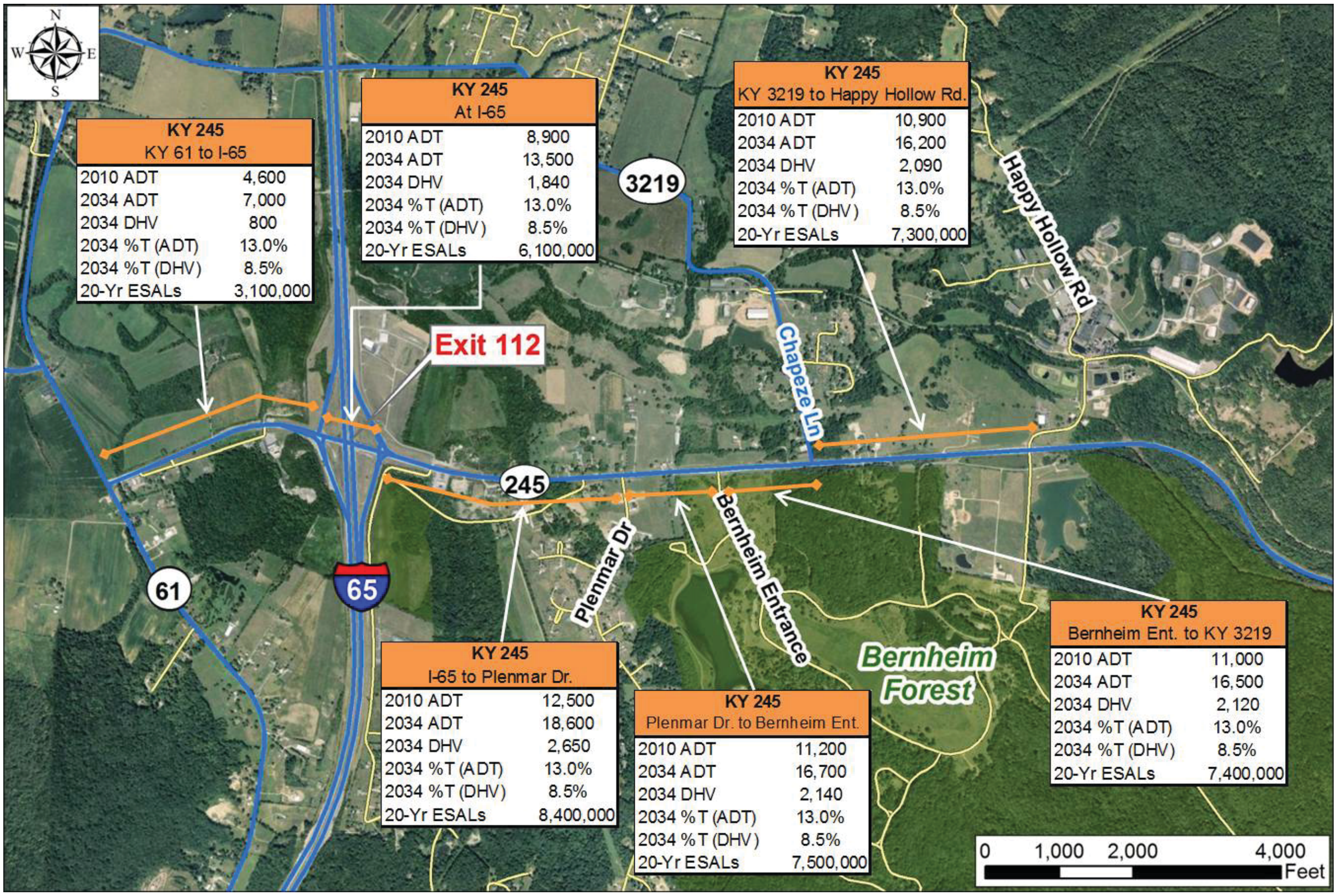


Figure 4-11. Example traffic forecast graphic.

Tables and figures (charts, maps, and diagrams) are a very important part of a traffic forecast report. They should be used to

- Summarize the results of technical analyses,
- Provide a spatial reference to specific information,
- Convey information that cannot be conveyed easily in text, and
- Reinforce important details contained in the text.

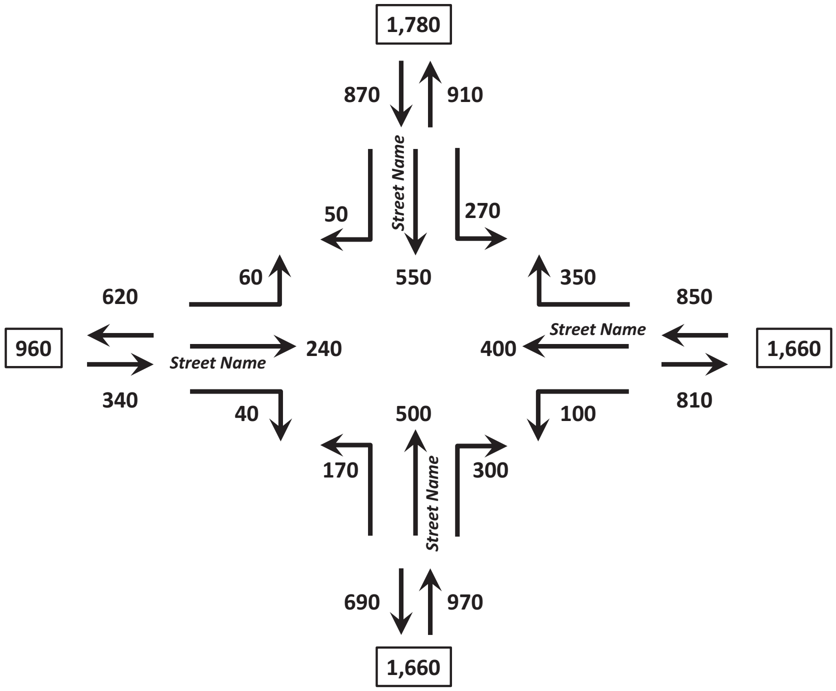
Maps should include a north arrow, legend, and scale. Where multiple data items are displayed (for example, directional segment volumes and intersection turning movements), the forecaster should exercise caution and avoid trying to present too much information on a single map so that it does not become too "busy."

Intersection turning movement summaries often are conveyed in both tabular and graphic form. The tabular format is clear, effective, and useful when multiple time periods are shown, but some readers become confused with cardinal directions. Schematic turning movement diagrams are very effective, but the temptation to include too much detail should be avoided.

Street names and turning volumes should be clearly labeled. An example of forecasted turning movements presented in both tabular and schematic format is shown in Figure 4-12.

Tables and figures should include supporting captions, which should be referenced in the text. Figures should be clearly labeled and should include enough detail to convey the message effectively, but not so much detail that the reader becomes distracted or confused. Both figures and tables should be able to stand independently; that is, they should contain a sufficient level of detail and information so that the reader does not have to refer to the text for further understanding.

Performance measures and MOEs, whether presented in graphic form, tabular form, or both, should be clear, concise, and simple. In a tabular format, row and column headings should include the units of performance measurement. As numerical values, performance measures should be computed to a *practical* number of significant digits (for example, while it may be significant to display speed values to two decimal



Approach	Turning Volume			
	Left	Through	Right	Total
Northbound	170	500	300	970
Southbound	270	550	50	870
Eastbound	60	240	40	340
Westbound	100	400	350	850
Total				**3,030**

Figure 4-12. Example turning movement forecast graphic.

places, it would not be practical). Graphically, caution should be exercised when multiple performance measures are presented on the same diagram. Creation of thematic maps using tools such as GIS is an effective way of presenting multiple performance measures in a single graphic. Maps and related graphics should include a legend for clarification.

4.3 Role of Judgment

Forecasts are made within a decision-making context and are useful only to the extent that they aid decision-making. There are many factors in the decision-making process not related to model outputs that can influence the application of forecasting methodologies and the interpretation of analytical outputs. Some of these factors are the following:

- Uncertainty due to errors in data;
- Uncertainty with respect to the range of conditions on the network due to normal demand and capacity variations on the roadway network;
- Uncertainty due to typical errors in models and the inability to remove all those errors through refinement;
- The appropriate use of models when there may be a lack of sensitivity (or incorrect sensitivity) to a critical issue in the decision;
- The requirement that the analyst (planner, modeler, or engineer) use experience, professional judgment, and common sense to test the information that is being given;
- Type I and Type II errors and how they might affect the decision-making process when interpreting forecasts (see Section 4.3.3); and
- The ability of the model and other analytical processes to create performance indicators that align well with the goals and objectives of the project.

Introducing judgment into a forecast requires that the analyst have both sufficient professional experience and high personal integrity.

4.3.1 The Inevitability of Model Errors

There are always errors in the data and theory that underlie a forecast from a travel model. Refinement can reduce, but not eliminate, errors. This means that the accuracy and validity of a model's outputs should not be overstated. Professional experience and integrity should guide presentations of model outputs to decision-makers, so that errors do not unduly affect decisions.

4.3.2 The Decision-Making Process

In making the decision of whether to pursue a particular course of action, much depends upon how the forecasting process is perceived by decision-makers. There are really two types of decision-makers, technical and political, and their needs differ.

Forecasters should understand the decision-making framework within which they operate. They should provide the information that executives will need to apply their own judgment and intelligence in interpreting and using a forecast to reach a decision.

4.3.3 Types of Error

Traffic forecasts are developed to help make decisions; erroneous forecasts can produce the wrong decisions. From the field of statistical decision theory there are two types of errors. A Type I error is a false positive. It occurs when a forecast supports a course of action, the action is taken, and it is later found that there was no need. An example would be a repaving project for a two-lane road along with the possibility of adding another lane in each direction. If the decision was made (on the basis of a forecast) to add those lanes and if the increase in traffic upon which the need for the lane addition is predicated fails to materialize, then a Type I error has been made. Millions of dollars have been spent on lanes that were not needed. A Type II error occurs when the forecast supports no action, a decision is made to do nothing, and it is discovered that there was indeed a need to do something, after all. In the case of the repaving project, a Type II error would soon require another repaving as part of the eventual widening, in which case much of the value of the original pavement is lost.

For any given project, if the consequences of a Type I error are much larger than the consequences of a Type II error, then the decision-maker should demand ample justification that the action be taken. For the repaving project, the decision-maker might want tighter bounds on the range of confidence in the forecast or the decision-maker might want a higher quality threshold of forecasted traffic volumes before being convinced that the extra lanes should be built.

4.3.4 Lack of Sensitivity or Incorrect Sensitivity

Travel forecasting models contain a limited set of decision variables, and travel forecasting models are most often calibrated using cross-sectional data. These two practices, individually or together, can lead to no sensitivity or incorrect sensitivity to a critical decision variable. An example of lack of sensitivity might be a travel model that omits carpools as a possible mode. This omission would make it difficult to test certain policies to encourage ride sharing. An example of incorrect sensitivity would be the use of a volume delay function (VDF), such as a Bureau of Public Roads (BPR) curve, which does not incorporate the effects of conflicting and opposing traffic. It is entirely possible to calibrate such a model to cross-sectional data and obtain seemingly reasonable validation statistics, but the delay effects of non-uniform increases in traffic volumes could be incorrect. Model deficiencies such as these can often be detected through sensitivity testing. However, the analyst needs to be aware of the possibility of poor sensitivity through knowledge of fundamental principles. If the decision could be affected by model sensitivity issues, then there is a need for the analyst to offer additional calculations or personal judgment as to the true implications of the model outputs.

A related issue is the possibility of implausible model parameters that can distort the forecast. Implausible parameters may be a consequence of a flaw in the calibration data, insufficient calibration data, or an unintended interaction between parameters during the statistical estimation process. In many cases, a reasonable range for a parameter may be known from earlier local forecasts or forecasts from other places. In such cases, the analyst needs to use professional judgment to ensure that a suspect parameter is not unduly influencing the desired outputs.

Corrective measures may range from re-estimating the parameter to "asserting" a parameter value that is more plausible according to the consensus of the profession.

4.3.5 Common Sense Validation

Validation most often happens entirely within a base year data set, and methods to determine whether the model is functioning well over time (such as backcasting) are not often employed. In addition, calibration data can be faulty, and calibrated parameters could be statistically weak or affected by multicollinearity.

Thus, there is always a need to employ professional experience when interpreting the outputs from a travel forecasting model, even when best practices have been applied throughout the model's creation. Forecasts must be intuitively correct. Judgment based primarily on intuition, experience, and expertise should contribute to the decision. The appropriate actions when a model fails the common sense test can vary from rebuilding the model from scratch to providing a professional interpretation of the results.

4.3.6 Wrong Performance Indicators

Sometimes, it is possible that performance indicators chosen by decision-makers are not completely compatible with forecasting methodology. For example, a decision-maker might want to know the fraction of lane miles worse than level of service (LOS) C, as defined in the *Highway Capacity Manual* (HCM). However, if the travel forecasting model does not compute the required service measure according to the HCM, then the indicator will be inaccurate, at best. Therefore, the analyst must find an imperfect, but truthful, way to calculate the indicator through post-processing and, perhaps, professional interpretation.

4.3.7 Personal Integrity

It is critical that the analyst maintain personal integrity. Integrity can be maintained by working closely with management and colleagues to provide a truthful forecast, including a frank discussion of the forecast's limitations. Providing transparency in methods, computations, and results is essential. In extreme cases, it may be necessary to request the assistance of an outside consultant or request a peer review of the model.

The analyst should document the key assumptions that underlie a forecast and conduct validation tests, sensitivity tests, and scenario tests—making sure that the results of those tests are available to anyone who wants to know more about potential errors in the forecasts.

4.4 Forecast Accuracy

4.4.1 Need for Consideration of Forecast Accuracy

Forecasts are not known with absolute certainty and any errors in a forecast can affect the design or the go-or-no-go decision for a transportation project. Forecast accuracy is the ability of the forecast to match actual future conditions. Experience with a forecasting methodology in past projects may give an indication of how well the methodology could work for new projects.

A forecast must have inputs; often these inputs come from a travel forecasting model, a time-series model, another formal methodology, or prior experience. These inputs may be refined with highly localized data or combined in a variety of ways with the objective of improving accuracy.

4.4.2 Travel Forecasting Model Error

4.4.2.1 Model Error

Model error is the difference between the model's outputs and existing and future conditions. The raw outputs of a model may or may not constitute a forecast. The true amount of error in a model is unknowable at the time of the model run, so planners must estimate the amount of error through surrogates, such as the difference between the base-case results and the known base-case ground data. There are many sources of error in a typical regional model. These sources can be organized into several groups. Errors can stem from the following:

- Differences between the actual future and assumptions made about the future within the model;
- Inadequate theory;
- Imprecise application of theory;
- Inadequate model specification;
- Lack of spatial or temporal resolution;
- Input data;
- Calibration data; and
- Computation, such as lack of convergence of iterative processes.

There are two types of error to consider in the context of understanding the quality of a travel demand model: systematic and random. Many, but not all, systematic errors can be removed through careful model calibration. Random errors, on the other hand, are unavoidable. It is possible to reduce the magnitude of random errors through improvements to the model or by aggregating the results of model.

Model error can be real or apparent. Apparent errors occur because of faulty comparison data. Apparent errors should be removed or mitigated by improving the comparison data set, not by adjusting the model. Outliers in comparison data can be detected through the use of statistical analysis or visual inspection.

The presence of outliers in comparison data does not necessarily signify an apparent error, but an outlier's validity should be confirmed or it should be removed.

Reducing errors to negligible amounts would be impractically expensive, so planners must make trade-offs between model development cost (and time) and the amount of error. A model can still be validated if it contains appreciable error, provided the amount of error is sufficiently small for the forecast requirements (*9*).

There have been many documented instances of actual outcomes substantially disagreeing with the forecasts from a model (*79*). These situations can be embarrassing and costly. The recognition that a better understanding of model error is necessary has been heightened by the central role of traffic forecasts in developing public-private partnerships for toll roads or seeking investors for private toll roads (*80*).

4.4.2.2 Measuring Model Error

The *Travel Model Validation and Reasonableness Checking Manual* (*9*) describes many different tests to determine whether or not a model is performing sufficiently well. However, planners and engineers involved in project-level travel forecasts tend to focus on the quality of traffic volumes and speeds. This focus can be justified because (1) traffic volumes and speeds are among the very last items to be computed by a model and all model errors are, to some extent, present in these outputs, and (2) traffic volumes and speeds are singularly important for project-level decision-making. Turning movements are also outputs of a model that can impact project-level decision-making, but turning movements are not traditionally subject to validation (the second edition of the *Travel Model Validation and Reasonableness Checking Manual* does not even mention turning movements). Traffic volumes may be compared for individual facilities (e.g., road segments), across a wide area, or at screenlines. Obtaining good ground speeds is a more involved process than obtaining good traffic counts, so speed comparisons, where done, usually cover many facilities along a corridor, taken together.

The amount of error in a base-case forecasted traffic volume can be obtained through statistical measures or by plotting the difference between traffic volumes and ground counts. Statistical measures include mean absolute deviation, root-mean-square error (RMSE), coefficient of determination, and the GEH statistic (*81*). The GEH statistic (see Subsection 5.4.1 for a definition) is sometimes used in the calibration of traffic microsimulation models, but the RMSE is more commonly used for travel models. An RMSE has the advantage of a long history of experience, and it has properties that are well understood. The RMSE for forecasted traffic volumes is given by this formula:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(V_i - C_i)^2}$$

where V_i is a volume forecast for a road segment, C_i is the traffic count for the same segment, and n is the number of segments (*9*).

The RMSE is often calculated by facility type or functional classification. Counts and volumes should be for the same time period, preferably 1 hour in duration for highway projects.

A well-calibrated travel model should have a mean error (ME) that is very close to zero for the base case. That is (if there are sufficient counts):

$$ME = \frac{1}{n}\sum_{i=1}^{n} V_i - C_i \approx 0$$

Elementary error theory suggests that the ME is related to the RMSE through the "square root law," provided that the error in each segment is independent of all other segments. As a practical matter, a large ME indicates the need for additional calibration before proceeding with the forecast.

Sometimes, it is helpful to compare the size of the error to the amount of observed traffic. Elementary error theory provides a statistic, called the signal-to-noise ratio (SNR), for making this comparison. The SNR is the mean count divided by the RMSE. Large SNRs are better than small SNRs. The reciprocal of an SNR, when multiplied by 100, is often reported as the "percent RMS error" (*9*) in travel model documentation.

A typical travel model produces RMSEs that decrease with increasing traffic volumes (or counts). So it is more informative to calculate SNRs (or percent RMSE) within several count bands.

Plots of error, segment by segment, can be informative. The most typical plots include absolute errors versus counts and volumes versus counts (X-Y plot).

4.4.2.3 Limits for Model Error—Conventional Guidance

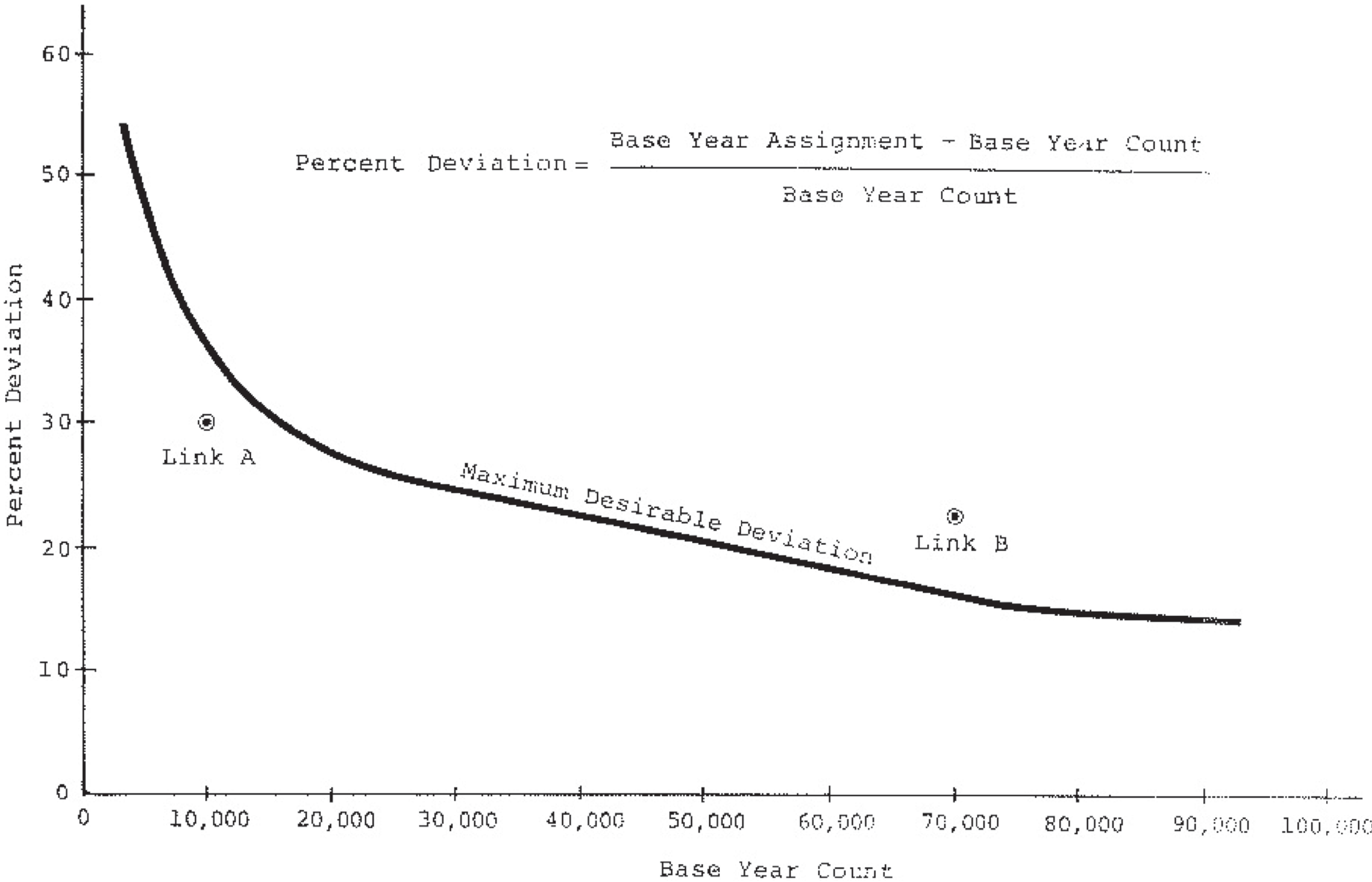
There are both upper and lower limits to model error. *NCHRP Report 255* provided a graph of maximum desirable percent error, where the count is an ADT, shown as Figure 4-13 (*1*). The underlying philosophy of this graph is that errors falling below the curve are unlikely to affect a decision as to the number of lanes on a highway. This curve is still relevant for many projects involving road widening and road diets.

The FHWA report *Calibration and Adjustment of System Planning Models* (*82*) superimposed an additional curve onto this same graph, showing the amount of error in a traffic count (see Figure 4-14). This report made the case that model errors should never be better, overall, than the errors in the counts used for comparison. A perfect model should still have apparent error, and the amount of this apparent error should be such that about one-third of the points fall above the count-error curve and about two-thirds of the points fall below the count-error curve. Models performing better than this are likely to be matching the error in the traffic counting rather than the true levels of traffic.

The second edition of the *Travel Model Validation and Reasonableness Checking Manual* did not include specific standards for model error. That manual suggested that standards vary considerably depending upon how model outputs might influence a decision.

4.4.2.4 Limits for Model Error—Expectations

In a summary of 46 responses by experts to a post on the TMIP-L (Travel Model Improvement Program email listserv), Bain (*83*) reported forecast accuracy expectations as a function of the time horizon of the forecast for major highways (see Table 4-2). These responses were unrelated to the forecasted traffic volume, but indicate how planners' level of uncertainty increases as the forecast becomes more distant in time.



Source: *NCHRP Report 255* (*1*), Figure A-3, p.41.

Figure 4-13. Maximum desirable error.

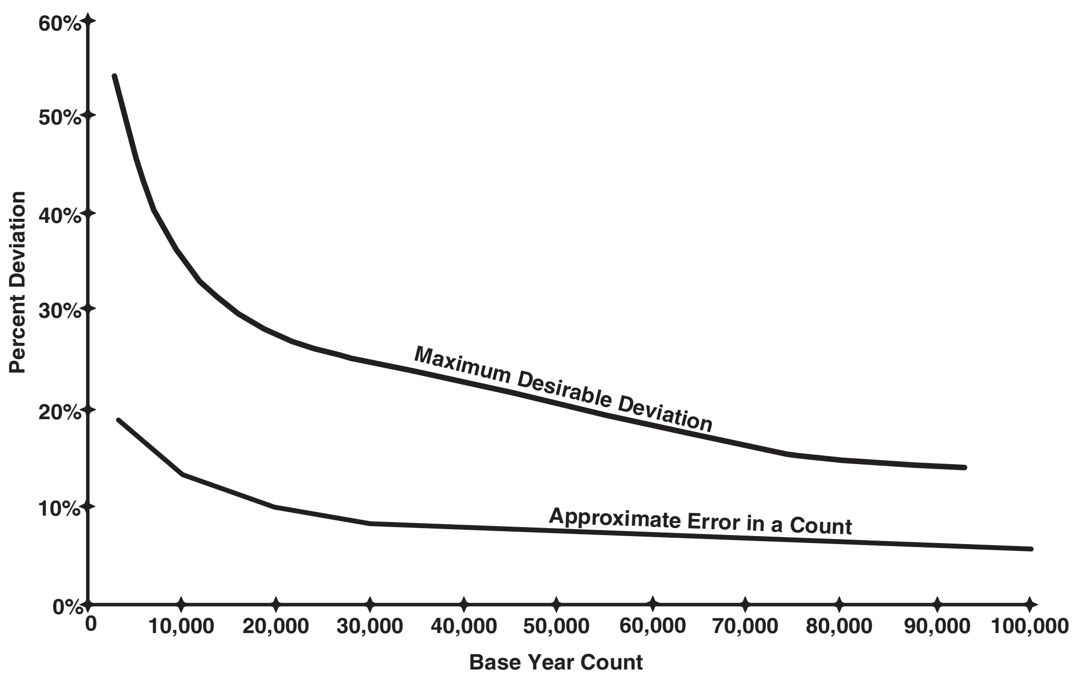


Figure 4-14. Maximum desirable error for link volumes.

Table 4-2. Model accuracy expectations as a function of time horizon.

Forecast Horizon	Existing Road	New Road
Next Day	±7.5%	NA
1 Year	±12.5%	±17.5%
5 Years	±20.0%	±27.5%
20 Years	±42.5%	± 47.5%

4.4.2.5 Limits for Model Error—Volume Accuracy Standards and Best Practical Experience for Regional Models

Regional models may or may not produce traffic forecasts with sufficient accuracy for project purposes. MPOs often publish statistics as to how well they fit ground data. Results vary considerably. Several organizations have contributed statistics of forecast error to the TMIP-L in reply to different posts since 2001. In addition, Granato (*84*) provided comparison statistics for 11 MPO models from the 1990s. Perhaps the most definitive guidance is given by the low end of these validation statistics, which should be considered the best practical accuracy with the current set of models. Even these accuracies may be insufficient for some project-level forecasts.

Table 4-3 gives the current validation standards for MPO models in Ohio within the jurisdiction of the Ohio DOT and statistics for one of their MPO models, the Wood-Washington-Wirt Interstate Planning Commission model, which includes the metropolitan area of Parkersburg, West Virginia. Note that the "Parkersburg" model was selected because it uses dynamic traffic assignment (DTA) and has detailed specification of traffic controls according to the HCM, thus going substantially beyond the norm for MPO models. Full-day volumes from Parkersburg are essentially found by summing the volumes over 24 separate 1-hour time slices. Other MPOs along the West Virginia/Ohio border using the same techniques showed results similar to those of Parkersburg. The Parkersburg validation statistics are only slightly higher than the lower curve from *Calibration and Adjustment of System Planning Models* (*82*) for counts greater than 5,000 ADT. The Ohio standard is quite similar to the Maximum Desirable Deviation from *NCHRP Report 255* (*1*).

Elementary error theory suggests that the percent error of a link volume should decline as the square root of the volume. To illustrate this point, Table 4-3 shows the percent RMSE times the square root of the volume for Parkersburg for each volume range. The results show that elementary error theory is doing fairly well in explaining the amount of error in Parkersburg's volume estimates. So, the percent RMSE for Parkersburg, representing best practical experience, can be explained by this equation:

$$\%RMSE = \frac{e}{\sqrt{V}}$$

where V is volume and *e* is about 2,150 for Parkersburg.

Standards may differ from state to state. As a comparison to the Ohio standards, Table 4-4 shows both acceptable and preferable standards in Florida.

The Florida preferable standard also follows elementary error theory fairly well (where *e* is approximately equal to 2,750).

Most travel forecasting models are very poor when forecasting traffic on low-volume roads. However, errors on low-volume roads (e.g., 2,500 vehicles per day or lower) are rarely important to a project decision. Unless special circumstances

Table 4-3. Minimum standards and best practical experience from models managed by Ohio DOT, percent RMSE.

Volume Range, ADT	Ohio Minimum Standard	Best Practical Experience (Parkersburg, WV)	Percent RMSE Multiplied by the Square Root of Volume, *e*, (Parkersburg, WV)
0–499	200%	166%	2622
500–1499	100%	80%	2529
1500–2499	62%	48%	2146
2500–3499	54%	47%	2574
3500–4499	48%	32%	2024
4500–5499	45%	27%	1909
5500–6999	42%	25%	1976
7000–8499	39%	23%	2025
8500–9999	36%	18%	1731
10000–12499	34%	19%	2015
12500–14999	31%	16%	1876
15000–17499	30%	14%	3603
17500–19999	28%	11%	1506
20000–24999	26%	10%	1500

Table 4-4. Minimum standards for traffic volumes in Florida, percent RMSE.

Volume Range, ADT	Florida Acceptable Standard	Florida Preferable Standard
5,000	100%	45%
5,000–9,999	45%	35%
10,000–14,999	35%	27%
15,000–19,999	30%	25%
20,000–29,999	27%	15%
30,000–49,999	25%	15%
50,000–59,999	20%	10%
60,000+	19%	10%

Source: *FSUTMS-Cube Framework Phase II: Model Calibration and Validation Standards* (85).

dictate otherwise, it is reasonable to ignore road segments with low counts during validation.

Standards on full-day, bidirectional volumes may also be applied to directional volumes over a full day.

4.4.2.6 Limits for Model Error—Effect of Aggregation

Aggregation tends to reduce relative random error. Aggregation can occur within model steps, particularly during multipath, equilibrium traffic assignments, but it also can occur during post-processing.

Many system-level MOEs involve aggregation. MOEs contain both systematic and random errors. The amount of random error can be predicted with the "square root law." Relative error declines roughly inversely with the square root of the number of links included in the MOE. Many system-level MOEs are functions of link volume, link speed, and link length, such as

$$MOE = \sum_{i=1}^{n} V_i f(S_i(V_i), L_i)_i$$

where n is the number of links in the system, V is traffic volume, *f()* is a function of speed (S) and link length (L), with speed being a function of volume and many other factors depending upon model specification. Examples include vehicle hours traveled, air pollution emissions, and fuel consumption. The impact of an error in volume is somewhat amplified by the impact of that volume error on speed estimates. This combined impact is greatest when volumes are near capacities (See "The Evaluation of Transportation Model Random Error in Social and Environmental Indices" [*86*] for computational details). Vehicle miles of travel and toll revenue are MOEs that can have lower relative errors due to aggregation, but speed is not part of the computation.

System-level MOEs tend to play a large role in long-range transportation planning, but have a subordinate role in project planning. However, the use of MOEs is encouraged, simply from a perspective of accuracy, in order to avoid big mistakes associated with errors on a few links in the model.

In a review for FDOT, Cambridge Systematics (*85*) compiled validation standards for typical MOEs (shown in Table 4-5). There is little guidance on the use of these MOEs, given that the accuracy of any MOE should vary depending on the number of links that are involved in computing the MOE. Nonetheless, an MOE with an RMSE greater than 5% is not likely to be of much help in project-level decision-making.

4.4.2.7 Limits of Model Error—Speed Accuracy Standards

Observed speeds have been used for model calibration, but (to date) there are no published standards for speed validation.

4.4.2.8 Predicting Model Error

Given the complexities of a typical travel forecasting model, it is impractical to predict the amount of error in a forecast through fundamental principles. Errors in inputs propagate through the various steps of the model, with each step either amplifying or dampening the amount of error. For example, the trip distribution (destination choice) step involves disaggregation and, therefore, is more likely to increase relative error. Traffic assignment involves aggregation and, therefore, is more likely to decrease relative error. Steps introduce their own errors, as well.

A particular input may be so critical to the quality of a forecast that its effect on model error should be separately investigated through sensitivity analysis. For example, fuel prices are difficult to predict, but affect the amount of traffic. The

Table 4-5. Typical validation standards for MOEs.

MOE	Maximum Percent Error
Vehicle Miles Traveled	±5%
Vehicle Hours Traveled	±5%

Source: *FSUTMS-Cube Framework Phase II: Model Calibration and Validation Standards* (*85*) and *Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee* (*87*).

sensitivity between traffic volumes and fuel price might be worth knowing so that confidence limits can be reasonably established for the forecast.

4.4.2.9 Time-Series Model Accuracy

Statistical software packages used for estimation time-series models provide goodness of fit statistics that may be used to judge the accuracy of the model, at least to the extent that the model correctly represents historical patterns.

4.4.3 Traffic Forecasting Error

4.4.3.1 Hourly Volume Accuracy

The amount of error in a directional design hourly volume (DDHV) estimate is critical to decisions related to the number of lanes in a project.

On the one hand, hourly volumes and counts are smaller than daily volumes and counts, so hourly volume estimates should inherently contain more relative error, on average. On the other hand, models that are customized for a single hour should do better than daily models that must encompass a variety of conditions throughout the day. Planning agencies only rarely publish statistics on hourly forecast accuracy, so only a little guidance is available in the literature. For example, Ohio (*2*) sets accuracy standards for peak-hour volume estimates from regional models to be the same as its daily accuracy standards, but applied to the proportion of volume in that hour. For example, from Table 4-3, the allowable error for an hourly link with a count of 1,100 vehicles per hour (VPH) would be 34% when 10% of all traffic is within that hour—the same as the percent error for a daily count of 11,000 vehicles per day (VPD).

Table 4-6 shows the validation statistics for AM and PM peak hours in the Parkersburg, West Virginia/Ohio model. The data suggest that the hourly percent RMSEs are about the same as the daily RMSEs on the same road.

Table 4-6 lines up well with Table 4-3 if an assumption (maybe a little high) is made that 10% of all traffic occurs in a peak hour. For example, roads with counts of about 800 VPH have nearly the same percent hourly percent RMSE (23%) as roads with daily counts of 8,000 VPD (23%).

Due to the presence of uncorrected systematic errors in a forecast, there is an expectation that an error in an hourly volumes estimate will be related (both in sign and magnitude) to the error in the daily volumes estimate for the same road. That is, if a daily volume exceeds the actual amount of traffic then the hourly volume estimate will also tend to exceed the actual amount of traffic.

For greatest accuracy, hourly volume estimates should come from a procedure or model that is specifically designed for the hour of interest rather than factored from results for longer time periods.

4.4.3.2 Confidence Limits and Accuracy

RMSEs behave similarly to standard deviations. An assumption of a Gaussian (normal) distribution of errors is reasonable when the errors are small. So, if errors can be assumed to be normally distributed, it is possible to place confidence limits on any forecast. For example, the 50% confidence limit is at 0.6745 of one standard deviation (see Table 4-7), and the 95% confidence limit is at 1.9599 of one standard deviation.

The selection of a confidence limit depends upon its use. The 95% confidence limit is often used to reject statistical hypotheses, but this limit could greatly overstate the amount of error in a forecast. A more reasonable confidence limit for

Table 4-6. Best practical experience, hourly from Ohio DOT, percent RMSE.

Volume Range, ADT	AM (Parkersburg, WV)	PM (Parkersburg WV)
0–49	156%	199%
50–149	75%	73%
150–249	61%	65%
250–349	43%	33%
350–449	42%	38%
450–549	28%	31%
550–699	31%	23%
700–849	20%	23%
850–999	24%	23%
1000–1249		15%
1250–1749	--	12%
1750–2499	--	14%
1000–1749	23%	--

Table 4-7. Relation between confidence level and number of standard deviations from the mean (z-value).

Confidence Level	Z-Value
50.00%	0.6745
68.27%	1.0000
90.00%	1.6449
95.45%	1.9600
99.00%	2.5750
99.73%	3.0000

implying the accuracy of a travel forecast in planning documents is 50%, corresponding to the "probable error." A traffic forecast could be given as XXXX ± YYYY, where XXXX is the forecast and YYYY is the probable error, taken to be RMSE multiplied by 0.6745.

However, a 95% confidence limit might be appropriate for decision-making when the cost of a wrong decision is high. For example, a four-lane road may be required when the DDHV is greater than 1,200 vehicles, and a six-lane road may be required when the DDHV is greater than 3,200 vehicles. A DDHV forecast of 2,500 would suggest a need for a four-lane road provided that the error is less than 700 vehicles, either high or low. To be sure of the decision with 95% confidence, then RMSE should be less than 700/1.9599 = 357 or about 14%.

It is possible to formally establish forecast accuracy standards for a project by following this procedure, along the lines of the previous example:

- Identify those forecasted items that are critical to a design decision or to a go-or-no-go decision.
- Determine or assume a probability distribution for error in those forecasted items. A normal probability distribution may be assumed by default if the errors are small.
- Determine the levels of confidence in these items that are necessary to avoid making a mistaken decision. Confidence needs to be greater (e.g., 95% rather than 50%) when a mistake could be costly or irrevocable. Confidence can be less when there are numerous forecasted items that will affect the decision.
- Determine the ranges of each data item associated with a decision. Determine whether the decision can tolerate a large error on the low side or a large error on the high side (one-tailed) or whether the decision is intolerant of an error on both the high and low sides (two-tailed).
- Apply the probability distribution and confidence limits to the decision ranges of the data items to determine the acceptable RMSE of the item.

4.4.3.3 Importance of Scenarios

Scenarios are different futures for the same set of build alternatives. Scenarios can vary the social, political, and economic environments in ways that greatly affect forecasts. The formulation and testing of a variety of scenarios is one way to protect the planner from unknown future events and personal biases that can introduce systematic errors into a forecast.

4.4.3.4 Reasonable Corrective Measures for Improving Forecasting Accuracy

Some corrective measures have already been mentioned for improving upon model accuracy: better calibration, scenario building, and aggregation. The second edition of the *Travel Model Validation and Reasonableness Checking Manual* (*9*) makes numerous straightforward recommendations as to how models may be improved during calibration. Beyond these, there are not any simple ways to correct errors from models. Chapters 6 and 7 of this report describe refinement methods for improving model accuracy when there are reliable ground data near the project. More expensive solutions involve upgrading model data and model steps, as described in the discussion of the travel model ideal in Chapter 3 of this report.

It is important to resist the temptation to make arbitrary empirical adjustments to a model simply to make the base-case errors smaller. Empirical adjustments are not inherently bad, but they need to be justified and well understood with a travel behavior framework. Otherwise, it is possible to undermine the long-term validity of the model as the social/political/economic environment changes over time.

4.5 Traffic Forecasting Rules of Thumb

As in any complex human endeavor, the practitioner needs rules of thumb to help ensure that he/she is within the realm of accepted practice. Traffic forecasting has developed many informal rules over the years. In fact, some agencies have even codified them. These rules of thumb are as follows:

1. Every effort should be made to forecast traffic on the basis of an analysis of the interaction of transportation demand and supply using well-validated travel demand models. Traffic demand forecasts should be based on behavioral/socioeconomic factors, rather than trend line extrapolations of traffic growth whenever possible.
2. Additional area detail (additional zones and links) may be created for project-level forecasts.
3. Adjustments for over/under forecasting should be conducted at the level of the trip table first, before link-level adjustments are made.

4. Link-level adjustments for over/under estimation against base year traffic counts should not exceed 15%.
5. Intersection turning movement forecasts beyond a 5-year time frame are highly susceptible to error and should be avoided.
6. Projected decreases in traffic (negative growth rates) volumes in a study area should be examined carefully and explained fully. Possible causes include economic factors; creation of new, parallel routes; shifts in through traffic; and forecasting procedures based on unusual, unrepresentative traffic conditions.
7. Benefit/cost analysis should be applied to traffic forecasting for investment decision-making whenever possible.
8. Traffic forecasts should be documented in a brief report that includes sufficient information to inform a reader about the purpose of the analysis, the principal finding of the analysis, the rationale or supporting evidence for the finding of the study area's existing conditions, and the approach/methodology used to conduct the analysis.
9. Good traffic forecasting depends on reliable and timely baseline data. At a minimum, hourly traffic counts for automobiles and trucks should be collected at a project site for traffic forecasting.
10. The assumptions, analysis process, and results of a traffic forecasting process should be thoroughly documented and made available for public review.
11. K factor rules of thumb (*77*): K factors generally decrease as AADT increases and as development density increases. Highest K factors generally occur on recreational routes followed by rural, suburban, and urban facilities in descending order.
12. Rounding should be done by AADT levels to avoid implied precision, see Table 4-8.

Table 4-8. Traffic forecast precision.

Traffic Forecast Precision	
Forecast Volume	Round to Nearest
<100	10
100 to 999	50
1,000 to 9,999	100
10,000 to 99,999	500
>99,999	1,000

Source: *Project Traffic Forecasting Handbook: 2012* (*113*).

CHAPTER 5

Working with a Travel Model

5.1 Understanding the Model

5.1.1 Model Component Checklist—Getting Started

In areas where models are available for use in project-level traffic forecasts, the model components should include a checklist of items or steps to be performed or reviewed prior to beginning an analysis. This checklist consists of components from basic, intermediate, and advanced models. The following list presents model components to be reviewed in the decision-making process for using travel models in the development of project-level traffic forecasts for areas with models:

Model Scope

- Modes of travel (highway, transit, non-motorized, and other).
- Trip purposes (home-based-work [HBW], home-based-other [HBO], non-home-based [NHB], freight, external-to-external [E-E], and other trips)
- Analysis time period (daily, peak period, hourly, and other).
- Geography of the study area (statewide, regional, small area, site, and corridor).
- Time horizon (short, interim, and long).

Trip Generation Step (may differ by purpose)

- Automobile availability model.
- Trip production model
  - Cross-classification by household workers, children, size, income, automobiles available, etc.
  - Table look-up.
  - Constant rates.
- Trip attraction model (linear regression by employment, households, school enrollment, and other).
- Balancing (constrain to productions, attractions, or both).
- Specific generations.

Trip Distribution Step (Internal-Internal [I-I], Internal-External [I-E], and External-Internal [E-I])

- Gravity model (single or doubly constrained, friction factors) (generalized cost impedance).

  Destination choice model (logit equation)

- Log-sum.
- Empirical methods.
- E-E trips (survey table expansions, frataring, empirical methods, etc.).
- Time-of-day (TOD) and direction-of-travel step.
- TOD choice model.
- TOD factors (post-distribution, post-mode-choice, and post-assignment).
- Automobile occupancy choice model (part of mode split).
- Automobile occupancy factors (by purpose, time of day, distance, carpool category, etc.).

Mode Choice Step

- Modes including automobile (drive alone, shared ride), transit (local bus, premium service), non-motorized (walk and bike), other.
- Logit equations (simple, nested, and mixed) based on in-vehicle time, out-of-vehicle time, walk time, wait time, transfer wait time, cost (automobile operating, parking, transit), etc.
- Table of mode split factors.

Highway Assignment Step

- Assignment type (static, equilibrium, multipath, etc.).
- Assignment purposes (single or multi-class)—automobile, single-occupancy vehicle (SOV), high-occupancy vehicle (HOV), truck, etc.

- Convergence criteria (feedback and assignment).
- Feedback of congested travel time to trip distribution.
- Delay function (volume delay function [VDF], *Highway Capacity Manual* [HCM]).
- Turn penalties.
- Exclusion sets.

Transit Assignment Step

- Assignment type (all or nothing, pathfinder, equilibrium, etc.).
- Transit skims.
- Route system (routes and stops).

Other Steps

- Freight model (truck-based, commodity-based, table, etc.).
- Toll model.

Advanced Methods

- Dynamic traffic assignment (DTA).
- Hybrid with traffic microsimulation.
- Land use, activity allocation.
- Tour-based demands.
- Activity-based demands.
- Peak spreading.
- Reliability.

An example of a model checklist from the Virginia Department of Transportation (DOT) is shown in Appendix H (*89*).

5.1.2 Model Data

There is an extensive checklist of data that drive regional travel models. The main data include zonal data, network data, calibration data, and validation data.

Zonal data are the following:

- Number of households (by persons, workers, students, income, automobile availability, etc.),
- Number of employees at workplace by the North American Industrial Classification System (NAICS),
- Land area and area type,
- Population density,
- Average income,
- Average automobile ownership, and
- Group quarters.

Network data are the following:

- Functional classification,
- Posted speed/free flow speed,
- Distance,
- Capacity or saturation flow rate,
- Intersection control (stop sign, roundabout, signal, etc.),
- Intersection approach geometry (left, through, right, shared lanes),
- Heavy vehicle passenger car equivalents (PCEs) and percent heavy vehicles,
- Tolls and other monetary charges,
- Turn restrictions and penalties, and
- Vehicle class restrictions and penalties.

Calibration data are the following:

- Household-level trip data,
- Household characteristics data,
- Trip rates by purpose (attractions and productions),
- Average trip length by purpose,
- Number of trips by trip length,
- E-E origin-destination (OD) table by survey, and
- Automobile occupancy.

Validation data are the following:

- Traffic counts (historical counts, classification counts, TOD counts),
- Turning movement counts,
- Ridership counts (boardings and loadings), and
- Speeds and/or link travel times.

5.2 Project-Level Forecast Validation

Project-level travel forecasts, to the extent that they follow a conventional travel model, should be validated following the guidelines of the *Travel Model Validation and Reasonableness Checking Manual, Second Edition* from FHWA (*9*). Similar guidelines are provided in *NCHRP Report 716* (*6*). This level of validation is necessary, but not sufficient, for project-level forecasts. Project-level forecasts often require better accuracy than can be obtained from a travel model alone.

5.2.1 The Half-Lane Rule and Validation Standards

NCHRP Report 255 introduced the maximum desirable deviation curve as a very basic standard for accuracy (*1*). The maximum desirable deviation curve was developed principally for sizing of roads and gives an approximate amount of daily traffic in one-half-lane, with some broad assumptions about the design volume of roads of different functional classes. The curve is still applicable to many projects as a first step in validation. It is important to note that the curve does not make reference to root-mean-square error (RMSE) or other goodness of fit statistics. Each volume estimate must be interpreted separately.

The principle of a half-lane of tolerable error can be extended to situations beyond sizing roads. It can be used, with modification, for freeway interchanges and at-grade intersections. The principle applies less directly to such situations as traffic flow improvements, site impact studies, work zones, and access management.

The rule can be more generally restated as *tolerable error in a forecast should be less than one-half of the difference between thresholds in a decision-making process.* This more general rule should be interpreted stochastically, by establishing confidence intervals, given that measured forecast errors are influenced by random error in traffic counts and other ground measurements.

There are many ways that traffic forecasts can be used in project-level decision-making, so there are many ways to validate a forecast. Below is an elementary example of a work zone traffic management plan to illustrate the principle.

5.2.1.1 Work Zone Example Situation

A freeway work zone is being planned. A traffic forecast is undertaken to determine the number of drivers that can be diverted from the freeway through on-ramp closures and driver information. Ideally, the plan would reduce volumes on the freeway such that long queues rarely form. A single lane of the work zone has a service flow (at the design level of service [LOS] D) of 1,500 vehicles per hour. There is a choice of keeping two lanes open or keeping three lanes open. At these traffic levels, there is approximately a 10% RMSE in a traffic count.

5.2.1.2 Work Zone Example Solution

The old half-lane rule would suggest that for decisions as to the number of lanes, the error should be no greater than 750 vehicles per hour. However, this decision is more about the level of service than about the overall traffic amount. The difference between LOS D and LOS E is 200 vehicles per hour per lane, and the difference between LOS C and LOS D is similar. LOS C would be considered too little traffic, and LOS E would be considered too much traffic, so the tolerable error is 200 vehicles per hour per lane. For a two-lane work zone, the relative tolerable error would be 200/3,000 or about 7% of the actual volume. The error in a traffic count is about 300 vehicles per hour (10%). The 200 vehicles per hour of tolerable error will be interpreted as a standard deviation, and the level of confidence implied by the use of a standard deviation is acceptable to the engineer for this project. This means that when compared to known traffic counts, the forecast should be capable of validating to 361 vehicles per hour RMSE (or about 12%) after adding the variances of the two effects.

The example gives a rough outline of the steps necessary to determine a validation standard for a project that cannot use the half-lane rule:

1. Determine the traffic variable that most influences the decision.
2. Determine the critical thresholds of the decision for this traffic variable.
3. Choose a level of confidence for the decision. A simple standard deviation implies a level of confidence (two-tailed) of about 68%.
4. Determine one-half of the difference between the thresholds that are bounding the range of an alternative. Convert this one-half difference to a standard deviation, considering the level of confidence.
5. Estimate the amount of error in the comparison ground statistic, preferably as an RMSE.
6. Find the combined standard deviation of the ground statistic error and the one-half difference of the tolerable range (that is, add the variances).
7. Ensure that the travel forecast can produce calibration results to within this combined standard deviation or consider ways to augment the travel forecast.

5.2.2 Scenario/Sensitivity Testing

Scenario testing is a very important part of travel model validation for projects. In many cases, the project engineer or planner will be taking forecasts done by others without actually knowing all of the intricate details of how the model works. It is not advisable to assume that the model will always give plausible results. In addition, preparing project plans with respect to multiple scenarios will strengthen the decision-making process by providing resiliency in case of unforeseen future events.

A scenario is most often thought of as being a state of the "environment" of the project, excluding those items that are controllable within the decision framework of the project. The "environment" can consist of all the social, demographic, economic, behavioral, and political forces that can influence travel. Scenarios can involve a variety of items such as the cost of fuel, population growth rates, incomes, cost of automobile ownership, vehicle mix, land use controls, parking availability, and housing availability.

Sensitivity testing (where a single input is varied to see how the outputs behave) is more limited than scenario testing. However, sensitivity testing can also be done on inputs that relate to the project design, rather than just to the environment in which the project is set. Sensitivity testing can reveal either a complete lack of sensitivity to an input or an incorrect sensitivity. Models may have incorrect sensitivities because the person creating the model did not anticipate the need for a particular input or there was an issue within a statistical estimation, such as multicollinearity, which is causing misleading results. If an incorrect sensitivity is discovered, then it is incumbent on the project engineer or planner to ensure that the problem is not unduly influencing project forecasts.

5.2.3 Relationship of Refinements to Model Validation

This guidebook recommends a variety of refinement techniques. Refinements are empirical adjustments to travel model outputs. As such, refinements are making corrections for which the behavioral rationales are unknown. Refinements can improve short- to medium-term forecasts, but can undermine the validity of long-range forecasts. Project engineers and planners would prefer to avoid refinements, but they are often necessary to meet the tight validation standards required for project-level decisions. Project engineers and planners need to exercise judgment as to how far into the future a refined forecast can still be considered reasonable.

5.3 Understanding Variability in Speed and Volume Data

5.3.1 Variations in Traffic Counts

Any given traffic count is a sample of a random number. Except for locations with continuous traffic counting (or with automated traffic recorders [ATRs] or counters [ATCs]), annual average daily traffic (AADT) is estimated from counts over much shorter durations, typically 48 hours in the United States. These shorter duration counts are very often adjusted for typical variations across days of the week and across months in a year. Traffic counts can vary considerably from day to day, and any given traffic count (even after adjustment) can differ from the true annual average. It is important to consider the amount of variation in a traffic count when validating travel forecasting models and when using traffic counts for refinement purposes. Local data on traffic count variation should be used if available.

Occasionally, a DOT analyzes count data from ATRs in order to develop day-of-week and month-of-year adjustment factors, and sometimes goodness of fit statistics are provided. These goodness of fit statistics could conceivably be interpreted as the amount of variation in a daily traffic count for those sites with ATRs. However, it is important to recognize that almost all counts of short duration are adjusted with factors borrowed from other sites, so the adjustment process contains significant inaccuracies. Granato (*90*) found in an analysis of a single site that borrowed factors only reduced the variation by 25% relative to factors specific to the site. Therefore, goodness of fit statistics at ATRs should be considered optimistic. At Granato's site, average deviations from the true AADT ranged from 2.1% to 10.9%, depending upon the year, for 48-hour counts with borrowed factors and a true AADT equal to approximately 10,000 vehicles per day (VPD). A study of 20 sites in Florida by Oak Ridge National Laboratory (ORNL) (*91*) also found significant inaccuracies from borrowed factors, but the inaccuracies were not as severe as those found by Granato. Nonetheless, this ORNL study reported variations (RMSE) of between 5.7% and 15.7% across all sites with borrowed factors for 24-hour counts with AADTs ranging from about 4,000 to about 150,000 VPD.

Forty-eight-hour counts are only slightly better than 24-hour counts, indicating that variations across days are strongly and positively correlated. Granato found only a fractional percent improvement in variation between 24 hours and 48 hours. A study of numerous sites in Texas, Florida, and Minnesota by Gadda, Magoon, and Kockelman (*92*) showed a mean absolute error (MAE) for 24-hour counts of 11.7% and a MAE of 11.0% for 48-hour counts. Similar tiny improvements were found by Sharma, Gulati, and Rizak (*93*).

Gadda, Magoon, and Kockelman (*92*) found only a weak relationship between the size of the AADT and the amount of variation in a short duration count. In Minnesota, MAEs decreased "from roughly 20% at 2,000 VPD to just 5.54% at 120,000 VPD, increasing slightly to 6.14% at 140,000 VPD" (*92*). For Florida, MAEs ranged from 12% to 15% regardless of AADT.

5.3.2 Variations in Speed and Travel Time Estimates

There is a greater range of technologies for obtaining speed and travel time data than there are technologies for obtaining traffic count data. Speed and travel time data can come from such sources as spot speed devices, floating car runs, Bluetooth detectors, and mobile phone tracking. Each technology has its own inherent strengths and weaknesses. Variations in speeds or travel times can stem from device errors, variations in traffic volumes and turning movements, variations in driver behavior, incidents, variations in weather, peculiarities of traffic control devices, the number of samples, and the distance over which the data are taken. Traffic theory suggests that variations will be greater as congestion increases. Statistical theory suggests that variations in estimates will be less when there are more samples and when the distance between check points increases.

Perhaps the most recent and comprehensive study of travel time variability was performed by the Hyder Group (*94*, *95*) for ascertaining travel time reliability in the United Kingdom. Hyder collected data using floating car runs and was interested in run-to-run differences in travel time. Hyder found that the coefficient of variation (CV) of travel time for single run was at about 16% when there was no appreciable delay, with the CV increasing almost proportionally with the fractional amount of delay and with the CV declining with distance.

5.4 Fixing Issues in Input or Validation Data

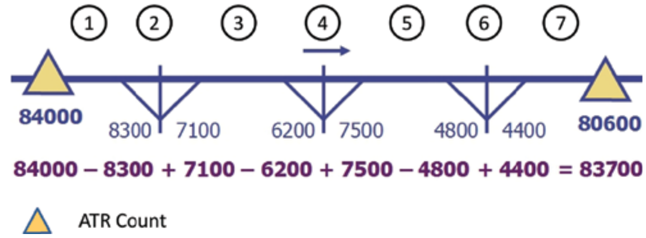
5.4.1 Balancing Volumes in a Corridor

The following method can be applied to the preparation of a travel model, as discussed in this section, and in the use of travel model output, as discussed in Chapter 6. Therefore, this method is presented in both chapters.

At the project level, there are usually inconsistencies between traffic volumes derived from a travel model and volumes derived from traffic counts, even when the model is calibrated and the counts are accurate. Also there are usually inconsistencies among traffic counts themselves—the count data are collected at different times or using different technologies, and there are inherent errors in either the counting or processing of the data. In order to have a consistent data set from which traffic forecasts can be developed, the data must be adjusted or "balanced" to obtain this mathematical consistency.

Balancing helps to "clean" traffic volume data by tempering the effects of outliers (for example, counts collected on an atypical day) and counting errors. It also results in a faster convergence when OD matrix estimation is applied because the matrix estimation algorithms tend not to oscillate between different solutions when attempting to match conflicting goals. Whether a forecaster is using only traffic counts or a combination of traffic counts and travel model assignments, the balancing process can be applied to produce a consistent data set.

At a corridor level, the most straightforward balancing approach is to begin with a mainline location where the count is known to be accurate and proceed in the direction of travel, keeping a running total by adding entry volumes and subtracting exit volumes, until the next known count location is reached. For this straightforward application, the balancing is constrained by the ATR stations and a pro rata distribution of the difference is applied to the ramp volumes.



Source: Wisconsin Department of Transportation.

Figure 5-1. Example imbalance between upstream and downstream traffic counts with ramp entrance and exit volumes.

An example of this approach is shown in Figure 5-1.

In this freeway example, there are ATR average daily traffic (ADT) volumes at either end of the section, supplemented by 24-hour traffic counts on the entrance and exit ramps. Moving in the direction of travel, a running total is computed for each segment by adding the ramp volume to, or subtracting it from, the mainline volume, as shown in Table 5-1.

When compared to the mainline count at the downstream end of the section, the running total is 3,100 vehicles per day higher. Each ramp volume is adjusted in proportion to the sum of the ramp volumes. In this particular example, the running total was 3,100 vehicles per day higher than the downstream count, so each of the ramp volumes was adjusted accordingly:

$$Adjustment_i = Difference * \frac{RampVolume_i}{\sum Entrance, Exit\ Volumes}$$

$$= 3{,}100 \frac{RampVolume_i}{38{,}300}$$

Table 5-1. Freeway volume balancing—Example #1.

Segment	Mainline Count	Exit Volume (-)	Entry Volume (+)	Running Total	Adjustment	Adjusted Ramp Volumes Adj. Exit Volume	Adjusted Ramp Volumes Adj. Entry Volume	Adj. Running Total
1	84,000			84,000				84,000
2		8,300		75,700	672	8,972		75,028
3			7,100	82,800	575		6,525	81,554
4		6,200		76,600	502	6,702		74,852
5			7,500	84,100	607		6,893	81,745
6		4,800		79,300	389	5,189		76,556
7	***80,600***		4,400	83,700	356		4,044	***80,600***
		Difference =		3,100	3,100			
		Σ|Entrance, Exit Volumes| =		38,300				

where i is the segment number. Depending on whether the difference is positive or negative, the adjustment is added or subtracted to the ramp volumes so that the running total agrees with the downstream count.

Volume balancing requires an objective function or optimization algorithm. In the previous example, which is a straightforward process using two known traffic counts, the objective (to minimize the difference between the second count and the adjusted running total) was achieved by constraining the solution to be the difference between the ATR volume at the downstream end and the running total and then allocating the difference on a pro rata basis among the ramp volumes.

In practice, an ATR station may not be available, particularly at both ends of a project. When this is the case, balancing is performed along the length of the project and typically begins at one end or the other. When this approach is applied, the difference in traffic counts is "pushed" along to the other the end of the project. If the option exists, the analyst may choose to expand the project limits, at least for the purpose of traffic forecasting, if there are ATR stations on adjacent or nearby segments that will help to constrain the solution.

Manually balancing a larger network can be very labor intensive and frustrating, with no unique solution. The Wisconsin Department of Transportation (WisDOT) has developed an automated mathematical balancing solution that can be used for complex networks, including freeway-to-freeway interchanges (*88*). The procedure computes imbalances in traffic volumes by means of running totals, using trusted ATR sites as the reference point for the computation. Traffic counts are adjusted using mathematical optimization, subject to the constraint that the imbalance must be zero. The objective function for optimization is to minimize the difference between adjusted and unadjusted volumes.

The WisDOT process measures the difference using the GEH formula, developed in the 1970s in London, England, by transport planner Geoffrey E. Havers. The formula, though similar to the statistical chi-squared test, is not a true statistical formula but rather an empirical formula that has been useful to WisDOT for a variety of applications.

For hourly traffic flows, the GEH formula is

$$G_H = \sqrt{\frac{2(m-c)^2}{m+c}}$$

where

G_H = hourly traffic volumes as estimated by the GEH model,
m = traffic model volume, vehicles per hour (VPH), and
c = traffic count, VPH.

The GEH model was created for hourly traffic volumes. For daily traffic volumes, a simplistic approximation can be applied based on an assumption that peak-hour traffic is about 10% of the daily traffic flow:

$$G_D = \sqrt{\frac{0.2M^2 - 0.4MC + 0.2MC^2}{M+C}}$$

where

G_D = daily traffic volumes,
M = traffic model volume, ADT, and
C = traffic count (ADT).

WisDOT applies the following rules of thumb using the GEH formula:

GEH < 5	Acceptable fit, probably OK
5 ≤ GEH < 10	Caution: possible model error or bad data
GEH ≥ 10	Warning: high probability of model error or bad data

This method can be automated using software or spreadsheets such as those developed by WisDOT. This is illustrated in Example #2, shown in Table 5-2. In Example #2, there are two ATR stations on a section of US 45 (Stations 400020N and 400007P). The remaining count stations represent temporary 48-hour counts. Proceeding down the table in the direction of travel, there is a difference of −558 vehicles per day between the running total (Column F) and the actual count (at Station 400007P). Using the Excel Solver program and minimization of the GEH value as the optimization objective, the difference is allocated among the ramp volumes and the short freeway segments between the ramps. Because of the number of "good" counts involved, an exact solution was not reached in which the difference was reduced to zero—an imbalance of −165 vehicles per day remained. However, the difference was reduced and was minimized through the optimization process.

In Table 5-2, the computed running total at the end of the section is shown in cell F24. From the results, it can be concluded that (1) the balancing process produces reasonable results for all of the ramps and segments, with the exception of the volume for the segment shown in Row 13 of the table, and (2) the count for the segment in Row 13 (Station 40-1941) is suspect and either should be ignored or recounted. If the suspect count is ignored, the overall G_D is reduced from 11.1 to 2.1.

For arterials and other non-access-controlled facilities, this balancing process also can be applied, provided that directional volumes are available and provided that side streets and driveways are treated in a manner similar to

Table 5-2. Freeway volume balancing—Example #2.

1/A	B	C	D	E	F	G	H	I	J	K
2	**AADT**	**2010**	**Segment 01 - US 45 SB / I-894 EB**	**USH 45 SB/I-894 EB Wisconsin (40-0020) to Cleveland (40-0007)**						
3				**Raw**	**Running**	**Balanced**				
4	**Station**	**Type**	**Location**	**AADT**	**Total**	**Volume**		**Change**	**% Chng**	**G_D**
5	**400020N**	**A**	**US 45 SB between Wisconsin Ave and Zoo Interchange**	**80,800**	**80,800**	**80,800**			**0.0%**	**0.0**
6	40-3677	0	Zoo Interchange N-E ramp	19,227	19,227	19,227		0	0.0%	0.0
7		B	Btwn Ramps at US 45 SB Zoo (North) Interchange		61,573	61,573				
8	40-3678	0	Zoo Interchange N-W ramp	9,302	9,302	9,302		0	0.0%	0.0
9	40-3679	F	US 45 SB Center of Zoo Interchange N-S		52,271	52,271				
10	40-3176	1	Zoo Interchange E-S ramp	11,611	11,611	11,611		0	0.0%	0.0
11		B	Btwn Ramps at US 45 SB Zoo (South) Interchange		63,882	63,883				
12	40-3178	1	Zoo Interchange W-S ramp	16,046	16,046	16,047		1	0.0%	0.0
13	40-1941	F	I-894 EB Btwn Zoo Interchange and STH 59 (Greenfield Ave)	72,077	79,928	79,930				9.0
14	40-3377	0	Greenfield Ave off-ramp	6,571	6,571	6,496		-75	-1.1%	0.3
15		B	Btwn Ramps at STH 59 (Greenfield Ave) Interchange		73,358	73,434				
16	40-3378	1	Greenfield Ave on-ramp	7,761	7,761	8,077		316	4.1%	1.1
17	40-1940	F	I-894 EB Btwn STH 59 (Greenfield Ave) and Lincoln Ave		81,119	81,512				
18	40-3380	0	Lincoln Ave off-ramp	7,089	7,089	6,924		-165	-2.3%	0.6
19	40-1932	F	I-894 EB Btwn Lincoln Ave and National Ave		74,030	74,588				
20	40-3383	0	National Ave off-ramp	5,290	5,290	5,290		0	0.0%	0.0
21		B	Btwn Ramps at National Ave Interchange		68,740	69,298				
22	40-3384	1	National Ave on-ramp	4,429	4,429	4,432		3	0.1%	0.0
23	**400007P**	**A**	**I-894 EB between National Ave and Oklahoma Ave**	**73,727**	**73,727**	**73,730**			**0.0%**	**0.0**
24			*Calculated Volume*		*73,169*	*73,730*		316		
25			*Imbalance*		*-558*	*0*		-165		**11.1**

Location Code

A - ATR Station
0 - Exit Ramp
1 - Entrance Ramp
F - Calculated Freeway Segment Volume
B - Calculated Segment Volume Between Ramps

The optimization objective is to minimize the value of this cell.

the way that ramps are treated in the previously discussed examples.

5.4.2 Balancing Turning Movements at Intersections

A traffic model represents a closed system and therefore a fundamental system equilibrium principle applies: the sum of all inputs is equal to the sum of all outputs.

In this case, the inputs and outputs are traffic volumes and the principle applies to network elements, including intersections. Within a defined system, balance is achieved when the input and output sums are equal.

A single intersection by its nature is balanced—the sum of volume inputs is equal to the sum of volume outputs whether the inputs and outputs are forecasts or actual traffic counts. When a system involves multiple intersections, the balance can be more difficult to achieve when actual traffic counts are involved.

For example, for an arterial segment with intersections at either end, the departing volume from Intersection A will equal the arriving volume at Intersection B in a modeled system, but the volumes may differ when using actual intersection counts, for the following reasons inherent to collecting traffic count data:

1. Traffic counts taken at different times and/or on different days and
2. Mid-block driveways or side streets that serve as internal origins or destinations (network "sinks" and "sources").

Most turning movement forecasts will use existing intersection counts as a starting point. When these forecasts involve multiple intersections, existing turning movements should be balanced before forecasts are developed.

Balancing can be done manually or through software using OD matrix estimation. Where OD matrix estimation is used, existing turning movements represent the information contained in the network flows to determine the most likely OD matrix. (For more information on OD matrix estimation, see Chapter 7 of this guidebook.) Once the process has been completed, the OD matrix is assigned to the network and model turning movements are compared with actual counts. Summary statistics like the percent RMSE should be used as an overall comparison of total assigned movements to total counts. Comparisons should be made between individual turning movements as well, with the analyst determining what is a reasonable difference (20%, for example) and considering factors like relative traffic volumes and the purpose of the forecast. Where differences exceed the accepted threshold, the potential reasons for error should be examined in the order they appear above.

Manual balancing can be performed for simple systems like an arterial section having a few intersections. For situations like this, multiple OD paths do not exist. A manual method for balancing inconsistent volumes at adjacent intersections is to select one or two key intersections where approach and departure volumes will take precedence over other adjacent intersections. If more than one intersection is considered a key intersection, they should be separated by at least one “non-key” intersection, but preferably by as many as possible.

The manual process prioritizes through movements at the key intersections along the arterial and adjustments are made to the turning movements and cross-street volumes to achieve the balance. For the intersection where turning movements are to be adjusted, the movements are arranged into an OD matrix where the rows denote origin (approach) legs and the columns denote destination (departure) legs, as illustrated in Figure 5-2.

5.4.2.1 Turning Movement Matrix Framework

For the intersection leg adjacent to the key intersection, the approach (row total) and departure (column total) volumes are replaced with the corresponding departure and approach volumes from the adjacent key intersection leg, and the Fratar process is used to balance the turning movements that contribute to the adjacent intersection leg volumes. In the Fratar process, OD matrix cells corresponding to the left-turn, through, and right-turn movements for the approach leg (row) being adjusted are multiplied by the ratio of the adjacent key intersection volume to the approach volume, and the OD matrix is recalculated.

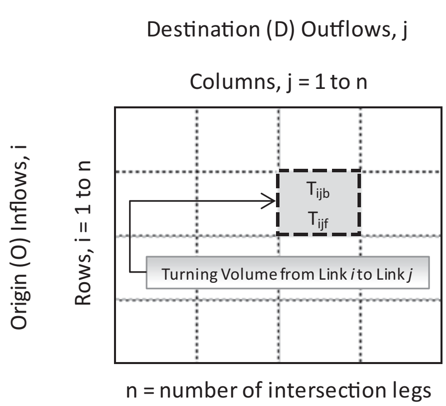


Figure 5-2. Intersection balancing flow chart.

While the row total for the subject approach is now equal to the departure volumes from the adjacent key intersection, the departure volumes likely will not be equal. A second iteration is performed in which the turning movements that contribute to the departure volumes for the subject link (column) are multiplied by the ratio of the adjacent key intersection approach volume to the subject intersection link departure volume.

The matrix row and column totals are recalculated. The new row and column totals for the subject link should equal the corresponding departure and approach volume totals for the adjacent key intersection link. Moving along an arterial section, the adjusted intersection becomes a new “key” intersection and the next adjacent intersection is adjusted in the same manner. The method is illustrated in Figure 5-3.

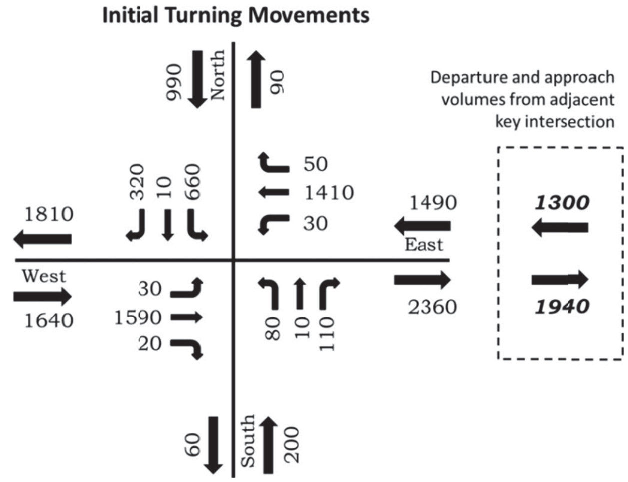
5.4.2.2 Example Manual Intersection Balancing

The analyst may determine that a cross-street volume of the intersection to which adjustments have been made also is significant and should be held constant. To illustrate, referring to the previous example, the south leg of the adjusted intersection represents the access driveway to an office building, and it is determined that those intersection volumes should remain the same.

The process is applied as before, but subsequent row and column adjustments are made to the cross-street link in a similar manner. This will result in a change to the row and column totals for the approach/departure volumes on the major street links, and the process should be reiterated until balance is achieved. In some cases, it may be necessary for the analyst to make a slight, manual adjustment to selected turning movements to achieve the desired results on all legs. This is illustrated in Figure 5-4 using the turning volumes from the previous example.

5.4.2.3 Example Intersection Balancing—Cross-Street Leg Held Constant

Regardless of the balancing method used, the reason for balancing must be considered. Are the differences in input and output sums due to errors in turning movement counts or due to sums being collected at different times or on different days? Is there a difference because of mid-block driveways and side streets? If the former is the case, the balancing can be used as a means of “smoothing out” or distributing the error across the network. If the latter is the case, these access points can be used as internal sinks and sources, so that the differences are concentrated here and not spread across the study intersections. This can be done as long as the differences are relatively small compared to the intersection volumes. Professional judgment should be used to determine the volume levels at which access drives and cross streets should be included in the forecast and not used solely to balance the differences.



Destination (D) Outflows, j

Origin (O) Inflows, i

	East	North	West	South	Totals
East		50	1,410	30	*1,490*
North	660		320	10	990
West	1,590	30		20	1,640
South	110	10	80		200
Totals	*2,360*	90	1,810	60	

Initial Turninng Movement Matrix

	East	North	West	South	Totals
East	0	44	1,230	26	*1,300*
North	660	0	320	10	990
West	1,590	30	0	20	1,640
South	110	10	80	0	200
Totals	*2,360*	84	1,630	56	

East leg approach (row) cells multiplied by 1300/1490

	East	North	West	South	Totals
East	0	44	1,230	26	*1,300*
North	543	0	320	10	873
West	1,307	30	0	20	1,357
South	90	10	80	0	180
Totals	*1,940*	84	1,630	56	

East leg departure (column) cells multiplied by 1940/2360

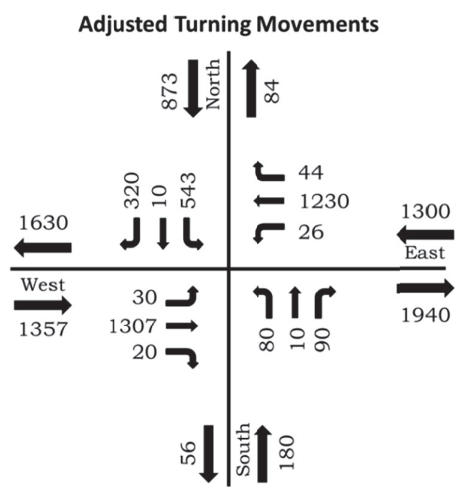
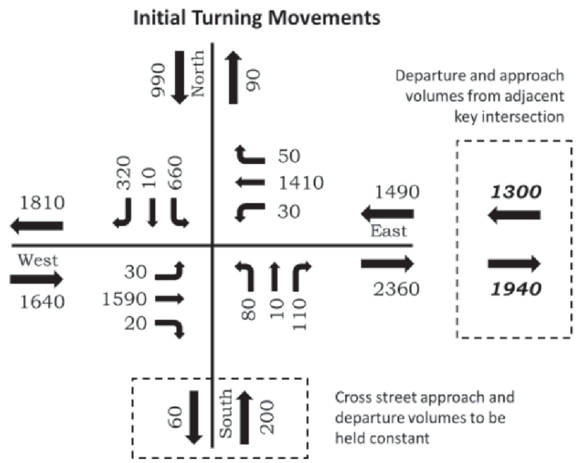


Figure 5-3. Intersection balancing process.



	East	North	West	South	Totals
East		50	1,410	30	*1,490*
North	660		320	10	990
West	1,590	30		20	1,640
South	110	10	80		200
Totals	*2,360*	90	1,810	60	

Initial Turninng Movement Matrix

	East	North	West	South	Totals
East	0	44	1,230	26	*1,300*
North	660	0	320	10	990
West	1,590	30	0	20	1,640
South	110	10	80	0	*200*
Totals	*2,360*	84	1,630	*56*	

East leg approach (row) cells multiplied by 1300/1490

	East	North	West	South	Totals
East	0	44	1,230	28	*1,302*
North	543	0	320	11	874
West	1,307	30	0	21	1,358
South	90	10	80	0	*180*
Totals	*1,940*	84	1,630	*60*	

East leg departure (column) cells multiplied by 1940/2360

South leg departure (column) cells multiplied by 60/56

	East	North	West	South	Totals
East	0	44	1,228	28	*1,300*
North	538	0	320	11	869
West	1,302	30	0	21	1,353
South	100	11	89	0	*200*
Totals	*1,940*	85	1,637	*60*	

South leg approach (row) cells multiplied by 1300/1302

Final manual adjustments made

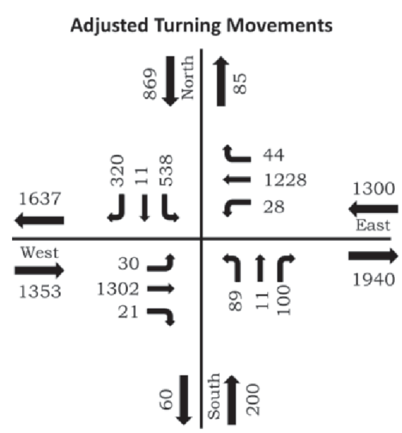


Figure 5-4. Intersection balancing example.

This would include collecting updated traffic counts, including counts at the mid-block intersections.

5.4.3 Spatial Interpolation of Traffic Counts

In some cases, it may be necessary to develop a forecast for a roadway segment for which there are no existing traffic counts or for which the traffic counts are too old to be considered useful, yet it is desirable to compare a base year model estimate to a "synthesized" count. In this situation, the analyst should examine available roadway counts for segments upstream and downstream of the subject section. If such counts exist, then the analyst may be able to develop an estimate for the subject section using interpolation. Considerations include the following:

- Upstream and downstream segment counts should be for the same year (or very close) in order for the interpolation to be valid.
- Entering/exiting volumes for the subject section should be obtained, if possible. If they exist, traffic counts for intermediate on-ramps, off-ramps, and access roads should be obtained and included in the interpolation.

Growth trends from historic traffic counts on upstream and downstream segments should be developed and applied to the subject section in the development of a base year estimate to be compared with the model estimate.

5.4.4 Improving Capacity Estimates

Most traditional travel demand models use generalized look-up tables to estimate capacity for individual network segments. These generalized capacities typically are based on facility type, functional classification, area type, and other parameters. While this approach has been a standard practice historically for area-wide travel demand models, estimated capacities for individual network links may vary considerably from the calculated capacity using specific link attributes like lane width, shoulder/median width, grade, and so forth.

The HCM is the definitive reference for calculating capacity (*21*). The HCM includes methods for computing capacity for the facility types that typically make up a travel demand model network—basic freeway segments, multilane highways, two-lane highways, urban streets, and ramps. Using default values and simplifying assumptions, generalized or average inputs can be developed for those inputs needed for capacity calculations. For each of the facility types, capacity calculations can be automated within the traffic model stream.

The HCM also includes guidance on the development of generalized service volume tables. This is a planning application of the HCM, where the methods are the same as the operational analysis methods, but with default or representative values for input parameters. An example of a generalized service volume table for basic freeway segments is shown in Table 5-3, parts a through d.

Table 5-3. Example service volume tables (HCM basic freeway segments).

(a)

Peak Hour/Peak Direction

No. Lanes	LOS B	LOS C	LOS D	LOS E
2	1,510	2,440	3,300	4,000
3	2,280	3,660	4,890	5,870
4	3,030	4,880	6,520	7,820

Peak Hour/Both Directions (D = 0.55)

No. Lanes	LOS B	LOS C	LOS D	LOS E
4	2,750	4,440	6,000	7,270
6	4,150	6,650	8,890	10,670
8	5,510	8,870	11,850	14,220

Daily/Both Directions (K = 0.10)

No. Lanes	LOS B	LOS C	LOS D	LOS E
4	27,500	44,400	60,000	72,700
6	41,500	66,500	88,900	106,700
8	55,100	88,700	118,500	142,200

(b)

Inputs	
Peak-Hour Factor (*PHF*)	0.94
Directional Distribution, *D*	0.55
Design Hour Factor, *K*	0.10
% Heavy Vehicles	5
% Recreational Vehicles	0
Base Free Flow Speed (FFS) (mi/h)	75.4
Lane Width (ft)	12.0
Total Ramp Density (TRD) (Ramps/mi)	0.5
Driver Population Factor (f_p)	1.00
Level Terrain	

The tables were created manually, using the following steps:

1. Compute the base free flow speed:

$$FFS = 75.4 - F_{LW} - F_{LC} - 3.22TRD^{0.84}$$

where

FFS = Base Free Flow Speed (mph),
F_{LW} = Lane Width Adjustment,
F_{LC} = Lateral Clearance Adjustment, and
TRD = Total Ramp Density (ramps/mi).

2. Compute capacity as a function of free flow speed.

Table 5-3. (Continued).

(c)

Free Flow Speed (mph)	Capacity (pc/h/l)
75	2,400
70	2,400
65	2,350
60	2,300
55	2,250
*Ch. 11 Basic Freeway Segments, HCM2010	

3. Compute demand flow rate, v_p, according to Equation 11-2 from the HCM (*21*):

$$v_p = \frac{V}{PHF \times N \times f_{HV} \times f_p}$$

where

v_p = Demand flow rate under equivalent base conditions (passenger cars/hour/lane),
V = demand volume under prevailing conditions (vehicle/hour),
PHF = peak-hour factor,
N = number of lanes,
f_{HV} = adjustment factor for presence of heavy vehicles, and
f_p = adjustment factor for unfamiliar driver populations.

4. Compute density as a function of the demand flow rate and mean speed of the traffic stream:

$$D = \frac{v_p}{S} \qquad (HCM2010\ Eq. 11-4)$$

where

D = density (passenger cars/mile/lane),
v_p = demand flow rate (passenger cars/hour/lane), and
S = mean speed of traffic stream under base conditions (mile/hour).

5. Compute LOS as a function of density according to Exhibit 11-5 of the HCM2010 (*21*):

Table 5-3. (Continued).

(d)

LOS	Density (passenger cars/mile/lane)
A	≤ 11
B	> 11 – 18
C	> 18 – 26
D	> 26 – 35
E	> 35 – 45
F	> 45

Source: HCM2010, Ex. 11-5 (*21*).

The service volume tables can be created manually using software that implements the HCM methodology. Using the selected representative inputs, the input volumes are varied, and resulting LOS thresholds are identified. Capacity is considered to be those volumes that define the LOS E threshold.

The HCM method is directional, and computed capacities are in peak-hour directional volumes; these are shown in the top portion of Table 5-3a. Two-way directional peak-hour volumes are shown in the middle portion of Table 5-3a and were computed by dividing the volumes in the top portion by the representative directional distribution factor, D = 0.55. Similarly, two-way daily directional service volumes, shown in the bottom section of Table 5-3a, were computed by dividing the volumes in the middle portion of the table by the representative design hour factor, K = 0.10. The values in Table 5-3a can be used either for 24-hour models or TOD models.

The freeway facilities methodology is new to the HCM (see HCM2010, Ch. 10) (*21*). This methodology incorporates the individual freeway elements—basic freeway segments, merge/diverge segments, and weaving sections—as a system. Unlike other HCM methods, the freeway facilities method is an iterative method that accounts for oversaturated conditions and the effects of traffic backups on upstream sections. Currently the adaptation of the methodology to a planning application that can be used in traffic forecasting does not exist. However, further research, to be performed as part of developing a "Planning and Preliminary Engineering Applications Guide to the HCM," is expected to produce such a planning application.

5.4.5 Improving Free Flow Speed Estimates

Travel demand models typically use an estimate of free flow speed as part of the traffic assignment process. Historically, this has been done in a fashion similar to capacities, by using generalized look-up tables. While this may be appropriate on an area-wide basis, it is subject to scrutiny when applied at the link level, i.e., roadway segments for which forecasts are to be developed.

Many variables can affect link-specific free flow speeds. These include geometric-based parameters like lane width, shoulder/median width, and access point density and grade. Traffic control parameters like posted speed limit also have an effect, as do variables like traffic composition and traffic control for interrupted flow facilities. Because so many variables have an effect, it is advisable to avoid the use of general default free flow speeds.

Analysts traditionally have used the posted speed limit as a surrogate for base free flow speed. Caution must be used if this approach is taken, as posted speed limits do not take into consideration geometric and other variables that influence free flow speeds, even under conditions of low traffic flow.

Wherever possible, use of actual speed studies or travel time data is advised. If speed/travel time data for the roadway segments in question are not available, the analyst may opt to use related data for similar types of facilities in the area. Care must be taken that the speed/travel time data are collected for free flow conditions. If commercially available data are utilized, it is desirable that the possibility exists to disaggregate these data by time of day so that representative speeds during low flow traffic conditions can be used.

Similar to the estimation of link-specific capacities, methods in the HCM2010 can be used to estimate free flow speeds for roadway segments, based on facility type. The various methods (basic freeway segments, multilane highways, two-lane highways, and urban streets) all begin with a default base free flow speed, from which adjustments based on geometric parameters, traffic control, and traffic composition are made. Typical base free flow speeds used in the HCM2010 methods are shown in Table 5-4.

As with link-based capacity calculations, estimates of base free flow speeds for individual links within the travel demand model network can be computed using HCM methods, and these can be automated as a batch process within the traffic model stream.

5.4.6 Estimating Traffic Signal Parameters

When developing traffic forecasts, it is difficult to obtain valid traffic assignments for urban street links in a travel demand model network without incorporating traffic control delay, i.e., increased travel times as a result of signals and other traffic control devices.

Methods for estimating link-based capacity and free flow speed for urban streets, as mentioned in previous sections, are documented in the HCM (*21*). For urban streets, it can be assumed that link capacity is a function of the capacity for through movements at signalized intersections (nodes) that define the end of the links. Link-based capacity is computed using Equation 18-15 from the HCM2010:

$$c = Ns\frac{g}{C}$$

where

c = capacity (vehicle/hour),
N = number of through lanes,
s = adjusted saturation flow rate (vehicle/hour), and
g/C = representative or average effective green-to-cycle length ratio for through movement.

Guidance for estimation of an adjusted saturation flow rate is provided in Chapter 18 of the 2010 HCM.

Estimation of the effective green-to-cycle length (g/C) ratio is an important parameter for computing through movement capacity of urban street links. For an urban street section consisting of multiple signalized intersections, g/C values may vary from one intersection to the next. The analyst may choose to select a g/C ratio representative of the section as a whole. This can be done by averaging individual g/C values from each of the intersections, but caution must be used if the g/C ratio for one intersection varies significantly from the rest (for example, the g/C ratio for an intersection of two major arterials may be lower that the individual g/C ratios for the other intersections along an urban street section). This would constitute the critical intersection along the section and would have an effect on the overall through movement capacity of the section as a whole. One approach is to compute a weighted average g/C as the average of the critical intersection g/C and the average g/C ratio of the remaining intersections to account for the metering effect of the critical intersection. More guidance on selection of a representative g/C ratio can be found in *NCHRP Report 599: Default Values for Highway Capacity and Level of Service Analyses* (*70*).

It should be clarified that this approach is applicable for undersaturated conditions. When conditions of oversaturated

Table 5-4. Example service volume tables (HCM basic freeway segments).

HCM Method	Base Free Flow Speed (mph)	Criterion
Basic Freeway Segments	75.4	
Multilane Highways	Posted Speed + 5 mph	Posted Speed $\geq$ 50 mph
Multilane Highways	Posted Speed + 7 mph	Posted Speed $\leq$ 50 mph
Two-Lane Highways	45 – 70	Little guidance given; based on speed data and local knowledge of operating conditions
Urban Streets	25 – 55	Based on recommended speed constant and geometric/traffic control parameters (HCM2010, Ex. 17-11, *21*)

flow are expected, including queue spillback from turn lanes and/or along urban street segments, the HCM (Chapter 17, Urban Street Segments, and Chapter 18, Signalized Intersections) should be consulted.

Where STOP-controlled intersections exist along an urban street section, guidance for estimating capacity is provided in the HCM2010 (Chapter 16, Urban Street Facilities, and Chapter 20, All-Way STOP-Controlled Intersections).

For models that incorporate node delay attributable to signalized intersections, it is necessary to include estimate signal timing plans. Signal timing plans typically are specific to time of day and thus should be used only for TOD models. The HCM2010 includes a quick estimation method determining critical intersection signal timing and delay for a signalized intersection. This method can be used when minimal data are available for analysis and only approximate results are desired. Guidance on the quick estimation method can be found in Chapter 31 of the HCM2010.

5.4.7 Input Data Quality Assessment/Adequacy

It is natural to assume that travel demand model data are accurate and adequate. Given the importance of having good quality data in making accurate traffic forecasts, it is important for the analyst to perform a thorough check of the data for both accuracy and adequacy. Input data that should be checked and verified include the following:

- Link network geometry and attribute data (e.g., number of lanes, lane/shoulder/median widths, grades, etc.),
- Traffic counts (including intersection turning movements, time of day, and directional volumes),
- Speed data (especially when data collected from field studies are used),
- Traffic control data (posted speed limits and signal timing parameters, for example),
- Model socioeconomic data, and
- Traffic analysis zone (TAZ) structure and centroid connectors.

Many travel demand models include geographic information system (GIS) thematic mapping functionality. The analyst should use a series of thematic maps to check both the quality and adequacy of input data. As an initial step, the analyst should develop an input data checklist that covers both spatial and temporal adequacy of the data.

5.4.8 Missing or Unavailable Data

Based on the assessment of input data, the analyst may determine that some of the required data are missing or unavailable. At this point, it must be determined whether the data are required inputs for methods used to compute capacity, free flow speed, or other parameters needed for developing traffic forecasts and whether there are suitable representative or default values that can be used in place of actual data. Given typical limitations in budget and/or schedule, the analyst should develop, once identified, a prioritization of the missing data elements so that resources can be focused on filling in the missing data or developing suitable defaults.

In the case of representative default values for capacity calculations, guidance can be found in *NCHRP Report 599: Default Values for Highway Capacity and Level of Service Analyses* (*70*). Regarding network geometry data, most state DOTs maintain publicly available databases that contain highway network attributes like functional classification, posted speed limits, lane/shoulder/median widths, and so forth. As discussed in Section 5.4.3, traffic counts estimated from interpolation can be used as a check against base year traffic assignments; however, as these are estimates and are based on counts from adjacent sections, they should not be included in the model calibration process as they will result in an overrepresentation of some of the traffic counts. As would be expected, professional judgment should be used in handling missing data.

5.5 Understanding Travel Model Outputs

Data developed by travel demand models are usually applied to project-level decision-making. These data are rarely suitable for use directly as model outputs and typically will need to be post-processed. This section discusses some of the common analyses of the travel demand model outputs that are used at the project level.

5.5.1 Select Link/Zone Analysis

Select link and zone analyses are used to identify the origins and destinations of trips corresponding to particular links or zones in the study area and the routing paths of the assigned trips. Select link analysis identifies trips traveling along particular segments of roads and is often conducted in conjunction with corridor studies and bridge projects to identify impacted populations and roads. Select link analyses are also used to build OD matrices for subarea models by analyzing a cordon line around the study area. Select zone analysis identifies trips associated with travel to and from a select group of zones and is often conducted in conjunction with site development studies and environmental justice analysis.

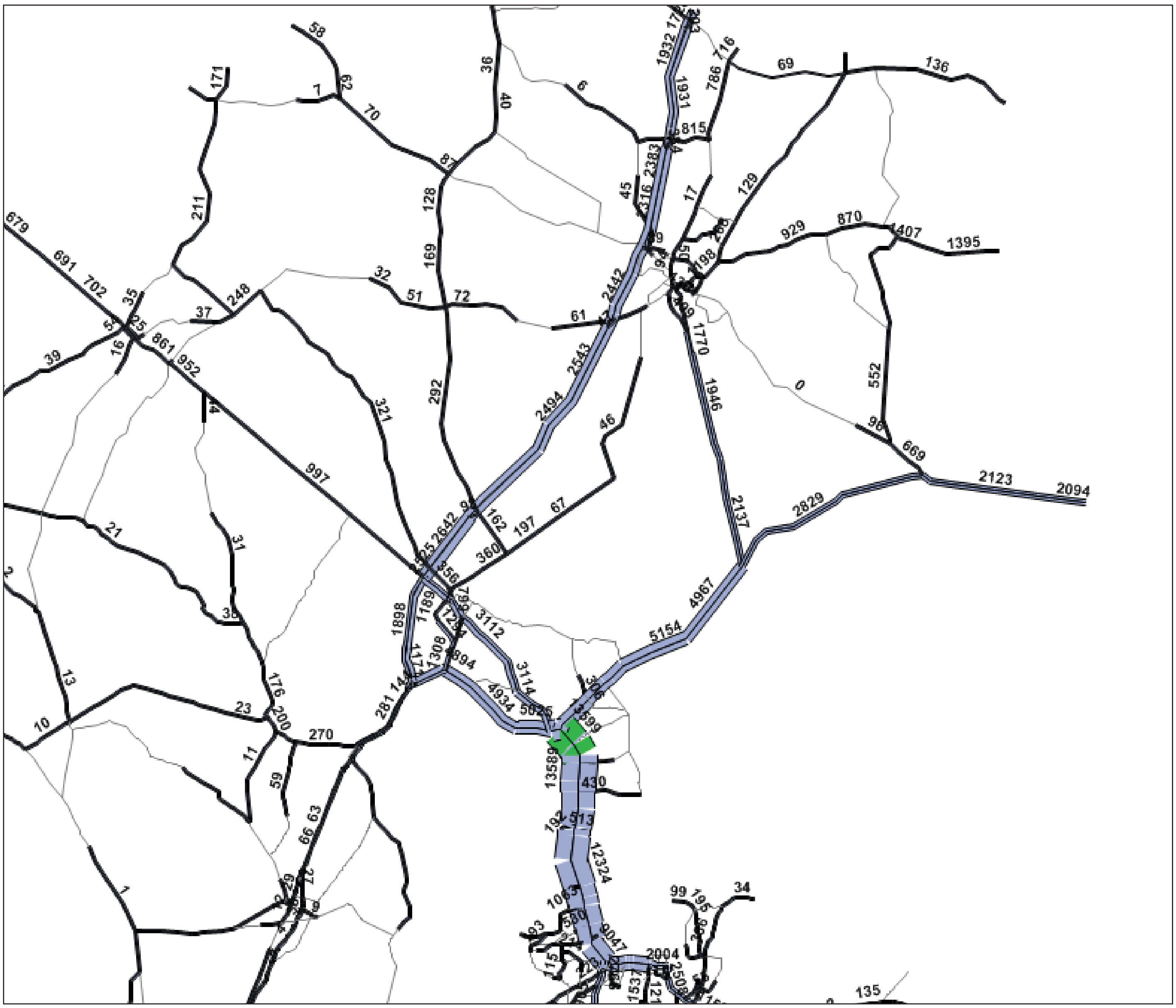
Select link/zone analysis can be performed for one or more geographical features (links or zones) in the study area. Thus, the analyst can determine assignment paths and OD pairs for trips common to more than one link or zone. This is especially useful for corridor-level analysis and point-to-point analysis. The output of select link/zone analysis includes a matrix of zonal trip interchanges that pass through the selected link(s)/zone(s) and an assignment to the network of the OD trips using the selected link(s) or traveling to/from the selected zone(s).

Graphically, the analysis can provide a clear picture of trip movements in the study area such as a scaled theme representation of where vehicles are coming from and going to that passes through the selected link(s) or zone(s). An example of this is shown in Figure 5-5. Based on review of the graphical results and the resulting OD matrix, the analyst can manually adjust the traffic assignment. These outputs can then be compared with base year traffic counts and OD studies to establish reasonableness and validity.

5.5.2 Graphical Tools

There are several graphical tools available to assist the analyst in applying model data in a project-level forecast. These tools describe traffic patterns visually and are used to obtain a clear picture of traffic movements within a study area. Such tools include the following:

- Shortest path diagrams,
- Turning movement diagrams,
- Geographic bands,
- Desire lines, and
- Thematic maps.



Source: Lowcountry TDM.

Figure 5-5. Select link analysis example.

Additional graphical and visualization tools can be referenced in the document *Showcasing Visualization Tools in Congestion Management* by FHWA (*71*). This document includes charts, graphics, and tables as well as animation tools.

5.5.2.1 Shortest Path Diagrams

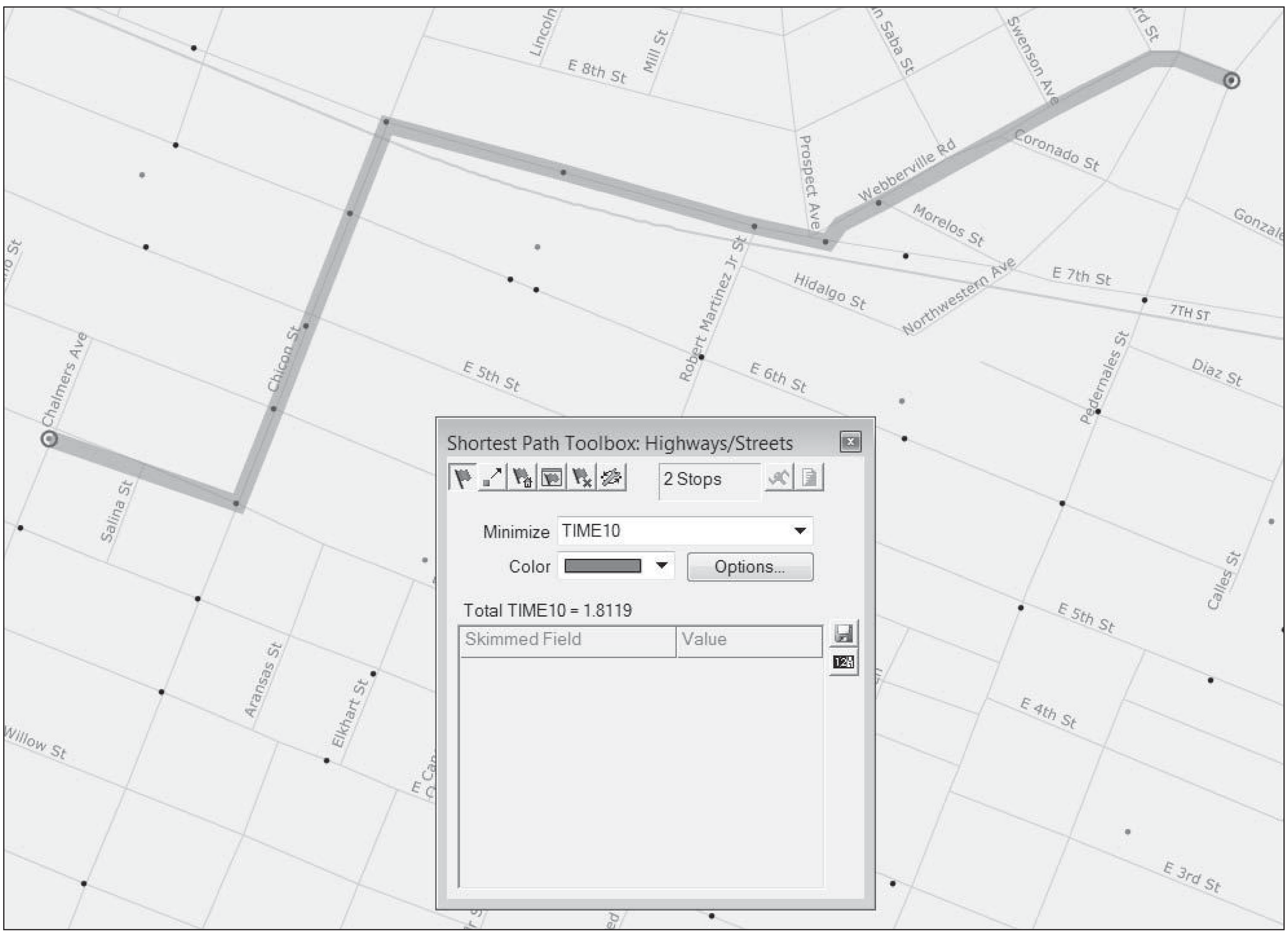
Shortest path diagrams represent a schematic of a path between two points based on minimizing a user-defined highway network attribute such as time or distance. Besides graphically viewing the path results, the user can employ this tool to check for network connectivity and verify direction of flow. Figure 5-6 shows an example of the shortest path tool being used to minimize travel time.

5.5.2.2 Turning Movement Diagrams

Turning movement diagrams represent a schematic of an intersection where at least three roadways intersect. The schematics present the volumes of traffic for each intersection movement and show the spatial orientation of the intersection legs. Directional arrows and different colors are used to distinguish the trip movements. An example of a turning movement diagram is shown in Figure 5-7.

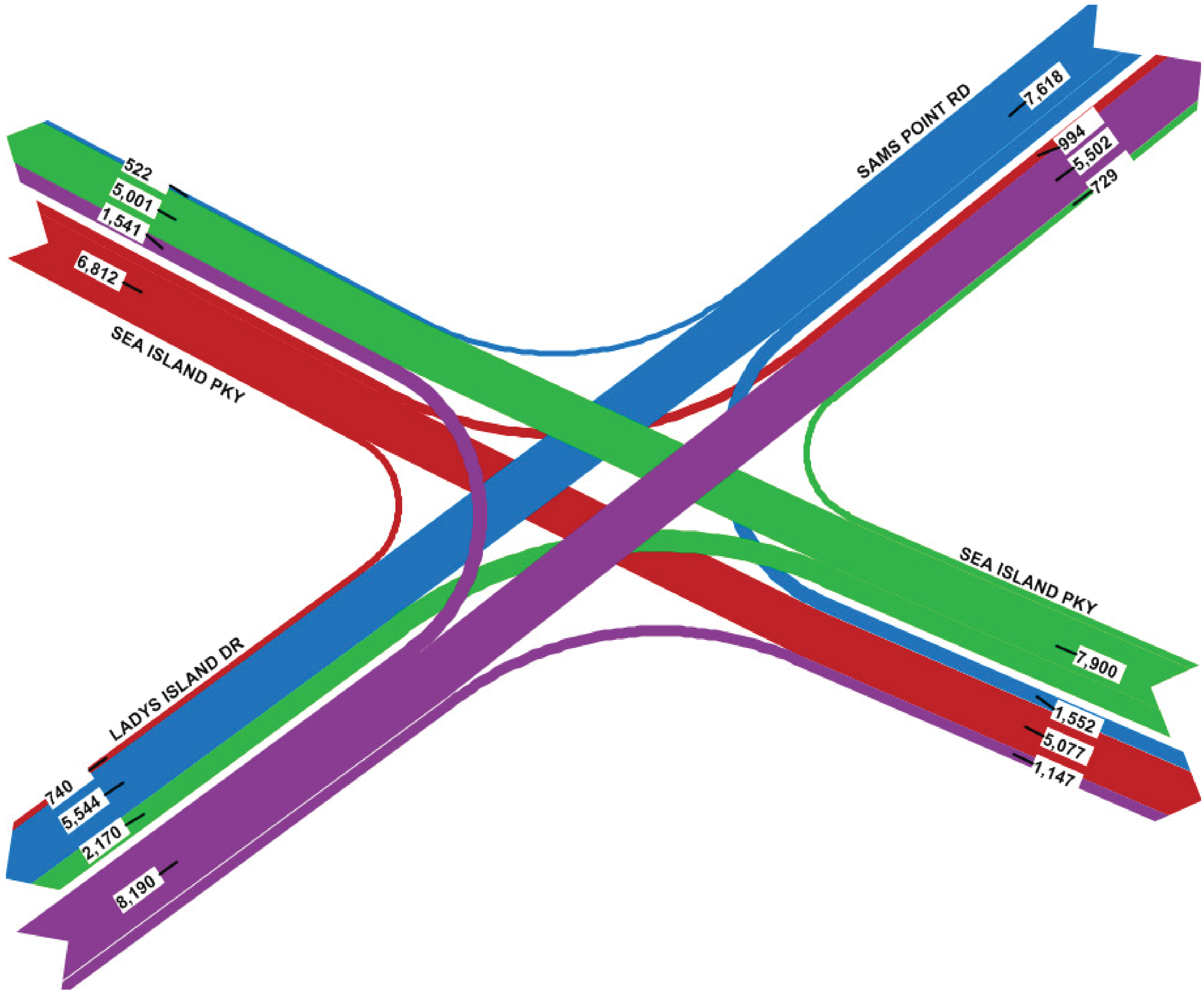
5.5.2.3 Geographic Contours or Bands

Geographic contours or bands represent a schematic of bands or buffers enclosing an area based on a specified attribute. Contours based on impedance such as travel time or distance are useful in analyzing the accessibility for different populations (transit users, workers, tourists, etc.) to different types of land uses. The bands can be created as a geographic file and color themed for visual presentation as well as additional analyses. Figure 5-8 shows an example of a travel time band based on three new developments (stores) in the study area. This image shows the areas (populations) with accessibility to the stores within 5, 10, and 15 minutes of travel time.



Source: CAMPO TDM.

Figure 5-6. Shortest path schematic from model.



Source: Lowcountry TDM.

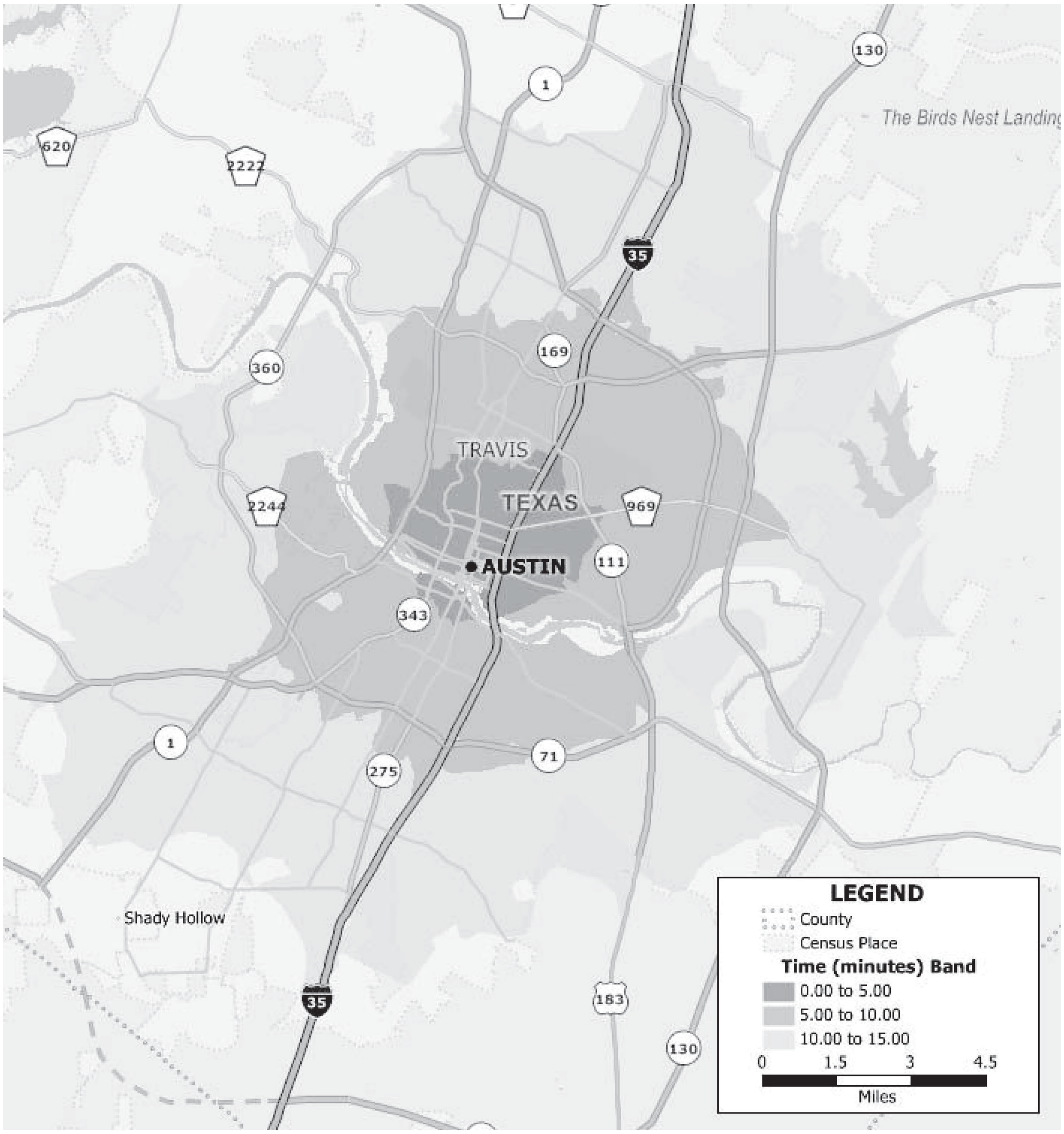
Figure 5-7. Turning movement schematic from model.

5.5.2.4 Desire Lines

Desire lines illustrate the flow of trips from one or more origins to one or more destinations based on lines connecting the origin(s) and destination(s). A matrix file of trip movements and a geographic file of the corresponding study area zones or nodes are required for this analysis. Related to project-level traffic forecasting, this analysis is useful for displaying the number of trips traveling to a new development from other zones in the study area. Representing the number of trips through the thickness of the lines, the analysis can show which zones generate the most trips to or from the development. This tool displays the magnitude of trips between the origin and destination and does not display the path that travelers use to get from the origin to the destination. Figure 5-9 shows desire lines representing the number of trips from Austin to surrounding counties.

5.5.2.5 Thematic Maps

Thematic maps are a clear way to represent various attributes of the study area roadways and land uses. Various thematic maps are useful for project-level forecasting including color or pattern themes, dot-density themes, and scaled-symbol themes. An example of a theme map based on posted speed for the highway network is shown in Figure 5-10.



Source: CAMPO TDM.

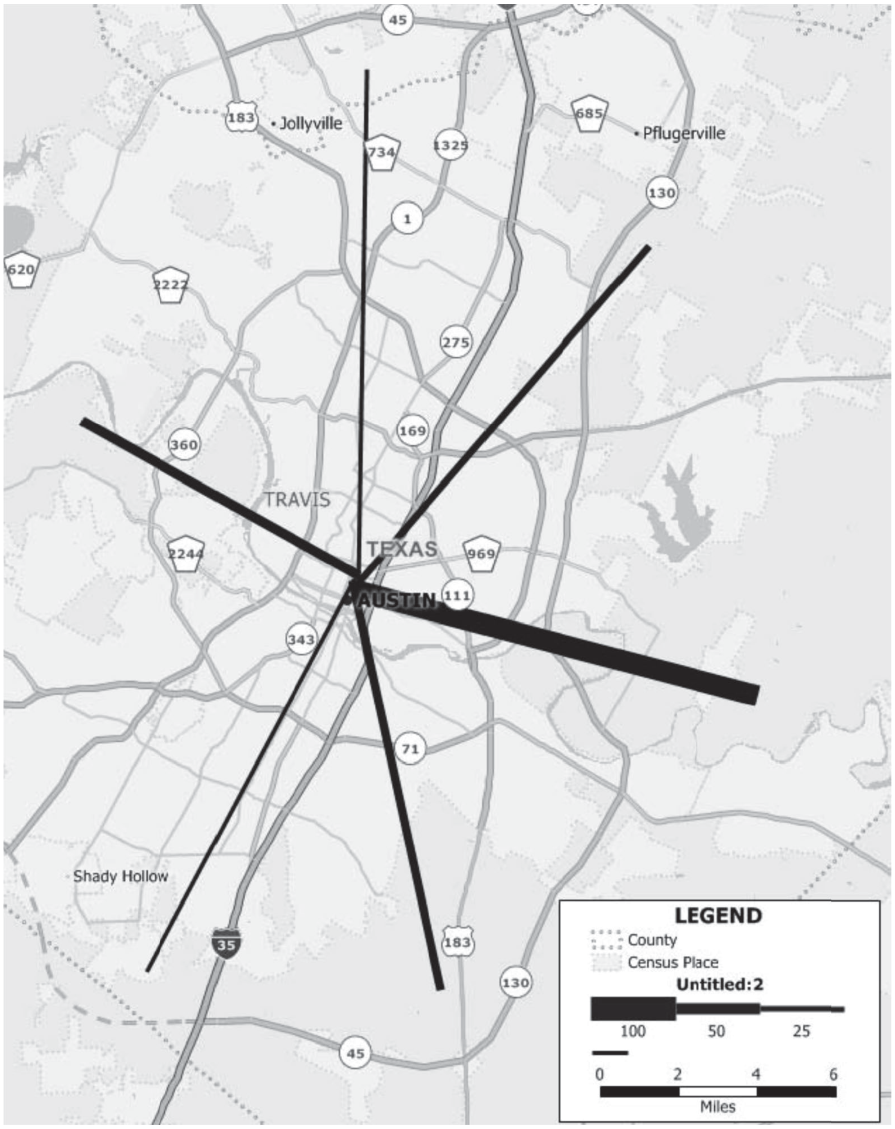
Figure 5-8. Travel time band.

5.5.3 Model Post-Processing

Post-processing of model outputs is a common and accepted practice in project-level traffic forecasts. Frequently, spreadsheet-based tools are used to refine or smooth model output data that results in balanced trips throughout the study area that match observed behavior. For example, in a corridor study, a spreadsheet tool may be used to adjust the base year model volumes to match observed counts and then apply that adjustment to the forecast year model volumes.

Additionally, post-processing of model data is used to convert the output volumes into the type of volume required for the study. Historically, travel demand models have been primarily 24-hour, daily models or peak-period models. These models represent total traffic occurring within a 24-hour period or a 3-hour, peak period, usually during an average weekday. These models are sufficient for most planning activities in which the purpose is to identify relative changes in volume between alternatives; however, for project-level forecasts, peak-hour estimates are generally of interest. Thus, post-processing of the data is necessary to convert the daily, or peak-period, volumes to peak-hour volumes.

Project-level traffic forecast studies may use different assumptions than the travel demand model and may need to



Source: CAMPO TDM.

Figure 5-9. Desire lines.

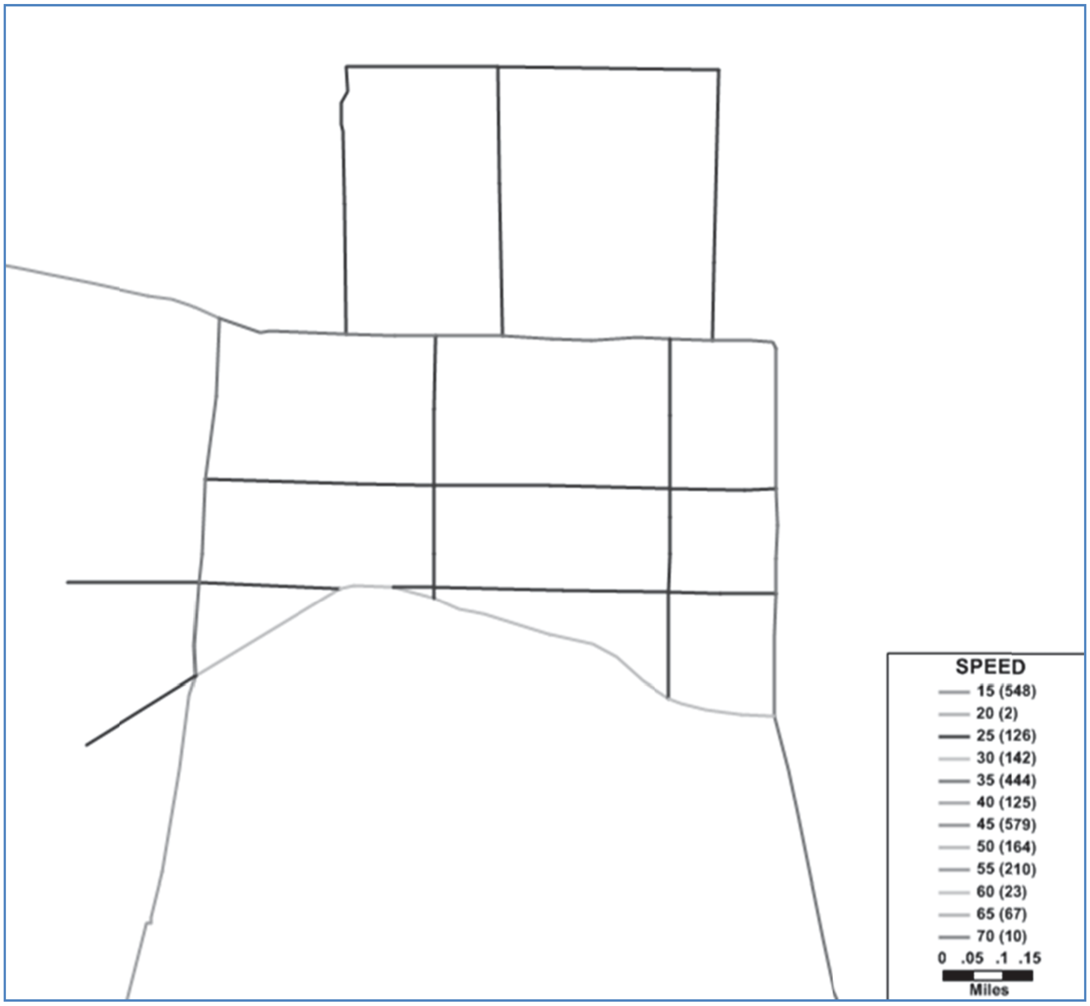
adjust the model data for these assumptions. One such example is the conversion of traffic volumes from average weekday volumes to average daily or vice versa. Another example is the use of PCE factors. The PCE factor is used to convert trucks into an equivalent number of passenger cars for the model's congestion calculations and for pavement thickness calculation for highway design.

5.6 Handling Outliers in Model Outputs

5.6.1 Volumes in Excess of Capacity

By definition, capacity is the maximum hourly sustainable flow rate at which persons or vehicles can be reasonably expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, environmental, traffic, and control conditions (*21*). Given that capacity represents a maximum hourly flow rate or traffic volume, it would seem logical that a travel model assignment for a network link or section would not exceed the link capacity. The reality is that model assignments can and do exceed capacity, for several reasons.

Capacity is expressed as an hourly flow rate, but many travel models are daily models. The term "daily capacity" is often used, but is somewhat of a misnomer—daily capacity is computed as the capacity divided by the design hour (K) factor or the ratio of the average peak-hour volume to daily traffic volume. For example, if a directional link capacity is 3,600 vehicle/hour and the K factor is 0.095, then the daily capacity might be computed as



Source: Low country TDM.

Figure 5-10. Thematic map of posted speeds.

$$\frac{3{,}600}{0.095} = 37{,}900 \text{ vehicles/day}$$

This daily capacity actually is the extrapolation of capacity (on an hourly basis) to a 24-hour equivalent, based on measured or assumed peaking characteristics. In reality, there is no daily capacity, at least not in the context of a maximum sustainable flow over a 24-hour period, but some travel models use daily capacity in the aforementioned context. This same concept also has been applied to peak-period capacities for TOD models.

Volume to capacity (V/C), the ratio of flow rate to capacity for a network link, is a typical travel model output that is easily computed. In principle, if capacity is the maximum flow rate, then V/C would never be greater than 1.0. Travel models commonly report a V/C ratio greater than 1.0, an indicator of oversaturated links. When this occurs, the numerator is actually the travel *demand* on the link and not the flow rate (volume). The demand-to-capacity (d/c) ratio often is used to quantify roadway or network deficiencies.

When d/c exceeds 1.0, peak spreading usually occurs; i.e., the travel demand becomes spread out over time and the peak hour becomes a peak period that lasts more than 60 minutes. In many major metropolitan areas, the peak period typically lasts 2 to 3 hours (and sometimes longer). When developing project-level traffic forecasts, the analyst must understand the peak spreading principle and how it should be applied as part of the forecasting process. Are the forecasts being developed for roadway expansion purposes or for operational purposes? For capacity expansion (adding a lane, for example), the forecasted demand in relation to the capacity is desired, but for operational purposes, the duration of traffic flow at capacity conditions would be of greater interest. Multi-hour (preferably 24-hour) traffic counts should be collected and summed at even intervals (1-hour minimum, 15-minute or smaller desirable), to define the occurrence and duration of the peak period(s). This is especially important when forecasts are being developed for operational applications.

Regarding travel demand and capacity, the type of traffic assignment technique that is used can have a significant effect on forecasted volumes. Most models consider travel time to be the most important determinant in route selection—models assign trips to network links according to paths that represent the shortest travel times between all origin and destination pairs. When an all-or-nothing assignment technique is used, trips are assigned as if there were no congestion or impedance to traffic flow; in other words, network links are assumed to have infinite capacity, and congestion-related impedance is ignored. When applying an all-or-nothing assignment technique, d/c ratios of 2.0 or more are not uncommon—they quantify the demand for travel on a given link or set of links in relation to the available capacity. In reality, some drivers will choose alternate routes, modify trip start times, or both.

There are many equilibrium-based assignment techniques. While the methods vary, the same basic principle applies—when travel demand approaches capacity, some drivers will divert or reroute to alternate paths in order to reduce their travel times. Algorithms are applied, and this iterative process adjusts routes, travel times, and traffic volumes among alternative paths until an equilibrium state is reached.

Depending on the purpose of the forecast, the analyst should understand the basic differences between the assignment methods in determining the best one for the task at hand. Where appropriate, screenlines should be used and assignments made using both all-or-nothing and equilibrium methods so that total flow, available capacity, and potential diversion to alternative routes can be incorporated into developing the forecast.

5.6.2 Differences between Travel Demand Models and Traffic Simulation Models

Travel demand models and traffic simulation models treat demand in excess of capacity differently. In travel demand models, the excess demand is recognized and quantified. Some of the trips may be rerouted if an equilibrium-based assignment technique is used, but the excess demand is accounted for and allocated to network links. The excess demand may be damped over time (peak spreading), but it is quantified.

Traffic simulation models handle demand in excess of capacity differently. Vehicles are introduced to the network at entry nodes and the demand is quantified at the entry nodes. In this situation, capacity becomes the maximum rate at which the network links can serve or accommodate the demand. Once vehicles enter the network, system elements (e.g., lane capacities, traffic control devices, queues, etc.) dictate the rate at which the system can "process" the demand. Similar to patrons waiting in line for a ride at an amusement park, the excess demand is queued or stacked at the model boundary and is not seen by the analyst.

When using traffic simulation models for forecasting, the analyst must be aware of the unserved demand when evaluating oversaturated conditions. Most simulation models report "unserved trips" as one of the outputs. Unserved trips are composed of two trip types:

- Trips that begin but are not completed before the end of the simulation period and
- Trips that do not begin before the end of the simulation period.

Depending on the simulation model being used, these unserved trips may or may not be disaggregated by type. When demand exceeds capacity, one way to fully account for the demand is to extend the duration of the simulation period, without changing the demand, to a point where all of the trips can be processed. The aggregation of output link volumes (and node turning movements) should be referenced back to the original simulation period duration in order to accurately reflect the demand-to-capacity relationship.

Some simulation models include DTA capability, which applies the principles of equilibrium-based assignment techniques at an operational level of analysis. Using DTA, simulation models re-route vehicle trips through a congested network as a function of vehicle speeds, signal delay, and queues. Caution must be used in applying DTA within simulation. In principle, DTA techniques assume that drivers have some level of information about congested traffic conditions ahead and make route choices in real time based on that knowledge. The analyst should have a good understanding of the extent to which such information would be known by drivers before DTA is applied. In other words, how likely are drivers to divert when congestion is encountered, and what are their tolerances?

5.7 Computation Technology Issues and Opportunities

Today's inexpensive desktop computers are sufficiently powerful to run a basic conventional urban or statewide travel forecasting model. Computational resources can become stretched when advanced techniques are employed. The advanced methods most likely to cause problems are DTA, traffic microsimulation, and OD table estimation. Many models today require hard drive space measured in hundreds of megabytes or more per scenario. These requirements can increase if additional network, zonal, or computational detail is incorporated in the model.

Software developers are now looking toward "64-bit executables" to increase the amount of memory available to an application and looking toward parallel processing to speed up computations.

Computers that contain processing clusters of 1,024 or more are available, but the computer configuration that has the greatest immediate potential for travel demand models, at this writing, is the multicore desktop.

Software must be specially programmed to make use of more than one processor, but tests have shown a nearly proportional reduction in computation time to the number of processors, up to the limits of today's technology. Intel's "hyperthreading" technology essentially provides the equivalent of two processors per core.

Path building and network loading are the substeps in the basic travel forecasting model that take the most computation time. The computation times for these substeps increase linearly with the number of links in the network, the number of zones in the network, the number of required equilibrium iterations, the number of vehicle classes, and the number of DTA time intervals.

Therefore, computation time is closely related to the precision of the model in terms of spatial detail, network detail, temporal detail, and vehicle class detail. Vine building, which is important for project-level traffic forecasts, takes approximately three times longer than tree building using conventional methods. Planners and engineers may be reluctant to increase the precision of the model if the computation time becomes excessive.

OD table estimation from traffic counts is another time-consuming step. There are heuristic methods that are quicker than rigorous methods, so required computational resources depend on the software and the selected method. Different methods produce different results, so the trade-offs between quality and computation time savings are not straightforward. A typical rigorous method is whole-table estimation by least squares. This method can be applied statically or dynamically. The number of variables to be estimated is proportional to the number of origins, the number of destinations, and the number of time intervals. Computation time is usually estimated to be proportional to the square of the number of variables and proportional to the number of ground count stations. Thus, computation time increases rapidly with the amount of spatial and temporal detail.

OD table estimation can also stretch memory resources, particularly for dynamic applications. The largest consumer of memory is an array of the proportion of each OD pair's trips that pass each count station at each time interval. This array must be stored completely in memory during the estimation process.

CHAPTER 6

Model Output Refinements

Outputs from most travel models need to be checked and further refined to be used for highway project planning and design. This process of model checking, refining, and adjustment is an important part of traffic forecasting procedures. This chapter documents various procedures and standards in this refinement procedure. Following a determination that many procedures prescribed in *NCHRP Report 255* (*1*) are still valid and applicable in this context, some material from *NCHRP Report 255* was used in this chapter.

Chapter 5 detailed the types of outputs that a travel model generates. Each of these types of outputs requires the analyst to apply different refinement procedures. This chapter details all the available refinement procedures by grouping them into four broad categories—volume outputs, turning movements, directional splits, and speed (and travel time) outputs from the travel model.

Most travel models lack sufficient detail for producing accurate turning movement forecasts directly from model output. The limitations are both spatial and temporal. These spatial and temporal limitations are discussed below.

Spatially, while model network nodes can be used to represent physical roadway intersections and junctions, not all facilities for which turning movement forecasts may be desired are represented by a typical network link-node configuration. Some intersections involving driveways and lower hierarchy streets may be omitted from the model network or may be consolidated to simplify the link-node scheme. The result is that those intersections included as nodes within the network sometimes act as surrogate intersections for lower-order intersections that are omitted from the network, and the resulting turning movements represent an accumulation of local turning activity within that part of the network. Other nodal intersections may include a "leg" that is actually a centroid connector, either as a replacement for one of the approach legs or in addition to all of the physical approaches; thus an artificial set of turning movements is introduced at the node. Where equilibrium-based traffic assignments are employed, nodal turning movements may vary significantly from observed intersection turning movements as a function of other network parameters not specific to the intersection. In short, model network limitations alone are a good reason to avoid using turning movement outputs directly.

Temporally, turning movement analyses are typically applied in increments of 1 hour or a shorter duration. Travel demand models often are 24-hour models or time-of-day (TOD) models that are aggregated into multi-hour periods. While bi-directional link volumes may be reported, the apparent directionality of the link volumes is more a function of trip balancing than of actual travel characteristics. Thus, where turning movement forecasts are needed, a process of converting daily or peak-period volumes to peak-hour directional volumes is needed.

Turning movement forecasts should begin with existing turning movement counts or a reasonable estimation of turning movement activity in the absence of counts. It is important to recognize the effect that land use and particularly land use changes can have on travel patterns and turning movement activity. A new development in one quadrant of an intersection can cause a significant change in turning activity. Thus, while collection of existing traffic count data is important, the need for professional judgment cannot be overlooked, especially when anticipated land use changes will alter area traffic patterns.

The methods discussed in this section provide alternative ways to develop turning movement forecasts from travel model output, depending on the output level of detail. The methods can be applied using 24-hour or TOD traffic assignments, directional or non-directional volumes, and with or without model turning movement assignments.

There are three categories of procedures for forecasting turning movements from model output:

- Factoring procedures (see Sections 6.2 and 6.3),
- Iterative procedures (see Sections 6.4 and 6.5), and
- "T" intersection procedures (see Sections 6.6 and 6.7).

Factoring procedures are the simplest, but may be limited in their applicability. They require base year turning movement counts, base year turning movement assignments, and future year turning movement assignments. Factoring procedures assume that traffic patterns will remain relatively constant between the base year and forecast year. When travel patterns are expected to change significantly (for example, a major new development near one of the intersection approaches), other procedures may be more appropriate. Factoring procedures include the ratio method and difference method.

Iterative procedures differ depending on whether directional or non-directional volumes are used for the approach links. The directional volume procedure adjusts future year turning movements based on either base year turning movement counts or future year turning movement estimates and the ratio of approach link forecasts to link counts. The process may involve multiple iterations to reach the desired level of closure and is most frequently applied using a spreadsheet or other computational software. The non-directional volume procedure is considerably more subjective and requires the analyst to produce a reasonable estimate of turning percentages as an input to the process. This procedure is most appropriate when only minimum information is available—estimated turning percentages at the intersection and bi-directional link volumes. The procedure should be used mainly for planning and preliminary engineering applications, not for design.

"T" intersection procedures are used for intersections having only three approach legs. Directional turning volumes can be computed if the approach volumes and at least one turning movement are known. Where only two-way turning movements are available, a unique solution can be obtained if directional approach volumes are known. Table 6-1 provides guidance on which procedure should be applied based on available input data.

While all these procedures attempt to refine outputs from a travel model to be used in developing project-level traffic forecasts, the analyst must always apply professional judgment during and following the applications of these procedures. Reasonable checks, engaging stakeholders with local knowledge, and accounting for any extraneous factors that the travel models might not be able to capture are recommended in order to successfully apply the following procedures.

6.1 Screenline Refinement with Base Volumes

This section shows how model output volumes can be refined by adjusting the trip tables using screenline- (or intersection-) based refinement techniques that can be achieved by adjusting base volumes and capacities.

6.1.1 Abstract

Small projects often affect traffic in a localized area only. For these projects, region-wide travel model outputs need to be checked and further refined to obtain the desired results. This technique can also be applied to refine screenline volumes for the regional travel demand model for future assignment forecasts. These techniques are often applied in spreadsheets after collecting all the relevant input data. Detailed description of the input data, a sample spreadsheet, and example calculations are provided in this section.

6.1.2 Context

Typical applications include new corridors/facilities, site impact studies, road diet/cross-section modification, lane widening, equivalent single axle loads (ESALs)/load spectra, access management, intersection design, and detours.

Table 6-1. Turning movement forecasting procedures and input elements.

Input Elements	Procedure			
	Factoring (Ratio or Difference Method)	**Iterative—Directional Volume Method**	**Iterative—Non-Directional Volume Method**	**"T" Intersection**
Turning Movements	Base Year Count Base Year Assignment Future Year Assignment	Base Year Count or Estimated Turning Percentages	Estimated Turning Percentages	Future Year Directional (one turning movement known or estimated)
Link Volumes		Base Year Directional Volume Future Year Directional Assignment	Base Year Bi-Directional Assignment Future Year Bi-Directional Assignment	Base or Future Year Bi-Directional Base or Future Year Directional

Geography is site, corridor, and small area.

Typical time horizons are short range, interim, and long range.

Required input data are traffic counts, travel demand model results for base and forecast year, traffic network, and recent intersection counts.

Optional input data are turning movement counts.

Related techniques are screenline refinements with traffic counts and screenline refinements with additional network details.

6.1.3 Background

Screenline refinement procedures were previously documented in Chapter 4 of *NCHRP Report 255* (*1*). The future year link volumes are adjusted by the procedure across a screenline based on relationships among base year traffic counts, base year assignments, and future year link capacities.

6.1.4 Why This Technique

The purpose of the screenline refinement procedure is to improve upon the link-by-link traffic forecasts produced by travel demand models. These procedures are also needed to adjust travel demand models to ground counts before using them for project-level traffic forecasts.

6.1.5 Words of Advice

The most accurate results from screenline refinements are obtained if the inputs include reasonably good base year traffic counts, a base year assignment, and a future year forecast. The procedure has less validity if base year data are not available. In addition, the procedure is not always suitable for use in situations where only one or two link volumes are in need of refinement. The procedure is also limited to situations in which reasonable screenlines can be constructed across parallel facilities. Accuracy is lost when non-parallel facilities are introduced into the screenline.

6.1.6 Executing the Technique

6.1.6.1 Special Data Preparation

Before applying these refinement procedures, the analyst must gather all the required input data. The following five items need to be assembled:

1. **Definition of study area.** In general, all the facilities impacted by the project in consideration must be included in the study area. In this context, words of advice from the Ohio Department of Transportation's (DOT's) traffic forecasting manual are presented (*2*):

   > Care should be taken to distinguish the project study area defined by the project manager from the traffic analysis study area defined by the traffic forecasting analyst. The project study area will most likely have been based on other factors such as environmental impacts while the traffic analysis study area should encompass all areas whose traffic will be significantly impacted by any of the project alternatives (consider, for example, remediation of a short bottleneck such as a narrow bridge within existing right of way whose project study area might be quite small while its traffic impacts could be regional). When the two study areas are different, coordination should occur to determine if the project study area should be revised. If the project study area ends up larger than the traffic analysis study area, the project study area should be used for traffic analysis, otherwise the traffic analysis study area (henceforth simply called the study area) is used. A study area should at a minimum include the following parts of the network:
   >
   > – The next parallel facility to either side of the project facility
   > – Two intersections or interchanges before and after the last one impacted by the project and one beyond the parallel facilities on cross routes
   > – All of the remaining network facilities connected to and bounded by these
   >
   > For large major projects and above, a preliminary traffic assignment using the alternative likely to produce the greatest impact can be compared to the base case to determine links with "significant impact." In this case, the study area could be defined to include the links with more than a 10% change in traffic volumes between the base case and the alternative scenario, but at a minimum would still include the area defined by the three bullet points above.

2. **Definition of base and future year.** The specific years for which refinement of traffic volumes is desired. Sometimes the project opening year or the design year may not match the base or future year. In this case, the analyst needs to adjust the traffic forecasts to these specific years, the process for which is also detailed in this section.
3. **Identification of link and node characteristics.** The analyst must identify the links (or screenlines) that are of interest and collect all the necessary information about facility types, number of lanes, length, directionality, type of traffic control, and adjacent land use characteristics.
4. **Base year traffic counts.** These should be obtained from any data that might be available from local, regional, or state agencies. Count data by time of day and directionality can be obtained, if available.
5. **Base and future year assignment results.** These should be obtained from the model runs. The model runs need to be performed after taking into account any possible

capacity-related adjustments that need to be made due to the project.

6.1.6.2 Technique Configuration

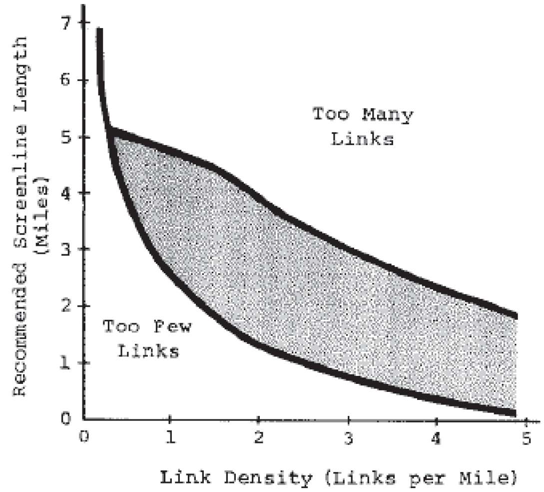
Typically, screenline refinement is performed in a spreadsheet after gathering all the inputs mentioned above. An example spreadsheet (Traffic_Volumes_Refinement.xlsx) illustrating the concept of screenline/intersection refinement (similar to the one developed and used by the Ohio DOT) is provided on *CRP-CD-143*, which is bound into this report. An .iso image of *CRP-CD-143* and instructions for burning this image onto a CD-ROM are available on the *NCHRP Report 765* web page on the TRB website.

6.1.6.3 Steps of the Technique

STEP 1. Define the List of Screenline/Intersections of Interest

The first step in the process is to select screenlines that will be used to adjust volumes. *NCHRP Report 255* (*1*) provides a guideline for selecting screenlines that are still valid and are widely adopted in the industry. For the convenience of the user, these guidelines are repeated here:

> Selecting the screenlines for analysis is not always a straightforward process. In areas where roadways parallel one another for several miles or where geographic boundaries clearly define alternative routes (e.g., river crossings), screenlines are fairly easy to select. However, there will be a number of instances where these situations do not occur in any study area. Screenlines should, therefore, be based on judgment and a familiarity with roadway network. It is suggested that the following guidelines be used in developing screenlines:
>
> 1. Determine the context with which the screenlines will be used. Generally one or more of the following situations will apply:
>   - Small area analysis.
>   - Wide corridor analysis.
>   - Regional analysis.
>
>   The scale of the analysis will dictate both the length of the screenline and the number of screenlines to be analyzed.
> 2. A screenline should intersect roadways that represent likely alternatives for directional traffic within a corridor. In some areas, the screenlines should be curved to follow a natural barrier such as a river or hill. However, meandering or diagonal-type roadways should be avoided. . . .
> 3. In most cases, zone connectors that are crossed by a screenline should not be included in the analysis. . . .
> 4. A screenline should cross a minimum of 3 roadways and preferably no more than 7 roadways. . .
> 5. Screenlines should be no longer than necessary. Figure A-7 [see Figure 6-1] provides a guide for selecting screenline length based on link density. For instance, in densely developed areas with many roadways, a practical limit of 2 miles is suggested, while in outlying, less dense areas, 4 to 5 miles would represent a reasonable screenline length. . . .



Source: *NCHRP Report 255,* Figure A-7, p. 48 (*1*).

Figure 6-1. Guide for selecting screenline lengths.

> 6. Separate screenlines should be constructed midway between major roadway crossings or every 2 miles—whichever is less. This is important because link traffic volumes along a facility can change considerably within a short distance, especially on either side of a major intersection or interchange. Comparison of results from parallel screenlines will be a major check of reasonableness of the refinement procedure.

STEP 2. Check Base Year Results

Chapter 5 detailed the procedures and measures used to compare the model outputs with traffic counts. In the screenline refinement procedure, the user should use one such procedure of checking percentage deviation of screenline assignments in base year with counts in base year. If the deviation is too large, the analyst must not proceed further and should work on rerunning the model and checking the model results and intermediate steps. The analyst can also consider extending the screenline length to include additional facilities. This would help in reducing the deviations across screenline.

STEP 3. Perform Spreadsheet Computations

The spreadsheet identifies required inputs by light-yellow-colored cells and optional inputs by light blue color. The output (adjusted future assignment) results are shown in dark blue. Enter the following data into the spreadsheet for each link in the screenline or each leg of intersection:

1. Road/link—road name or link ID for each link.
2. Count year—year of the actual base year traffic count.
3. Count—actual base year traffic count.
4. Af—future year traffic assignment (see Table 6-2 for a definition of this variable).
5. Most recent count year (optional)—year of the most recently available actual count data.

Table 6-2. Description of fields in spreadsheet.

Column	Variable	Definition
1	Road/Link	The name/route number of each facility bisected by the screenline and/or the link numbers from network.
2	Min Diff	Minimum Count/Model Ratio for using differences, below this use ratios alone.
3	Max Rat	Maximum Count/Model Ratio for using ratios, above this use differences alone.
3.5	Use SL	Set to "Enable" to allow use of screenline adjustments for this leg. If no count available, set to "Disable" to disable giving no adjustment of model result. Set to "Force" to force SL adjustment
4	COUNT Year	Year of the actual base year traffic count.
5	COUNT	Actual base year traffic count.
6	Ab	Base year traffic assignment—user to input year.
7	$Ab^{interpolate}$	Interpolation between base and future year assignment—used when year of count data differs from base year assignment. If opening year no-build exists, use opening year no-build to base year interpolation. If opening year no-build does not exist, use design year to base year interpolation.
7.1	R	Calculated Ratio (COUNT/Ab).
7.2	D	Calculated Difference (COUNT - Ab).
7.3	MR	Model Ratio (Af - D/Ab).
7.4	SLR	Screenline Ratio (Σ Count/ Σ Ab).
8	Af	Future year traffic assignment Af-D: (near) design year model run. Af-ON: (near) opening year no-build run (optional) Af-OB: (near) opening year build model run (optional).
8.5	SLRATIO	Adjusted future year traffic forecast (Σ Count/ Σ Ab)*Af.
9	RATIO	Adjusted future year traffic forecast (COUNT/Ab) * Af.
10	DIFF	Adjusted future year traffic forecast (COUNT - Ab) + Af.
10.5	MRATIO	Adjusted future year traffic forecast. Modified "ratio method" to weight towards DIFF method for large model increases. If MR < 1 then MRATIO = RATIO. else MRATIO = ((MR-1)*DIFF + RATIO)/MR.
11	RAf	Adjusted future year traffic forecast (AVERAGE[MRATIO,DIFF]).
12	Selected Adjustment	Selects the type of future year adjustment based on the ratio of actual base year traffic count to interpolated base year traffic assignment. *If MR < 1 then* *if RATIO ≤ 1.0 then use RATIO,* *if RATIO ≥ 2.0 then use DIFF,* *else use RAf,* *If MR > 1 then* *if RATIO ≤ 0.5 then use MRATIO,* *if RATIO ≥ 2.0 then use DIFF,* *else use RAf (based on MRATIO)*
13	Selected Volume	Selected adjusted forecast year model volume
14	Most Recent Count Year	Year of the most recently available actual count data (should be less than opening year. If opening year is same as base year, then generally will not use).
15	Most Recent Count Data	Most recently available actual count data for the facility.

Table 6-2. (Continued).

Column	Variable	Definition
16	Recent Count Delta	Forecast adjustment based on difference of more recent count from interpolation resulting from base count and first forecast year.
17	Opening Year	Final refined forecast for the opening year—user to input year.
18	Design Year	Final refined forecast for the design year—user to input year.
19	Growth Factor Opening Year	Growth factor to apply to most recent count to obtain opening year (Set to 1.0 if no count given).
20	Growth Factor Design Year	Growth factor to apply to most recent count to obtain design year (Set to 1.0 if no count given).

6. Most recent count data (optional)—most recently available actual count data for the facility.

Table 6-2 provides a description of all the fields used in the spreadsheet and the options that users can choose to adjust future year assignment results.

General notes on the screenline refinement technique are the following:

- If Columns 2 and 3 in the spreadsheet are set to very large values, then the ratio method will be enforced. If Columns 2 and 3 are set to zero, then the difference method will be enforced.
- Make sure that the model opening year (if used) is greater than the existing year and less than the forecast year. An exception to this rule would be situations in which the base year runs are used to establish trends. In such cases, set Af-ON = Ab, set the model opening year = base year = count year. Also, place the build run results in Af-OB (Col. 8b) and do not use Columns 14 and 15 in this case.
- The spreadsheet can be used to interpolate and calculate a growth rate for a non-model forecast. To do so, the user is directed to enter the volumes in Column 8 (Af), then copy Column 5 to Column 6, and set the model base year to the count year.
- The design year no-build is a separate alternative; the user is to create a new sheet for it.
- The spreadsheet can be used to develop an opening year build forecast or both opening year build and no-build forecasts, but it cannot be used to develop only an opening year build forecast unless the link is a new link.
- A new link is assigned a growth rate of 1.0. In order to forecast turning movements for new links, the user must enter the model turns in Section 2 of the turning movement worksheets.
- The user is to leave a field blank (and not zero) if it is to be ignored (i.e., a value of zero in a field is interpreted as zero). If a link does not exist in the base year, the count field ("Ab") is left blank. If a link does not exist in the build year, a zero should be entered in this field (Af-OB actually controls this).
- As a cautionary note, the original authors of this spreadsheet tool made no guarantee that a forecast volume of zero will be carried through as zero by the *NCHRP Report 255* method adjustments.
- If there is an existing intersection link that does not exist in the model, its counts should be entered in the appropriate places in the link volume and turning movement worksheets. The user will need to override Columns 19 through 20 of the link volume worksheet sheet with exogenously supplied growth rates.
- If there is a new intersection on an existing road, the user can enter the mainline counts or traffic model volumes (Ab and Af-ON) in the link volume and turning movement worksheets (as through movements) and then enter the full set of volumes/turns for Af-OB and Af-D. The user may opt to disable screenlines in this case.

6.1.7 Illustrative Example

The calculation steps involved in screenline refinement procedures are presented in spreadsheet format along with this report. As an example, the intersection of SR 18 at Mitchell Road is analyzed. For this example, the year of base traffic counts is 2011, base year of the model is 2008, model forecast year is 2038, while the project opening and design years are 2016 and 2036. Other relevant input data are incorporated into the spreadsheet. The spreadsheet with the input data is shown in Table 6-3. The spreadsheet following completion of Steps 1 through 3 (shown in Section 6.1.5.3) is shown in Table 6-4. It should be pointed out that the two-way link volumes shown in this illustrative example are relatively low. The spreadsheet that is available with this guidebook (Traffic_Volumes_Refinement.xlsx) can be applied in situations having higher traffic volumes.

Table 6-3. Spreadsheet form with input data.

(1) Road/Link	(2) Min Diff	(3) Max Rat	(3.5) Use SL	(4) Count Year	(5) Count Data	(6) Ab	(7) $Ab^{interpolate}$	(7.1) R	(7.2) D	(7.3) MR	(7.4) SLR
SR 18 (State St)	0.5	2	Enable	2011	2215	1687					
Mitchell Rd	0.5	2	Enable	2011	520	416					
SR 18 (Deshler Rd)	0.5	2	Enable	2011	2011	1861					
Mitchell Rd	0.5	2	Enable	2011	592	157					

(8) Af-D	(8.5) SLRATIO	(9) RATIO	(10) DIFF	(10.5) MRATIO	(11) RAf	(12) Adj.	(13) Vol.	(14) Count Year	(15) Count Data	(16) Delta	(17) Opening Year	(18) Design Year	(19) Opening Year Growth Factor	(20) Design Year Growth Factor
912								-	-					
848								-	-					
0								-	-					
1167								-	-					

Table 6-4. Completed spreadsheet.

(1) Road/Link	(2) Min Diff	(3) Max Rat	(3.5) Use SL	(4) Count Year	(5) Count Data	(6) Ab	(7) $Ab^{interpolate}$	(7.1) R	(7.2) D	(7.3) MR	(7.4) SLR
SR 18 (State St)	0.5	2	Enable	2011	2215	1687	2243	0.99	-28	0.41	0.99
Mitchell Rd	0.5	2	Enable	2011	520	416	490	1.06	30	1.73	0.99
SR 18 (Deshler Rd)	0.5	2	Enable	2011	2011	1861	2479	0.81	-468	0.00	0.99
Mitchell Rd	0.5	2	Enable	2011	592	157	184	3.22	408	6.34	0.99

(8) Af-D	(8.5) SLRATIO	(9) RATIO	(10) DIFF	(10.5) MRATIO	(11) RAf	(12) Adj.	(13) Vol.	(14) Count Year	(15) Count Data	(16) Delta	(17) Opening Year	(18) Design Year	(19) Opening Year Growth Factor	(20) Design Year Growth Factor
912	902	901	884	901	893	RATIO	901	-	-	0	804	892	0.363	0.403
848	839	900	878	891	885	RAf	885	-	-	0	750	873	1.442	1.679
0	0	0	-468	0	-234	RATIO	0	-	-	0	0	0	0.000	0.000
1167	1154	3755	1575	1919	1747	DIFF	1575	-	-	0	1372	1557	2.318	2.630

6.2 Factoring Procedure—Ratio Method

6.2.1 Abstract

Factoring procedures are used to predict future year turning movements based on the relationship between base year turning movement counts and base year model turning movement assignments. The assumption is that future turning movements will be similar in nature to existing turning movements. Based on this assumption, future year turning movements can be estimated by comparing the relative ratios between base year and future year turning movement assignments. The procedure can be applied for both directional and non-directional turning movements.

6.2.2 Context

Typical applications are intersection design, intersection capacity analysis, site impact studies, traffic signal timing, and interchange studies.

Geography is site, corridor, and wide area.

Typical time horizons are short range, interim, and long range.

Required input data are traffic counts, traffic model link assignments.

Optional input data are turning movement estimates and manual link forecasts.

Related techniques are factoring procedure—difference method, iterative turning movement estimation procedures, and "T" intersection turning movement estimation procedures.

An advantage of the ratio method is that it is simple to use and can be applied manually or implemented in software.

A disadvantage is that the ratio method needs more data than other related techniques.

Case study is Case Study #1 - Arterial.

6.2.3 Background

The ratio method was previously documented in *NCHRP Report 255* (*1*). The procedure requires base year intersection turning movement counts, base year traffic model turning movement assignments, and future year traffic model turning movement assignments as input. Future year turning movement forecasts are estimated by comparing relative ratios between the base year counts and turning assignments and applying those relationships to future model turning movement assignments.

6.2.4 Why This Technique

Accurate intersection turning movement projections are needed for a variety of applications, including intersection design, traffic signal timing, site impact studies, interchange justification/modification studies, and air quality analyses.

6.2.5 Words of Advice

6.2.5.1 Caveats

The ratio method should be used with caution. Significant differences between the base year forecasts and future year forecasts may produce unreasonable results, especially if there is a significant change in land use within the study area. A zero or very low value for any of the three terms on the right-hand side of the equation—base year count for turning movement i (BC_i), future year model assignment for turning movement i (FA_i), or base year model assignment for turning movement i (BA_i)—may have a significant effect on the forecast, FF_{ri}. Traffic model assignments should be checked for reasonableness before this method is used. The method assumes that base year turning movement counts are correct.

6.2.5.2 Special Considerations

For the ratio method only, if base year turning volumes are not available, approach link volumes may be substituted for BC_i and BA_i. This substitution will result in each turning movement on a given approach being adjusted by the same ratio. This substitution does not produce an adjustment as specific as that derived by using individual base year turning movements, but it will account for major differences between the base year and forecast year.

6.2.6 Executing the Technique

The ratio method creates a future year turning movement forecast by applying the ratio of the future year model turning movement assignment to the base year model turning movement assignment and multiplying that by the base year turning movement count. The method form is the following:

$$FF_{ri} = BC_i * \left(\frac{FA_i}{BA_i}\right)$$

where

FF_{ri} = future year forecast volume for turning movement i,
BC_i = base year count for turning movement i,
FA_i = future year model assignment for turning movement i, and
BA_i = base year model assignment for turning movement i.

Turning movement forecasts are computed individually and summed to get the approach volumes. The method can be applied for both 24-hour and TOD model turning movement assignments. When TOD model assignments are used, the turning movement counts, assignments, and forecasts all should be for the same general time period (PM peak, for example).

Data needed for the technique are the following:

- Base year intersection turning movement counts,
- Base year traffic model turning movement assignments, and
- Future year traffic model turning movement assignments.

6.2.7 Illustrative Example

In the following illustrative example, the data are as follows:

- Count = 200 vehicles per hour (VPH),
- Base year turning movement assignment = 260 VPH, and
- Future year turning movement assignment = 500 VPH.

In this example, applying the method yields the following result:

$$FF_{ri} = BC_i * \left(\frac{FA_i}{BA_i}\right) = 200 * \frac{500}{260} = 385$$

The method can be applied using the ratio of 24-hour assigned turning movements as well. In this case, the data are as follows:

- Count = 350 VPH,
- Base year turning movement assignment = 3,700 average daily traffic (ADT), and
- Future year turning movement assignment = 4,800 ADT.

In this case, applying the method yields the following:

$$FF_{ri} = BC_i * \left(\frac{FA_i}{BA_i}\right) = 350 * \frac{4,800}{3,700} = 455$$

6.3 Factoring Procedure—Difference Method

6.3.1 Abstract

Factoring procedures are used to predict future year turning movements based on the relationship between base year turning movement counts and base year model turning movement assignments. The assumption is that future turning movements will be similar in nature to existing turning movements. Based on this assumption, future year turning movements can be estimated by comparing the relative differences between base year and future year turning movement assignments. The procedure can be applied for both directional and non-directional turning movements.

6.3.2 Context

Typical applications are intersection design, intersection capacity analysis, site impact studies, traffic signal timing, and interchange studies.

Geography is site, corridor, and wide area.

Typical time horizons are short range, interim, and long range.

Required input data are traffic counts and traffic model link assignments.

Optional input data are turning movement estimates and manual link forecasts.

Related techniques are factoring procedure—ratio method, iterative turning movement estimation procedures, and "T" intersection turning movement estimation procedures.

Advantages of the difference method are that it is simple to use and can be applied manually or implemented in software.

A disadvantage is that the difference method needs more data than other related techniques.

Case study is Case Study #1 - Arterial.

6.3.3 Background

The difference method was previously documented in *NCHRP Report 255* (*1*). The procedure requires base year intersection turning movement counts, base year traffic model turning movement assignments, and future year traffic model turning movement assignments as input. Future year turning movement forecasts are estimated by comparing relative differences between the base year counts and turning assignments and applying those relationships to future model turning movement assignments.

6.3.4 Why This Technique

Accurate intersection turning movement projections are needed for a variety of applications, including intersection design, traffic signal timing, site impact studies, interchange justification/modification studies, and air quality analyses.

6.3.5 Words of Advice

6.3.5.1 Caveats

The difference method should be used with caution. Careful attention must be paid to the correct signs so that volumes are added and subtracted correctly. Significant differences between the base year forecasts and future year forecasts may produce unreasonable results, including negative volumes. Traffic model assignments should be checked for reasonableness before this method is used.

6.3.5.2 Choosing between the Ratio and Difference Methods

While both ratio and difference methods are categorized as factoring procedures, these methods can produce dramatically different results, especially where model errors might exist. Furthermore, most models are not capable of generating accurate turning movements unless they account for turning movement delay. However, valid results can be obtained when the relative relationship between base year and future year assignments is applied to existing turning movements. The relationship between the two is assumed to be correct even if the model assignment is off. For these reasons, the ratio method is better, particularly over a longer time horizon.

A fundamental assumption of both the ratio and difference methods, as stated previously, is that future turning movements will be similar in nature to existing turning movements. This assumption can be extended to land use, general development patterns, and resulting traffic patterns within the area. *NCHRP Report 255* discussed averaging the results from the ratio and difference methods as a means to reduce the extremes that may be reached by one of the individual methods. While averaging the results from the two methods may indeed reduce the extremes, it is also believed that averaging will reduce the accuracy of one method or the other. It is advised that the analyst evaluate the results from both methods within the context of existing traffic volumes and turning movements and select a preferred method.

6.3.6 Executing the Technique

The difference method creates a future year turning movement forecast by applying the difference between the base year turning movement count and the base year model assignment to the future year model turning movement assignment. The method form is the following:

$$FF_{di} = FA_i + (BC_i - BA_i)$$

where

FF_{di} = future year forecast volume for turning movement i,
FA_i = future year model assignment for turning movement i,
BC_i = base year count for turning movement i, and
BA_i = base year model assignment for turning movement i.

Turning movement forecasts are computed individually and summed to get the approach volumes. The method can be applied only when the counts and model assignments are within the same analysis period (hourly, for example).

Data needed for the technique are the following:

- Base year intersection turning movement counts,
- Base year traffic model turning movement assignments, and
- Future year traffic model turning movement assignments.

6.3.7 Illustrative Example

In the following illustrative example, the data are as follows:

- Count = 200 VPH,
- Base year turning movement assignment = 260 VPH, and
- Future year turning movement assignment = 500 VPH.

$$FF_{di} = FA_i + (BC_i - BA_i) = 500 + (200 - 260) = 440$$

6.4 Iterative Procedure—Directional Method

6.4.1 Abstract

Iterative procedures can be applied to produce either directional or non-directional turning volumes. The directional method uses an iterative approach to alternatively balance entering traffic and departing traffic volumes until an acceptable level of convergence is reached. The method requires an initial estimate of turning percentages at an intersection.

6.4.2 Context

Typical applications are intersection design, intersection capacity analysis, site impact studies, traffic signal timing, and interchange studies.

Geography is site, corridor, and wide area.

Typical time horizons are short range, interim, and long range.

Required input data are traffic counts and traffic model link assignments.

Optional input data are turning movement estimates and manual link forecasts.

Related techniques are iterative procedure—non-directional method, "T" intersection turning movement estimation procedures, and factoring procedures.

Advantages of the iterative procedure—directional method are that it is simple to use and can be applied manually or implemented in software.

A disadvantage is that the iterative procedure—directional method needs more data than other related techniques.

Case study is Case Study #1 - Arterial.

6.4.3 Background

The iterative procedure—directional method was previously documented in *NCHRP Report 255*. The method has been automated through spreadsheets and other computational software and has been applied by numerous transportation agencies and consultants. The method requires directional link volume forecasts and an estimate of intersection turning movement percentages. Estimated turning percentages can be based on existing turning movement counts, turning movement patterns at similar intersections, or professional judgment associated with knowledge of nearby land use or travel patterns.

The method alternatively balances intersection approach (inflow) and departure (outflow) volumes in an iterative process until an acceptable level of convergence is reached. The number of required iterations is dependent on the ability of the analyst to estimate turning percentages.

There have been other iterative directional methods or variations of this method developed in the past. However, this iterative technique, as initially documented in *NCHRP Report 255*, has been most widely understood and applied by practitioners since it was introduced.

6.4.4 Why This Technique

Accurate intersection turning movement projections are needed for a variety of applications, including intersection design, traffic signal timing, site impact studies, interchange justification/modification studies, and air quality analyses.

6.4.5 Words of Advice

This method is intended for general planning purposes where approximate directional turning movements are desired. It is most commonly applied to four-legged intersections, but also can be applied for intersections with more than four legs by adding the appropriate rows and columns to the turning movement matrix.

6.4.6 Executing the Technique

The directional method uses an initial estimate of intersection turning movement percentages to alternatively balance intersection approach (inflow) and departure (outflow) volumes in a turning movement matrix until an acceptable level of convergence is reached. Initial turning movements are frequently obtained from existing turning movement counts, but also can be estimated if no counts are available. Future year link volumes are fixed, and turning movements in the matrix are adjusted to match the approach and departure volumes. The number of required iterations depends on the desired level of convergence. Where large differences between base year conditions and future year forecasts are expected to occur, several iterations may be required. Normally, the volumes converge in 6 to 10 total iterations.

6.4.6.1 Data Needed

Data needed for the technique are the following:

- Directional future year link volume forecasts and
- Base year intersection turning movement counts *or* estimated intersection turning movement percentages.

Future year link volumes may be obtained either from a travel demand model or by using one of the other manual techniques discussed in this guidebook. It is preferable that base year turning movement data be obtained from actual intersection counts, but a traffic model assignment may provide a suitable initial estimate of turning movement activity in the absence of turning movement counts. If actual counts or a model assignment are not available, the analyst will need to make a reasonable estimate of turning movement percentages as an input to the process.

6.4.6.2 Steps of the Technique

The directional volume method consists of five steps, as illustrated in Figure 6-2. Steps 4 and 5 may be repeated, depending on the number of iterations required to reach the desired level of convergence.

The following notation is used in the process:

n = number of intersection legs,
b = base year,
f = future year,
O = inflows ("from Origin"),
D = outflows ("to Destination"),
i = inflow (origin) link number,
j = outflow (destination) link number,
T = traffic volume,
P = estimated percentage of traffic flow (expressed in decimal form), and
* = adjusted value in each iteration.

Notation is combined to define the elements that make up the method:

O_{ib} = base year inflow to the intersection on link *i*,
O_{if} = future year inflow to the intersection on link *i*,
D_{jb} = base year outflow from the intersection on link *j*,
D_{jf} = future year outflow from the intersection on link *j*,
T_{ijb} = base year traffic flow entering through link *i* and departing through link *j*,
T_{ijf} = future year traffic flow entering through link *i* and departing through link *j*, and
P_{ijf} = future year estimated turning movement percentage (expressed in decimal form) of traffic flow entering through link *i* and departing through link *j*.

The elements are illustrated in Figure 6-3.

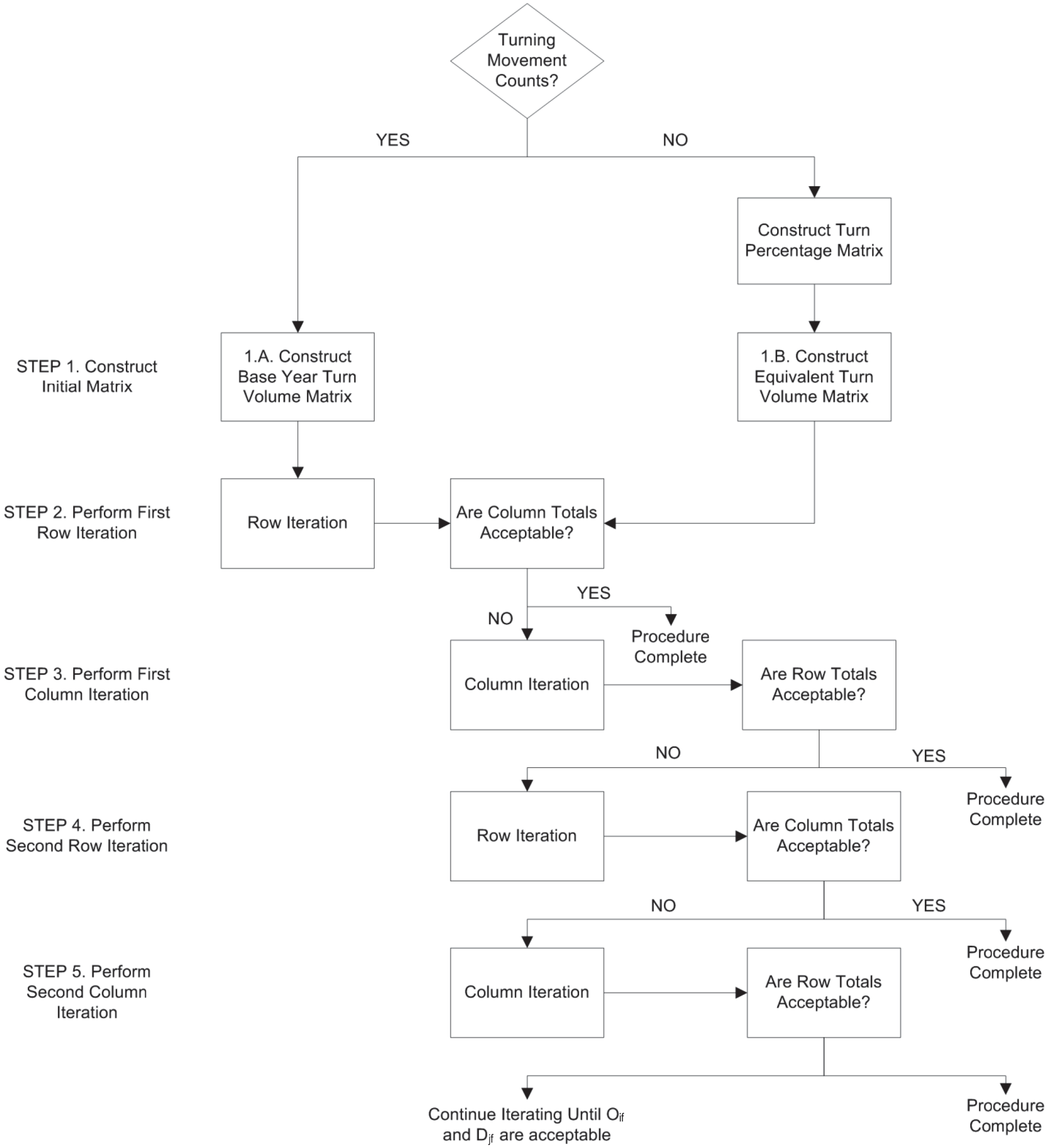


Figure 6-2. Directional turning volume iterative procedure.

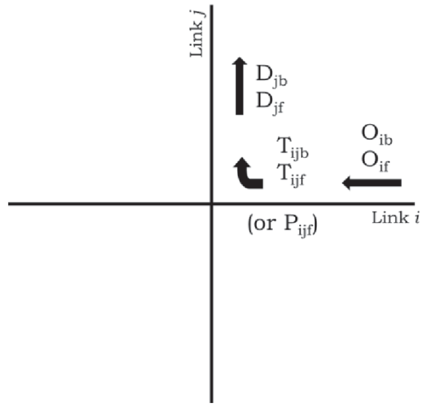


Figure 6-3. Directional turning movement iterative procedure elements.

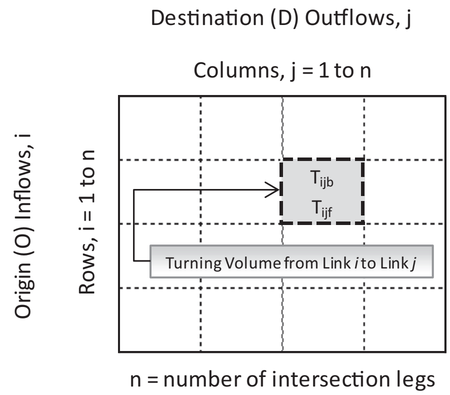


Figure 6-4. Turning movement matrix framework.

The computational steps (Steps 1 through 5) are described below.

STEP 1. Construct Initial Turning Movement Matrix

In the first step, turning movements are assembled into an initial matrix to be used in the iterations. The framework for the matrix is illustrated in Figure 6-4.

The matrix is a square matrix, with one row and one column for each intersection leg (link). Intersection inflows (origins) are arranged in matrix rows and outflows (destinations) are arranged in matrix columns. Each cell in the matrix represents the corresponding turning movement "from link *i* to link *j*." Diagonal elements ($i = j$) always will be zero unless U-turns are allowed.

As shown in Figure 6-2, the way that the matrix is constructed depends on whether or not base year turning volumes are known.

STEP 1.A. Base Year Turning Volumes Known

When base year turning movements are known, they are assembled in the matrix as shown in Figure 6-5.

An example set of turning movements and the assembled matrix are shown in Figure 6-6.

If base year turning movements are not known, skip this step and go to Step 1.B.

STEP 1.B. Base Year Turning Volumes Unknown

When estimated future turning percentages are used, the assembled matrix is shown in Figure 6-7.

An example set of estimated turning percentages and the assembled matrix are shown in Figure 6-8.

Row totals of P_{ijf} must equal 1.00. Column totals will not equal 1.00 except by coincidence, but the sum of all columns (and the sum of all rows) should equal the total number of intersection legs times 1.00 (e.g., for a four-legged intersection, ΣProws, ΣPcolumns = 4 x 1.00 = 4.00).

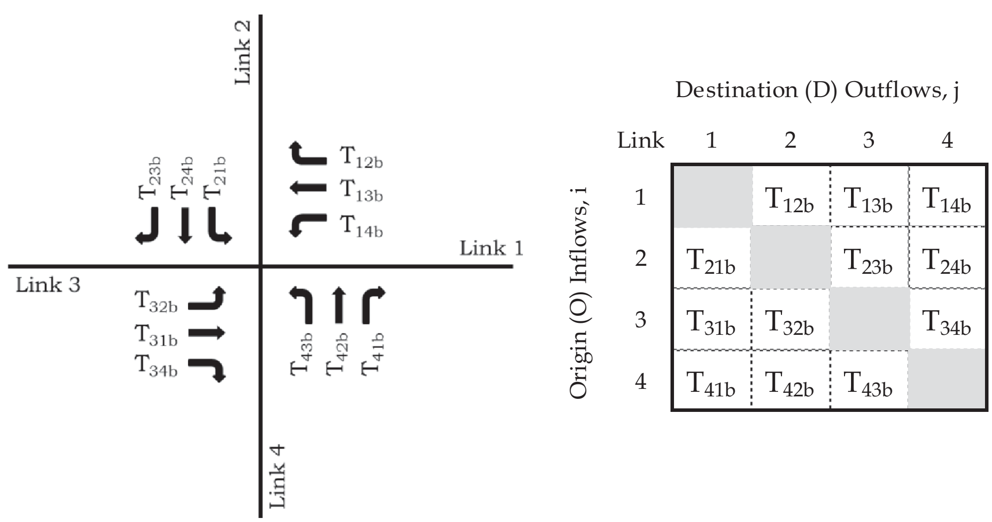
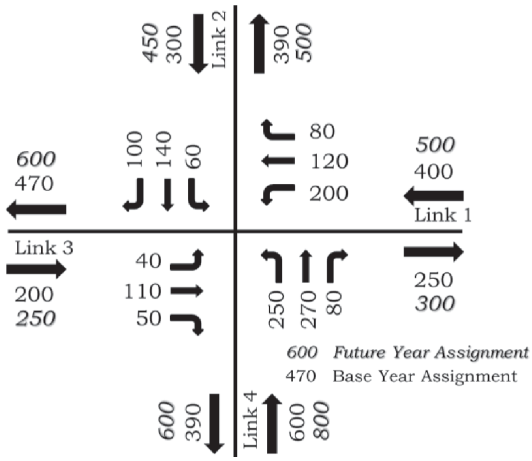


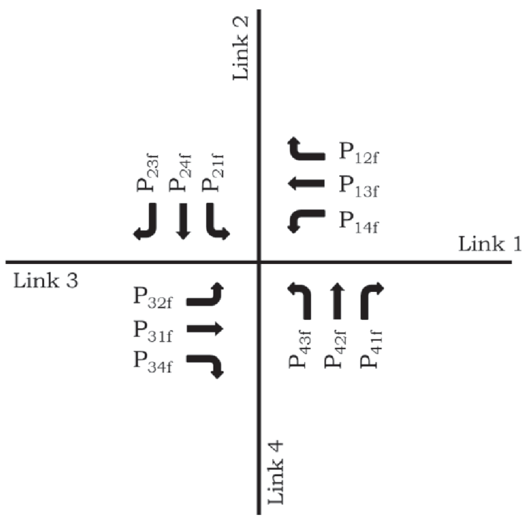
Figure 6-5. Iterative procedure—turning movements known.



Destination (D) Outflows

Origin (O) Inflows						
Future Year		*300*	*500*	*600*	*600*	D_{jf}
	Base Year	250	390	470	390	D_{jb}
500	400	0	80	120	200	
450	300	60	0	100	140	
250	200	110	40	0	50	
800	600	80	270	250	0	
O	O					

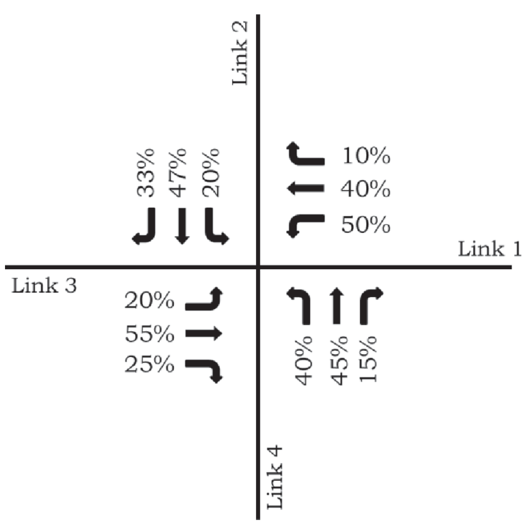
Figure 6-6. Example turning movements matrix.



Destination (D) Outflows, j

Origin (O) Inflows, i — Link	1	2	3	4
1		P_{12f}	P_{13f}	P_{14f}
2	P_{21f}		P_{23f}	P_{24f}
3	P_{31f}	P_{32f}		P_{34f}
4	P_{41f}	P_{42f}	P_{43f}	

Figure 6-7. Iterative procedure—estimated turning percentages.



Destination (D) Outflows, D_{jb}

Origin (O) Inflows, O_{ib}	0.90	0.75	1.13	1.22
1.00		0.10	0.40	0.50
1.00	0.20		0.33	0.47
1.00	0.55	0.20		0.25
1.00	0.15	0.45	0.40	

Figure 6-8. Example turning percentages matrix.

The matrix cells are populated by multiplying the future year link inflows (O_{if}) by the corresponding turning movement percentage (P_{ijf}):

$$T_{ijf}^{*} = O_{if} \times P_{ijf}$$

STEP 2. Perform First Row Iteration

This step is performed after Step 1.A. only; when estimated turning percentages are used in lieu of turning movement counts; the construction of the initial turning movement matrix is equivalent to this step.

In the turning movement matrix, base year inflows (O_{ib}) are replaced with future year inflows (O_{if}). Each individual turning movement (i.e., matrix cell) is adjusted according to the following:

$$T_{ijf}^{*} = \frac{O_{if}}{O_{ib}} T_{ijb}$$

where T_{ijf}^{*} is the adjusted future turning volume for this iteration.

A new matrix consisting of the adjusted turning movements and the future year origin inflows (rows), O_{if}, is constructed. The new destination outflows (columns), D_j^{*}, result from summing the adjusted turning movements T_{ijf}^{*} in each column *j*:

$$D_{jf}^{*} = \sum_{i=1}^{n} T_{ijf}^{*}$$

The adjusted column totals, D_{jf}^{*}, from the adjusted turning movement matrix are compared with the original column totals, D_{jf}, from Step 1.A. If the difference between them is acceptable, then the procedure is considered to be complete. For most applications, a difference within ±10% is acceptable. If the difference is greater than the desired criterion, then further iteration is required.

STEP 3. Perform First Column Iteration

The adjusted turning movements from Step 2 (or 1.B.) are adjusted further in this step. The previously adjusted matrix is used, but the adjusted outflows, D_{if}^{*}, are replaced with the original outflows, D_{if} (i.e., the outflow forecasts). The individual turning movements then are adjusted by the ratio of the original outflow forecasts to adjusted outflows according to the following:

$$T_{ijfNEW} = \frac{D_{if}}{D_{jf}^{*}} T_{ijfOLD}$$

where

T_{ijfOLD} = T_{ijf}^{*} matrix value from Step 2 (or 1.B.), and
T_{ijfNEW} = Adjusted turning movement matrix value, T_{ijf}, after this column iteration.

In all subsequent iterations (if needed), T_{ijfNEW} created in this step becomes T_{ijfOLD} in the next step.

Now create a new matrix consisting of adjusted turning movements, T_{ijfNEW}, and the future year destination outflows (columns), D_{if}. Adjusted row totals, O_{if}^{*}, are computed by summing T_{ijfNEW}^{*} in each row:

$$O_{if}^{*} = \sum_{j=1}^{n} T_{ijfNEW}^{*}$$

Similar to the previous step, adjusted row totals, O_{if}^{*}, should be compared with the original inflows, O_{if}. If the difference between these values is acceptable using the same convergence criterion, then the process is complete. If the discrepancy is greater, then subsequent iterations should be performed.

STEP 4. Repeat Row Iteration

If necessary, repeat the procedure described in Step 2 for row iterations. Calculate the new values for T_{ijfNEW}^{*} and D_{jf}^{*}, and then compare D_{jf}^{*} with D_{jf}.

STEP 5. Repeat Column Iteration

If necessary, repeat the procedure described in Step 3 for column iterations. Calculate the new values for T_{ijfNEW}^{*} and O_{if}^{*}, and then compare O_{if}^{*} with O_{if}.

Row and column iterations should be continued until acceptable differences between D_{jf}^{*} and D_{jf} and O_{if}^{*} and O_{if} are obtained. When the differences are determined to be acceptable, the T_{ijf}^{*} values in the final matrix will be the final estimated turning movements.

6.4.7 Illustrative Example

Referring to the example shown in Figure 6-6, the turning movement counts are arranged in the accompanying matrix. The base year inflows, O_{ib}, and outflows, D_{jf}, are shown as row and column totals, ΣO_{ib} and ΣD_{jb}, respectively. Similarly, forecast year inflows, ΣO_{if}, and outflows, ΣD_{jf}, are shown in the adjacent rows and columns.

The analyst determines the desired closure, i.e., the difference between forecasted inflows/outflows and the row/column totals of adjusted turning movements, ΣT_{ijf}^{*}. In most cases, a desired difference of ±10% is acceptable. For the purposes of this example, a smaller closure, ± 1%, was desired.

Initial Turning Movement Matrix, T_{ijb}

			East Leg	North Leg	West Leg	South Leg		
	Forecasts		***300***	***500***	***600***	***600***	D_{jf}	outflows, *j*
		Counts	250	390	470	390	D_{jb}	
East Leg	***500***	400	0	80	120	200		
North Leg	***450***	300	60	0	100	140		
West Leg	***250***	200	110	40	0	50		
South Leg	***800***	600	80	270	250	0		
	O_{if}	O_{ib}						
	inflows, *i*							

first row iteration

	D_{jf^*}			
	335	510	633	523
500	0	100	150	250
450	90	0	150	210
250	138	50	0	63
800	107	360	333	0

compare

	D_{jf^*}	D_{jf}	change
j=1	335	300	12.0%
j=2	510	500	2.0%
j=3	633	600	6.0%
j=4	523	600	-13.0%
Totals	2001	2000	

Figure 6-9. Initial turning movement matrix and first row iteration.

Step 1 (Construct the initial turning matrix) as illustrated in Figure 6-6.

In Step 2 (Perform first row iteration), each initial cell matrix (i.e., turning movement count), T_{ijb}, is multiplied by the ratio of the forecasted inflow, O_{if}, to the sum of the inflow counts, O_{ib}, as shown in Figure 6-9. The sums of the adjusted column totals, D_{jf}^*, are compared to the forecasted outflows, D_{jf}. The differences range from −13% to +12%.

Note: When comparing column totals, D_{jf}^*, to forecasted outflows, D_{jf}, the totals should equal. Slight differences may exist due to rounding.

In this example, because the differences are outside the desired ±1% closure, the process is continued in Step 3 (Perform first column iteration). In Step 2, the initial counts in the turning movement matrix were replaced with the adjusted values, T_{ijf}^*, and these become the "old" values, T_{ijfOLD}. As shown in Figure 6-10, a new turning movement matrix is created by multiplying T_{ijfOLD} times the ratio of the forecasted inflows, O_{if}, and the row sum of the matrix from Step 2, O_{if}^*:

$$T_{ijfNEW} = \frac{O_{if}}{O_{if}^*} T_{ijfOLD}$$

The row total differences between forecasted inflows, O_{if}, and adjusted row sums, ΣO_{if}^*, range from −4% to +5%.

The process is continued in Step 4 (Repeat row iteration) and Step 5 (Repeat column iteration) until, following a third set of row and column iterations, the desired closure is reached. The adjusted values in the turning movement matrix at the end of this step, T_{ijf}^*, are the final forecasted turning movements, as shown in Figure 6-11.

first column iteration

	300	500	600	600
527	0	98	142	287
464	81	0	142	241
245	124	49	0	72
765	96	353	316	0
O_{if^*}				

compare

	O_{if^*}	O_{if}	change
i=1	527	500	5.00%
i=2	464	450	3.00%
i=3	245	250	-2.00%
i=4	765	800	-4.00%
Totals	2001	2000	

Figure 6-10. First column iteration.

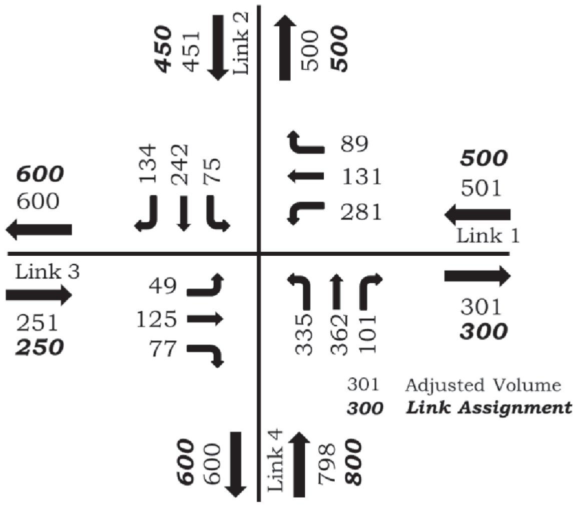


Figure 6-11. Turning movement forecasts.

6.5 Iterative Procedure—Non-Directional Method

6.5.1 Abstract

The iterative non-directional method is intended for general planning purposes where approximate non-directional intersection turning movements are desired. The method relies on an initial estimate by the analyst of total turning percentages at the intersection. This estimate may be varied in an iterative process until an acceptable comparison of computed two-way intersection leg volumes with projected or assigned link volumes is reached.

6.5.2 Context

Typical applications are intersection design, intersection capacity analysis, site impact studies, traffic signal timing, and interchange studies.

Geography is site, corridor, and wide area.

Typical time horizons are short range, interim, and long range.

Required input data are traffic counts and traffic model link assignments.

Optional input data are turning movement estimates and manual link forecasts.

Related techniques are factoring procedures, iterative procedure—non-directional method, and "T" intersection turning movement estimation procedures.

Advantages of the iterative non-directional method are that it is simple to use and can be applied manually or implemented in software.

A disadvantage of the iterative non-directional method is that it needs more data than other related techniques. The non-directional method produces only two-way turning movements.

Case study is Case Study #1 - Arterial.

6.5.3 Background

The iterative procedure—non-directional method was previously documented in *NCHRP Report 255* (*1*). The method has been automated through spreadsheets and other computational software and has been applied by numerous transportation agencies and consultants. The method requires non-directional link volume forecasts and an estimate of intersection turning movement percentages. Estimated turning percentages can be based on existing turning movement counts, turning movement patterns at similar intersections, or professional judgment associated with knowledge of nearby land use or travel patterns.

6.5.4 Why This Technique

Planning-level intersection turning movement projections are needed for a variety of applications, including intersection design, traffic signal timing, site impact studies, interchange justification/modification studies, and air quality analyses.

The non-directional method was initially documented in *NCHRP Report 255* (*1*). It produces two-way turning volumes at an intersection based on two-way link volumes for each intersection leg and an estimate of the total vehicle turning percentage for the intersection. The method relies heavily on the judgment of the analyst to select a reasonable turning percentage, and the basic assumption is that the approach volume is a surrogate for land use productions and attractions downstream.

6.5.5 Words of Advice

This method is intended for general planning purposes where approximate non-directional intersection turning movements are desired. Where directional movements are needed, the directional iterative method discussed in Section 6.4 should be used.

The iterative—non-directional method is intended for four-legged intersections. It can be applied to intersections with more than four legs, but the approaches may have to be broken down into two or three partial intersections and the results combined manually. This may involve considerable judgment.

For intersections involving a one-way street, two-way trip interchanges cannot occur and the intersection must be broken into a set of one-way streets where one leg carries the flow into the intersection and all other legs carry flow away from the intersection. The results are then merged and adjusted to ensure that all traffic clears the intersection.

Where the intersecting streets have significantly different volumes (for example, a principal arterial intersecting with a residential collector), the volume difference for opposing legs will typically need to be increased. The method can be made to work by using different turning percentages for different approach directions instead of a single estimated turning percentage for the entire intersection. Familiarity with local conditions is helpful here. Also, if available, signal green phase durations for those movements can be used to estimate turning percentages.

6.5.6 Executing the Technique

6.5.6.1 Data Needed

Data needed for the technique are the following:

- Non-directional (i.e., two-way) future year link volume forecasts and
- Estimated intersection total turning percentage.

Future year link volumes may be obtained either from a travel demand model or by using one of the other manual techniques discussed in this guidebook. The analyst must estimate, of the total volume passing through the intersection, the percentage that is composed of left and right turns. Although the input link volumes are bi-directional, the estimated turning percentage is related only to inflowing (i.e., directional) volume. A 50-50 directional split is assumed for link volumes. A basic configuration for the method is shown in Figure 6-12.

6.5.6.2 Steps of the Technique

The non-directional volume method consists of five steps. The method does not iterate between steps until a specified closure is reached, but it is iterative in that the analyst may determine that initial assumptions should be modified and/or input adjustments made until more desirable results are achieved. The computational steps (Steps 1 through 5) are described below.

STEP 1. Estimate the Total Turning Percentage

Two-way link volumes are obtained for each intersection leg and the volumes are summed. Assuming a 50-50 distribution, the sum of the approach (inflowing) volumes is computed as half of the total volume. The percentage of the approach volumes that are turning movements—either left turns or right turns—is estimated and the assumed turning traffic (V_{turns}) is computed:

$$Total\ Int.\ Volume = \sum_{i=1}^{n} Two\text{-}Way\ Link\ Volume_i$$

where i represents each intersection leg and n equals the total number of approaches.

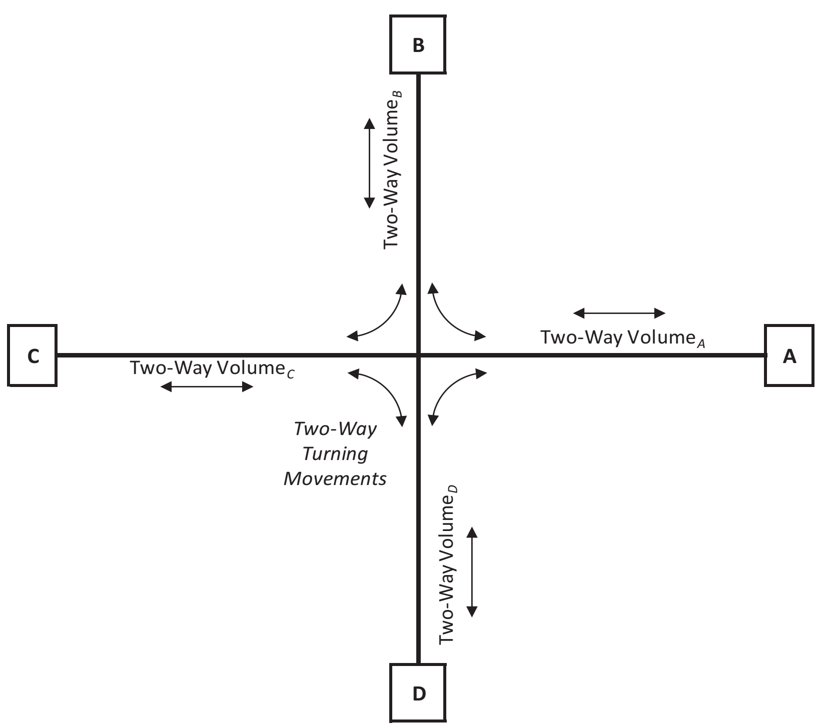


Figure 6-12. Non-directional method basic configuration.

$$Approach\ Volume = \frac{Total\ Int.\ Volume}{2}$$

then,

$$V_{turns} = Est.\ Turn\ Pct. \times Approach\ Volume$$

STEP 2. Calculate the Relative Weight of Each Intersection Approach

For each intersection leg, the relative weight of the two-way volume compared to the total intersection volume is computed. The relative weight is expressed as a proportion of the total volume:

$$Relative\ Weight_i = \frac{Two\text{-}Way\ Link\ Volume_i}{Total\ Int.\ Volume}$$

The sum of the proportions should equal 1.00.

STEP 3. Perform the Initial Allocation of Turns

The turning volume on each leg is allocated to the other legs based on the proportion of turning movements of those other legs. For example, right turns approaching intersection Leg A depart on Leg B; left turns depart on Leg D. The two-way volumes on Leg A are multiplied by the relative weight of turning volumes (see Step 2) for Leg B. Similarly, the two-way volumes on Leg B are multiplied by the relative weight of turning volumes for Leg A. These two values are averaged and represent the initial estimate of turning volumes between Leg A and Leg B. This step is repeated for each set of turning movements between adjacent intersection legs.

STEP 4. Adjust the Turning Volumes Based on the Total Turning Percentage

The sum of the four average turning movements computed in Step 3 is compared to the initially assumed total turning traffic, V_{turns}. The sum of the average turning movements typically will exceed V_{turns} and an adjustment must be made. The adjustment can be made using one of the factoring procedures previously described—the difference method or the ratio method. For each two-way turning movement, the initial average turning volume is adjusted based on its comparison with V_{turns} either by subtracting the difference between the two or multiplying by the ratio. For example:

(a) Total volume = 4,000.
(b) Total inflow volume = 4,000/2 = 2,000.
(c) Estimated turning percentage = 0.25 (25%).
(d) Total expected sum of turns = 0.25 x 2,000 = 500 = V_{turns}.
(e) Sum of average turns = 1,100 (computed from Step 3).
(f) Adjustment using factoring procedures:
  (1) Difference method: (500 − 1,100)/4 = −150 subtracted from the two-way volume on each leg (for a four-legged intersection).
  (2) Ratio method: 500/1,100 = 0.45, where each of the average turning volumes is multiplied by this factor.

As a check, the sum of the revised average turning volumes should equal V_{turns}.

STEP 5. Balance the Approach Volumes and Adjusted Turn Volumes

The preceding steps should produce a total turning movement estimate that equals V_{turns} as computed in Step 1 and computed two-way link volumes on the intersection legs that are close to the initial input volumes (where the computed two-way link volume is the approach volume plus the departure volume that is composed of the individual opposing through and turning movements). It is possible that some differences between initial input link volumes (from Step 1) and the computed link volumes (following Step 4) may exist. To check this:

(a) Record the total approach volume for the intersection leg,
(b) Subtract the turns made to/from the approach from the cross street, and
(c) Add the turns made to/from the approach on the opposite side of the intersection.

This computation is performed independently for each intersection leg. If balanced, the total volume on the opposing approach should be equal to the volume estimated for that same approach using the test described above. If the volumes do not agree, the out-of-balance numbers must be adjusted to bring the analysis into equilibrium and to account for all of the intersection volumes. Opposing approaches (i.e., those that facilitate through movements) should differ by an equal volume, with one approach being overestimated and the opposing approach being underestimated by the same volume.

When there are differences, two situations are normally encountered:

- Opposing intersection approaches exhibit a greater difference in the adjusted volumes (computed in Step 5) than seen in the original opposing volumes (from Step 1), or
- Opposing intersection approaches exhibit a smaller difference in the adjusted volumes (computed in Step 5) than seen in the original opposing volumes (from Step 1).

In the first case, iterating using the new link volumes generated at the beginning of this step will reduce the differences. The nature of the procedure reduces these differences through iteration, and a balanced solution should be reached with a few iterations. When this method is applied to intersections having drastically different volumes on each leg, it reduces the volume differences for the opposing approaches (i.e., through movements) and, if the number of iterations is sufficient, ultimately will yield the average of the two volumes for opposing approaches.

In the second case, where the volume difference for opposing legs needs to be increased, the difference must be apportioned between the two opposing link volumes, with the turning movements being held constant. The steps to make this adjustment are the following:

(a) Sum the volumes on opposing intersection legs using the original input volumes from Steps 1 and 2.
(b) Calculate the proportion of this volume from (a) represented by each of the two opposing legs. The proportions must sum to 1.00 (100%).
(c) Determine the volume difference on each leg between the adjusted estimate (from Step 5) and the original estimate. The absolute difference should be the same for an opposing pair, although the sign will be different.
(d) Multiply the proportions from (b) by the volume difference from (c). This difference is to be added to, or subtracted from, the appropriate calculated volumes.

Unless the proportions computed from (b) are 50%–50%, the result from (d) will yield a change in the sum of the opposing link volumes and also in the total intersection volume.

As a final check, the total adjusted intersection volume is compared to the initial total intersection volume computed in Step 1. There may be a slight difference; if the difference is greater than 2 or 3%, then the analyst may choose to make additional manual link and/or turning adjustments to reduce this difference to within an acceptable limit.

6.5.7 Illustrative Example

A turning movement forecast is desired for a four-legged intersection. Two-way design hourly volume forecasts have been developed for each intersection leg and the analyst has determined that approximately 20% of the total volume through the intersection is composed of turning movements. The information is arranged in the conceptual diagram shown in Figure 6-13.

In Step 1 (Estimate the total turning percentage), the two-way link volumes are summed, the total inflow volume is computed, and the percentage of turning traffic is estimated. Total turning traffic is computed as follows:

Total Two-Way Link Volume:	5,260
Total Inflow Volume:	2,630
Estimated Turning Percentage (Left Turns + Right Turns:	20%
V_{turns}:	526

In Step 2 (Calculate the relative weight of each intersection approach), the proportion of the total volume allocated to each approach link is computed. The total should equal 1.00; due to rounding, a slight deviation from 1.00 may occur (as shown in the example below).

Approach	Proportion of Total Volume
A	0.24
B	0.19
C	0.30
D	0.28
Check	1.01

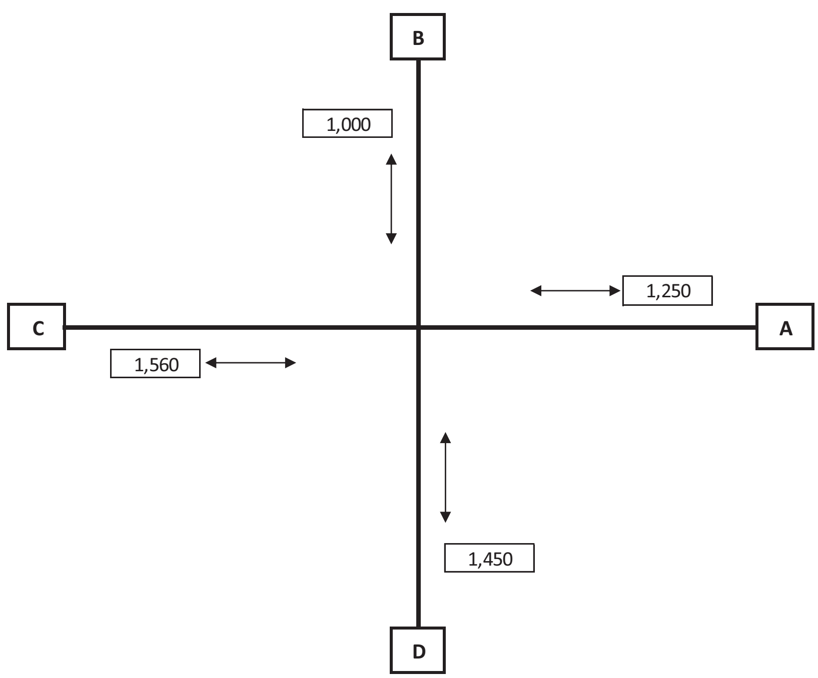


Figure 6-13. Example two-way intersection leg volumes.

Table 6-5. Turning movement values.

From Approach	To Approach	Turning Volume
A	B	238
	D	350
B	A	240
	C	300
C	B	296
	D	437
D	A	348
	C	435

In Step 3 (Perform the initial allocation of turns), the turning volume on each is allocated to the other legs based on the proportion of turning movements of those other legs. There are two values for each turning movement (see Table 6-5); the values are averaged and represent the initial estimate of turning volumes between two legs. This step is repeated for each set of turning movements between adjacent intersection legs, as shown in Figure 6-14.

For Step 4 (Adjust the turning volumes based on the total turning percentage) in the illustrative example, an adjustment must be made because the sum of the average turning movements exceeds $V_{turns.}$ The adjustment can be made using one of the factoring procedures—either the difference method or the ratio method. For the sake of this example, the adjustment is made using both methods to illustrate the differences. The analyst can choose the approach that produces the best result. For each two-way turning movement, the initial average turning volume is adjusted based on its comparison with V_{turns} either by subtracting the difference between the two or multiplying by the ratio as follows:

(a) Total volume = 5,260.
(b) Total inflow volume = 5,260/2 = 2,630.
(c) Estimated turning percentage = 0.20 (20%).
(d) Total expected sum of turns = 0.20 × 2,630 = 526 = V_{turns}.
(e) Sum of average turns = 1,322 (computed from Step 3).
(f) Adjustment using factoring procedures (See Figure 6-15):
  (1) Difference method: (526 – 1,322)/4 = –199 subtracted from the two-way volume on each leg (for a four-legged intersection).
  (2) Ratio method: 526/1,322 = 0.40, where each of the average turning volumes is multiplied by this factor.

As a check, the sum of the revised average turning volumes should equal V_{turns} or be very close. In this example, the sum of adjusted turns using the difference method is equal to V_{turns}; it is slightly different using the ratio method. This indicates that the difference method is likely to produce the better result, but the results should be checked again at the end of Step 5 before a final decision is made.

In this example, for Step 5 (Balance the approach volumes and adjusted turn volumes), it is determined that there are

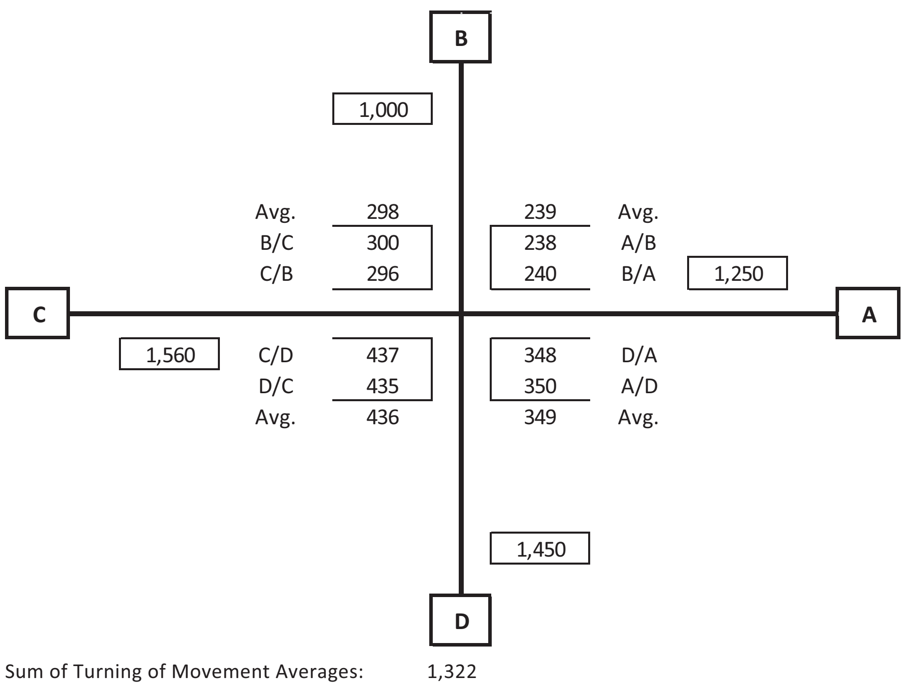


Figure 6-14. Initial estimate of turning movements between adjacent legs in a four-legged intersection.

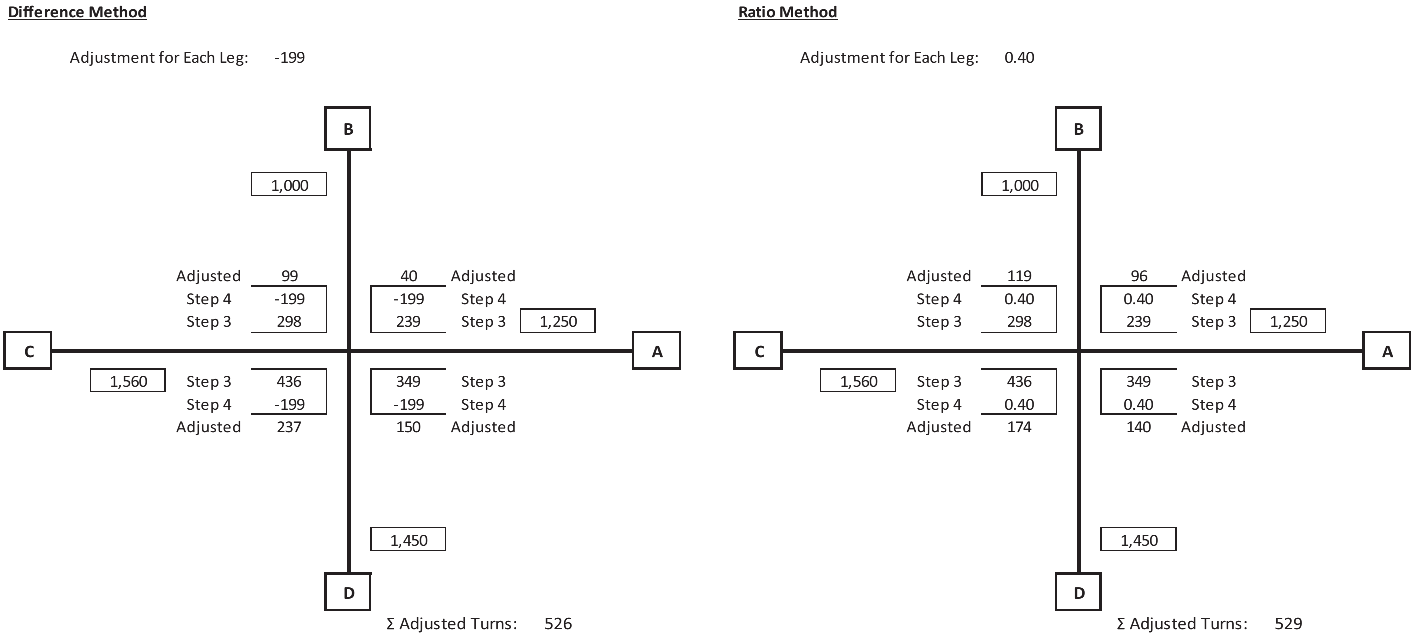


Figure 6-15. Adjusting initial average turning volume using factoring procedures (the difference and ratio methods).

differences between initial input link volumes (from Step 1) and the computed link volumes (following Step 4).

The initial differences (from Step 1) are 310 for Approaches A/C (1,560 – 1,250) and 450 for Approaches B/D (1,450 – 1,000). As shown in Figure 6-16, using the difference method, those differences are 18 (1,414 – 1,396) and 46 (1,248 – 1,202) for Approaches A/C and B/D, respectively. Using the ratio method, the differences are 196 (1,503 – 1,307) and 252 (1,351 – 1,099), for Approaches A/C and B/D, respectively. For either case, the second situation applies (as discussed in the description of Step 5 above)—the opposing intersection approaches exhibit a smaller difference in the adjusted volumes (computed in Step 5) than seen in the original opposing volumes (from Step 1). Those differences are apportioned between the two opposing link volumes, with the turning movements being held constant, as shown in Figure 6-17.

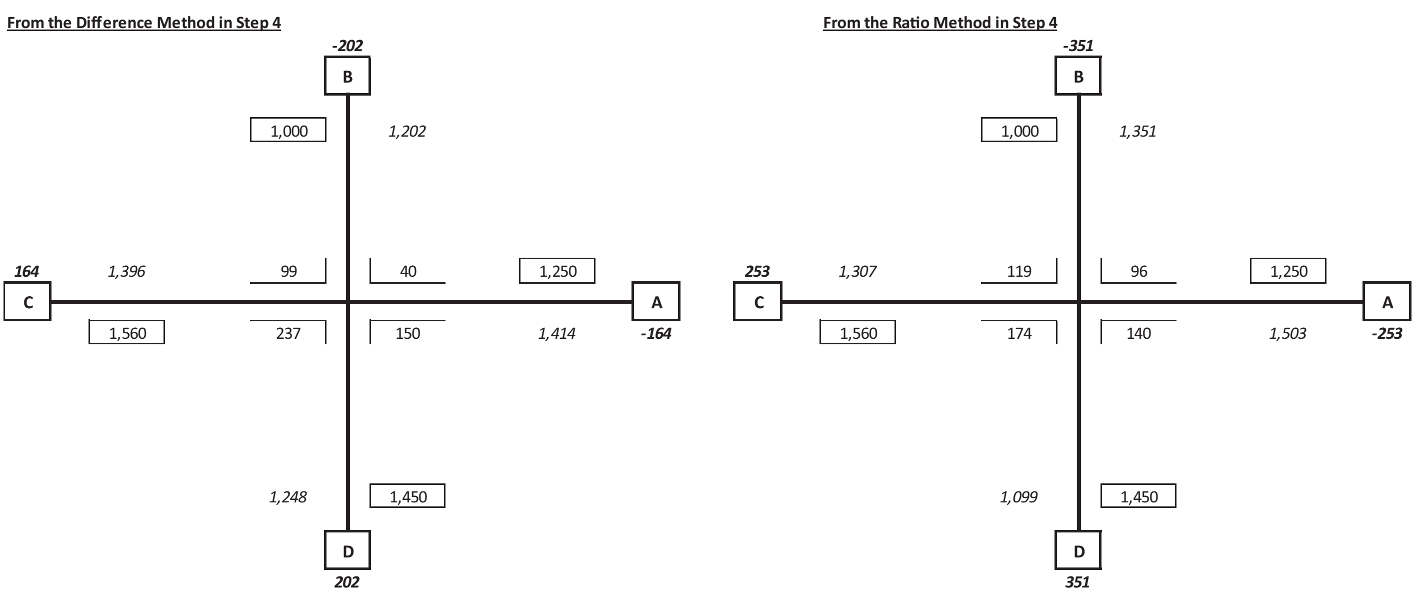


Figure 6-16. Balancing the approach volumes and adjusted turn volumes.

From the Difference Method

Approaches A/C		Approaches B/D	
Total Volume:	2,810	Total Volume:	2,450
Proportion A:	0.44	Proportion B:	0.41
Proportion C:	0.56	Proportion D:	0.59
Difference on A:	-164	Difference on B:	-202
Difference on C:	164	Difference on D:	202
Adjustment on A:	-72	Adjustment on B:	-83
Adjustment on C:	92	Adjustment on D:	119

From the Ratio Method

Approaches A/C		Approaches B/D	
Total Volume:	2,810	Total Volume:	2,450
Proportion A:	0.44	Proportion B:	0.41
Proportion C:	0.56	Proportion D:	0.59
Difference on A:	-253	Difference on B:	-351
Difference on C:	253	Difference on D:	351
Adjustment on A:	-111	Adjustment on B:	-144
Adjustment on C:	142	Adjustment on D:	207

Figure 6-17. Apportioning the difference between the two opposing link volumes (while holding the turning movements constant).

The final adjusted turning volumes using both the difference and ratio methods are shown in Figure 6-18.

For this example, it can be concluded that the difference method produces slightly better results, as the percent difference between the adjusted intersection leg total volumes and the initial input volumes is smaller. To reduce this difference, the analyst may choose to repeat the entire procedure by inserting the adjusted link volumes as input volumes in Step 1.

6.6 "T" Intersection Procedure—Non-Directional Method

6.6.1 Abstract

Estimates of turning movements at three-legged or "T" intersections can be determined using simpler procedures than those for four-legged intersections. There are two methods that can be employed:

- The non-directional turning movement method and
- The directional turning movement method.

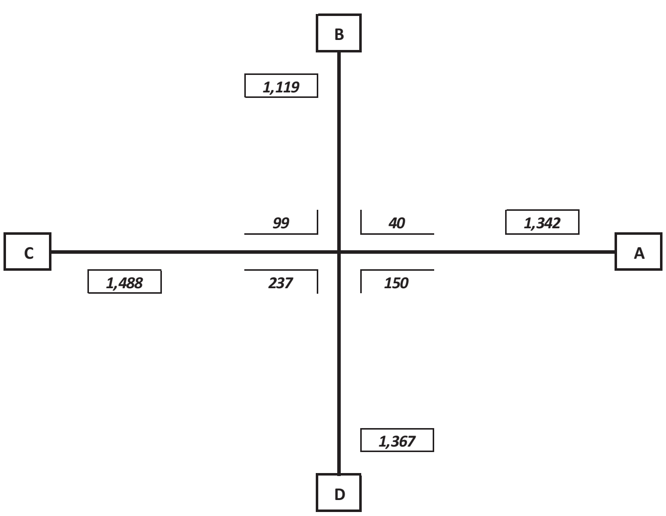
The simplest of the two is the non-directional turning movement method, which is discussed in this section. For this method, basic mathematical relationships among link volumes can be used for estimating turning movements.

6.6.2 Context

Typical applications are intersection design, intersection capacity analysis, site impact studies, traffic signal timing, and interchange studies.

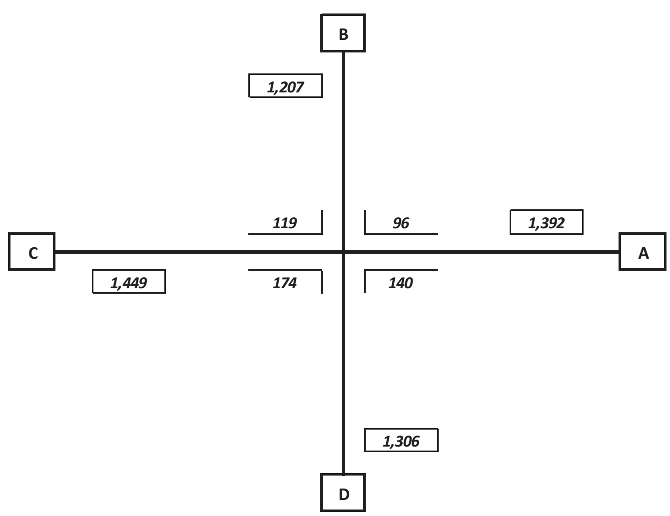
Final Adjusted Non-Directional Intersection Volumes

Using the Difference Method



Check sum (A+B+C+D):	5,316
Initial Two-Way Volume Sum (Step 1):	5,260
Percent Difference:	1.06%

Using the Ratio Method



Check sum (A+B+C+D):	5,354
Initial Two-Way Volume Sum (Step 1):	5,260
Percent Difference:	1.77%

Figure 6-18. Final adjusted non-directional intersection volumes using difference and ratio methods.

Geography is site, corridor, and wide area.

Typical time horizons are short range, interim, and long range.

Required input data are traffic counts and traffic model link assignments.

Optional input data are turning movement estimates and manual link forecasts.

Related techniques are "T"intersection procedure—directional method, factoring turning movement procedures, and iterative turning movement estimation procedures.

Advantages are that the "T" intersection procedure—non-directional method is simple to use and can be applied manually or implemented in software.

A disadvantage is that the "T" intersection procedure—non-directional method only produces two-way turning movements.

6.6.3 Background

The mathematical basis for the non-directional method lies in the algebraic relationships among the two-way volumes of the legs that make up the intersection.

6.6.4 Executing the Technique

Figure 6-19 illustrates the basic notation used to identify the intersection legs, two-way volumes, and turning movements. The data needed for the "T" intersection procedure—non-directional method are two-way volumes for each of the intersection legs. No turning volume estimates are required.

Two unknown turning volumes can be directly obtained from two independent equations:

$$X = \frac{A - B + C}{2}$$

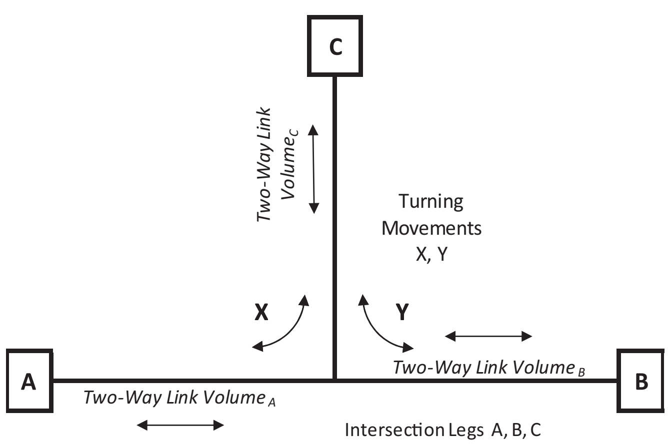


Figure 6-19. "T" intersection configuration and notations.

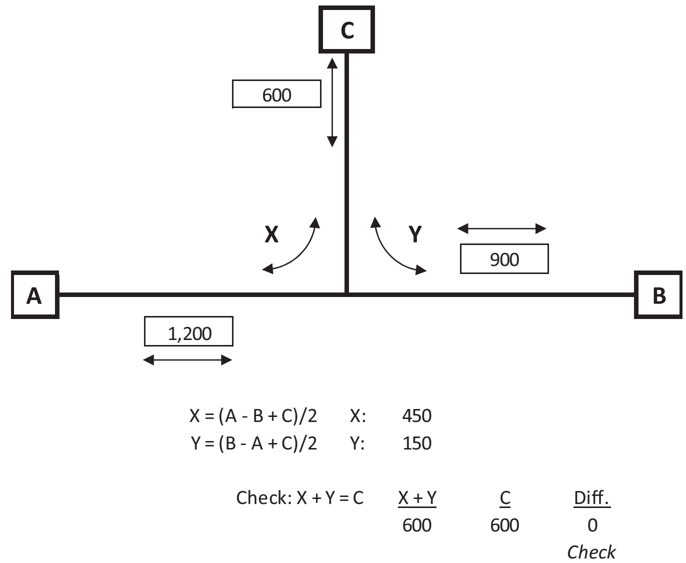


Figure 6-20. Example of "T" intersection procedure—non-directional method.

$$Y = \frac{B - A + C}{2}$$

As a check, the sum of turning movements X and Y should equal the two-way volume on the minor leg C:

$$X + Y = C$$

6.6.5 Illustrative Example

Figure 6-20 shows two-way link hourly traffic volumes in an example "T" intersection. Traffic volumes on Legs A, B, and C are as follows:

- Leg A—1,200 VPH,
- Leg B—900 VPH, and
- Leg C (minor approach)—600 VPH.

Turning movements are computed to be 450 VPH between A and C and 150 VPH between B and C. The method can be applied for hourly volumes or 24-hour volumes.

6.7 "T" Intersection Procedure—Directional Method

6.7.1 Abstract

The directional turning method, like the non-directional turning method uses basic mathematical relationships among link volumes for estimating turning movements. For the directional method, discussed in this section, one of the turning movements must be known or estimated.

6.7.2 Context

Typical applications are intersection design, intersection capacity analysis, site impact studies; traffic signal timing, and interchange studies.

Geography is site, corridor, and wide area.

Typical time horizons are short range, interim, and long range.

Required input data are traffic counts and traffic model link assignments.

Optional input data are turning movement estimates and manual link forecasts.

Related techniques are "T" intersection procedure—non-directional method, factoring turning movement procedures, and iterative turning movement estimation procedures.

Advantages of the "T" intersection procedure—directional method are that it is simple to use and can be applied manually or implemented in software.

A disadvantage of the "T" intersection procedure—directional method is that at least one of the intersection turning movements must be known or estimated.

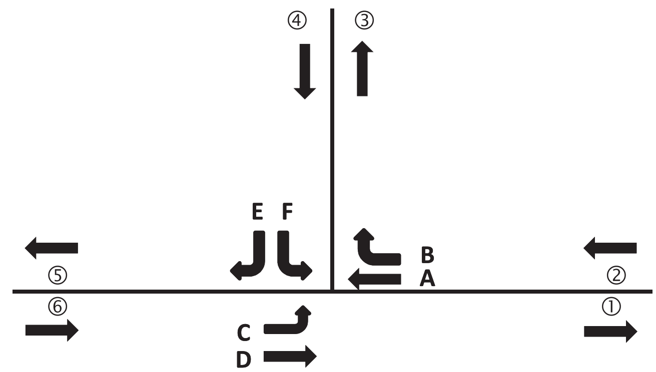
6.7.3 Executing the Technique

When directional turning movements are desired, a unique solution cannot be determined from directional link volumes alone; one known or estimated directional turning movement will produce a unique solution for all other directional volumes. Because only six directional movements are involved, simple mathematics can be used to derive the equations that will determine a unique solution. Any of the six turning movements can be known or estimated. Based on their known or estimated volume, the other movements are computed in a sequential fashion. The intersection configuration and notation are shown in Figure 6-21.

All of the directional approach and departure volumes must be known. Computations for each of the six possible scenarios where one of the turning movements is known or estimated are provided in Table 6-6.

Data needed for the "T" intersection procedure—directional method are

- Approach and departure volumes for all intersection legs and



Turning Movements A - F
Directional Approach Volumes ① - ⑥

Figure 6-21. Directional method configuration and notation.

- At least one known or estimated directional turning movement.

6.7.4 Illustrative Example

Figure 6-22 shows known directional link volumes, as well as Turning Movement "E" (350 VPH).

The computations are the following:

F = ④ – E = 400 – 350 = 50.
D = ① – F = 1,100 – 50 = 1,050.
C = ⑥ – D = 1,200 – 1,050 = 150.
B = ③ – C = 300 – 150 = 150.
A = ② – B = 800 – 150 = 650.

The results of the computations for the illustrative example are shown in Figure 6-23.

6.8 Refining Directional Splits from Travel Models

6.8.1 Abstract

Existing and/or historic traffic count data often form the basis for the development of traffic forecasting parameters like the directional distribution, D. However, when these data

Table 6-6. "T" intersection directional turning movement computations.

Known or Estimated Turning Volume	A		B		C		D		E		F	
Computed Turning Volumes	B:	② - A	A:	② - B	D:	⑥ - C	C:	⑥ - D	F:	④ - E	E:	④ - F
	C:	③ - B	E:	⑤ - A	F:	① - D	B:	③ - C	D:	① - F	A:	⑤ - E
	D:	⑥ - C	F:	④ - E	E:	④ - F	A:	② - B	C:	⑥ - D	B:	② - A
	F:	① - D	D:	① - F	A:	⑤ - E	E:	⑤ - A	B:	③ - C	C:	③ - B
	E:	④ - F	C:	⑥ - D	B:	② - A	F:	④ - E	A:	② - B	D:	⑥ - C

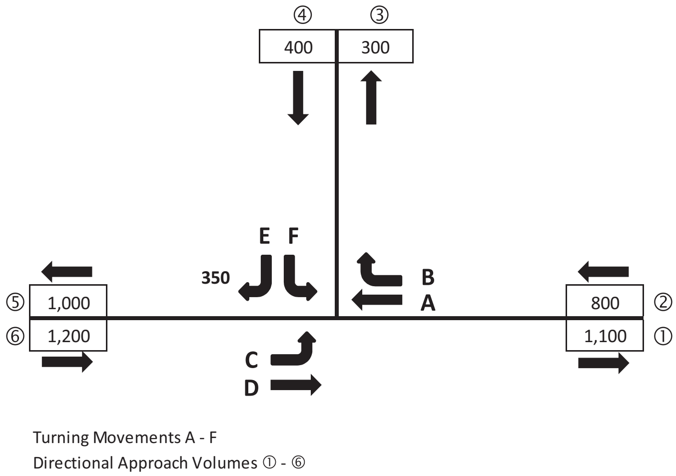


Figure 6-22. Known directional link volumes and Turning Movement "E" for illustrative example.

are not available or when future land use changes (suburbanization of a rural area, for example) are anticipated to alter travel patterns, travel models can be used to refine the estimation of D.

6.8.2 Context

Typical applications are new corridors/facilities, site impact studies, lane widening, and access management.

Geography is site, corridor, small area, and wide area.

Typical time horizons are short range, interim, and long range.

Required input data are directional traffic counts, traffic model link assignments, and traffic model zonal and/or socioeconomic data.

Optional input data include home-to-work travel data.

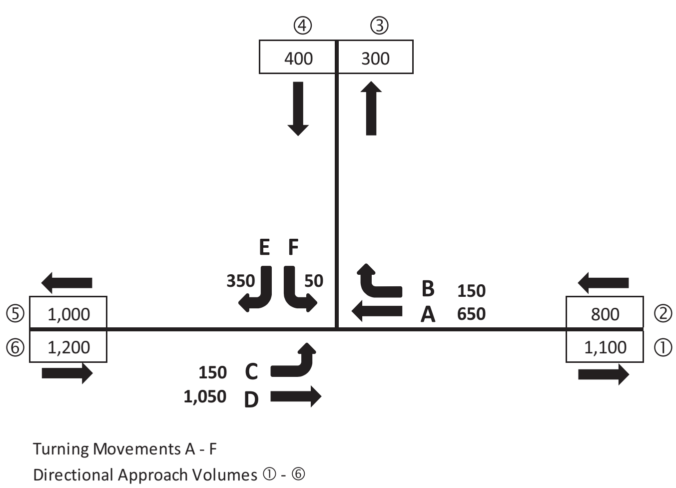


Figure 6-23. Computed values for Turning Movements A, B, C, D, and F.

Related techniques include screenline refinements.

An advantage of refining directional splits from travel models is that it is simple to use and produces reasonable results, especially with anticipated land use changes.

A disadvantage of refining directional splits from travel models is that it requires the use of travel demand modeling software or collection of area journey-to-work data.

Case study—Case Study #1 - Suburban Arterial.

6.8.3 Executing the Technique

As originally documented in *NCHRP Report 255* (*1*), there are two basic methods for using a travel model to estimate D. Both methods begin with collecting directional traffic counts and then computing D to use as a check and as a starting point.

The first method is more data intensive. It uses the prediction of home-to-work travel from a travel demand model as the basis for estimating D. A travel model is used to assign base year and future year productions and attractions to the network, representing peak-period home-to-work travel. The trips assigned represent the relative portion of work travel during the AM peak period; the PM peak direction simply would be the reverse of the AM direction. It is recognized from home interview surveys that this is not always the case, that multipurpose trips (shopping, medical-dental, school, or social recreational trips, etc.) resulting in "trip chaining" characteristically occur during the PM peak period. This would affect the directional distribution of PM peak-period traffic. If such data are available, the analyst should make adjustments to the initial estimates of D to reflect this pattern. It should be noted that trip-chaining effects may be localized and heavily dependent on land use (e.g., retail, school, medical, etc.) adjacent to the links in question.

The results should be checked for reasonableness. Generally, if the estimated D from the base year model output is within 10% of the D computed from the counts, then the predicted home-to-work travel from the model can be considered a reasonable source for estimating future directional distribution.

The final estimation of D can be done in one of two ways. The first way is to use professional judgment to estimate the difference between base year and future year work trip directional distributions and then adjust the computed base year D by a proportional amount.

The second way is to factor the base year directional distribution by the following formula:

$$D_F = D_B \times \frac{WT_F}{WT_B}$$

where

D_F = future year traffic directional distribution,
D_B = base year traffic directional distribution,
WT_F = future year work trip directional distribution, and
WT_B = base year work trip directional distribution.

Consideration should be given to the proportion of work travel to total travel in the future and whether or not it may constitute the same proportion as in the base year. If not, additional judgment may be needed.

The second method for using a travel model to estimate D is less data intensive, but begins the same way, by collecting directional traffic counts and computing the base year D from the counts. The next step is to compare the base year and future year distribution of home-based work productions (or residential land use) and home-based work attractions (or employment-related land uses) within the study area. The intent of this step is to determine whether or not the basic pattern of home-to-work travel is changing from the base year to the future year. From this comparison, the future year D is estimated using the base year traffic count information and the comparison between base year and future year productions and attractions (or land use changes).

An example of when there would be a need to change the future year D might be the construction of a large suburban office park. Travel model traffic analysis zones (TAZs) are characteristically larger in suburban areas than in downtown areas, and the increase in model attractions for the particular TAZ may not be significant, but the effect on directional distribution along adjacent arterials would be much more significant. In this case, the analyst may choose to revise the estimated D to account for changes in anticipated traffic patterns associated with the particular application.

The analyst also should realize that the trip distribution model of a regional travel model typically is validated to district-level trip flows. By its nature, a gravity distribution model will distribute more trips to nearby residential areas. Sources like U.S. Census Journey-To-Work data have shown the distribution of some types of jobs ("high" income downtown jobs, for example) to be based non-uniformly on land use variables other than trip length. Thus, the analyst should consider the quality of the trip distribution and associated assigned routing when considering these refinements.

6.9 Balancing Volumes in a Corridor

6.9.1 Abstract

At the project level, there are usually inconsistencies between traffic volumes from a travel model and traffic counts, even when the model is calibrated and the counts are accurate. Also, there are usually inconsistencies among traffic counts themselves—the count data are collected at different times or using different technologies, and there are inherent errors in either the counting or processing of the data. In order to have a consistent data set from which traffic forecasts can be developed, the data must be adjusted or "balanced" to obtain mathematical consistency.

Balancing helps to "clean" traffic volume data by tempering the effects of outliers (for example, counts collected on an atypical day) and counting errors. Balancing also results in a faster convergence when origin-destination (OD) matrix estimation is applied as the matrix estimation algorithms do not tend to oscillate between different solutions when attempting to match conflicting goals. Whether one is using traffic counts only or a combination of traffic counts and travel model assignments, the balancing process can be applied to produce a consistent data set.

6.9.2 Context

Typical applications are new corridors/facilities and area-wide/regional transportation plans.

Geography is corridor, small area, and wide area.

Typical time horizons are short range, interim, and long range.

Required input data are directional traffic counts, traffic model link assignments, and highway network geometry.

Related techniques are screenline refinements and directional split refinements.

An advantage of balancing is that it is simple to use and can be applied manually or in a spreadsheet.

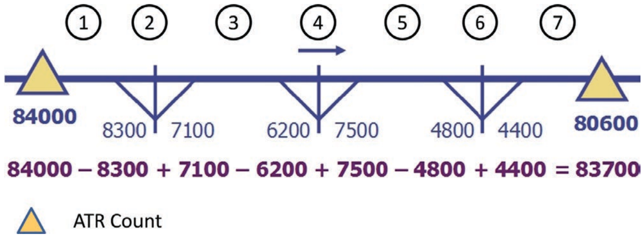
A disadvantage of balancing is that manual application is too cumbersome for larger networks and requires the use of software.

6.9.3 Executing the Technique

At a corridor level, the most straightforward balancing approach is to begin with a mainline location where the count is known to be accurate and proceed in the direction of travel, keeping a running total by adding entry volumes and subtracting exit volumes, until the next known count location is reached. For this straightforward application, the balancing is constrained by the automatic traffic recorder (ATR) stations and a pro rata distribution of the difference is applied to the ramp volumes.

An example of this approach is shown in Figure 6-24.

In this freeway example, there are ATR ADT volumes at either end of the section, supplemented by 24-hour traffic counts on the entrance and exit ramps. Moving in the direction of travel, a running total is computed for each segment by adding the ramp volume to or subtracting it from the mainline volume, as shown in Table 6-7.



Source: Wisconsin Department of Transportation.

Figure 6-24. Example imbalance between upstream and downstream traffic counts with ramp entrance and exit volumes.

When compared to the mainline count at the downstream end of the section, the running total is 3,100 vehicles per day higher. Each ramp volume is adjusted in proportion to the sum of the ramp volumes. In this particular example, the running total was 3,100 vehicles per day higher than the downstream count, so each of the ramp volumes was adjusted accordingly:

$$Adjustment_i = Difference * \frac{RampVolume_i}{\sum Entrance,\ Exit\ Volumes}$$

$$= 3{,}100 \frac{RampVolume_i}{38{,}300}$$

where *i* is the segment number. Depending on whether the difference is positive or negative, the adjustment is added or subtracted to the ramp volumes so that the running total agrees with the downstream count.

Volume balancing requires an objective function or optimization algorithm. In the previous example, which is a straightforward process using two known traffic counts, the objective (to minimize the difference between the second count and the adjusted running total) was achieved by constraining the solution to be the difference between the ATR volume at the downstream end and the running total and then allocating the difference on a pro rata basis among the ramp volumes.

Manually balancing a larger network can be very labor intensive and frustrating, with no unique solution. The Wisconsin Department of Transportation (WisDOT) has developed an automated mathematical balancing solution that can be used for complex networks, including freeway-to-freeway interchanges (*88*). The procedure computes imbalances in traffic volumes by means of running totals, using trusted ATR sites as the reference point for the computation. Traffic counts are adjusted using mathematical optimization, subject to the constraint that the imbalance must be zero. The objective function for optimization is to minimize the difference between adjusted and unadjusted volumes.

The WisDOT process measures the difference using the GEH formula, developed in the 1970s in London, England by transport planner Geoffrey E. Havers (GEH). The formula, although similar to the statistical chi-squared test, is not a true statistical test but rather an empirical formula that has been useful to WisDOT for a variety of applications.

For hourly traffic flows, the GEH formula is the following:

$$G_H = \sqrt{\frac{2(m-c)^2}{m+c}}$$

where

G_H = hourly traffic volumes as estimated by the GEH model,
m = traffic model volume (VPH), and
c = traffic count (VPH)

The GEH model was created for hourly traffic volumes. For daily traffic volumes, a simplistic approximation can be applied based on an assumption that peak-hour traffic is about 10% of the daily traffic flow:

$$G_D = \sqrt{\frac{0.2M^2 - 0.4MC + 0.2MC^2}{M+C}}$$

Table 6-7. Freeway volume balancing—Example #1.

Segment	Mainline Count	Exit Volume (-)	Entry Volume (+)	Running Total	Adjustment	Adjusted Ramp Volumes: Adj. Exit Volume	Adjusted Ramp Volumes: Adj. Entry Volume	Adj. Running Total
1	84,000			84,000				84,000
2		8,300		75,700	672	8,972		75,028
3			7,100	82,800	575		6,525	81,554
4		6,200		76,600	502	6,702		74,852
5			7,500	84,100	607		6,893	81,745
6		4,800		79,300	389	5,189		76,556
7	***80,600***		4,400	83,700	356		4,044	***80,600***
		Difference =		3,100	3,100			
		Σ|Entrance, Exit Volumes| =		38,300				

where

G_D = daily traffic volumes,
M = traffic model volume (ADT), and
C = traffic count (ADT).

WisDOT applies the following rules of thumb using the GEH formula:

GEH < 5	Acceptable fit, probably OK
5 ≤ GEH < 10	Caution: possible model error or bad data
GEH ≥ 10	Warning: high probability of model error or bad data

This method can be automated using software or spreadsheets such as those developed by WisDOT. This is illustrated in the second example, which is shown in Table 6-8. In this example, there are two ATR stations on a section of US 45 (Stations 400020N and 400007P). The remaining count stations represent temporary 48-hour counts. Proceeding down the table in the direction of travel, there is a difference of –558 vehicles per day between the running total (Column F) and the actual count (at Station 400007P). Using the Excel Solver program and minimization of the GEH value as the optimization objective, the difference is allocated among the ramp volumes and the short freeway segments between the ramps. Because of the number of "good" counts that were involved, an exact solution was not reached in which the difference was reduced to zero—an imbalance of –165 vehicles per day remained. However, the difference was reduced and was minimized through the optimization process.

In Table 6-8, the computed running total at the end of the section is shown in cell F24. From the results, it can be concluded that (1) the balancing process produces reasonable results for all of the ramps and segments, with the exception of the volume for the segment shown in Row 13 of the table, and (2) the count for the segment in Row 13 (Station 40-1941) is suspect and either should be ignored or recounted. If the suspect count is ignored, the overall G_D is reduced from 11.1 to 2.1.

For arterials and other non-access-controlled facilities, this balancing process also can be applied, provided that directional volumes are available and provided that side streets and driveways are treated in a manner similar to the way that ramps are treated in the previously discussed examples.

6.10 Travel Time Reliability

6.10.1 Abstract

Travel time reliability describes the quality, consistency, and predictability of travel over an extended period of time. Mathematically, it is the distribution of trips using a facility

Table 6-8. Freeway volume balancing—Example #2.

1/A	B	C	D	E	F	G	H	I	J	K
2	**AADT**	**2010**	**Segment 01 - US 45 SB / I-894 EB**	**USH 45 SB/I-894 EB Wisconsin (40-0020) to Cleveland (40-0007)**						
3				**Raw**	**Running**	**Balanced**				
4	**Station**	**Type**	**Location**	**AADT**	**Total**	**Volume**		**Change**	**% Chng**	**G_D**
5	**400020N**	**A**	**US 45 SB between Wisconsin Ave and Zoo Interchange**	**80,800**	**80,800**	**80,800**			**0.0%**	**0.0**
6	40-3677	0	Zoo Interchange N-E ramp	19,227	19,227	19,227		0	0.0%	0.0
7		B	Btwn Ramps at US 45 SB Zoo (North) Interchange		61,573	61,573				
8	40-3678	0	Zoo Interchange N-W ramp	9,302	9,302	9,302		0	0.0%	0.0
9	40-3679	F	US 45 SB Center of Zoo Interchange N-S		52,271	52,271				
10	40-3176	1	Zoo Interchange E-S ramp	11,611	11,611	11,611		0	0.0%	0.0
11		B	Btwn Ramps at US 45 SB Zoo (South) Interchange		63,882	63,883				
12	40-3178	1	Zoo Interchange W-S ramp	16,046	16,046	16,047		1	0.0%	0.0
13	40-1941	F	I-894 EB Btwn Zoo Interchange and STH 59 (Greenfield Ave)	72,077	79,928	79,930				9.0
14	40-3377	0	Greenfield Ave off-ramp	6,571	6,571	6,496		-75	-1.1%	0.3
15		B	Btwn Ramps at STH 59 (Greenfield Ave) Interchange		73,358	73,434				
16	40-3378	1	Greenfield Ave on-ramp	7,761	7,761	8,077		316	4.1%	1.1
17	40-1940	F	I-894 EB Btwn STH 59 (Greenfield Ave) and Lincoln Ave		81,119	81,512				
18	40-3380	0	Lincoln Ave off-ramp	7,089	7,089	6,924		-165	-2.3%	0.6
19	40-1932	F	I-894 EB Btwn Lincoln Ave and National Ave		74,030	74,588				
20	40-3383	0	National Ave off-ramp	5,290	5,290	5,290		0	0.0%	0.0
21		B	Btwn Ramps at National Ave Interchange		68,740	69,298				
22	40-3384	1	National Ave on-ramp	4,429	4,429	4,432		3	0.1%	0.0
23	**400007P**	**A**	**I-894 EB between National Ave and Oklahoma Ave**	**73,727**	**73,727**	**73,730**			**0.0%**	**0.0**
24			*Calculated Volume*		*73,169*	*73,730*		316		
25			*Imbalance*		*-558*	*0*		-165		**11.1**

Location Code

A - ATR Station
0 - Exit Ramp
1 - Entrance Ramp
F - Calculated Freeway Segment Volume
B - Calculated Segment Volume Between Ramps

The optimization objective is to minimize the value of this cell.

over this extended period. The distribution arises from a number of factors that influence travel times, including congestion, severe weather, incidents, work zones, and special events. Travel time reliability influences travel behavior and is reflected in the paths people choose to reach their destination. Research has demonstrated that drivers are averse to the risk of extensive delays. They tend to select routes with little variability in travel time over routes that carry the risk of excessive delays, everything else being equal. Inclusion of travel time variability in a travel forecast requires specialized software that integrates activity-based modeling and dynamic traffic assignment (DTA) with the ability to handle non-additive impedances, but projects with only one or two alternative routes may be handled with less sophisticated methods. At this writing, the routine use of travel time reliability in travel forecasts is unusual.

6.10.2 Context

Typical applications are lane widening, access management, new corridors/facilities, detours, and traffic control.

Geography is corridor and wide area.

Typical time horizons are short range, interim, and long range.

Required input data are traffic counts, traffic network, and method of measuring travel times through intersections and along uninterrupted segments.

Optional input data are historic or modeled OD table.

An advantage of using travel time reliability is that it may give better estimated impedances when the project will relieve congestion on road segments with unreliable travel times.

A disadvantage of using travel time reliability is the need for highly specialized software, which can be limiting.

6.10.3 Background

Travel time reliability has recently been recognized as an important positive attribute of a traffic system. Reliability indices have been created to inform drivers of best routes, to monitor the condition of traffic systems, and to assess the benefits of an improvement to a traffic system. Reliability is the opposite of variability. Several academic studies have introduced the idea that inclusion of travel time variability (as an indicator of the unreliability of a trip) in impedance functions (or utility equations) can improve forecasts by making models sensitive to reliability considerations.

Academic studies have related travel time variability to the standard deviation (which has the same units as travel time, e.g., minutes) and skewness of travel time distributions. In particular, travelers are concerned with excessively long deviations from average travel times, and travelers seem to weight the standard deviation of travel time as almost as important as travel time itself. The combined impedance, I, between travel time and standard deviation of travel time is:

$$I = t + R\sigma$$

where t is an average travel time, σ is the standard deviation of travel time, and R is the "reliability ratio." This expression does not incorporate skewness, which can be important for facilities subject to incidents or other sources of long delays. Researchers have measured the reliability ratio to be roughly between 0.5 and 1.0. For purposes of public information, variability is most often expressed as a percentage of a baseline travel time or as a range of expected travel time.

The standard deviation of the travel time of even a single facility is difficult to estimate, unless probe-vehicle data are available. It is considerably more difficult to estimate the standard deviation of a full path, which can consist of many links and nodes. The most comprehensive study, to date, on the standard deviation of travel times was performed by the Hyder Group in the United Kingdom (*94*, *95*). This study found a relationship between the proportional amount of delay and the coefficient of variation (CV), which is the standard deviation of travel time divided by the travel time, for a link. That is,

$$CV = \gamma\left(\frac{t}{t_0}\right)^{\delta} L^{\phi}$$

where t is the average travel time, t_0 is the free travel time, L is the length of the link in suitable units (miles or kilometers), and γ, δ, and ϕ are parameters to be calibrated. The Hyder Group proposed specific parameter values from their studies. The standard deviation of the travel time is found by multiplying the CV by the travel time:

$$\sigma = t * CV$$

The Hyder Group also proposed a method for finding the standard deviation of a path from the standard deviations of all the links in the path. The method works with the variance of a link, which is the square of the standard deviation of the same link:

$$\sigma_{path}^2 = \sum_{i=1}^{M} \sigma_i^2 + \sum_{i=1}^{M-1} 2r_{i,i+1}\sigma_i\sigma_{i+1}$$

where σ_{path}^2 is the variance of the travel time on a path, σ_1^2 is the variance of the travel time on link i, M is the number of links in the path, and $r_{i,i+1}$ is the correlation coefficient between the travel time on link i and the travel time on the next link, i+1, along the path.

6.10.4 Why This Technique

Impedance in the form of travel time, alone, will likely underestimate the negative aspects of the trip because it does not incorporate information about the variability of travel time. Drivers will be attracted to routes that are both faster and more reliable.

6.10.5 Words of Advice

Software that builds paths with variations on the Dijkstra algorithm, i.e., most travel forecasting packages, cannot correctly handle non-additive impedances, which will occur with the Hyder Group's methods and other theoretically correct formulations. In addition, it is not possible to externally modify impedances prior to path building so that a Dijkstra-like algorithm can find the shortest path between an origin and a destination in all cases. Variability in travel time is not routinely used for project-level travel forecasting.

6.10.5.1 Disadvantages/Issues

The method cannot, at this time, be applied with most travel forecasting packages. It is difficult to measure the reliability ratio in the field with access to a substantial amount of probe-vehicle data, so default values from the literature must often be used.

The coefficients of the equations for this technique were developed using probe-vehicle data in the United Kingdom, where the mix of traffic controls is different than in most U.S. cities. Therefore, it is recommended that locally derived coefficients be used whenever possible.

6.10.5.2 Possible Strategies to Mitigate/Minimize Impacts of Disadvantages/Issues

Unless special software is available, it is best to limit the application of this method to small networks where all reasonable alternative paths can be identified and separately calculated.

6.10.6 Executing the Technique

An equation (or equations) for path standard deviation needs to be selected. In the absence of locally validated equations, the Hyder Group's equations may be adopted.

Parameters for the CV and path standard deviation equations need to be selected. Additionally, a value for the reliability ratio needs to be selected. A conservative default value for a reliability ratio is 0.5. The Hyder Group's studies suggest that the following values could be used as a starting point for calibrating the CV equation:

$\gamma = 0.16$
$\delta = 1$
$\phi = -0.4$ (freeways); $\phi = 0$ (arterials)
$r = 0.4$

Coefficients from a small U.S. city may be found in a recent study by Horowitz and Granato (*138*).

The four steps of the technique are provided below.

STEP 1. Obtain OD Data

The method works by assigning traffic to a network, so the origins and destinations of trips through the network must be obtained. Any suitable method for obtaining an OD table can be used, such as a gravity model, a destination choice model, or an OD table that is estimated from ground counts.

STEP 2. Obtain Traffic Data

Traffic data include everything necessary to determine free travel time on a link, everything necessary to determine the relationship between travel time and volume, and the length of the link. If intersections are included in the network, the traffic data would include those parameters necessary for calculating intersection delays. The use of probe-vehicle data is highly recommended to establish baseline conditions, should lead times and budgets permit. Time slices should be of sufficiently short duration to capture the transition of traffic states between uncongested and congested regimes. Time slices between 5 and 15 minutes are typically used. About 3 months of probe data are required to establish normal variation. A minimum of 1 year of probe data is needed to begin to establish unusually heavy congestion events.

STEP 3. Identify Any Unusual Sources of Variability in Travel Time and Select Parameters

Any links or intersections that might show greater amounts of variability than would be suggested by studies of normal traffic should be identified. Probe-vehicle data are especially useful in identifying unreliable road segments. Any source of large travel time variations should be investigated. Parameters should be selected for the equations of this method that match observed conditions.

STEP 4. Assign Traffic while Calculating the Impact of Variability

Simple networks, where all logical paths can be easily identified, may be assigned by hand with the assistance of a spreadsheet. More complicated networks require specialized algorithms that are capable of finding shortest paths when link impedances are not additive.

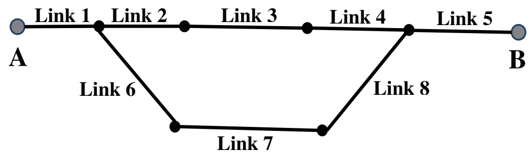


Figure 6-25. Example network.

Results of a traffic assignment may be interpreted in the same way as if reliability had not been included.

6.10.7 Illustrative Example

Consider the network in Figure 6-25 with eight links that can carry traffic between points A and B along a freeway. A work zone is proposed for Link 3, which will introduce delays and increased and unusual variability in travel time. There are only two possible paths, so there is a good chance that this problem can be solved without complicated software.

There are 3,200 vehicles making the trip from A to B on the freeway (Links 1–5) in 1 hour. There is also local traffic on the arterial (Links 6–8). An engineer initially guesses that 600 vehicles will divert from the freeway to the arterial because of warnings about delays from the work zone.

Table 6-9 shows some of the calculations necessary to estimate the impedances on both paths (delay calculations are not shown for the sake of brevity.) The calculations use the Hyder Group's equations, the default coefficients provided earlier in this section, a correlation coefficient of 0.4, and a reliability ratio equal to 0.8.

It should be noted that the travel time between A and B is the same, regardless of path, at 17.6 minutes, which means that a traditional equilibrium situation should exist when 600 drivers divert to the arterial. However, the path standard deviation for a trip from A to B along the freeway is 4.75 minutes; and the path standard deviation for the trip from A to B through the arterial is just 2.09 minutes. So the path impedance (combining travel time with its variability) along the freeway is 21.4 minutes; and the path impedance through the arterial is 19.3 minutes. The path through the arterial is preferred when 600 drivers have diverted. So if drivers were to have good information about delays, we should expect more than 600 drivers to divert to the arterial.

Successful operation of the arterial path requires traffic signal adjustments to accommodate the additional demand. Field observations and fine tuning should be made to ensure that the increased load can be accommodated. If estimated correctly, the addition of the travel time variability parameter will provide a more accurate initial estimate of traveler diversion and result in a more successful transition to the arterial path.

6.11 Model Refinement with Origin-Destination Table Estimation

6.11.1 Abstract

OD trip table estimation from ground counts (referred to here as "synthetic OD table estimation") has become an essential tool of strategic travel forecasting. This section explains the basics of OD table estimation and applies the method to estimating turning movements at an intersection where no historical turning movement counts are available, one of the most elementary applications of this technique.

6.11.2 Context

Typical applications are lane widening, road diet/cross-section modification, site impact study, intersection design, access management, new corridors/facilities, and detours.

Geography is site, corridor, and wide area.

Typical time horizon is short range.

Required input data are traffic counts, traffic network, historic traffic volumes, and OD table estimation software.

Table 6-9. Finding link standard deviation from free travel time, estimated travel time, and length.

Link	Free Travel Time	Estimated Travel Time	Length(Miles)	Functional Class	Link CV	Link Standard Deviation
1	2	2.4	2	Freeway	0.1455	0.3492
2	2	2.1	2	Freeway	0.1273	0.2674
3	2	8.6	2	Freeway	0.5214	4.4841
4	2	2.1	2	Freeway	0.1273	0.2674
5	2	2.4	2	Freeway	0.1455	0.3492
6	3	3.8	1.5	Arterial	0.2027	0.7701
7	4	5.2	2.5	Arterial	0.2080	1.0816
8	3	3.8	1.5	Arterial	0.2027	0.7701

Optional input data are historic or modeled OD table.

Related techniques are screenline refinements with traffic counts, screenline refinements with additional network details, refinement with OD table estimation, windowing to forecast traffic for small areas, and turning movement refinement.

An advantage of model refinement with OD table estimation is that it is a fast method of obtaining an OD table without a model.

Disadvantages of model refinement with OD table estimation are that it often requires many assumptions, often lacks behavioral underpinnings, and has limited applicability for long-range travel forecasting.

Case study is Case Study #2 - Network Window.

6.11.3 Background

Synthetic OD table estimation software is designed to closely match ground counts while deviating only minimally from a seed (or approximate) OD table. There are many techniques for performing a synthetic OD table estimation. One of the earliest popular techniques was called "entropy maximization." It finds a set of factors (one for each OD pair) that were each made up of other factors (one for each ground count) that, when applied, would closely reproduce the ground counts. Entropy maximization was difficult to control, so other methods have become more prominent in recent years. This section will illustrate a synthetic OD table estimation method called "whole table least squares." It is similar in concept to regression analysis from statistics. The technique requires the minimization of a very large objective function with many (perhaps hundreds of thousands) variables. One formulation is shown in Figure 6-26.

In Figure 6-26, *i* is an origin, *j* is a destination, and *a* denotes a link. The variable *s* is a scale factor to adjust for a systematic underestimation (or overestimation) in the seed OD table, which is common. The concept hinges on obtaining estimates of the p_{ij}^{a} array of proportions (*p* is proportion), which embodies all essential information of a traffic assignment. This array, which is fundamental to synthetic OD table estimation in general, contains the proportion of trips between origin *i* and destination *j* that use link *a*. For an all-or-nothing traffic assignment, these proportions are always either 0 or 1. For a multipath traffic assignment, these proportions can vary between 0 and 1. The proportions are usually obtained by performing a select link analysis on every link with a traffic count. In networks where paths are predetermined, these proportions may be set by hand; otherwise, computer software is required. These proportions allow the computation of link volumes from any OD table that might be calculated during the estimation process.

Seed OD table

OD table scale

Known traffic count

$$\min P = \sum_{a=1}^{A} w^{a}\left(V^{a} - s\sum_{i=1}^{N}\sum_{j=1}^{N} p_{ij}^{a} T_{ij}\right)^{2} + z\sum_{i=1}^{N}\sum_{j=1}^{N}\left(T_{ij}^{*} - sT_{ij}\right)^{2}$$

Weight, to emphasize certain counts

OD table weight

Adjusted OD table

Volume as if adjusted OD table is assigned to the network

Results of a select link analysis on every link with a ground count, expressed as a proportion

Figure 6-26. Anatomy of whole table least squares synthetic OD table estimation for a static forecast.

6.11.4 Why This Technique

This technique is particularly useful when a behaviorally derived OD table is either unavailable or incorrect. An OD table may be considered incorrect if it fails to validate closely to observed ground counts or has a structural issue, such as zone sizes that are too large.

Synthetic OD table estimation interpolates, smoothes, and balances ground counts, all of which are important for traffic operational analysis.

6.11.5 Words of Advice

It is critical to have a good understanding of the amount of error in the traffic counts that are used in the estimation. It is inappropriate to try to fit traffic counts more closely than warranted by the quality of the traffic counts.

A set of ground counts is likely to contain many contradictions. It is not necessary to resolve all of the contradictions before performing an estimation, provided serious mistakes have been eliminated. In addition, it is possible to have a set of ground counts that could never be reproduced closely with a traffic assignment, regardless of any manipulations to the seed OD table.

6.11.5.1 Disadvantages/Issues

This method is highly empirical. There is usually no obvious behavioral basis for the adjustments to the seed OD table. The estimation OD table is likely to age quickly and cannot be relied upon for longer-range forecasts.

In some circumstances, it is possible to obtain very close agreements with ground counts at the cost of severe distortions of the seed OD table. If the seed OD table has any validity at all, the amount of distortion needs to be monitored and controlled. For example, the average trip length for the estimated OD table should not differ much from the average trip length of the seed OD table.

An estimated OD table can be obtained that corrects for issues in the traffic assignment step, but is not appreciably better than the seed OD table. It is important to ensure that the traffic assignment step is functioning well before doing any estimation.

Some solution algorithms from the literature are known to malfunction from time to time. For example, it is possible for a solution algorithm to reach a local optimum or to reach a "saddle point" (rather than a global optimum), or simply stall.

6.11.5.2 Possible Strategies to Mitigate/Minimize Impacts of Disadvantages/Issues

It is advisable to have a target value for the amount of deviation between the ground counts and the estimated traffic volumes. This target should be set no lower than the amount of error in a ground count. Fitting the ground counts more tightly will result in an OD table that reproduces the ground count error, which is undesirable. With least squares methods, it is possible to adjust weights to increase or decrease the deviation from ground counts.

6.11.6 Executing the Technique

6.11.6.1 Special Data Preparation

Ground counts must be prepared for the time period of analysis. Twenty-four-hour counts must be factored into the correct time period. Bi-directional counts must be split into directional counts.

A seed OD table must be prepared for the time period of analysis. Any of several methods may be used to create a seed OD table, depending upon data availability.

6.11.6.2 Configuration of the Technique

Optimization methods require convergence criteria. Very tight convergence criteria can greatly increase execution times. It is recommended that trial estimations be performed with loose convergence criteria in order to determine the necessary settings. Trial estimations can also be performed to set weights appropriately.

If there is congestion on the network, then the OD table should be estimated within an equilibrium traffic assignment framework. If a behavioral OD table is being used as a seed table, then it may be necessary to feed equilibrium travel times back to earlier model steps once the estimated OD table has been assigned to the network.

6.11.6.3 Steps of the Technique

STEP 1. Obtain OD Data

Synthetic OD table estimation requires a seed OD table. The seed OD table may be obtained from a variety of sources including the following:

- Surveys—two types of surveys for obtaining a seed OD table are a household travel survey and a cordon survey.
- Vehicle re-identification methods—vehicle re-identification methods include Bluetooth detectors, aerial surveillance, cell phone tracing, and license plate matching.
- Travel forecasting models.
- Assumptions about driver behavior within small areas.

The format of the OD table will depend upon the software used for analysis. The table needs to be scaled to match the amount of traffic seen in the ground counts if the software does not do this automatically. Scaling the seed table removes the effects of a systematic error from the estimation process. "Static OD tables" consist of a single matrix with all trips within a period of time. "Dynamic OD tables" consist of several matrices, each matrix containing all trips that begin within a time slice, with enough time slices to compose the whole time period of analysis.

STEP 2. Obtain Traffic Data

Traffic counts must match the time period of the seed OD table. Traffic counts must be directional. Directional split factors must be applied to bi-directional counts. TOD factors must be applied to 24-hour counts.

Counts can differ radically in quality. For example, counts from continuous counting stations will be more reliable than counts from temporary stations. Therefore, it might be desirable to assign weights to all counts to emphasize those counts of greatest reliability. Not all road segments require counts, but the number of counts should exceed the number of origins or the number of destinations, and the counts should be spread across the network.

Counts should be inspected for outliers. There are numerous reasons why a count may be entirely wrong. Outliers should be fixed or discarded.

STEP 3. Choose Estimation Technique, Choose Error Target, and Set Parameters

Small synthetic OD tables may be estimated using a spreadsheet when all path choices are obvious. All other cases require specialized software. Software packages differ substantially in how synthetic OD table estimation is implemented. Therefore, results from one package can differ considerably from another package. It is critical that the user confirm that the software package meets the needs of the forecast.

STEP 4. Run Estimation and Inspect Results for Reasonableness

Trial estimations with loose convergence criteria are recommended. Computation times and memory requirements should be observed. Settings should be adjusted before tightening convergence criteria. Statistics from the estimations should be inspected for reasonableness. A static OD table should be estimated prior to attempting an estimation of a dynamic OD table. Check how well the estimated OD matches the seed table, and check how well the estimated volumes match the ground counts. Compare statistics from the estimated OD table to other available ground data.

6.11.6.4 Working with Outputs of the Technique

The estimated OD table can be assigned to the network directly, or the estimated OD table can be factored to satisfy the needs of medium-range forecasts.

6.11.7 Illustrative Example

Synthetic OD table estimations may be performed on a spreadsheet with "solver" functionality when all paths are predetermined. Perhaps the simplest of such cases is the estimation of turning movements at an intersection. Turning movements constitute an OD matrix, where traffic flows between each leg of the intersection or from a single "in" link (an approach) to a single "out" link. A typical four-way intersection would have 12 nonzero OD pairs, if U-turns are ignored. The seed OD table could come from historic turning movement counts or it could be assumed. For this example, the OD table is assumed using area-wide turn percentages.

Data input to the OD table estimation problem are shown in Figure 6-27 and in Table 6-10. Origins and destinations are named by cardinal direction. Each approach ("in" link) is named according to the direction it is coming from. The "out" link shares the same name, which is therefore the direction traffic is going. The seed matrix was created simply assuming 1,000 vehicles at each approach, with 15% turning left, 20% turning right, and 65% going through.

The counts do not agree with the 1,000 vehicles assumed by the seed OD table, and they do not balance. That is, the sum of the "ins" does not equal the sum of the "outs." Balanced flows at this stage are desirable but not essential.

The first step is to scale the OD table (turning movements, in this case) so that the total of all movements agrees with the average of the "ins" and "outs." For this problem, the scale factor is 0.924. Technically, movements are "ins," but the "outs" provide important redundant information that should be used in the scaling, as well.

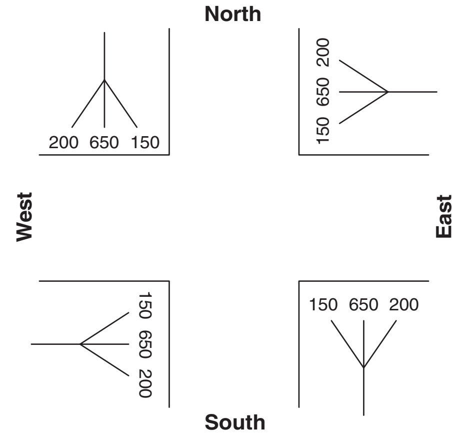


Figure 6-27. Initial turning movements constituting a seed OD matrix.

The p_{ij}^a array consists entirely of 1s and 0s. For example, all the through trips from North to South use North In and South Out, but no other links. Left turns from East to South, use East In and South Out, but no other links.

For this example, the trip table weight, z, is arbitrarily set to 1.

A spreadsheet can be set up to calculate the sum of squares of the deviations from the seed OD table and to calculate the sum of squares of the deviations from the traffic counts, and then add these two numbers together. A "solver" feature of the spreadsheet can be used to minimize this sum by varying the values of the estimated OD table. The starting point for the minimization process is the seed OD table.

Table 6-11 gives the estimated OD table.

The link root-mean-square (RMS) error is 51 vehicles, which is fairly tight to the ground counts considering the amount of error in a typical link count. The flows are bal-

Table 6-10. Measured directional counts at each link.

	North	South	East	West
In	845	1242	866	751
Out	653	865	1197	974

Table 6-11. An estimated OD table.

	North	South	East	West
North	0	567	168	147
South	604	0	335	221
East	110	147	0	605
West	18	147	627	0

anced everywhere. The estimated OD table RMS deviation from the seed table (excluding U-turns) is about 68 vehicles, which is reasonable.

The spreadsheet may be used, with modification, for any other refinement of intersection turning movements.

See Section 11.2, Case Study #2 - Network Window for a real-world application of the technique.

6.12 Refinement with Origin-Destination Table Estimation, Small and Wide Areas

6.12.1 Abstract

When performing travel forecasts over a small or wide area, refining a whole OD table, which comes from a travel demand model, can better match traffic counts and can lead to more realistic traffic assignments. The technique can also be used to smooth out inconsistencies in ground counts.

6.12.2 Context

Typical applications are access management, new corridors/ facilities, lane widening, road diets, detours, ESALs/load spectra, and traffic impact.

Geography is wide area and small area.

Typical time horizons are short range and interim.

Required input data are traffic counts, travel forecasting model OD table and volumes, traffic network, and OD table estimation software.

Optional Input data are turning movement counts.

Related techniques are screenline refinements with traffic counts and screenline refinements with additional network details.

An advantage of refinement with OD table estimation, small and wide areas, is that it uses a potentially large number of traffic counts, so the resulting OD table is statistically stronger and the new traffic volumes are likely to be more realistic than screenline methods.

Disadvantages of refinement with OD table estimation, small and wide areas, are that it is highly empirical, the estimation process can mask deficiencies in the network (such as incorrect speeds and capacities), it requires specialized OD table estimation software, it requires a travel demand model, and the OD table may be influenced by counts that are a considerable distance from the project.

Case study is Case Study #2 - Network Window

6.12.3 Background

Travel demand models can output traffic volumes that differ considerably from ground counts and are, thus, unsuitable for project-level work. Thus, it is often necessary to further refine these volumes. OD table estimation software can be used to improve the realism of an OD table that comes from a travel demand model.

Many methods of OD table estimation work by simultaneously minimizing the deviation between estimated volumes and actual volumes while also minimizing the deviation between the estimated OD table and a "seed" OD table.

The seed OD table can be supplied by a travel demand model, in which case it can be considered to be at least fairly accurate and to embody reasonably correct behavioral principles.

Deviations, either additive or multiplicative, between the estimated OD table and the seed OD table may be applied to future forecasts.

6.12.4 Words of Advice

This method will tend to reduce the strength of any behavioral assumptions of the original model. Networks with many origins and destinations can cause long computation times. There is a need for many traffic counts throughout the network. Preparation of traffic counts may require substantial human resources. Some traffic counts may have large errors in them. OD table estimation methods require some judgment when setting parameters. There are a variety of OD estimation methods available, and the properties of those methods are not always obvious.

It is helpful if the OD table estimation software is integrated with the travel demand model; however, such integration is not essential. The refinement itself may reveal which traffic counts are suspect by comparing the assigned volumes after refinement to the traffic counts. Large differences are causes for concern.

6.12.5 Executing the Technique

See software documentation for any special data requirements or parameter settings. The steps of the technique and instructions for working with the output are provided below.

STEP 1. Prepare or Adopt a Raw Travel Forecast from a Travel Demand Model

A good, trusted travel model is important for this method because it will supply a raw OD table that has behavioral realism. It is possible to execute all the steps of the method without a good, trusted model; however, additional caution must then be exercised to ensure that the forecasts are reasonable as to traffic volumes, turning movements, and path selection. Software documentation, best-practice guidelines, and validation guidelines should be consulted to obtain the best possible forecast before proceeding to the next step.

The raw travel forecast, by definition, does not contain the project. The travel model output needs to be appropriate for the time period of analysis for the project, for example, a single PM peak hour.

STEP 2. Obtain Traffic Counts (and Turning Movement Counts)

OD table estimation software methods vary as to their input requirements. Most software can accommodate traffic volumes.

Turning movements may also be an input, depending upon the software. However, turning movement counts are essential for understanding whether the OD table estimation has been executed well. Where possible, counts should be bi-directional and by time of day. Hourly (or shorter) counts need to be aggregated to the time period of the travel model.

Factoring a daily count by applying hourly factors should be avoided unless those hourly factors are specific to the location of the count. See optional Step 6 for advice on obtaining hourly factors and directional split factors.

STEP 3. Determine the Desirability for a Refinement

The major justification for this type of refinement is significant deviation between base case forecast and known ground counts for one or more road segments that are critical to the project's evaluation. This deviation should be substantially greater than predicted error in a single ground count.

STEP 4. Execute the Refinement, Obtain Adjustments, and Validate the Refinement

OD table estimation software allows for considerable tuning of the results. Different counts can be given different weight in the estimation. The amount of deviation from the seed table can also be controlled. It is critical that the seed table OD remain strongly represented in the estimated table because the seed OD is the only source of behavioral information within the process. The following rule should be applied: *under no circumstance should the weight of the OD table be diminished to a point where the deviations between the estimated volumes and the ground counts are below the known error in the ground counts.* If ground counts are matched too closely, then the estimated OD table will embed traffic count error, thereby undermining any behavioral realism in the raw forecast. Some OD table estimation techniques, such as entropy maximization, are difficult to control and may automatically provide volumes that are too close to the ground counts. In such cases, a different OD table estimation technique should be sought.

There are two possible adjustments, additive adjustments and multiplicative adjustments, sometimes referred to as "K" factors (not to be confused with "k" factors from calculations of directional design hourly volume). The small OD matrices in Figure 6-28 illustrate those adjustments. Adjustments to intrazonal trips are usually unimportant and are set to 0 (additive) or 1 (multiplicative).

If turning movements were not used to perform the OD table estimation, then they can serve as a way to validate the refinement. These items should be compared, if possible:

- Turning percentages for the area without refinement, from a traffic assignment;
- Turning percentages for the area with refinement, from a traffic assignment; and
- Turning percentages for the area, as approximated from actual counts.

A validated, refined OD table should have turning movement percentages that are closer to reality in the base year.

Drivers' route choices are influenced by congestion. The OD table refinement procedure must be capable of handling congestion where it exists. If a simulation uses equilibrium traffic assignment to model congestion, then the OD table should be refined with equilibrium conditions in place.

STEP 5. Forecast with the Refined OD Table

A new model run is made with the project. Adjustments found in Step 4 are assumed to hold for the project.

STEP 5A. Additive Adjustments

Figure 6-29 illustrates how additive factors, as obtained from the OD table estimation method for the base year, would be combined with the future OD table from the model.

STEP 5B. Multiplicative Adjustments (K Factors)

Figure 6-30 illustrates how multiplicative factors, as obtained from the OD table estimation method for the base year, would be combined with the future OD table from the model.

Raw, Base OD Matrix From Model			
Zone	A	B	C
A	0	90	75
B	100	0	45
C	80	50	0

Refined, Base OD Matrix			
Zone	A	B	C
A	0	105	70
B	95	0	55
C	70	60	0

Additive Factors			
Zone	A	B	C
A	0	15	-5
B	-5	0	10
C	-10	10	0

Multiplicative Factors			
Zone	A	B	C
A	1.00	1.17	0.93
B	0.95	1.00	1.22
C	0.88	1.20	1.00

Figure 6-28. Calculation of additive and multiplicative adjustment factors.

Raw, Future OD Matrix From Model				Additive Factors				Refined, Future OD Table			
Zone	A	B	C	Zone	A	B	C	Zone	A	B	C
A	0	110	80	A	0	15	-5	A	0	125	75
B	105	0	60	B	-5	0	10	B	100	0	70
C	95	65	0	C	-10	10	0	C	85	75	0

Figure 6-29. Application of additive adjustment factors.

STEP 6 (OPTIONAL). Dealing with 24-Hour and Bi-Directional Counts for Hourly or Peak-Period Forecasts

OD table refinement requires that there be counts in each direction at each count station and that the counts are specific to the time period of analysis. Many traffic counts are taken over a 24-hour period of time or are bi-directional, that is, both directions on a two-way road are added together. An hourly or peak-period forecast needs counts in compatible time units. Obviously, a failure to adjust 24-hour counts for the time period of analysis will cause the refined OD table to be too large, overall. Less obviously, a failure to adjust bi-directional counts will tend to have an equalizing effect on all directional splits after the refined OD table is assigned to the network.

The process of adjusting counts is similar in concept to the application of "k" and "D" factors when calculating directional design hourly volume (DDHV). In this case, "k" and "D" factors must be selected for each count direction, individually.

The adjustment is made by multiplying the raw count with each factor, as appropriate. For example, if a count were both 24-hour and bi-directional, then the adjustment would be made with the following equation:

$$\textit{Adjusted Count} = k * D * (\textit{Raw Count})$$

Counts so adjusted are likely to be inferior to directional counts for the correct time period, so they should be afforded less weight in the estimation process.

STEP 6A. Adopting "k" and "D" Factors from Nearby Roads

If there are only a few 24-hour or bi-directional counts, then it is possible to prudently adopt "k" and "D" factors from nearby count stations. The direction of the highest flow rate is important. "k" factors are likely to transfer to new locations better than "D" factors. For best results, the donating station should be on a road that is parallel to, similar to, and proximate to the receiving station.

STEP 6B. Adopting "k" and "D" Factors from Model Runs

If there are many 24-hour or bi-directional counts, then the model outputs can be efficiently used to make the adjustment. In order to do this adjustment for 24-hour counts, there must be both a 24-hour forecast and a forecast for the time period of analysis. It is also important that the model apply TOD factors ahead of the assignment step, either post-distribution (for all modes) or post-mode-split (for individual modes), because pre-assignment TOD factors have directionality built into them. Such TOD factors may be found in *NCHRP Report 716* (*6*) if local parameters are not available. The ratio of the two forecasted volumes gives the necessary "k" factor. The forecasted split between directions on the same link gives the "D" factor.

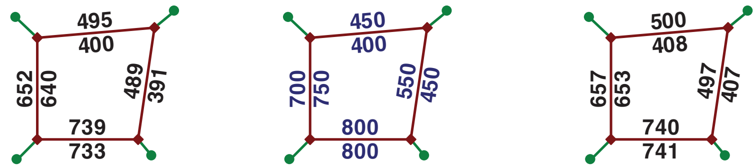
The refined forecast may be used directly for project-level planning and engineering. Turning movements may require additional treatment.

6.12.6 Illustrative Example

Figure 6-31 shows how a forecast on a small network from a fictitious city may be refined by fitting the model to ground counts. The forecast is for the evening peak hours. Demand was calculated from behavioral principles, and the traffic assignment was equilibrium with feedback to distribution. Zones are named by the corners of the network, northeast, northwest, southeast, and southwest. The first two network images shown in Figure 6-31 show the base year run (a) and the base year ground counts (b). The error in any ground count for this network is known to be about 10%. Although the fit is not bad (RMS error of 11%), the planner feels that a closer agreement with ground counts (better than 10%) is

Raw, Future OD Matrix From Model				Multiplicative Factors				Refined, Future OD Table			
Zone	A	B	C	Zone	A	B	C	Zone	A	B	C
A	0	110	80	A	1.00	1.17	0.93	A	0	128.33	74.67
B	105	0	60	B	0.95	1.00	1.22	B	99.75	0	73.33
C	95	65	0	C	0.88	1.20	1.00	C	83.13	78.00	0

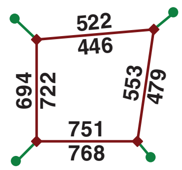
Figure 6-30. Application of multiplicative adjustment factors.



(a) Base Year Run

(b) Base Year Ground Counts

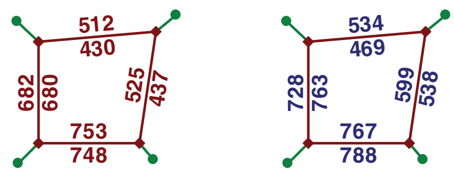
(c) Refinement Run A



(d) Refinement Run B

	NE	NW	SE	SW
Northeast	0.0	-33.6	-9.1	21.3
Northwest	-18.3	0.0	34.0	67.5
Southeast	-25.8	33.4	0.0	28.7
Southwest	65.4	105.0	10.2	0.0

(e) Additive Adjustments to OD Table



(f) Future Year Run, No Adjustment

(g) Future Year Run, Adjusted

Figure 6-31. Illustrative example in a four-zone network.

desirable, particularly near the southwest corner of the network where the project is located. The software available to the planner uses a method called weighted least squares. Link weights were all set to one, while a variety of OD table weights were tried. Two of those runs, Refinement Run A and Refinement Run B (Figure 6-31c and d, respectively), are shown. Refinement Run A had an OD table weight of 10 and Refinement Run B had an OD table weight of 1. It can be seen that Refinement Run A, for the most part, shifted the base year forecast closer to the counts, but the improvement was paltry due to the large OD table weight.

Refinement Run B saw a greater shift. Most links in Run B had volumes that were closer to their respective counts. Since Run B differed from ground counts by about 6% on average, it was considered acceptably close.

The difference between the Base Year Run OD table and the Refinement Run B OD table gives the additive adjustments to the OD table (Figure 6-31e). Additive adjustments were chosen simply because of convenience. The Future Year Run, No Adjustment (Figure 6-31f) shows the forecast without any refinement. The Future Year Run, Adjusted (Figure 6-31g) combines the additive adjustments with the OD table as calculated by the model from behavioral principles. A quick inspection of the combined OD table determined that all the new OD flows were reasonable. It should be noted that the link volume differences between the adjusted and unadjusted forecasts are logical in magnitude, but link volumes are not additive, since the equilibrium traffic assignment has a tendency to move traffic from high-volume links to low-volume links.

CHAPTER 7

Refining the Spatial Detail of Traffic Models

The process of refining the spatial detail of a highway traffic model involves a variety of techniques that (1) increase the spatial resolution of the model itself, (2) use ground data to enhance what might have been directly output, or (3) post-process the results to improve their fidelity to the actual system.

A key approach to increasing spatial detail in traffic models is subarea analysis. There are three basic types of subarea methods: focusing, windowing, and custom applications. FHWA defines focusing as a subarea analysis method that involves detailing the trips and network inside the subarea and performing analysis within the entire model (*97*). The focusing method is used for observing system-wide effects over the entire modeling region. This approach requires adding substantial additional detail to the traffic analysis zones (TAZs) and network inside the subarea while leaving the area outside the subarea unmodified. See Figure 7-1 for a graphic representation of this method and the windowing method.

The three basic types of subarea analysis are detailed in this chapter, with suggestions on when and how each type should be used, input requirements, and procedural steps, as well as words of advice and illustrative examples.

Additional spatial detail may be obtained by post-processing the results of a travel model through multiresolution modeling. Multiresolution modeling is the blending of a macroscopic travel forecast with a traffic microsimulation or a dynamic traffic assignment (DTA), potentially with feedback between them.

Functionality may be improved by integrating multiple levels of models: statewide, regional, or local. A related topic, external station refinements, can improve the inputs to travel models, which can result in better forecasts for subareas, in particular.

7.1 Method: Subarea Focusing, Custom Networks, or Customization of a Region-Wide Network

7.1.1 Abstract

Traffic forecasts for projects within a small area may need considerable spatial detail beyond the level typically available in a region-wide travel forecasting model. In such cases, it may be beneficial to either add detail to a region-wide network, thereby creating an enhanced focus for the small area, or to build a focused network from scratch.

A subarea focused network can take one of three forms: a conventional regional network that has been enhanced within the subarea; a custom network for the subarea, which includes a coarse network for the surrounding region; or a conventional regional network that has been both enhanced within the subarea and simplified across the rest of the region.

Subarea focusing is particularly suitable for site impact assessment. The network can be used to forecast all traffic within the subarea or just to forecast incremental traffic due to a specific trip generator.

7.1.2 Context

Typical applications are intersection design/signalization, general land use changes, lane widening, road diets, and traffic impact.

Geography is site, corridor, and small area.

Typical time horizons are short, interim, and long.

Required input data are area maps; demographic data by small geographical units; independent variables for trip generation at the site; site maps, particularly showing parking lots, and entrances/exits; mean trip length in minutes for any

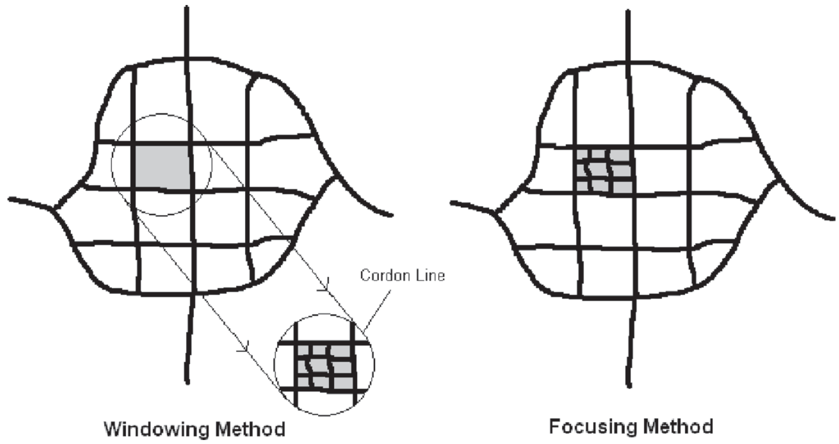


Figure 7-1. Illustrative example of subarea focusing and windowing methods to increase spatial detail.

modeled trip purpose; peak-hour speeds; time-of-day (TOD) factors; and directional split factors.

Optional input data include region-wide travel forecasting model.

Related techniques are hybrid/multiresolution models and DTA.

Advantages of subarea focusing are that it uses conventional travel forecasting software, can use an existing region-wide travel model, and has the potential for better traffic routing and delays than an unfocused model.

Disadvantages of subarea focusing are the possibility for imprecise traffic routing and delays over large portions of the region outside the focused area and potential difficulties in correctly implementing capacity-constraints according to equilibrium principles.

7.1.3 Why This Technique

The primary importance of subarea focusing is to create additional spatial detail where it is required for project-level planning and engineering. Some previously published articles on subarea focusing emphasized this method's relative computational efficiency over traditional region-wide models. With advances in computers, computational efficiency is now only a minor consideration. Nonetheless, subarea focusing still offers considerable advantages in terms of data preparation costs and speed of implementation.

7.1.4 Words of Advice

7.1.4.1 Disadvantages/Issues

For networks that are greatly simplified outside of the subarea, traffic routing and delays may be imprecise over large portions of the region. Networks that forecast only incremental traffic from a trip generator cannot be correctly capacity constrained according to equilibrium principles.

7.1.4.2 Possible Strategies to Mitigate/Minimize Impacts of Disadvantages/Issues

It is most beneficial if a regional model can be modified by enhancing the subarea, leaving the rest of the model intact.

7.1.5 Executing the Technique

7.1.5.1 Special Data Preparation

Special efforts need to be made to accurately represent traffic controls within the subarea and to ensure that turn penalties are selected appropriately.

There are two forecasting styles:

- Forecasting only the incremental travel due to new generator(s) and
- Forecasting all traffic within the region.

7.1.5.2 Configuration of the Technique

For enhanced regional models, parameters should be the same as for the original regional model, except those for upgraded traffic controls within the subarea and those for roads of a lower functional class.

7.1.5.3 Steps of the Technique

STEP 1. Identify Subarea and Develop TAZ System

Many networks designed for subarea focusing are dealing with highly localized impacts, such as new traffic from a trip generator or a lane widening over a short road segment. It is important to make the subarea large enough to achieve a good approximation to changes in trip making attributable to the project. If the project is within a congested portion of the region, then the subarea needs to be larger than it would need to be if the project were within a lightly traveled portion of the region. The number of nearby roads for absorbing the impact is another consideration. Wide road spacing means that impacts will extend farther from the project. Often the road system outside of the subarea is drawn sketchily, so it is important to make sure that the subarea, which is much more detailed and potentially more accurate, encompasses all critical aspects of the impacts. If the subarea is currently within a regional model, it is helpful if the subarea is defined as a contiguous set of regional-model TAZs.

Newly defined TAZs within the subarea need to be quite small, usually about the size of one or a few city blocks. Subdividing regional-model TAZs is often an efficient way to create subarea TAZs.

To the extent possible, TAZs need to be compact and homogeneous. For a development site, a zone should be a single parking lot or the area of a large parking lot that is served by a single exit/entrance.

If TAZs are sufficiently small, there is no need to orient them in any particular way relative to the project. Demographic data need to be obtained or calculated for each subarea TAZ. For site developments, trip generation characteristics must be obtained from sources such as the Institute of Transportation Engineers' (ITE's) *Trip Generation Handbook* (*11*) and attributed to each parking lot at the site.

STEP 2. Develop Network

The network within the subarea should be as detailed as practical, including all arterial streets and collectors. Certain local roads and driveways from parking lots may be needed for continuity purposes. Centroids and centroid connectors must be created for each zone within the subarea. Because of the need for consistent turning movement volumes, centroid connectors should attach to arterials at mid-block within the subarea.

The network outside the subarea can be constructed in a variety of ways, depending upon needs:

- Network from the regional model, essentially intact;
- A simplified network from the regional model; or
- A network with only paths to and from the subarea.

The design of the network within the subarea will be the same, regardless of the style of network outside the subarea.

The time period of analysis needs to be established at this stage, such as a 1-hour peak period for impacts from site developments.

Using the regional model's network is elementary. Presumably, this network is already in good condition, except for the subarea, and will be able to handle either all traffic in the system or incremental traffic from site development, as needed.

When only incremental traffic from the site is being forecast, it is possible to simplify the regional network by reducing detail or by creating a sketch network with only paths to and from the subarea. Reducing detail is best accomplished by eliminating roads of lower functional class, checking the road system for continuity, and restoring the few links that break continuity. There is an expectation that vehicle paths outside the subarea will be only approximately correct.

There are multiple strategies for building sketch networks with only paths to and from the subarea. Perhaps the simplest strategy is to build a skim tree from every centroid within the subarea, then combine the skim trees into a single network.

It would be best if the impedances on the network were appropriate for the time period of the forecast. Ideally, impedances should be ascertained from an equilibrium traffic assignment. Combining skim trees usually has the effect of allowing alternative paths between any one point within the subarea and the rest of the network.

Outside of the subarea, centroid connectors can be placed at any convenient location, usually at an intersection within a TAZ closest to the subarea.

STEP 3. Estimate Trip Generation for Subarea

Trip generation can be disaggregated from the regional model or developed from scratch or both. It is important when adopting data from ITE's *Trip Generation Manual* (*108*) or similar data to be mindful of the directional split from sites, so that traffic can be routed in the correct direction. It is also helpful if the peak hour of the site is the same as the peak hour of the region-wide model.

When only incremental traffic is being forecast, it is quite helpful to have collected mainline traffic counts and turning movement counts for existing traffic without any new trip generators. Traffic from new generators can be combined with existing traffic to arrive at a total amount of traffic for assessing level of service or other purposes.

If incremental traffic from the site is being forecast, then it is best to designate all site traffic as "productions" with all "attractions" at off-site zones (using the parlance of a gravity equation). Thus, it is necessary to determine a measure of trip attractiveness for all off-site zones. If the site traffic falls neatly within a trip purpose, then attractiveness can be calculated from trip attraction equations of the regional model or from trip attraction equations borrowed from such sources as *NCHRP Report 716* (*6*). Otherwise, professional judgment should be used to establish a measure of attractiveness consistent with the nature of the site traffic.

STEP 4. Setup and Run Travel Model on Focused Network

Different travel forecasting software packages require different setups, but the general concept is the same. Parameters of particular interest for making this work well are the following:

- Time of day and direction of travel for a peak hour for trip purposes in the regional model,
- Time of day and direction of travel for site traffic,
- Choice of equation for trip distribution step, and
- Method of traffic assignment.

When only incremental traffic from a site is being forecast, trip distribution can be accomplished with either a singly constrained gravity equation or a destination choice equation. Within the parlance of a gravity equation, all "productions" should be at the site, and all "attractions" should be at off-site zones.

A singly constrained gravity equation will ensure that the amount of site traffic is consistent with trip generation estimates, but the amount of traffic going to off-site zones is not constrained to agree with the number of trip attractions. A singly constrained gravity equation takes the following form:

$$T_{ij} = \frac{P_i A_j F_{ij}}{\sum_{j=1}^{N} A_j F_{ij}}$$

Where T_{ij} is the number of trips from production zone I to attraction zone j, P_i is the "productions" at the subarea zone i, A_j is the attraction (or attractiveness) at off-site zone j, F_{ij} is the friction factor between the origin and destination, N is the number of zones.

Destination choice models usually take the form of a multinomial logit equation:

$$p_j = \frac{e^{V_j}}{\sum_{k=1}^{M} e^{V_k}}$$

where p_j is the probability that destination j is chosen and V_j is the deterministic utility of travel between the origin zone and the destination zone. The deterministic utility term consists of a zone-size variable and time, cost, and convenience variables:

$$V_j = \ln(s_j) + a_1x_1 + a_2x_2 + a_3x_3 + \cdots$$

where

s_j = the size of destination zone j,
a_1, a_2, a_3, and so forth = empirical coefficients, and
x_1, x_2, x_3, and so forth = variables for describing a trip.

A traffic assignment of incremental site traffic would be logically all or nothing or multipath, that is, not capacity restrained. It is not possible to do a good equilibrium traffic assignment with only incremental traffic. If all traffic in the subarea is being forecast, then an equilibrium method is recommended.

7.1.5.4 Working with Outputs of the Technique

When all traffic in the region is being forecast, the subarea forecast may be used directly for project-level planning and engineering. Turning movements may require additional treatment.

If only incremental traffic is being forecast, then the incremental traffic should be added to background traffic, established by counting, to obtain total traffic for input into traffic operations software products.

7.1.6 Illustrative Example

This illustrative example, QTown, is similar to an example problem found in *NCHRP Report 187* (*8*) and later simplified for a short course on quick response techniques offered by FHWA.

QTown is considering a building permit for an office park that is located in an already congested section of the city.

Figure 7-2 shows the location of the office park within a quadrant of QTown, and Figure 7-3 shows the location of this

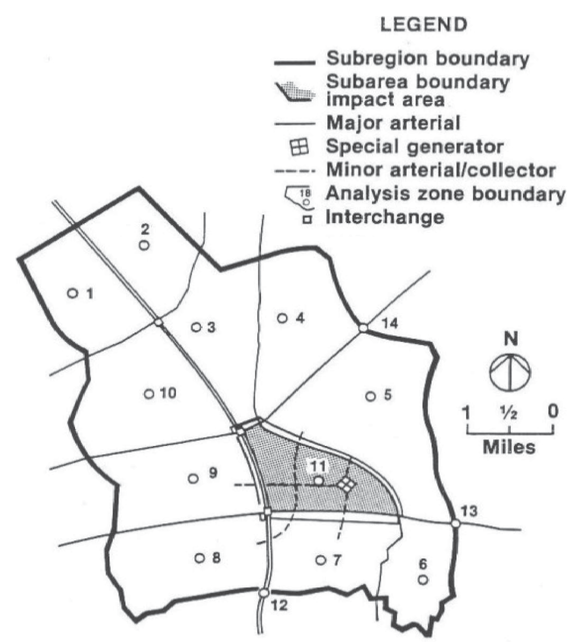


FIGURE 2. STUDY AREA

Figure 7-2. Subarea focused zone system for QTown, showing important roads, location of site, and 11 zones nearest the site.

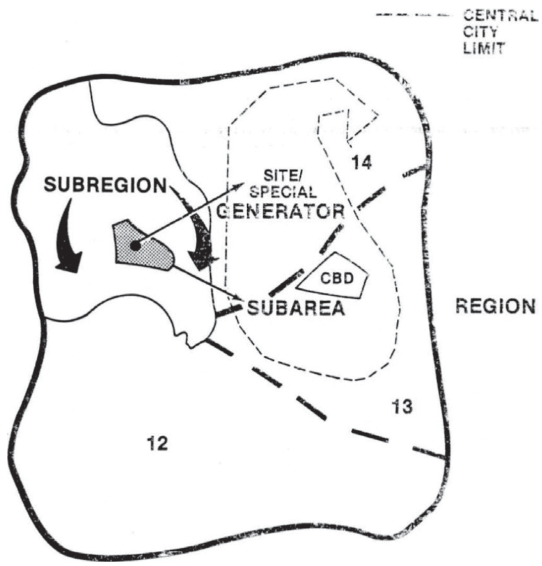


Figure 7-3. Location of site's quadrant within metropolitan QTown.

quadrant within the larger QTown metropolitan area. The office park is expecting 315,000 sq ft of floor area and 2,000 employees. The average speed of traffic on arterials is 22 mph. The average speed of traffic on freeways is 46 mph. Due to the nature of the road system (which has been influenced by the terrain of the area), most of the trips to and from Zone 11, where the office park is located, are made on the roads shown in the figures. The population of QTown is 90,000.

Table 7-1 lists the number of dwelling units in each zone. It should be noted that Zones 12, 13, and 14 are much larger than the others and are much more distant from the arterial network of Figure 7-2.

Table 7-1. Number of households in each zone in QTown.

Zone	Households
1	782
2	505
3	957
4	651
5	960
6	537
7	542
8	645
9	743
10	852
11	548
12	7,092
13	4,970
14	10,216

The network in Zone 11 has both major and minor arterials. The network for the remaining zones has only freeways and major arterials. The portions of the network leading to and from Zones 12, 13, and 14 have been simplified to a single road segment.

The limited availability of data about the rest of QTown and the need for fast results dictate that a custom network be drawn focused on Zone 11, which only estimates incremental traffic owing to the site. Existing traffic is assumed to be constant. Of greatest interest is traffic during the AM peak hour, because traffic moving toward the site could logically make a potentially problematic left turn at one or two currently busy intersections.

The network shown in Figure 7-4 contains only those streets that are required for this incremental forecast. It is important to observe that the office park gets its own centroid, separate from the centroid for Zone 11. Each zone has just one or two centroid connectors; centroid connectors leading away from the site are unnecessary. The measure of zonal attractiveness, number of households, is shown next to the centroids. Since the office park has only one entrance to its parking lot, it needs only one centroid (and one centroid connector). A more complicated parking arrangement at the site might have necessitated additional centroids.

The amount of incremental traffic to and from the site during the AM peak hour may be obtained from ITE's *Trip Generation Handbook* (*11*). The statistics in ITE's *Trip Generation Manual* (*108*) for employees are stronger than those for floor area, so the traffic estimates are computed from the 2,000 employees at an average trip rate of 0.43 vehicle trips per employee and with a directional split of 92% in and 8% out. This means that 791 trips are going to the site during the AM

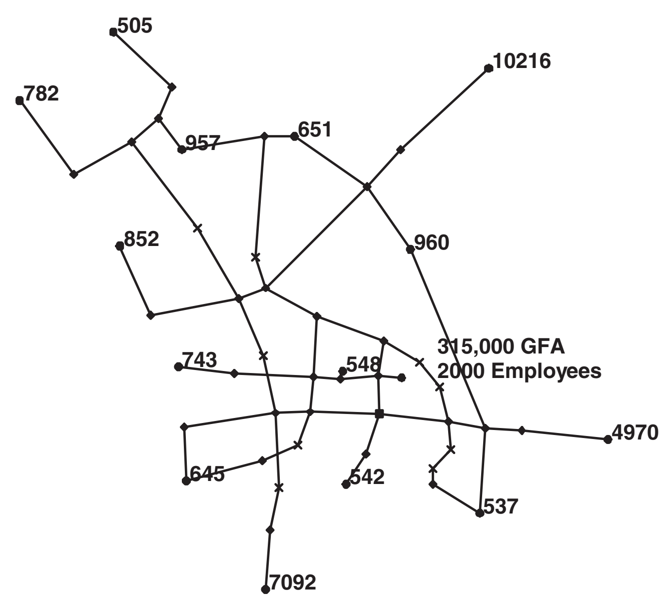


Figure 7-4. Network for the QTown office park problem (GFA = gross floor area).

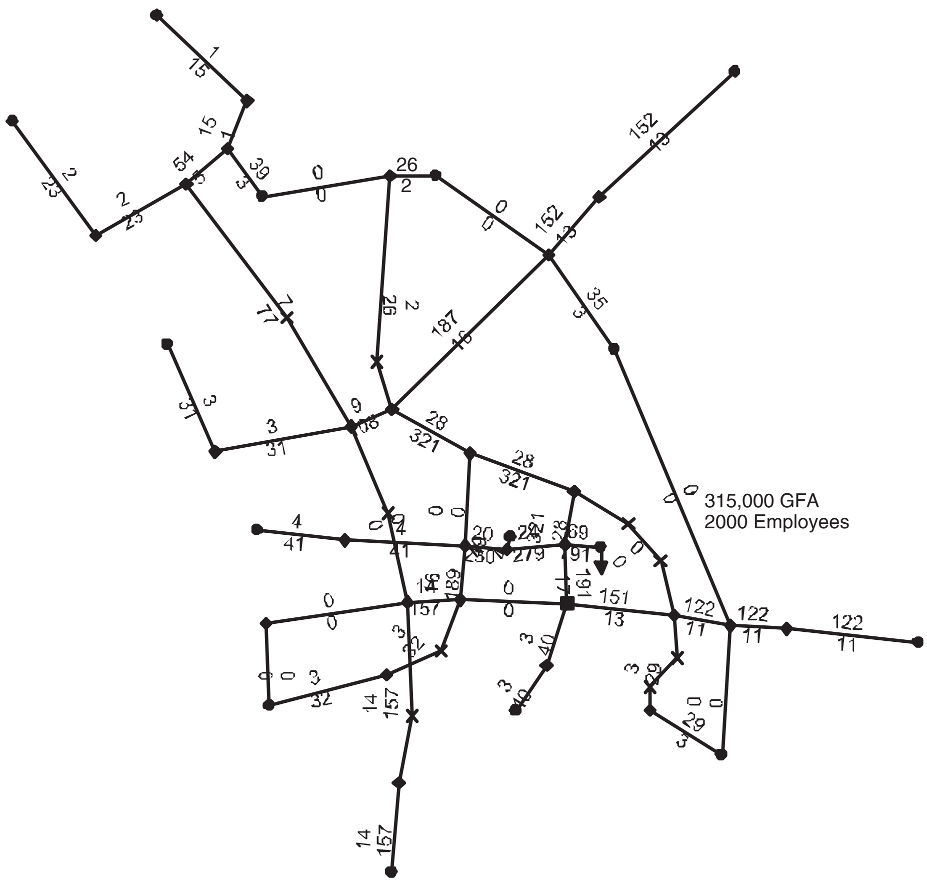


Figure 7-5. QTown assigned traffic volumes (GFA = gross floor area).

peak and 69 trips are leaving the site. All 860 trips are distributed from the site to off-site zones using a singly constrained gravity model. Friction factors are computed with a negative exponential function having a coefficient of 0.1, chosen to match the historical average work trip length (13 minutes) in QTown. Figure 7-5 shows the forecasted incremental traffic on the network traveling to and from the site on each link.

The intersections of 2nd and Main (just south of the office park, shown as a square dot in Figure 7-5) and 1st and Main (immediately to the west) already had a large number of left turns, eastbound to northbound. It can be readily seen that there are 157 new left turns occurring at the intersection of 1st and Main which warrants further study.

7.2 Windowing to Forecast Traffic for Small Areas

7.2.1 Abstract

Windowing can be used when performing travel forecasts over a small area where a region-wide model is not available or will be cumbersome to use, but where many ground count stations exist in the area. Windowing isolates the small area from the rest of the traffic network, estimates an origin-destination (OD) table for that window by principally matching ground counts, and allows assignment of the estimated OD table to links within that window to ascertain traffic impacts.

7.2.2 Context

Typical applications are intersection design, access management, new corridors/facilities, lane widening, road diets, detours, ESALs/load spectra, and traffic impact.

Geography is small area.

Typical time horizons are short.

Required input data are traffic counts, traffic network, and OD table estimation software.

Optional input data are turning movement counts, and cordon survey.

Related techniques are screenline refinements with traffic counts, screenline refinements with additional network details, and refinement with OD table estimation.

Advantages of windowing to forecast traffic for small areas are that it is much faster than building a traditional regional model and provides very precise traffic estimates within the small area.

Disadvantages of windowing to forecast traffic for small areas are that it is highly empirical, requires specialized OD table estimation software, and requires a seed OD table that is unlikely to be based on behavioral principles.

Case study is #2 - Milwaukee/Mitchell Network Window.

7.2.3 Why This Technique

Small projects often affect traffic only in a localized area. For these projects, a region-wide travel model is not required. It may be more efficient in time and resources to build a custom model for the localized area only and a limited buffer around that area, which together form a "window." The technique requires estimating an OD table for the window by using mostly empirical methods and then assigning traffic to a network that covers the window. The technique employs OD table estimation from ground counts. Many methods of OD table estimation work by minimizing the deviation between estimated volumes and actual volumes while also minimizing the deviation between the estimated OD table and a "seed" OD table.

The seed OD table can be supplied from survey data or it can be built from reasonable expectations of driver behavior over the short distances across a window.

The estimated OD table is used, as is, for short-term, project-level forecasts. However, it may be possible to extrapolate the OD table into the not-to-distant future.

7.2.4 Words of Advice

7.2.4.1 Disadvantages/Issues

There is a need for traffic counts throughout the window, but especially at the edges of the window where traffic enters and exits. Some traffic counts may have large errors in them. OD table estimation methods require some judgment when setting parameters.

There are a variety of OD estimation methods available, and the properties of those methods are not always obvious. In the absence of a cordon survey for the window, the creation of the seed OD table requires considerable expert judgment.

7.2.4.2 Possible Strategies to Mitigate/Minimize Impacts of Disadvantages/Issues

If the window is large and has complex traffic patterns, then a cordon survey is desirable. The cordon survey must be precise as to the actual points where drivers enter and exit the window. Surveys that identify the actual origins and destinations of full trips or surveys that identify trip ends by zones are not as useful. Turning movement counts within the window will help validate the seed OD table because OD flows through the window are closely related to turns within the window.

7.2.5 Executing the Technique

7.2.5.1 Special Data Preparation

All counts and turning movements must be adjusted to the same time period. An OD table from a cordon survey, if one is available, should be appropriately factored to match traffic counts at the edges of the network. Balancing of counts along freeway corridors (that is, ensuring agreement between on-ramp flows, off-ramp flows, and mainline flows) may be desirable.

7.2.5.2 Configuration of the Technique

See software documentation for any parameter settings for OD table estimation.

7.2.5.3 Steps of the Technique

STEP 1. Define the Window and Network

The window must be large enough to contain a large majority of impacts from the project. In congested networks, traffic impacts can spread to considerable distances from the project, especially if adjacent alternative routes are already operating near capacity. If the extents of the impacts are difficult to ascertain ahead of time, an amply large window should be created. The boundaries of the window should be convex, so that a single vehicle path enters the window exactly once and does not exit and then reenter the window. A convex window also tends to minimize the number of entry and exit points, which is beneficial.

A complete traffic network needs to be defined for the window. The traffic network should contain all road functional classes that may see new traffic or lose traffic due to the project. The network should apply the highest standards of coding traffic-controlled intersections and should ascertain capacity on uncontrolled road segments in accordance with the latest *Highway Capacity Manual.*

Depending upon the software available, zones or external stations need to be defined at all entry and exit points to the window. Small windows may not need internal zones, but large windows may have significant internal trip generation and may require internal zones. For internal zones, elementary ("quick response") trip generation relations similar to those from *NCHRP Report 365* (*7*) or *NCHRP Report 187* (*8*) should suffice.

In the absence of already defined TAZs, U.S. Census boundaries, such as block groups, should be chosen.

Windows work best if they are precise as to a time period. A single hour is especially convenient, coinciding with the reporting period for many traffic counts.

STEP 2. Obtain Traffic Counts (and Turning Movement Counts)

OD table estimation software methods vary as to their input requirements. Most software can accommodate mainline traffic counts. Turning movement counts may also be an input, depending upon the software. However, turning movement counts are essential for understanding whether the assumptions or other evidence underlying the seed OD table are valid. Where possible, counts should be bi-directional and by time of day. All counts need to be adjusted to the same period of time.

Factoring a daily count by applying hourly factors may be necessary. Bi-directional counts should be factored into directional counts using historical data or data from nearby streets. See optional Step 6.

Counts at all entry and exit points of the window are important. More counts make for a more accurate OD table.

STEP 3. Develop a Seed OD Table

A seed OD table may be developed from cordon survey data or from assumptions of driver behavior over short distances. If the window is small, an OD table with just external traffic will suffice. However, large windows with internal trip generation may need additional information about the distribution of traffic to and from the windowed area.

STEP 3A. Develop a Seed OD Table from a Cordon Survey

A cordon survey can be expensive and time-consuming, but it may be essential if there is substantial uncertainty as to the paths that drivers take through the window. Various technologies now exist to perform cordon surveys that do not require direct interaction with drivers, including license plate matching, toll transponder readers, Bluetooth detectors, cell phone records, and aerial photography. However, these technologies require the rental or purchase of specialized equipment or data and require substantial lead times.

Each technology has its own detection rates, and it is possible for detection rates to vary from location to location. The raw OD table obtained from the survey will require considerable factoring to make it suitable for further analysis. Ideally, traffic counts can be taken at the same time and locations as the cordon survey, so the detection rates can be determined exactly.

STEP 3B. Develop a Seed OD Table from Assumptions of Driver Behavior

In the absence of a cordon survey, it is still possible to obtain a good seed OD table by modeling driver behavior over short distances. Because of the short distances, conventional theories of destination choice do not pertain.

All destinations are roughly equally accessible from all origins (considering only a fraction of most drivers' full trips occur within a window), so the probability of arriving at a given destination is almost insensitive to typical impedance measures such as distance or travel time. In addition, drivers rarely backtrack and most drivers tend to keep moving in the direction they originally were traveling when they entered the window. Said another way, there is a low probability that any driver will turn at any given intersection.

The only information that usually exists to suggest that one destination is superior to another in attracting a trip is the traffic volume exiting the window at that location.

Turning movement counts within the window should allow for the calculation of the probability that any given trip will make zero, one, two, or three turns within the window. Trips with four or more turns can be safely ignored. Right turns are more likely than left turns. Strictly as a matter of probabilities, drivers will seem to prefer destinations that can be reached with fewer turns, overall, and fewer left turns than right turns. A gravity-like model, which should be conveniently available within travel forecasting software packages, may be executed to obtain such a seed OD table by treating turns as a Markov process:

- Select an impedance value for a left turn.
- Select an impedance value for a right turn, presumably lower than the impedance value for a left turn.
- Find the set of lowest turn-impedance paths between all origins and all destinations. Call this impedance t_{ij}, where i is the origin (entry point of the window) and j is the destination (exit point of the window).
- Calculate the number of trips between entry and exits using this equation for a doubly constrained gravity model with an exponential friction factor function:

$$T_{ij} = X_i Y_j O_i D_j exp(-\beta t_{ij})$$

- where X_i is chosen such that:

$$\sum_j T_{ij} = O_i$$

- and where Y_i is chosen such that:

$$\sum_i T_{ij} = D_j$$

- Where exp() is the exponential function, O_i is the number of vehicles originating at entry point i, and D_j is the number of vehicles with destinations at exit point j.
- It is helpful to remember that exp(−0.693) = 0.5, so an increase in the term βt_{ij} by about 0.7 decreases the probability of a destination being selected by half.
- So, if the impedance of an individual turn is 7 and the value of β is 0.1, then the probability of a zero-turn trip will be twice that of a one-turn trip and four times the probability of a two-turn trip, everything else being equal.

- Assign the seed OD table to the window's network and check the percentage of turning movements throughout. Adjust turn impedances, if necessary, to achieve a reasonable number of turns.

For a small window, a suitable seed OD table may be developed on a spreadsheet, but larger windows might require modeling software. Impedances based on turns are not used in the forecast itself, just in creating the seed OD table.

STEP 3C. Optional Special Handling of Internal Zones

For most windows, strictly internal-internal (I-I) trips can be ignored. Larger windows and windows with major trip generators should consider trips coming in and out of the windows—internal-external (I-E) and external-internal (E-I). Thus, the seed OD table must be adjusted for this travel. A conventional, singly constrained, gravity model can be used for these estimates, but all "productions" should be at the internal zones and all "attractions" should be at the entry and exit points of the network. That is, from the gravity model's viewpoint, all trips coming to and going from internal zones are defined as productions. The conventional gravity model should use conventional measures of impedance (time, distance, tolls, etc.) plus a substantial constant to adjust for the portions of trips beyond the window. The number of I-E trips versus the number of E-I trips can be ascertained from ITE's *Trip Generation Manual* (*108*) or from TOD tables from such sources as *NCHRP Report 716.* A singly constrained gravity model is executed twice:

$$T_{ij} = \frac{P_i A_j F_{ij}}{\sum_{j=1}^{N} A_j F_{ij}}$$

where P_i is the "production" at the internal zone i, A_j is the entering or exiting traffic volume at entry or exit point j, F_{ij} is the friction factor between the origin and destination, and N is the number of attraction zones. If the window is small relative to the length of an average trip, all the friction factors can be the same. Trip purposes may be aggregated together.

Calculate the number of I-E and E-I trips at each exit and entry, respectively, and adjust the volumes for input into Steps 3a and 3b, accordingly.

STEP 4. Execute the Estimate and Validate the OD Table Estimation

Once the seed OD table has been checked for plausibility, it can be fed into OD table estimation software. OD table estimation software allows for considerable tuning of the results. Different counts can be given different weights in the estimation. The amount of deviation from the seed table can also be controlled. A good rule of thumb it to set the weights such that the deviations between assigned volumes and ground counts are approximately the same as the error in an individual ground count.

OD table estimation software needs to build shortest paths through the network. The method for path building should be consistent with conventional travel forecasting practice using impedances based on time, distance, cost, and modest turn penalties.

Drivers' route choices are influenced by congestion. The OD table refinement procedure must be capable of handling congestion where it exists. The OD table should be estimated with equilibrium conditions in place.

STEP 5. Forecast with the Estimated OD Table

A typical application is the forecast of volumes before and after the project. If the project is near term, then there is no need to extrapolate the OD table to future conditions. Projects well into the future might require an OD table that has undergone some further adjustment.

The results should be checked for reasonableness.

STEP 6 (OPTIONAL). Dealing with 24-Hour and Bi-Directional Counts for Hourly or Peak-Period Forecasts

OD table estimation requires that there be counts in each direction at each count station and that the counts are specific to the time period of analysis. Many traffic counts are taken over a 24-hour period of time or are bi-directional, that is, both directions on a two-way road are added together. An hourly or peak-period forecast needs counts in compatible time units. Obviously, a failure to adjust 24-hour counts for the time period of analysis will cause the estimated OD table to be too large, overall. Less obviously, a failure to adjust bi-directional counts will tend to have an equalizing effect on all directional splits after the estimated OD table is assigned to the network.

The process of adjusting counts is similar in concept to the application of "k" and "D" factors when calculating directional design hourly volume (DDHV). In this case, "k" and "D" factors must be selected for each count direction, individually. The adjustment is made by multiplying the raw count with each factor, as appropriate. For example, if a count were both 24-hour and bi-directional, then the adjustment would be made with the following equation:

$$\text{Adjusted Count} = k * D * (\text{Raw Count})$$

so adjusted counts are likely inferior to directional counts for the correct time period, so they should be afforded less weight in the estimation process.

If there are only a few 24-hour or bi-directional counts, then it is possible to prudently adopt "k" and "D" factors from nearby count stations. The direction of the highest flow rate is important. "k" factors are likely to transfer to new locations better than "D" factors. For best results, the donating station should be on a road that is parallel to, similar to, and proximate to the receiving station.

7.2.5.4 Working with Outputs of the Technique

The forecast may be used directly for project-level planning and engineering. Turning movements may require additional treatment.

7.2.6 Illustrative Example

Figure 7-6 shows a window around a sewer repair project on Seventh Street between Elm and Maple (see arrow).

The sewer repair will completely close this section of Seventh Street for 6 months. The city is interested in retiming its signals near the project to better serve traffic in the area. Figure 7-6 also shows hourly traffic counts on all streets. Some of the counts are recent, but others are several years old, so inconsistencies are expected.

The window is only about 0.3 miles across, and every street of significance is included in the network.

External stations (look like Monopoly houses) are placed at all the entry and exit points. Internal TAZs, although optional, are defined within the window as census block groups, and each was given a centroid (dot).

The E-I and I-E portions of the seed OD table need to be estimated first. Local databases are used to establish the employment levels and number of dwelling units within each

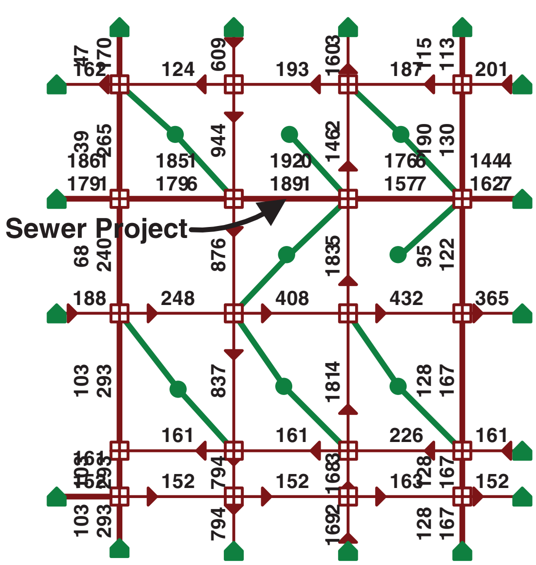


Figure 7-6. Window around a road closure for a sewer.

zone. Then, borrowed average trip rates are used to find total trips in and out of each zone. The units of trips are automobiles per hour. I-I trips are ignored.

One portion of the seed OD table is created for E-I trips and a second portion is created for I-E trips. For the I-E trips, productions are at the internal zones and attractions are at the exit points; vehicles travel in the I to E direction.

For the E-I trips, productions are also at the internal zones and attractions are at the entry points; but vehicles travel the opposite way, that is in the E to I direction. Care is taken to transpose the E-I matrix before it is added to the I-E matrix. Because of the small size of the window, all friction factors are chosen to be the same (nominally, 100, although the actual value does not matter). This window is mostly in a business area of the city, and there are dwelling units only in a single internal zone, so there are very few I-E trips.

I-E trips are more significant to the seed OD table, although they too are only a small fraction of the total trips in the window.

The two OD tables are summed, and row and column totals are found.

These row and column totals must be subtracted from traffic counts at the entry and exit points before the E-E portion of the seed OD table is created. The net counts at entry and exit points can be used to find the E-E portion.

Building a good E-E portion of the seed OD table is a trial and error process, but there are some useful guidelines. The few turning movement counts available for the window indicated that right turns outnumber left turns by a 3 to 2 ratio. This means the weighted impedance for left turns should be 0.4 greater than right turns (ln[0.667] = 0.405). So, with an arbitrary value of β of 0.1, left turns should get an unweighted impedance of about four units more than right turns.

Only about 15% of vehicles turn at any intersection within this window, and each vehicle has about four turn opportunities. We can guess that zero-turn trips are about twice as likely as a one-turn trip, one-turn trips are about twice as likely as two-turn trips, and so forth. So the probability of zero turns (P_0) may be found from:

$$1 * P_0 + 0.5 * P_0 + 0.25 * P_0 + 0.125 * P_0 = 1$$

which gives a probability of a 0-turn trip of 0.533. The average number of turns per trip can be computed from this probability:

$$1 * P_0 * 0 + 0.5 * P_0 * 1 + 0.25 * P_0 * 2 + 0.125 * P_0 * 3 = 0.733$$

So an average trip makes 0.733 turns in four opportunities or about 0.184 turns per opportunity, which seems reasonable. The exact percentage of turns needs to be checked later, after traffic is assigned to the window. For a gravity-like model with an exponential friction factor function to compute similar probabilities, the unweighted impedance for each turn must be about 7 (see earlier discussion) on average, but left turns should be 4 more than right turns. The OD table should get about the correct turn percentages with an unweighted right turn impedance of about 6 units and an unweighted left turn impedance of about 10 units.

A version of the network for the window is configured with all left turns getting a penalty of 10 minutes and all right turns getting a penalty of 6 minutes. The impedance (or travel time) between intersections is set to an arbitrarily small value of 0.01 minutes for all links. The seed OD table is found. As a check, the seed OD table is assigned to the original network to see how well it replicates ground counts. The root-mean-square (RMS) error between the seed OD table's volumes and the ground counts is found to be 86 vehicles per hour or about 14% of the average ground count. The quality of the seed OD table is deemed acceptable.

The combined seed OD table (I-E, E-I, and I-I) along with traffic counts are fed into an OD table estimation procedure. After a few trials, a table was selected that brought the RMS error in traffic counts down to about 56 trips or about 9% of the mean traffic count. A tighter fit to ground counts is unwarranted given known errors in ground counts. Two runs ("before closure" and "after closure") are performed. These are compared in Figure 7-7 and Figure 7-8. The "before closure" run reproduces the counts fairly closely. The "after closure" run shows how the traffic diverts throughout the network. Fairly substantial volume changes are seen everywhere except

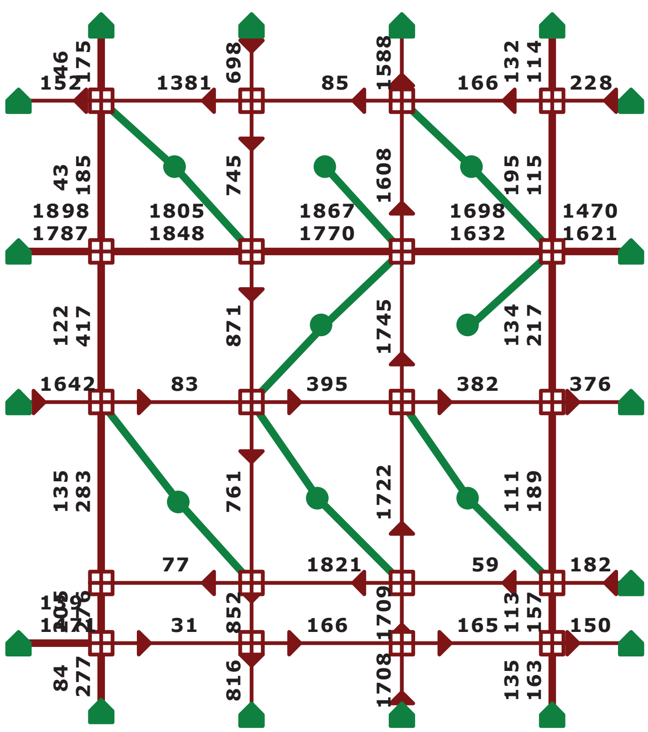


Figure 7-7. Forecast traffic volumes before closure.

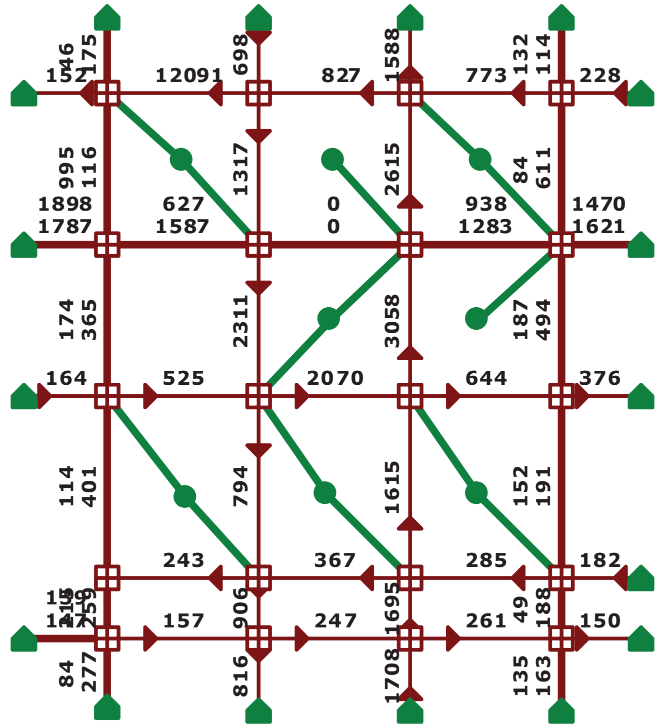


Figure 7-8. Forecast traffic volumes after closure.

on those links directly connecting to entry and exit points, where the structure of the network prohibits any impacts.

7.3 Method: Multiresolution Modeling

7.3.1 Abstract

Project-level traffic forecasting generally calls for information at a high level of spatial and temporal detail critical to understanding traffic phenomena and flow patterns at individual facilities within specific time periods. Multiresolution modeling approaches involve the blending of travel models operating at different resolutions including macroscopic travel demand models, mesoscopic DTA models, and microscopic traffic simulation models. Such blending of models makes it possible to more accurately reflect vehicular movements, queue formation and dissipation, traffic dynamics at bottlenecks, lane-changing behavior particularly at weaving sections, and interactions between vehicles and pedestrians, transit vehicles and personal vehicles, and bicyclists and motorists.

7.3.2 Context

Typical applications are changes in roadway geometry, high-occupancy vehicle (HOV)/high-occupancy toll (HOT) lane ramp metering, intelligent transportation systems (ITS) applications, signal configurations, and site impact study.

Geography is corridor, intersection, and site (subarea).

Typical time horizons are short term.

Required input data varies depending on the type and configuration of the multiresolution model system, OD matrix for subregion of interest, network configuration and attributes, traffic control, traffic counts, travel times, and speeds.

Optional input data are driver characteristics and vehicle characteristics.

Related techniques are subarea analysis and windowing.

Advantages of a multiresolution model system are that they offer a rigorous framework for capturing traffic dynamics along individual corridors and provide a high level of detail for facilities where information of great fidelity is desired.

Disadvantages of a multiresolution model system are that set up and calibration require good data, a high level of staff expertise and resources, and computational power.

7.3.3 Background

There is growing interest in the integration of macroscopic travel demand models and more detailed mesoscopic and/or microscopic traffic simulation models in the context of project-level traffic forecasting. Although in practice there is increasing application of such blended models, the field is still maturing and there is no established method for creating and applying such blended model systems. The descriptions presented in this section therefore differ somewhat in format from descriptions of other techniques, where established algorithms and procedures are in place. This section is meant to provide general guidance and information that will help professionals get started with blending models at different resolutions, including macroscopic, mesoscopic, and microscopic transportation models. Users should refer to the latest literature and case studies to identify the methods and techniques that would be most appropriate in a specific application context. As the field continues to evolve, it is envisioned that documentation of guidelines and best practice will be developed further.

Travel demand models generally operate at a level of spatial-temporal aggregation that makes it difficult to use forecasts from such models for project-level forecasting and analysis. Four-step travel demand models, and even the more recent activity-based or tour-based travel demand models, generally operate at the level of the TAZ. Traditional traffic assignment procedures provide estimates of traffic volumes on individual links in the network. With a TOD modeling step or a peak-period or peak-hour model, estimates of traffic volumes may be obtained at a temporal resolution that is more amenable for project-level analysis. If, however, the traffic assignment is done on a daily basis with post-processing using hourly factors to derive peak-hour volumes, then the fidelity of such forecasts may not be sufficient for project-level analysis or applications. With the advent of activity-based microsimulation models of travel demand and DTA algorithms that incorporate a vehicle simulation component, integrated macroscopic-mesoscopic-microscopic modeling of travel demand and vehicular flows is becoming increasingly feasible. Rapid advances in practice can be expected.

For the purposes of this section, DTA models are largely considered mesoscopic models (although it can be argued that the line between mesoscopic DTA models and microscopic traffic simulation models is becoming increasingly fuzzy) with speeds and positions of vehicles updated based on macroscopic speed-flow relationships rather than microscopic car-following paradigms (or other simulation methods based on an individual vehicle/driver, such as cellular automata).

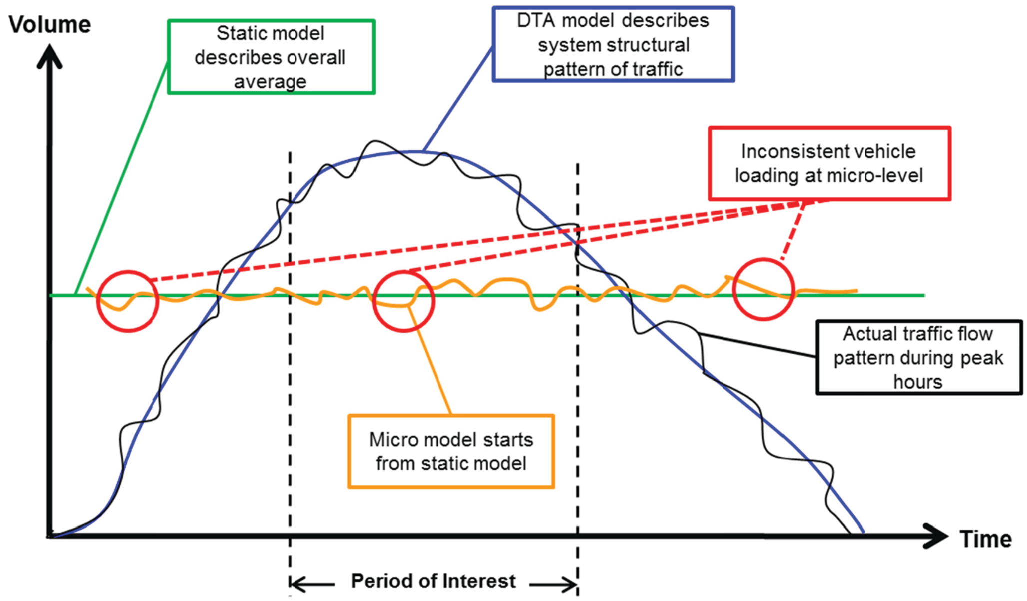
This discussion that follows assumes the use of a four-step travel demand model with regular static traffic assignment procedures. However, the discussion is also applicable to situations in which activity-based models and DTA algorithms are being put into place, albeit with the recognition that these types of models offer higher spatial and temporal fidelity, thus making it easier to apply the outputs of such models in traffic microsimulation models for project-level analysis and forecasting.

Multiresolution model systems may come in different forms including the following:

- Macroscopic travel demand model blended with a microscopic traffic simulation model;
- Macroscopic travel demand model blended with a mesoscopic DTA model;
- Mesoscopic DTA model blended with a microscopic traffic simulation model; and
- Macroscopic travel demand model, mesoscopic DTA model, and microscopic traffic simulation model all blended together in a stream.

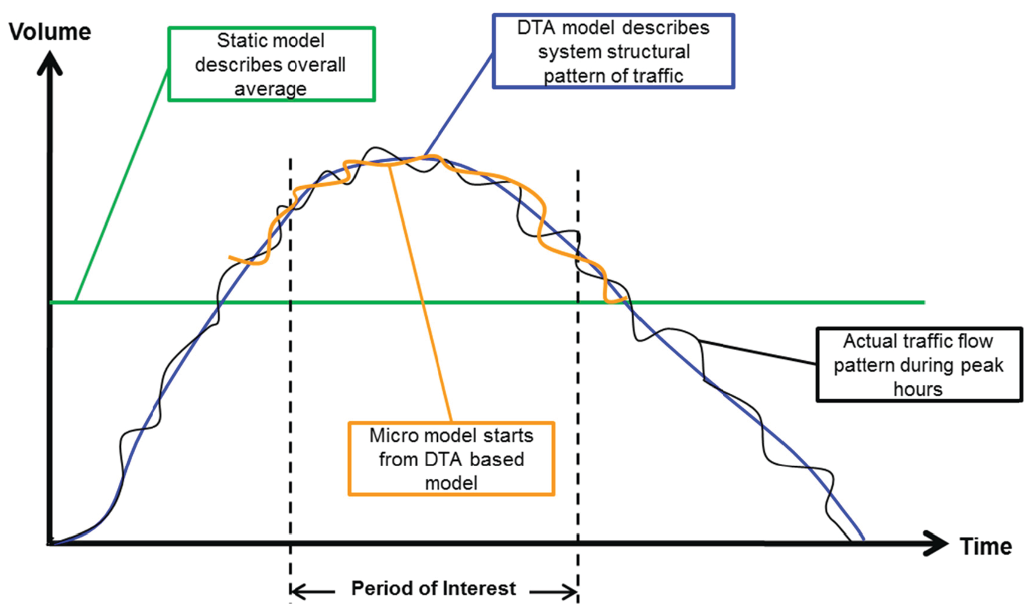
Many multiresolution modeling integrations involve mesoscopic and microscopic models. There are important considerations and concerns in going directly from macroscopic to microscopic travel models. First, macroscopic models for the most part are not absolutely capacity constrained, so it is possible to have a V/C ratio > 1, resulting in unrealistic flows in areas of heavy congestion. Second, macroscopic models load *constant* volumes over larger time slices, which would make traffic flows unrealistic during transitions from peak to non-peak hours.

Figure 7-9 schematically shows forecasted traffic volumes over a peak period when a static macroscopic model is merged with a traffic microsimulation model, illustrating a potential lack of realism. Figure 7-10 shows the improvements in volume outputs when a DTA model replaces a static model before those outputs are fed to a traffic microsimulation. The straight line is the volume from a static macroscopic travel demand model converted to a microscopic traffic simulation model. While it



Source: Jeff Shelton, Texas Transportation Institute, NCHRP 8-83 Panel Member.

Figure 7-9. Issues associated with merging a static macroscopic model with a microsimulation model.



Source: Jeff Shelton, Texas Transportation Institute, NCHRP 8-83 Panel Member.

Figure 7-10. Improvement in temporal fidelity by merging a DTA with a microsimulation model.

may not be entirely accurate to say that multiresolution models should only go from mesoscopic to microscopic resolution, the fact that there is a big discrepancy in flows between alternative types of conversions is something that should not be overlooked. It can be seen from the image above that integration between macroscopic and microscopic would show overloading during off-peak periods and underloading during the peak period.

7.3.4 Why This Technique

Project-level traffic forecasting generally calls for information at a high level of spatial and temporal detail critical to understanding traffic phenomena and flow patterns at individual facilities within specific time periods. Along the spatial dimension, project-level forecasting applications are often concerned with traffic phenomena on specific links or along individual corridors such as freeway facilities or arterials. Project-level forecasts may be concerned with phenomena at a variety of nodes including intersections (signalized and unsignalized) and grade-separated interchanges. Along the temporal dimension, project-level analysis involves the examination of traffic flows, congestion patterns, and bottlenecks within detailed time periods such as a peak hour or an interval less than an hour. Although TOD assignment procedures are getting increasingly sophisticated in their representation of congestion patterns, it is often necessary to use blended macroscopic-mesoscopic-microscopic simulation models (or combinations thereof) to truly understand vehicular movements, queue formation and dissipation, traffic dynamics at bottlenecks, lane-changing behavior (particularly at weaving sections), and interactions between vehicles and pedestrians, transit vehicles and personal vehicles, and bicyclists and motorists. In these situations, multiresolution simulation models are desirable.

Such higher resolution analysis is often warranted when examining the impacts of policies or strategies that operate at the level of a specific corridor, junction, time period, or class of vehicles. If ITS strategies are deployed along a corridor (e.g., incident management systems, electronic toll collection mechanisms, signal coordination or priority schemes, variable message signs, and/or ramp metering), then the performance of the corridor can best be analyzed by simulating the movements of individual vehicles along the corridor, on the ramps, and through the interchanges/intersections. However, information on traffic volumes (demand) is critical to accurately analyze such traffic dynamics and macroscopic or mesoscopic travel models serve as the ideal source of such data. The study of other corridor-level strategies such as carpool lane conversion, HOT lane implementation, dynamic pricing strategies, and truck restrictions (during certain hours of the day) are all worthy of the application of blended travel demand and traffic microsimulation models.

7.3.5 Words of Advice

The development and calibration of a multiresolution model system can be a time- and resource-intensive exercise. All of the data needed to develop, calibrate, and validate the model system should be assembled, and appropriate quality control mechanisms should be exercised to ensure that the data are high quality and accurate. Adequate time and resources should be allocated to ensure that the multiresolution model system is capable of simulating the scenarios of interest. Agencies should also ensure that they have adequate computational resources to run blended simulation model systems in reasonable run times.

7.3.5.1 Disadvantages/Issues

Several issues need to be considered in the development of blended multiresolution model systems:

- Data needs for developing, calibrating, and applying such model systems may be more extensive relative to other techniques.
- There are alternative configurations of blended multiresolution model systems, and the type of configuration adopted may impact the results obtained. Careful consideration should be given to whether feedback loops across the blended model components are necessary and/or desirable.
- It is important to define an appropriate study region or influence area for the analysis. While it may be tempting to define a larger analysis region in the interest of being conservative, it should be recognized that microscopic traffic simulation models operate best within a geographically focused and temporally well-defined area.
- Outputs of macroscopic travel demand models (such as OD tables) must be post-processed so that they are suitable for use in mesoscopic and microscopic traffic simulation models. Post-processing generally involves factoring and slicing OD tables to be consistent with the spatial and temporal resolution of the mesoscopic and/or microscopic traffic simulation models.

7.3.5.2 Possible Strategies to Mitigate/Minimize Impacts of Disadvantages/Issues

The configuration of the blended model system should be guided by the application scenarios of interest. Although it is conceivable to have a blended model system that includes only a macroscopic travel demand model and a microscopic traffic simulation model, it may be advisable to include a mesoscopic DTA model within the blended model system to enhance the fidelity of information that flows from one model to another.

In defining an influence area, the analyst should attempt to include geographic territory and portions of the network that are likely to be impacted by the proposed strategy or policy. For Interstate projects, it is suggested that the model network should extend up to 1.5 miles (or at least one interchange) from both ends of the proposed improvement and up to 1 mile on either side of the Interstate route. For arterial projects, it is suggested that the model network extend for at least one intersection beyond the boundaries of the improvement and include potential intersecting and parallel corridors that may be affected by diverted traffic.

Agencies implementing blended model systems should assemble data, staff and consultant support, and computational resources prior to commencing such a modeling exercise.

7.3.6 Executing the Technique

7.3.6.1 Configuration of the Technique

Multiresolution models may include different combinations of models. In general, information will flow from a model of low resolution (more coarse) to a model of higher resolution (higher fidelity in space and time). Depending on the application scenario of interest, the level of detail required for planning and operations, and the level of spatial and temporal fidelity offered by the lower resolution models, appropriate combinations of models may be considered to form the multiresolution model system. For example, if the four-step travel demand model is a peak-hour model that provides a high level of spatial detail (fine zonal definition and high level of network detail), then it may be appropriate to proceed directly from a four-step travel demand model to a microscopic traffic simulation model. However, in the event that the four-step travel demand model is a daily model and uses a coarse spatial representation of zones and network, then it may be more appropriate to blend the travel demand model with a mesoscopic DTA model and, if desired, to then proceed on to a microscopic traffic simulation model. In some applications, it may be entirely feasible to skip the four-step macroscopic travel demand model step. OD table estimation methods can be applied (using traffic count data) to synthesize an OD matrix for a subregion or subnetwork of interest. This OD matrix can be used in a blended model system that includes only a mesoscopic and a microscopic traffic simulation model suite. Figure 7-11 shows all possible configurations of blended model systems.

There are two ways in which models may be blended together.

- **Offline.** In the offline blended model system, data sets are transferred (usually manually) from a lower resolution to a higher resolution model in one direction. For example, trip tables generated from a four-step, trip-based model may be used as input to a regional mesoscopic DTA model. The DTA model subarea cuts can also be converted to microscopic models for high-fidelity analysis. In Figure 7-11, the configuration on the right-hand side may be considered an offline blended model system.
- **Inline.** An inline multiresolution model is one where a model of higher fidelity runs within a larger, coarser resolution model with feedback taking place (e.g., a windowed/subarea runs in microscopic simulation while simultaneously modeling the surrounding area at a lower resolution). Simultaneous feedback is the key in inline multiresolution models, which is quite different from the offline approach.

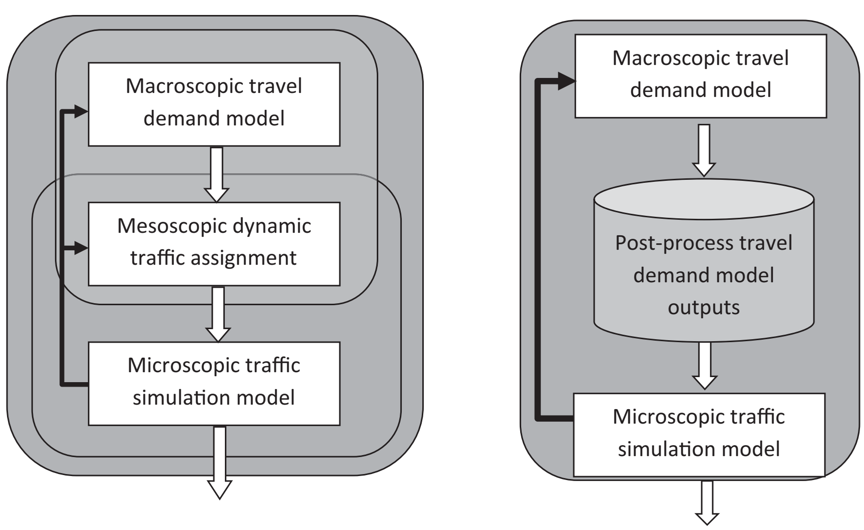


Figure 7-11. Configurations of blended model systems (post-processing of outputs may also be involved in the blending of models depicted in the image on the left).

In Figure 7-11, the configurations shown on the left-hand side may be engineered to be a inline multiresolution model system.

7.3.6.2 Steps of the Technique

STEP 1. Obtain and Assemble Necessary Data for Model Development and Calibration

The first step is to assemble all of the data necessary for model development and calibration. The exact set of data that needs to be assembled depends to some degree on the configuration adopted, but the data identified in this step are generally needed to exercise a simulation model of high spatial and temporal fidelity. The input requirements of traffic simulation models are well documented elsewhere (*66*). The input data requirements may be summarized as follows:

- **Geometric Data.** As vehicular and other (pedestrian, bus, light rail, and bicycle) movements need to be simulated within a subnetwork, detailed geometric data should be collected and coded for the microsimulation model network. This may include such information as number of lanes; lane widths; turning radii; bus pull-outs; turn bays and lengths of turn bays; and presence of driveways, bicycle lanes, and on-street parking that may impact flow of traffic. Network data may also include information about lane closures, blockages, special event diversions, and work zones.
- **Traffic Control Data.** For intersections and interchanges, detailed traffic control data would be required. For unsignalized intersections, the type of traffic control (YIELD, STOP) needs to be specified. For signalized intersections, information on signal phasing, timing plans, and nature of control (actuated, pretimed) would be desired. At interchanges, the nature of ramp control (metered or not) needs to be specified. Any other traffic control data such as transit priority/preemption may also be specified to enhance the accuracy of the model.
- **Vehicle Characteristics Data.** As the traffic stream is likely to be composed of a number of different vehicle types, it is important to specify the characteristics of different vehicle classes that will be utilizing the subnetwork and whose movements will be simulated. Vehicle lengths, maximum speeds, acceleration and deceleration characteristics (average and maximum values), and jerk (rate of change of acceleration) are some of the vehicle characteristics parameters that should be specified for different vehicle types. These data are particularly relevant to traffic microsimulation models, although DTA models (mesoscopic models) are able to utilize such information, if available.
- **Driver Characteristics Data.** These data would be needed if the blended model system includes a traffic microsimulation model. A traffic microsimulation model is attempting to simulate the actions of individual drivers on the roadway corridor. This includes lane-changing behavior, acceleration and deceleration patterns, and car-following behavior. The analyst must provide to the traffic microsimulation model a series of run parameters that characterize the behavior of the driver. This includes headways (minimum and maximum), gap acceptance, and aggressiveness (proceeding in yellow, red-light running, and exceeding posted speed limit). In addition, driver behavior data include the characterization of the route diversion tendency of the driver, particularly in the availability of information. The degree to which information is available (pre-trip or enroute), probability of route diversion, and heterogeneity in driver behavior in response to traveler information are some of the additional pieces of data that may be useful in the context of studying the impact of ITS and information system deployments.
- **Demand Data.** In the context of a blended multiresolution travel model, the key information passed from the travel demand model to the mesoscopic and/or microscopic simulation model are demand data. The basic demand data that are needed by a higher resolution simulation model are the OD flows that need to be simulated on the subnetwork of interest. This information may be obtained from a regional travel demand model and then post-processed to obtain the spatial and temporal fidelity desired for the higher resolution traffic simulation model. It is entirely possible to construct OD flows and matrices for the subnetwork of interest from traffic counts, and other sections of the guidebook describe procedures for synthetic OD table estimation based on traffic count data. While that is certainly acceptable in a number of application contexts, it may be difficult to reflect the impacts of changing network conditions on the full range of travel demand characteristics (e.g., destination choice and mode choice) in the absence of a macroscopic travel demand model as part of the blended multiresolution model system. OD tables coming out of the travel demand model may be post-processed and spatially and temporally disaggregated for use in mesoscopic or microscopic traffic simulation models. In addition, when demand data are being derived from the travel demand model (as opposed to traffic counts or license plate observation surveys and other field measurement techniques), then feedback loops should be incorporated to reflect impacts of changes in network characteristics on travel demand patterns.

A variety of data are also needed for model calibration and validation. A base network corresponding to existing real-world conditions should be simulated, and model outputs and measures of performance should be compared against real-world data to ensure that the model is capable of reflecting actual operating conditions on the subnetwork of interest. Although a distinction can be drawn between calibration data and validation data, they may be treated as a group for most practical purposes. This set of data includes the following categories:

- **Traffic Counts.** Traffic counts by time of day and vehicle class should be collected for the subnetwork of interest. These traffic counts should be detailed in nature, preferably including counts by lane (or lane utilization factors), time of day (down to 15-minute resolution), and turning movements. The traffic counts should distinguish between different modes of transportation and user classes so that the impact of a variety of policies can be assessed. For example, it would be preferable to have traffic counts by vehicle occupancy to be able to analyze the impacts of a HOV lane addition or conversion project.
- **Travel Times and Speeds.** Appropriate travel time and speed studies should be conducted to get accurate metrics on travel times and speeds for links on the subnetwork of interest. Floating car methods, global-positioning-system-(GPS)-based travel studies, and data from loop detectors and sensors can be used to construct accurate travel time and speed profiles by time of day. Many agencies are also beginning to purchase data from commercial entities that collect and synthesize these.
- **Delays and Queue Lengths.** It is important that a higher resolution traffic simulation (whether mesoscopic or microscopic) model replicate the delays, congestion patterns, queue formation and dissipation phenomena, and spillover effects that are often observed, particularly in congested networks. Field studies should be conducted to measure delays, waiting times at intersections, queue lengths for a variety of movement types (turning movements and through movements), and durations of queue presence.

STEP 2. Choose and Configure Method

A determination needs to be made as to whether the model system should be an offline multiresolution model with manual data transfer and no feedback loops or an inline integrated multiresolution model with seamless data transfer, feedback loops, and automated spatial-temporal adjustments as data are passed from a model of one resolution to a model of a different resolution. The setup and calibration of an inline multiresolution model system may be more complex than an offline model system, but the presence of feedback loops and automated data conversion and transfer provides for a more robust representation of traffic dynamics.

In many applications, it is conceivable that an improvement in a facility will change travel times and network performance sufficiently so as to alter not only route choice (traffic assignment), but also alter destination choice, mode choice, and in some instances, trip generation itself. If the network changes are considered modest enough that there is unlikely to be any change in demand characteristics, then perhaps a feedback option can be avoided. However, if there is any possibility of a demand effect, then the lower resolution travel demand model and the higher resolution traffic simulation models should be run in an iterative loop until there is convergence (i.e., the travel times fed back to the lower resolution model do not show any appreciable difference from one iteration to the next).

STEP 3. Post-Process Lower Resolution Model Outputs

Outputs of travel demand models will need to be post-processed to serve the needs of the higher resolution mesoscopic or microscopic traffic simulation model. Outputs of travel demand models can be spatially and temporally disaggregated using multidimensional raking procedures or what are more commonly referred to as iterative proportional fitting (IPF) methods. In these methods, any information that is available at a larger aggregate scale can be disaggregated to obtain finer resolution information such that the constraints imposed by the data at the larger aggregate scale are met. These methods employ a seed matrix or table that may be generated using traffic counts or other locally available data and then iteratively adjust and expand the seed matrix until the data at the larger aggregate scale are replicated exactly.

Data from OD tables may be also disaggregated by loading trips onto the network at many different access points along the links in the subnetwork. In coarse macroscopic model networks, trips generally get loaded at a single point on a just some links (say, where a centroid connector joins a roadway link), which may not always be representative of reality. A number of systematically or randomly generated access points may be used to load trips at a variety of locations on a link, thus eliminating any lumpy traffic loading patterns. The presence of local streets and driveways may be helpful in identifying these access points.

STEP 4. Calibrate the Model

In this step, the blended multiresolution model system is run iteratively (if feedback is implemented) until convergence is achieved for the base year. The resulting measures of performance are compared against the real-world data that have been assembled in Step 1. In general, it is desirable to see model predictions that are representative of real-world conditions in terms of travel times, speeds, and volumes. If the model system is not able to replicate real-world conditions for the base year, then its ability to capture traffic dynamics under alternative scenarios is subject to question. Various parameters and input data configuration may need to be adjusted to ensure that the model replicates real-world conditions for the base year. Criteria for determination of an adequate level of model validity continue to evolve, and it is therefore difficult to provide hard targets that should be achieved. It would be prudent for the analyst to exercise best judgment and subject the model performance/outputs to peer review in the context of the application scenarios of interest.

STEP 5. Apply the Model to Project of Interest

Once the hybrid model is run to convergence, a number of measures of performance can be compared and assessed to determine the impacts of the proposed project. These may include such items as vehicle miles of travel, vehicle hours of travel, vehicle hours of delay, queue lengths at intersections, average speed by vehicle class, traffic density, link travel times, traffic volumes, and average/min/max headway values in the traffic stream that is being simulated. These performance measures can be used not only to assess the impact of the project, but also to assess the reasonableness of the model. If unreasonable values are obtained, the model can be refined and tweaked to ensure that it is able to accurately represent traffic dynamics.

If the model involves a microsimulation, the model should be run more than once, since each run of a simulation model is just one realization of an underlying stochastic process. Every time the simulation model is run (with a different random number seed), the results will be slightly different. The simulation model should be run repeatedly, and the measures of performance may be averaged over a number of runs to get the values of outputs to be used in a project impact analysis. If model runs are performed only once, then it is difficult to isolate the impact of the project from inherent variations arising from stochasticity in the simulation model. In addition, the distribution of outcomes from a number of simulation runs (say 20 simulation runs) may be used to represent the distribution of possible outcomes that may be realized in the event that a project is implemented. This distribution may be viewed as representing the day-to-day variability that may be encountered, the uncertainty in the forecast, and/or the distribution of travel times and conditions that drivers will encounter as they use the facility. It is difficult to say for sure how many simulation run repetitions are needed to do robust alternatives comparison. The number of runs may depend on the application context, the levels of congestion in the corridor being simulated (presumably more repetitions would be warranted where congestion levels are severe), and the nature of the policy or strategy under study (a very minor change in the network conditions may warrant more repetitions to confidently isolate the impact of such a modest change in the network).

7.3.6.3 Working with Outputs of the Technique

The outputs of the blended multiresolution model system are often very rich and diverse in detail. They offer macro-level indications of travel demand and high-resolution, micro-level indicators of network dynamics. The analyst should examine model outputs across spatial and temporal scales and ensure that they are reasonable and consistent. The outputs of the model, including such measures as travel times, speeds, volumes, delays, and queues, should be assessed for their reasonableness in the context of the scenario that is being considered. The measures of performance can be used to evaluate alternative policy and operational strategies, geometric configurations of the network, and technology deployments.

7.4 Method: Integrating Statewide, Regional, and Local Travel Models

7.4.1 Abstract

Facilities within a local area may be part of a larger regional, state, and even national network. Traffic forecasts on such facilities will be affected by regional or statewide travel demand that involves the use of the facility of interest. While a local travel model will be able to adequately account for trips within the geographic area, it will not be able to reflect changes in regional and statewide travel patterns that may affect traffic forecasts on the facility. Facility attribute changes may impact regional and statewide travel demand, thus rendering assumptions of the constancy of external and pass-through trips invalid. In such applications, it may be beneficial to integrate statewide, regional, and local models in a consistent manner to capture the full spectrum of travel demand adjustments.

7.4.2 Context

Typical applications are changes in roadway geometry; HOV/HOT lane deployment, roadway pricing/tolling schemes, and ITS applications.

Geography is corridor and interchange.

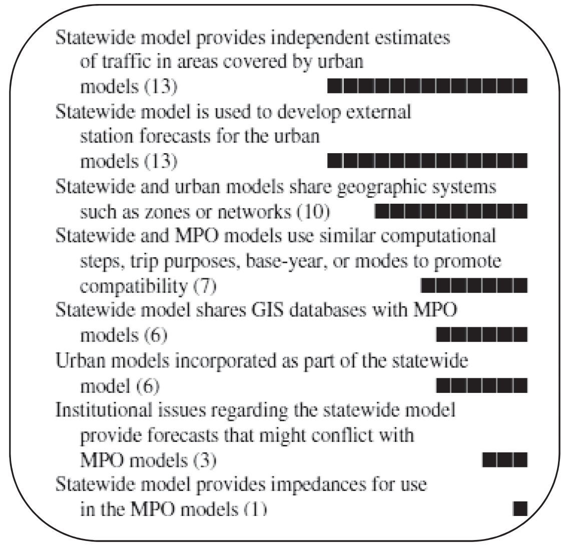
Typical time horizons are short term, medium term, and long term.

Required input data are already available in the context of the statewide, regional, and local travel models; there are no special input data requirements beyond those. All zonal, network, modal, spatial-temporal, and socioeconomic data should be already available as part of the model systems operating at different geographical scales; all of this data should be available to any study that seeks to integrate model platforms.

Related techniques are multiresolution modeling, subarea analysis, and windowing.

Advantages of integrating statewide, regional, and local travel models are providing the ability to accurately reflect changes in statewide, regional, and longer distance travel that may result from a change in facility attributes and providing a more accurate and robust method for accounting for external and pass-through traffic.

Disadvantages of the integration of disparate model systems operating at different geographical scales are that the integration may be time- and resource-intensive exercise, consistency in inputs and outputs has to be ensured at every step, and it may be difficult to identify and isolate sources of discrepancies as multiple models are merged.



Source: NCHRP Synthesis 358 (136, p. 31).

Figure 7-12. Relationship between statewide and urban models.

7.4.3 Background

Traffic flowing on a limited access facility is heterogeneous in nature. There may be trips that are very short in distance and localized in nature and other trips that may be regional in scope, including travel between origins and destinations in a larger metropolitan region to which the local area belongs. In addition, there may be longer distance trips that are merely pass-through trips, where origins and destinations are located outside the region as a whole. When there is such a heterogeneous mix of traffic, it is important to recognize that a change in the attributes of a facility may impact the characteristics of any or all of these trip types. If a facility is expanded, tolled, or enhanced with a new HOV lane, interchange, or ITS deployments, it is possible that long-distance, regional, and local travel demand may shift sufficiently enough as to impact the traffic on the facility. For facilities within local jurisdictions that serve a variety of trip types of varying lengths, it is not appropriate to assume that external travel demand remains constant even after the change in the facility attributes. Combining a statewide, regional, and local travel model would provide a system capable of reflecting the full spectrum of changes that will be experienced by the facility.

Several states in the nation have developed statewide travel demand models. *NCHRP Synthesis 358* (*136*) provides an excellent synthesis and review of statewide modeling practices. Since 2006, there has undoubtedly been further development of statewide models and their integration with regional and urban models. It is noted in *NCHRP Synthesis 358* that "[g]ood linkages between statewide and urban models are desirable, but not necessary" (*136*, p. 31). Based on a small survey of statewide modeling practices, *NCHRP Synthesis 358* offers a glimpse into the extent that states have integrated their statewide models with urban models. It is conceivable that further strides have been made since the administration of the survey reported on in *NCHRP Synthesis 358* in the integration of statewide models and urban models with a view to ensuring data and input/output consistency. Figure 7-12 is a summary of the status of statewide and urban model integration taken directly from *NCHRP Synthesis 358*.

Increasingly, attention is being paid to the effects of long-distance travel demand (both passenger and freight flows) on local facilities and project development efforts. A number of studies point to the increase in mega-commuting, where commuters regularly travel more than 50 miles (or 90 minutes) each way between home and work. As travel demand becomes increasingly complex, and growth in e-commerce changes the way in which goods and services flow, it is conceivable that the merger of statewide, regional, and local models will yield tangible benefits in project-level traffic forecasting.

7.4.4 Why This Technique

The merger of statewide, regional, and local travel models helps account for the full spectrum of travel demand that may exist on a facility. The travel demand on a facility passing through a local geographic area may include long distance, regional, and local travel (on both the passenger and freight sides). It is important to account for all of these trip types when developing project-level forecasts. If a major facility that served a variety of trips were expanded, thus resulting in improved speeds and travel times, it is conceivable that there would be spatial and temporal impacts on long-distance, regional, and local passenger and freight trips. The integration of statewide, regional, and local travel models makes it possible to account for these impacts, while benefiting from the spatial and temporal detail offered by a local travel model. While the use of a local travel model in isolation may be satisfactory in some applications, the impacts of a project on external trips (representing statewide and regional travel with at least one trip end outside the local jurisdiction) would not be adequately captured by a local model deployed alone.

There may be a number of additional benefits associated with integrating statewide, regional, and local travel models. Each of these models may inform the other in a variety of ways. Local jurisdictions may obtain or verify their input data against sources available at a regional or statewide level. State and regional planning agencies can, in turn, check their socioeconomic and network databases against information that is available at the local level. Traffic flows and demand estimates from different models may be compared to identify discrepancies and take corrective measures. Integration of model systems operating at differing geographic scales may also bring about greater coordination and data exchange among agencies.

7.4.5 Words of Advice

The integration of statewide, regional, and local travel models, which often run on different spatial and temporal scales, can be a time- and resource-intensive process. It is important to dedicate enough time and resources to the enterprise. Adequate quality control and consistency checks need to be put in place to ensure that there are no discrepancies across model systems that would adversely affect the ability of the model to forecast traffic at the project level. Running an integrated model system can be computationally intensive; any agency deploying an integrated statewide-urban model system should consider acceptable run times and acquire hardware/software systems that would provide efficiency in run times.

7.4.5.1 Disadvantages/Issues

Several disadvantages and issues need to be considered in implementing such integrated model systems:

- The effort involved may be substantial. Adequate time and money should be devoted to complete a model integration effort.
- The model run times can be an issue. Project-level traffic forecasts are often desired with short turnaround times; however, running a model system that integrates a statewide model, regional model, and local travel model can take a long time, depending on the hardware/software configuration.
- Ensuring consistency in data and network representation across models can be an issue, and any inconsistencies that remain in the model system would constitute a disadvantage of using an integrated model system where adequate care in ensuring data consistency has not been taken. Consistency in data and inputs/outputs must be realized in at least two places. First, in geographic areas or zones where the multiple models overlap, there should be consistency when drilling down from a larger geographical scale to a more disaggregate geographical scale. Second, at locations where these models connect with one another (e.g., at external station locations of local models), there should be a seamless connection with consistent traffic patterns that follow the law of conservation of traffic. If a statewide model shows 20,000 vehicles entering a local model cordon at a point on a freeway (that is an external station for the local model), then the local model should also show 20,000 vehicles entering the boundary at that point (in the absence of any other traffic breaks at that external station).
- There are a number of ways in which statewide, regional, and local travel models can be interfaced and integrated with one another. The type of configuration adopted may impact modeling results and affect consistency across model components. The exact choice of the integration framework should be driven by the application scenarios of interest and the time and resources available to carry out the model integration and associated model runs.

7.4.5.2 Possible Strategies to Mitigate/Minimize Impacts of Disadvantages/Issues

The issues raised in the previous section can be mitigated by exercising caution and due care in the integration of statewide, regional, and local travel models. Adequate time and monetary resources, as well as staff support, should be assembled and dedicated to the integration of model systems. Depending on desired run times and the size of the model systems, appropriate hardware/software solutions should be identified so that the multiple models can be run within acceptable computation time. Interfaces should be developed so that the models can communicate with one another and exchange data in a consistent and seamless fashion. Where there are data and input/output inconsistencies (for example, the statewide model is a 24-hour model and the local model is a peak-hour model), reasonable assumptions can be made or techniques described in other sections of this guidebook can be deployed to bring about consistency at the model component interfaces. Extensive effort should be devoted to identifying discrepancies and inconsistencies across models, and corrective action should be taken to eliminate all such discrepancies. The model system as a whole should be subject to a round of calibration and validation checks even if each individual model component (in isolation) was calibrated and validated to ground conditions.

There should be close coordination between agencies responsible for different models. It would be beneficial if the models that are being integrated adopt a common base year and update data and networks on a uniform periodic basis. In this way, the model components are consistent with one another in terms of temporal reference.

7.4.6 Executing the Technique

7.4.6.1 Configuration of the Technique

From a network consistency, data exchange, and visual presentation standpoint, it is important that networks at different geographic scales be conflated to perfectly align with one another. Network conflation is now quite easy to accomplish using geographic information system (GIS) tools and software programs. Network conflation will allow the identification of discrepancies in network representation and attributes (travel times, speeds) across different models.

There are essentially two approaches that may be adopted in the integration of statewide, regional, and local travel models. They may be described as follows:

- **Offline Integration.** In the offline integration approach, the models remain separate entities. The statewide, regional, and local travel models constitute three stand-alone models that are merely coupled together through the use of software and data exchange interfaces. Models would be run in sequence, with the broadest geographical scale model being run first, and its outputs being post-processed to serve as inputs to the model with the next level of geographic resolution. The outputs of the broader model may be processed, for example, to construct external trip tables that would serve as input to the subsequent model. Finally, the local travel model would be run, and outputs of the local travel model would serve the project-level traffic forecasting needs. Within this offline integration process, it is possible to implement a feedback process where travel times and skims from the local travel model can be fed back to the statewide model so that there is consistency in network travel times between the models of different resolutions. Regardless of whether there is a feedback process or not, the offline integration paradigm is one in which the model components are loosely joined in a sequential manner, with pseudo-automated or manual processes in place to facilitate data exchange across models.
- **Inline Integration.** In the inline model integration approach, the models are more tightly integrated with one another. The models are connected in a seamless fashion, and the entire model system can be run in a single process with data exchanges happening within the model system. Each model runs within the other in a nested structure, and there is a strong level of consistency across the model components. Within the urban areas, the statewide model utilizes information from the urban models that are in place. External travel demand is automatically fed from the statewide model to the more detailed regional or local model with minimal intermediate processing. Automated feedback loops are in place to provide updated travel times from the local travel model to the regional and statewide travel models.

A key aspect of the configuration of the model systems is the manner in which databases are established across model systems. Outside the metropolitan areas where no regional or local models exist, the statewide travel model would provide sole coverage. In regional metropolitan areas where there may be a regional model system, there may be dual coverage with both a statewide model and a regional model in place. In a local jurisdiction, there may be triple coverage with a statewide model, regional model, and a local model in place. In places where there is multiple model coverage, the integrated model may be set up in multiple ways. They are the following.

- **One-to-One Mapping.** In areas where there is model overlap, it is possible to use the zonal system that is in place in the highest resolution model in all models of lower resolution. For example, in an area with triple model coverage, it is possible to adopt the local model zone system and network in the regional and statewide models as well. In this configuration, there is perfect consistency across the models that are being integrated, and the need for additional consistency checks and resolution of discrepancies is minimized and possibly eliminated. This type of mapping system is very well suited for the inline model integration paradigm. In cases where it is not possible to use one-to-one mapping, possibly because of computational burden and too large a number of zones, a perfect nesting structure may be adopted. Local model zones may be perfectly nested in regional model zones, and regional model zones may, in turn, be perfectly nested within statewide model zones. The statewide model would run with the coarser geographic representation, producing trip tables that provide the external trips for the regional and local models. The regional and local models would then be executed to obtain more fine-grained (spatially and temporally) trip tables for assignment to the detailed local network.

- **Independent Systems of Data and Networks.** At the other end of the model configuration spectrum, it is possible to develop models at different geographic scales without necessarily mapping one to the other. In this configuration, the two or three models are developed rather independently and adopt zone and network configurations that are not consistent or coordinated with one another. Each model has its own set of data and networks and can be run accordingly. While this configuration may be easy to implement up front (because it may allow agencies to independently develop their respective models), it does not lend itself well to the inline integration paradigm. This approach lends itself more to offline integration. The statewide model would be run with its zone and network; the outputs of the statewide model would be manipulated, processed, and formatted to be compatible with the regional travel model. The regional travel model would be run, and its outputs would be formatted and processed to serve as inputs to the local travel model. This approach involves manual post-processing of outputs so that the information from a broader geographic scale model can inform the model at a higher resolution. This approach may not require a high level of coordination among agencies during the model development phase, but the approach will require a high level of data consistency checks and reconciliation during the model implementation and application stage.

An integrated model system may fall anywhere in the spectrum between these two extremes. Data and networks may not be perfectly matched or nested, but could be partially mapped and consistent where it is possible to implement such consistency without conflicts across model systems.

7.4.6.2 Steps of the Technique

STEP 1. Obtain and Assemble Model Components and All Associated Data and Networks

The first step in the development of an integrated statewide-regional-local travel model system is to develop the individual model components so that they are consistent with one another in the representation of zone systems, networks, and other data. As the different models are likely to be developed by different agencies, it is important that the agencies coordinate with one another and assemble all of the model components and databases/networks so that model integration can be accomplished. Where possible, the models can be updated or revised to bring about a greater level of consistency across models of different geographical scales. Databases that need to be assembled include zonal configuration data, socioeconomic data, network data, network attribute data (including travel times, lengths, facility type, and speeds), and built environment (such as land use data) and accessibility data critical to estimating travel demand. In addition to obtaining all of the model components and data required to run the model components, it would be desirable to collect data required for model calibration and validation. Data from travel surveys showing observed patterns of travel demand are very helpful for model calibration. Classification counts and other traffic volume data are very useful in model validation and re-calibration. Different agencies may have data for different facilities and at different spatial and temporal resolutions. It would be advantageous for the agencies to pool their resources and databases so that they have a rich set of information with which they can calibrate and validate the integrated statewide-urban models. Decisions need to be made on the configuration that will be adopted.

STEP 2. Configure and Establish Database and Network Consistency

This step is a critical phase in the development of an integrated statewide-regional-local travel model system. It is in this step that considerable effort must be expended to ensure data and network consistency across model components. The model components may have been estimated using data from different travel surveys. The model components may have different base years, which makes the merger of the model components subject to question. While a difference in base year of 1 or 2 years across model components may not be an issue, a difference in the base year greater than 3 years needs to be examined and resolved. Ideally, the models should all be updated at the next available opportunity to a common or near-common base year so that model integration can be accomplished while ensuring consistency in data and network representation.

Once the models are in place, then it is necessary to configure the integrated model and establish relations across databases and networks. The model may be configured as an inline or an offline system. While interface elements are likely needed in both configurations, it is conceivable that the amount of output processing would be much higher in the event of a model system that uses an offline configuration, particularly where the databases and networks were largely assembled independently by different agencies. At a minimum, geographic correspondence files need to be developed to relate disparate zonal and network systems to each other. The geographic correspondence file should map zone systems across models by depicting the fraction of a zone at one level falling into an overlapping zone at another level. The geographic correspondence should be available both top-down and bottom-up so that one can translate information from a broader geographic scale to a more detailed resolution or aggregate information from a detailed resolution to a broader geographic scale. Similarly, network conflation procedures should be implemented so that geographic correspondence between links and nodes of networks at different levels is clear. This geographic correspondence can be used to ensure consistency in speeds, travel times, and intersection penalties.

STEP 3. Develop Interface Elements to Facilitate Data Exchange Across Model Components

This step of the process involves the development of interface elements that need to be put in place to facilitate data exchange and flows across model components. Regardless of whether the model system is configured as an inline or offline system, data must pass from a model of one geographical scale to a model of another geographical scale. For example, the local model may derive its external travel estimates from the statewide or regional travel models. The outputs of the statewide and regional travel models need to be processed and formatted such that external travel estimates are input to the local model in a manner consistent with the geography, network, and temporal resolution of the local travel model. These interface elements need to be programmed in a flexible way to facilitate model application to a variety of project-level forecasting needs.

STEP 4. Calibrate and Validate the Integrated Statewide-Regional-Local Model System

When the individual models are developed by the various entities responsible for statewide, regional, and local travel models, the models are subject to a calibration and validation process in the framework and context within which they are developed. Just because individual models are calibrated and validated within their jurisdictional domain does not mean that the integrated model as a whole is automatically calibrated and validated as well. Once the interface elements have been put in place, the integrated model system needs to be run for the base year and outputs analyzed for their ability to capture patterns of travel in the region of interest. There may be discrepancies and inconsistencies in databases and networks that contribute to anomalies in the output of an integrated multiscale model system. The outputs of the integrated model need to be scrutinized and sources of discrepancies, if any, identified. Model calibration and validation efforts may involve adjusting model parameters at different levels and scales to better match ground truth. However, prior to making such adjustments, it would be prudent to check the consistency and quality of the input data. Inconsistencies in input databases across model components may contribute to some of the discrepancies in the model output and resolving such inconsistencies can eliminate discrepancies in predictions. Calibration and validation standards that apply to regional and local travel models can be used in the context of an integrated model system as well. Ultimately, the integrated model is going to be used to forecast traffic at a project level, and it is therefore desirable to meet calibration and validation standards at the highest (i.e., most disaggregate) spatial and temporal resolution. For a list of possible calibration and validation data that is useful for this purpose, see Section 7.3 on multiresolution modeling.

STEP 5. Apply the Model to the Project of Interest

The integrated model system that is calibrated and validated to acceptable standards may be applied to a project of interest. The model system would entail running the statewide-regional-local travel model chain with appropriate interface elements to facilitate data exchange and flows. Outputs from the completed model run may be sufficient to analyze the impacts of the project of interest; if the outputs are not sufficiently detailed to meet the objectives of the study, they can be further processed for application of a traffic microsimulation model system (similar to that described in the multiresolution modeling approach of Section 7.3). If any of the models constitute microsimulation models (for example, a four-step statewide travel demand model may be paired up with an activity-based microsimulation model of travel demand at the local or regional level), then it may be necessary to run the model multiple times to obtain a distribution of possible outcomes that may be realized as a result of implementing the project.

7.4.6.3 Working with Outputs of the Technique

The outputs of the integrated travel model system may be used to assess the efficacy of a project. Standard measures of output are obtained from an integrated travel model system that merges statewide, regional, and local travel models. Such measures include but are not limited to speeds, delays, traffic volumes, vehicle miles of travel, vehicle hours of travel, and emissions. Results from all model components should be examined for reasonableness to ensure that there are no discrepancies that may be adversely affecting estimates of traffic impacts of a project. The outputs of the model system may be further processed for use in a traffic microsimulation package so that detailed performance measures can be obtained (as explained in the previous section). Outputs of the different model systems should be consistent with one another, even when the model components are developed largely independently. Data consistency checks performed as part of Step 2 should ensure that large inconsistencies do not arise in model outputs provided by different model components. Nevertheless, it would be useful to have automated routines to perform simple consistency checks and flag any discrepancies worthy of further investigation. For example, suppose a statewide model suggested that there are 1,000 trip productions in a statewide model zone for which there is regional travel demand model coverage. When running the regional travel demand model, the estimate from the statewide travel demand model (for this statewide model zone) may be ignored considering that the regional travel demand model would be able to better capture the trip productions for that geographical area (because it is a higher resolution model). If the *n* regional travel model zones that correspond to the statewide travel model zone in question together generate only 100 trip productions, then there must be a discrepancy worthy of investigation. Model outputs from the local travel demand model may be further used to implement any number of project-level traffic forecasting techniques described in this guidebook (e.g., subarea analysis, windowing, or turning movement analysis).

7.5 Method: External-to-External Station Origin-Destination Table Refinement

7.5.1 Abstract

External-to-external (E-E) OD tables are required for a regional model or any model somewhat larger than a small window. An E-E OD table may come from a variety of sources and may contain significant errors. Such faulty E-E OD tables may be further processed to mitigate the effects of inherent error and thereby provide a more accurate forecast. Uncorrected errors in E-E OD tables may be especially problematic when the project is located near the edge of a network.

7.5.2 Context

Typical applications are lane widening, road diet/cross-section modification, site impact study, intersection design, access management, new corridors/facilities, and detours.

Geography is site, corridor, and wide area.

Typical time horizons are short range, interim, and long range.

Required input data are traffic counts, traffic network, historic traffic volumes, and demographic data.

Optional input data are urban travel model, statewide travel model, and OD table estimation software.

Related techniques are screenline refinements with traffic counts, screenline refinements with additional network details, refinement with OD table estimation, and windowing to forecast traffic for small areas.

An advantage of E-E station OD table refinement is that it improves the performance of a travel model near the boundaries of a region.

A disadvantage of E-E station OD table refinement is the need for additional analysis.

7.5.3 Background

External-to-external (E-E or X-X) trips are a component of most travel demand models, because networks and zone systems for those models are limited as to their spatial extent. External stations are artificial network elements that represent the origins and destinations of E-E trips. Since external stations are usually located on highways just outside of the region (as represented by TAZs), E-E trips are in actuality trip segments. The model cannot estimate the full trips for these segments from their true origin to their true destination. Thus, many of the relationships for internal travel do not apply well to purely external travel.

Many travel models import base-case E-E trip tables from other sources, either theoretical or empirical, and then extrapolate those tables to a future year. Future year E-E tables may also be obtained directly from another model of greater geographical extent, such as a statewide model sending an E-E table to a regional model. Both empirical and theoretical E-E tables may contain substantial error due to a variety of reasons, so there is often a need to refine those tables to improve their accuracy.

A method for developing full OD tables, including E-E trips, for small traffic windows is described in Section 8.2 of this report.

Only rough guidelines exist for the cases where there are no empirical or theoretical data about E-E trips. There have been some notable attempts to create stand-alone E-E trip models (*114*, *5*, *6*, *69*), but these are applicable to special cases only.

The first Quick Response Freight Manual (*69*) and *NCHRP Report 716* (*6*) provide similar methods of estimating E-E OD tables synthetically, but these methods are not automatic and require a considerable amount of professional judgment to obtain satisfying results.

Empirical E-E OD tables are typically extrapolated to a forecast year by applying Fratar factoring. This method requires an estimate of all directional E-E trips at each external station in the forecast year. Empirical methods, such as time-series analysis, can be used to provide a forecast of directional E-E trips.

E-E OD tables from a larger scale model may need to be interpolated or extrapolated, as necessary, depending on how well the forecast years of the different models align.

7.5.4 Why This Technique

The accuracy of an E-E trip table can be important if the project is located near the boundary of a regional model or if a specialized model is being created for the project.

7.5.5 Words of Advice

All empirically derived E-E OD tables need to be scrutinized for problems prior to being used for forecasting. Methods based exclusively on professional judgment should be used only as a last resort.

It is difficult to synthesize E-E OD tables from traffic counts because internal traffic counts contain more traffic than just E-E.

Additional cordon survey data improve knowledge about E-E trip data and E-E trip-making patterns.

7.5.6 Executing the Technique

7.5.6.1 Special Data Preparation

Data for E-E trips may come from a number of sources, such as the following:

- **Larger Scale Model.** Statewide models can provide E-E tables for regional models. Regional models can provide E-E tables for subregional models. Normally occurring errors in the larger scale model may affect results of the smaller scale model. Inconsistencies in networks can be problematic because smaller scale models tend to have road segments not found in larger scale models. These tables depend upon theory, but have the ability to reflect future year assumptions. Larger scale models may also be able to provide approximations of E-E traffic volumes on internal links, which may be helpful to a refinement process.
- **Cordon Survey.** A cordon survey is often a preferred way of obtaining E-E data because the survey can elicit information about the true origins, true destinations, purpose, vehicle type, and number of occupants. However, mailback surveys often have low return rates and biases, which can affect the accuracy of any E-E table. Tables from cordon surveys must be extrapolated to future year conditions.
- **Vehicle Re-identification.** Numerous newer technologies allow for identifying vehicles entering a region and then re-identifying vehicles as they leave the region. None of these technologies are perfect. For example, license plate matching and Bluetooth detectors are subject to significant errors that can vary by location. Tables from vehicle re-identification must be repaired to fix inconsistent match rates and extrapolated to future year conditions.
- **Others.** E-E tables may be constructed from a variety of other means such as cell phone records, aerial photographs, and professional judgment.

Traffic counts are the main source of data used to correct many errors in E-E OD tables. However, unlike small windows, traffic counts at the cordon of a regional model are often largely composed of E-I or internal- I-E trips. E-I and I-E trips need to be removed before counts can be used for adjusting raw E-E OD tables. *NCHRP Report 365* gives an approximate empirical model, somewhat dated, for obtaining a net E-E count for regional models. There is an inverse relationship between the size of the region and the percentage of E-E trips in a traffic stream. Ideally, a cordon survey is recommended for determining the composition of traffic passing by an external station.

Every raw E-E table needs to be inspected for logical flaws. Are the sums of rows and sums of columns less than traffic counts? Is there backtracking? Is the table consistent with geographical features that tend to funnel or inhibit travel?

Given the variety of data sources for raw E-E OD tables, there are a variety of methods for improving them:

- **Whole Table Factoring.** Whole table factoring applies a constant factor to every cell in the table to correct for a uniform, systematic bias. Uniform biases can arise, for example, when vehicles are sampled at a constant rate.
- **Traditional Fratar Factoring.** Traditional Fratar factoring is an iterative technique to manipulate row and column data in order to force row and column totals to match desired values. Traditional Fratar factoring applies to situations where location-dependent systemic errors occur. Traditional Fratar factoring is described in many readily available documents.
- **Fratar Factoring with Traffic Counts.** It is possible to add traffic count information to Fratar factoring, but the traditional iterative method cannot be readily used in many cases. Instead, the factoring problem can be reformulated as an optimization problem, thereby allowing for imperfect count information either at external stations or on links within the network.
- **OD Table Disaggregation with Screenlines.** OD table disaggregation applies to situations when the raw OD table has fewer rows or columns than there are external stations. Screenline refinement methods may be used to spread traffic to those external stations that were missing from the raw table.

The choice of method(s) depends upon data availability and assumptions about the source of error in the raw E-E OD table.

7.5.6.2 Configuration of the Technique

The analyst cannot necessarily assume that there is no correlation between the identification rate at the origin and the identification rate at the destination. Furthermore, it is prudent to assume that identification rates can differ depending upon the location of the detector, regardless of whether the location is considered an origin or a destination.

For adjusting raw E-E OD tables, it is helpful to know the vehicle identification rate and the vehicle re-identification match rate. The re-identification match rate is the conditional probability that a vehicle observed at external Station A and that passed through external Station B is identified at Station B. The re-identification match rate varies with the technology and how well the technology is deployed. Unless the re-identification is known to be perfect, it is recommended that the re-identification match rate be determined in the field.

Some data collection methods have very small samples, so the analyst should be aware of the possibility for substantial random errors in OD cells that have small numbers of reported trips.

7.5.6.3 Steps of the Technique

STEP 1. Obtain Raw OD Data and Traffic Data

Raw OD data for the base case may be obtained from a detection methodology, obtained from a larger-scale model, or synthesized from theory and professional judgment. The table needs to be inspected for any obvious errors in OD flows. Furthermore, the following questions should be addressed: Are there structural inconsistencies (too many rows/columns or too few rows/columns) in the table for the network? Are there cells that are subject to substantial sampling error? Are there origins or destinations that seem to be seriously underreported relative to other rows or columns?

Any correction to a raw OD table will require traffic counts on the roads at external stations. Traffic counts should be directional and by time of day (intervals of 1 hour or less).

STEP 2. Reconcile Any Structural Inconsistencies between the Raw OD Table and the Network

The raw OD table could have too many rows or columns for the network or too few rows or columns. The problem of too many rows or columns can be fixed by simply adding together rows and columns, provided that the added rows and columns were sampled at approximately the same rate. If sampling rates differ across rows and columns and the relative differences are known, then the aggregation process should be weighted to reflect those differences.

The problem of too few rows or columns requires that the OD table be disaggregated. The standard process of disaggregating zonal OD tables (*140*) may or may not be appropriate, depending upon the location of the external station corresponding to the missing rows and columns. This standard method splits cells according to row and column factors, such that:

$$T_{ij} = A_i B_j \tau_{kl}$$

where

i = an origin (row) in the disaggregated table,
j = a destination (column) in the disaggregated table,
k = an origin (row) in the aggregated table,
l = a destination (column) in the aggregated table,
T_{ij} = the disaggregated OD table,
A_i = a row split factor for each table origin,
B_j = a column split factor for each table destination, and
τ_{kl} = the aggregated OD table.

The standard method assumes that only one row or column in the aggregated table contributes data to each row or column in the disaggregated table. The row and column factors (A_i and B_j) can be easily computed by taking the ratios of traffic volume at the external stations in the new table.

The case where multiple rows or columns contribute data to a single new row or column is more typical for E-E tables. This case arises when the missing external station (X) lies in between two other external stations (Y and Z) and logically should have gotten traffic that was incorrectly given to both external stations Y and Z in the raw (aggregated) table. In this case, a slightly more complicated disaggregation process must be employed:

$$T_{ij} = \sum_{k=1}^{K} \sum_{l=1}^{K} A_{ik} B_{jl} \tau_{kl}$$

where

A_{ik} is the proportion of the row k's traffic to be given to row I, and
B_{jl} is the proportion of row l's traffic to be given to row j.

It is recommended that these proportions be established by using screenlines, as described in Section 7.1 of this report. It is usually reasonable to assume that E-E trips are proportional to total traffic at external stations in close proximity to each other.

STEP 3. Initial Factoring of E-E OD Table for the Base Case

The E-E OD table usually needs to be factored to match E-E traffic volumes in the base case. Traffic counts contain E-E, E-I, and I-E traffic, but only the E-E portion should be used for factoring. The amount of E-E traffic is obtained, ideally, from a larger scale model, a cordon survey, or an empirical OD table that contains all possible trips in and around the study area. Professional judgment should be used in the absence of these sources of data.

E-E net counts should be checked for consistency. The total of all E-E traffic entering the region should equal the total of all E-E traffic leaving the region. If this is not the case, then the error should be resolved by either factoring the E-E leaving traffic to match the E-E entering traffic or vice versa.

The raw E-E table must be factored up or down, as a whole, to remove constant sampling errors or other systematic errors that affect the whole table. After factoring, the total of all cells in the table should match the total of all E-E net counts entering (or leaving) the region. If, in addition, the row and column totals acceptably match the E-E net counts, then no further factoring is necessary for the base case.

STEP 4. Final Factoring of the Base Case OD Table

Errors that affect specific external stations, whether caused by detector problems or issues with a larger scale model, must be removed by a process of row and column factoring. The most common method of reconciling rows and columns simultaneously is Fratar factoring (*100*). The process of Fratar factoring is described in numerous texts. Fratar factoring seeks row and column factors, x_i and y_j, such that:

$$\sum_{i=1}^{n} x_i y_j T_{ij} = D_j$$

and

$$\sum_{j=1}^{n} x_i y_j T_{ij} = O_i$$

where T_{ij} is the original OD table, D_j is the number of destinations at station j, O_i is the number of origins at station i, and n is the number of stations.

In the presence of substantial errors in the original OD table and additional information, perhaps imperfect, that may be used to correct those errors, a Fratar-like factoring may also be conveniently accomplished by nonlinear least squares estimation by minimizing this objective function:

$$\min P = \left(\sum_{i=1}^{n} x_i y_j T_{ij} - D_j \right)^2 + \left(\sum_{j=1}^{n} x_i y_j T_{ij} - O_i \right)^2$$

subject to a variety of constraints, depending upon the information available. For example, it might be desirable to cap the amount of E-E traffic on any link internal to the region. A constraint that would create such a cap would be:

$$\sum_{i=1}^{n} \sum_{j=1}^{n} p_{ij}^{a} x_i y_j T_{ij} < V^a$$

where p_{ij}^{a} is the proportion of flow from i to j that uses link a, and V^a is the maximum volume on link a. While the amount of E-E traffic may not be known for any given link, the total volume might be known, and the E-E traffic volume must be less than the total volume.

The proportions of flow, p_{ij}^{a}, may be obtained from a select link analysis as part of a traffic assignment. The proportions are either 0 or 1 for all-or-nothing traffic assignments and are fractions between 0 and 1 for multipath traffic assignments.

Methods are available (*99*, *101*) for finding optimal Fratar factors when given fairly accurate traffic counts, but these methods are unlikely to be of much help in finding E-E OD tables because E-E link counts are rarely available.

STEP 5. Re-Factor the OD Table to Match Future External Station Volumes

The amount of E-E traffic, both leaving and entering the network, must be forecasted at each external station. The forecast may be obtained from a larger scale network, a time series, or another means.

The base case OD table, as modified in Steps 2 to 4, may be forecasted by applying traditional Fratar factoring so that the row and column totals match forecasted E-E volumes.

7.5.6.4 Working with Outputs of the Technique

The E-E OD table is combined with any E-I, I-E, or I-I trips that may be computed within the travel demand model. If the model is dynamic or multiclass, then additional steps will be required to factor the E-E table into time intervals or vehicle classes.

If the E-E table is obtained from vehicle identification and re-identification rates and if those rates are known with some precision, then it is possible to infer the number of E-I and I-E trips at each external station. An important requirement is that all sizable roads entering the study area must be included in the vehicle re-identification data collection, with all traffic counted at the same time. The empirical E-I values at external stations are computed from the difference between the entering traffic counts and row totals of the E-E table. Similarly, the empirical I-E values at external stations are computed from the difference between the entering traffic counts and column totals of the E-E table.

7.5.7 Illustrative Example

This example is a variation on a small network that appeared in the first edition of the *Quick Response Freight Manual* (*69*). There are five external stations, labeled A to E, and just five links that handle through (E-E) trips. Bluetooth detectors were placed near each external station; the numbers of vehicles detected during the PM peak hour are shown

Table 7-2. Sampled E-E trips for example small network.

		Destination					
		A	B	C	D	E	Sum
	A	0	12	12	7	10	41
	B	8	0	16	7	10	41
Origin	C	19	29	0	0	24	72
	D	6	9	0	0	8	23
	E	10	14	15	8	0	47
	Sum	43	64	43	22	52	

in Table 7-2. In addition, tube counters were placed at the external stations for the same hour. These traffic counts were adjusted downward to remove E-I and I-E traffic, resulting in the net E-E ground counts shown in Figure 7-13.

The analyst noted that in prior Bluetooth studies the identification rate was about 0.20 and the re-identification rate was about 0.80. This identification rate is higher than can be achieved with Bluetooth technology as of this writing. Therefore, it should not be surprising that the Bluetooth detectors are considerably undercounting the E-E flows. The total entering traffic is 1,375, the total leaving traffic is 1,375, but the Bluetooth detectors found only 224 vehicles. The overall sampling rate was 16.3%. This sampling rate may have varied depending upon detector location. Table 7-3 shows the sampled E-E table after it has been corrected by dividing by 0.163. This table shows that the total amount of E-E traffic has been corrected well, but there are significant errors at some external stations. Those errors are assumed to be due to problems in counting E-E trips by the Bluetooth detectors and not due to the adjustment of total trips down to E-E trips from the tube counters.

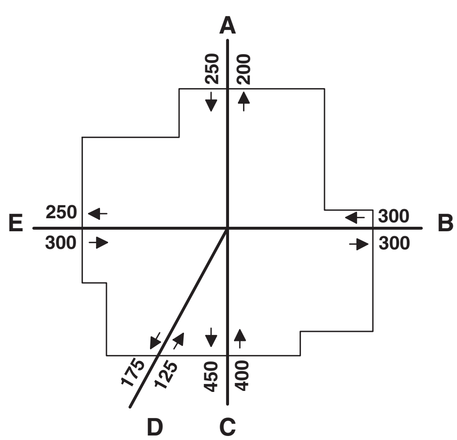


Figure 7-13. Example external stations and ground counts for small network.

The data in Table 7-3 can be further refined by factoring, such that the row and column totals agree with the net counts in Figure 7-13. Although traditional Fratar factoring would have sufficed, the analyst chose to use the least squares formulation so that other information could be added later as it becomes available. Table 7-4 shows the final, refined E-E OD table, the row and column factors, and the setup for optimization within a spreadsheet software package. The software minimized the cell labeled "sum of squares," which is essentially zero for the solution. The row and column factors vary about 1.0, with the largest change associated with vehicles leaving at Station C. This large change may be indicative of a re-identification issue at this location.

Table 7-3. Sampled E-E trips after being uniformly expanded.

		Destination					
		A	B	C	D	E	Sum
	A	0.0	73.6	73.6	42.9	61.3	251.5
	B	49.1	0.0	98.2	42.9	61.3	251.5
Origin	C	116.6	177.9	0.0	0.0	147.2	441.7
	D	36.8	55.2	0.0	0.0	49.1	141.1
	E	61.3	85.9	92.0	49.1	0.0	288.3
	Sum	263.8	392.6	263.8	135.0	319.0	1374.2

Table 7-4. Sampled E-E trips after being uniformly expanded and subjected to optimal row and column factors.

		Destination								
		A	**B**	**C**	**D**	**E**	**Row Sum**	**Row Factor**	**Target**	**Square Diff**
	A	0.0	41.0	120.9	53.8	34.4	250.0	0.856	250	0
	B	29.2	0.0	175.0	58.4	37.3	300.0	0.929	300	0
Origin	**C**	104.2	161.3	0.0	0.0	134.5	400.0	1.394	400	0
	D	32.2	49.0	0.0	0.0	43.8	125.0	1.364	125	0
	E	34.3	48.8	154.1	62.8	0.0	300.0	0.873	300	0
	Column Sum	200	300	450	175	250	1375			0
Column Factor		0.641	0.650	1.919	1.465	0.655				
Target		200	300	450	175	250				
Squared Diff		0	0	0	0	0			Sum of Squares	0

CHAPTER 8

Improving the Temporal Accuracy of Traffic Forecasts

Transportation planning has been steadily shifting from an emphasis on capacity expansion to a broad variety of issues, such as travel demand management, social equity and environmental justice, quality of life, energy sustainability, and environmental concerns. Four-step travel demand models are generally inadequate for these complex subjects.

Although four-step travel demand models have served the planning needs of metropolitan areas for many years, there is a steady transition to newer, microsimulation-based, activity-travel model systems that are capable of providing estimates of travel demand under a wide range of scenarios at the disaggregate level of the individual traveler and choice-maker. Activity-based travel demand models are being increasingly deployed around the country because of their ability to address emerging issues and complex questions that arise in the contemporary transportation planning context.

8.1 Method: Activity-Based Travel Demand Model Systems

8.1.1 Abstract

The activity-based approach to travel demand forecasting explicitly recognizes the derived nature of travel demand. Activity-based travel demand models involve the microsimulation of activity-travel patterns of individual travelers in a model region at a fine temporal resolution. The models are capable of reflecting interdependencies across trips, particularly in the context of trip chaining or tour formation. As project-level traffic forecasts are often desired at a high level of temporal resolution, activity-based travel demand model systems are increasingly being seen as a promising approach to addressing emerging policy questions related to corridor and subarea pricing, social equity and environmental justice, and land use changes. Activity-travel pattern outputs by activity-based models offer a richness of detail that can harness the full potential of dynamic traffic assignment (DTA) models. In the absence of a DTA model, the outputs of activity-based models can be readily aggregated across agents and time to create time-period-based origin-destination (OD) matrices suitable as inputs to traditional static traffic assignment models as well as traffic microsimulation tools.

8.1.2 Context

Typical applications are changes in roadway geometry/capacity, high-occupancy vehicle (HOV)/high-occupancy toll (HOT) lane deployment, roadway pricing/tolling schemes, intelligent transportation systems (ITS) applications, travel demand management strategies, and multimodal infrastructure investments.

Geography is regional, subarea, and corridor.

Typical time horizons are short term, medium term, long term.

Required input data are a variety of input data described in detail later in this section. Input data required include detailed socioeconomic and demographic data for traffic analysis zones (TAZs), census data for different levels of geography, activity-travel survey data for model estimation, and detailed secondary data including land use and multimodal network level of service and accessibility measures.

Optional input data are data required for calibrating and validating the model system and applying the model to a forecast scenario. Validation data typically include corridor and screenline volumes (counts) by time of day. Activity-travel survey data may aid in model calibration as models are calibrated to replicate observed activity-travel characteristics. Scenario data include all of the input data required to run the model for the forecast year or scenario of interest.

Related techniques are DTA and time-of-day modeling.

Advantages of activity-based travel demand models are that they are able to provide detailed information about activity-travel patterns at the level of the individual traveler at highly detailed levels of temporal and spatial resolution and are able to effectively reflect the influence of time-space constraints and interactions, intra-household interactions, and interdependencies among activities and trips in a chain or tour. By providing detailed information about activity-travel patterns at highly disaggregate levels of resolution, activity-based travel demand models are able to address emerging policy issues of interest including multimodal investments, dynamic pricing strategies, alternative work arrangements, land use effects, environmental justice, and demographic and technological shifts. Activity-based travel demand models deal with "lists"; all persons, households, activities, and trips that the model outputs are formatted as lists, thus eliminating (at least to some extent) the need to deal with large OD matrices that may have millions of cells in the four-step travel demand modeling framework.

A disadvantage is that the development and implementation of activity-based microsimulation models of travel demand can be labor and resource intensive. Appropriate computational hardware and software systems need to be in place to ensure that the model systems can be executed within reasonable run times (perhaps comparable to a four-step travel demand model run).

Case study is Case Study #4 –Activity-Based Model Application for Project-Level Traffic Forecasting/Analysis – HOV to HOT Lane Conversion. The Atlanta Regional Commission (ARC) used the activity-based travel demand model for a corridor-level project analysis and forecasting effort. This case study in Chapter 11 illustrates how the activity-based travel demand model provided a rich set of information useful to undertaking project-level traffic forecasting and evaluation.

8.1.3 Background

Although four-step travel demand models have served the planning needs of metropolitan areas for many years, there is a steady transition to newer microsimulation-based, activity-travel model systems that are capable of providing estimates of travel demand under a wide range of scenarios at the disaggregate level of the individual traveler and choice-maker. Activity-based travel demand models are being increasingly deployed around the country because of their ability to address emerging issues and complex questions that arise in the contemporary transportation planning context.

Transportation planning has been steadily shifting from an emphasis on capacity expansion to a broad variety of issues, such as travel demand management, social equity and environmental justice, quality of life, energy sustainability, and environmental concerns. Four-step travel demand models are inadequate for these complex subjects.

In light of the limitations of four-step travel models, agencies are increasingly taking advantage of microsimulation-based paradigms wherein the behavior of individual agents is explicitly modeled and simulated in the time-space domain. Microsimulation-based approaches are being implemented in the travel demand modeling arena, traffic assignment and simulation arena, and the land use modeling domain. In all of these domains, there is a common theme that pervades the microsimulation-based approaches—namely, representation and simulation of the behavior of individual agents who make choices; interact with one another; and engage in activities, transactions, and decisions at various time-space coordinates through the course of a day, week, month, or year.

8.1.4 Why This Technique

The development of activity-based travel demand models is fundamentally motivated by the recognition that travel demand is a derived demand—derived from the human need and desire to pursue activities that are distributed in time and space. With advances in econometric and statistical estimation methods, understanding of traveler activity scheduling and time allocation behavior, data collection and synthesis approaches, and computational hardware and software capabilities, the profession has been able to move from a more aggregate trip-based approach to a more disaggregate microsimulation-based approach to travel demand modeling that explicitly accounts for numerous interactions, constraints, and interdependencies that influence activity-travel patterns, while treating time as a continuous or near-continuous entity.

Activity-based models are also commonly referred to as tour-based models. Although there have been some attempts to draw a distinction between tour-based models and activity-based models, there is no clear consensus yet on such a distinction and, hence, these terms have been used rather interchangeably—at least in practice.

Activity-based models focus on activity engagement as the driver of travel demand. These models aim to simulate the series of activities that people will undertake in a day and all of the travel that needs to be undertaken to execute those activities, which are, by definition, distributed in time and space. From a behavioral representation perspective, activity-based travel demand models are able to account for myriad behavioral aspects that are critical to accurately modeling the impacts of alternative policies, strategies, and infrastructure investments.

One of the main issues associated with the four-step travel demand model is that it does not adequately capture interdependencies among trips, particularly those that are chained together in a tour. In the more aggregate four-step travel demand model systems, all of the trips are independent of one another. Modal, locational, travel party composition, and vehicle use interdependencies are not adequately taken into account in the four-step travel demand framework. When a series of trips are chained together, then the destination choice for an activity is dependent on the current location of the individual (i.e., the destination chosen for the preceding activity) and dependent on the subsequent location that the person wishes to visit. Trips in the same chain or tour will generally entail the use of a consistent mode; a person cannot abandon his or her car or acquire a car in the middle of a tour. If a person went to work by car, then the person will virtually always return home by car. If a person goes to work by transit, then the person cannot return home by car (unless he or she gets a ride from a co-worker). Similar interdependencies exist in the travel party composition and the vehicle that is chosen or used for the tour. When interdependencies across trips in a tour or chain are ignored, then modal shifts (e.g., due to a transit or non-motorized mode improvement) estimated using four-step travel models are likely to be erroneous.

In addition to accounting for interdependencies among trips, activity-based travel models incorporate the effects of constraints and interactions that are critical to accurately modeling traveler behavior. Travelers are subject to a number of constraints including household constraints, personal constraints, work constraints, child constraints, school constraints, modal constraints, situational constraints, and coupling constraints. All of these constraints influence activity-travel patterns, but can be reflected only if travel demand is being simulated at the level of the individual traveler while recognizing the household interactions and constraints that govern his or her behavior. Interactions among household members are critical determinants of travel demand, and activity-based microsimulation models of travel are increasingly reflecting the interdependencies and interactions among household members in the simulation of activity and travel patterns. A typical example is the dependency of children on adults to meet their travel needs and desires. From a time-space continuum standpoint, there are important "prism constraints" that cannot be ignored. There is a finite action space that an individual can access within a time window by the modes of transportation available to him or her. This action space defines the destination choice set and may influence the mode of transportation that an individual chooses (an individual may choose to use a faster mode to expand his or her action space). Activity-based models can explicitly represent the time-space interactions and "prism constraints" that define activity-travel patterns.

The move to activity-based travel demand models has been facilitated by advances in computational methods and hardware/software capabilities that make it possible to implement microsimulation frameworks with ease while maintaining reasonable model run times. The microsimulation framework, which is becoming increasingly common not only in activity-travel demand modeling but also in traffic assignment and traffic simulation models, provides the ability to simulate activity-travel choices and patterns at the level of the individual traveler, agent, or decision-maker. Being able to model and simulate travel at such a disaggregate, agent-based level eliminates issues associated with aggregation biases and provides the ability to generate a rich set of information about activity-travel demand in a region. The information from such models can be aggregated in a number of ways and along several different dimensions to explore spatial and temporal patterns of trip making in a region; bottlenecks in networks; user costs and benefits for any demographic, geographic, or market segment; and exposure and risk measures.

8.1.5 Words of Advice

The development of activity-based travel models is a quickly maturing area of practice with methodologies and computational approaches rapidly evolving. It may not be advisable to try and develop the most advanced activity-based travel model with every possible feature of interest in a single step. Rather, a multiphased approach to model development and implementation may be advisable because that would allow for continuous development, testing, and improvement. Agencies contemplating the transition to activity-based travel models should be aware of the time, staff, monetary, and computational resources required to make the transition. The activity-based travel model should be designed in such a way that a seamless integration with DTA models is possible.

8.1.5.1 Disadvantages/Issues

Data requirements for activity-based model development are not necessarily more than data requirements for standard four-step travel demand models; many activity-based travel demand models have been developed with the same data sets and networks used for four-step travel demand models. As mentioned previously, the development and implementation of activity-based travel demand models takes time and calls for considerable staff resources and computational hardware/software investments. Agencies not ready to devote the effort and resources may not be able to effectively implement an activity-based travel demand model. Activity-based travel demand models provide very detailed and rich outputs; the information can be overwhelming, and issues related to big-data handling and manipulation may arise. Microsimulation models offer a slightly different output every time the model is run. So, if the change in network is subtle, the analyst may not be able to isolate the effect of the change from random stochasticity inherent to the microsimulation model.

8.1.5.2 Possible Strategies to Mitigate/Minimize Impacts of Disadvantages/Issues

A number of strategies may be implemented to minimize the disadvantages or issues associated with activity-based model development. Travel surveys should be designed with a view to collecting information from an activity-based perspective as opposed to a trip-based perspective (ask the respondent: "What did you do next?" instead of "Where did you go next?"). Agencies should line up the necessary resources (time, staff, money, and computational hardware/software) so that the development and implementation cycles can proceed unhindered. When applying the model to scenario analysis, it may be necessary to run the model a number of times to isolate the effect of the scenario from variability due to random stochasticity inherent to the model.

8.1.6 Executing the Technique

8.1.6.1 Configuration of the Technique

Activity-based travel demand models come in a variety of forms. Unlike the four-step travel demand model, where there is a consistent foundational structure at the heart of the modeling approach, activity-based models continue to evolve with advances in computational science and behavioral understanding. Although activity-based travel demand models differ from one another in a variety of ways, there are some fundamental building blocks of all activity-based microsimulation model systems.

Activity-based travel model systems aim to simulate activity-travel patterns at the level of the individual traveler and, hence, they are inevitably implemented via a microsimulation framework. This framework requires the generation of a synthetic population for the model region of interest. Thus, all activity-based model systems begin with a synthetic population generation process so that individual agents and their relationships are enumerated. The synthetic population is generated by expanding a census sample (such as the Public Use Microdata Sample [PUMS] of the U.S. Census) such that the synthetic population exhibits distributions of various attributes of interest that closely mirror those reported at the aggregate level by the Census Bureau.

Activity-based travel demand models implemented in practice have focused on the generation, formation, and characterization of tours that people undertake in the course of a day. These models involve a series of components for generating and scheduling tours, identifying stops that will be undertaken in each tour, modeling destinations and modes for tours and trips within a tour, and accounting for intra-household interactions that lead to serve-passenger and joint trips. The temporal resolution of the model systems may differ. While some models operate in continuous time at 1-minute resolution, other models operate at a somewhat coarser resolution of 15-minute or 30-minute time intervals. Regardless of the methods and behavioral frameworks employed, the central idea in activity-based modeling is to simulate a day in the life of each agent in the synthetic population in a behaviorally consistent and intuitive way. Figure 8-1 shows a simple schematic illustrating the activity-travel schedule and agenda of a worker.

A variety of model components may be included in activity-based travel demand models. These include the following:

- **Location Choice Models.** Activity-based travel demand models typically include a series of location choice models that focus on the longer term location decisions of households and workers. Residential location choice models, work location choice models, and school location choice models are often critical ingredients of activity-based microsimulation model systems.

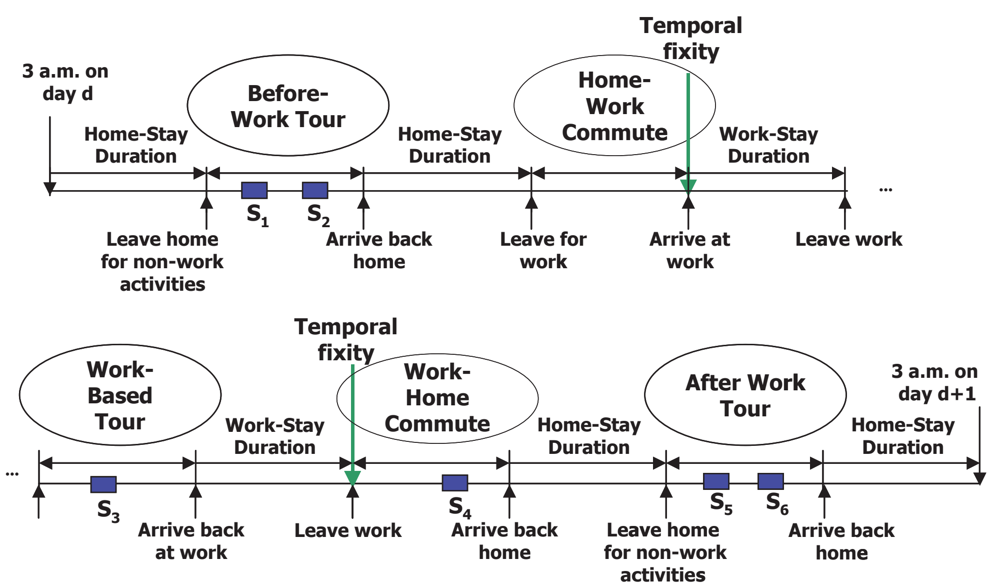


Figure 8-1. Representation of a worker's daily activity-travel pattern.

- **Vehicle Ownership Models.** Vehicle ownership and availability continues to be a key driver of travel demand and mode choice behavior. More recently, vehicle ownership models are being enhanced to include the ability to predict vehicle fleet composition by body type, vintage, and fuel type. Such information is valuable for environmental and energy impact analysis.
- **Fixed Activity Generation and Scheduling.** Depending on the work or school status of an individual, some activities may be considered mandatory in nature and rather fixed in time and space. Model components that estimate participation in and scheduling of fixed activities (such as work and school episodes) help establish an activity skeleton and identify open (available) time windows of opportunity to pursue other activities; these time windows of opportunity are often referred to as "time-space prisms."
- **Tour Formation and Scheduling Models.** Activity-based travel models may include a series of tour formation, generation, and scheduling models that identify the tours that an individual will undertake.
- **Activity Type Choice Models.** For each tour that is generated and placed along the time axis, models of activity type choice may be exercised to identify the types of activities (stops) that will be undertaken in each tour. In addition to the primary activity, a series of secondary activities or stops may be included in a tour. The models can be further extended to consider the duration of the activities, the sequencing of the activities, and the activity party composition (the specific household members participating in a specific activity together).
- **Activity Destination and Mode Choice.** Due to the interdependency among trips in a chain, it is important to model mode choice first at a tour level, and then at a stop or trip level (while considering the constraints that a tour-level mode choice would impose on trip-level mode choice). Depending on the number and nature of stops in a tour, the duration of the tour, and the travel party composition, destination choice models can be exercised to determine the locations where various activities will be undertaken. The destination choice models can consider the current location of the individual and time-space prism constraints in determining a feasible destination choice set.

The list of model components included in an activity-based travel model above is not meant to be exhaustive, but merely an illustration of the types of choice dimensions that may be considered in the development and implementation of an activity-based travel demand model. Activity-based travel models in practice are likely to have a number of additional model components, depending on the context in which they are developed and applied. Activity-based travel models may have upwards of 100 model components with separate components for different market segments (say, workers, non-workers, students, and children) and heuristic elements to account for intra-household interactions and ensure consistency in activity-travel patterns (both within-person and across-persons in the same household).

In virtually all activity-based travel models, a series of econometric and statistical models (including discrete choice models, regression-based models, and duration models) capable of representing the behavioral choices of interest are tied together. Maximum likelihood approaches are typically used to estimate model parameters. In application mode, Monte Carlo simulation procedures are employed to simulate choices for millions of agents in the model region; if warranted, the procedure can be repeated a number of times to obtain a distribution of possible outcomes in response to a set of inputs or to obtain the "average" output. Any one run constitutes a single realization of an underlying stochastic process and hence multiple runs will yield different answers, depending upon the random seed.

Activity-based travel demand models are increasingly moving toward a continuous representation of time at the resolution of 1 minute. While some models of activity-travel schedule formation have already fully implemented a continuous-time, 1-minute resolution framework, other models that are currently operating at 15-minute or 30-minute resolution are being enhanced and improved to incorporate a more fine-grained representation of time.

8.1.6.2 Steps of the Technique

STEP 1. Assemble Data Required for Model Estimation, Calibration, and Validation

The first step in the development of an activity-based travel demand model is the assembly of the variety of data sets needed to estimate, calibrate, and validate the model system. As mentioned earlier, the first step in any activity-based travel demand model system is the generation of a synthetic population. The synthetic population generation process calls for the compilation of several data sources, including but not necessarily limited to these items:

- **Census (Survey) Sample Data.** The synthetic population generation process involves the expansion of a sample file with a view to replicate aggregate population-wide distributions on household and person attributes of interest. The U.S. Census PUMS data set is a good candidate for this purpose. The sample records are geolocated to the Public Use Microdata Area (PUMA), which is a rather coarse and aggregate spatial unit encompassing several census tracts.
- **Census Aggregate Population-Wide Distributions.** Distributions of a number of household and person attributes

of interest at the population level are usually available from the census for different levels of geography such as block, blockgroup, and census tract. In some cases, synthetic populations may be generated at the TAZ level, in which case such population-level marginal distributions must be procured at the TAZ level.

- **Geographic Correspondence File.** The geographic correspondence file maps the PUMA to the census geography (block, blockgroup, or tract) for which population-wide aggregate marginal distributions are available for attributes of interest (such as household size, number of children, number of workers, dwelling unit type, income, race, sex, gender, and employment status).

Model estimation is critical to the development of an activity-based travel demand model. Once models are estimated, they can be calibrated to ensure that predictions from the model mimic observed activity-travel patterns and distributions of different activity-travel variables in the data sets. Estimated parameters can be adjusted or model specifications can be refined to obtain predictions that match the observed distributions in the survey data sets. Model estimation and calibration data sets include, but are not necessarily limited to, these items:

- **Travel Survey Data.** The most critical data that are needed for model estimation and calibration are good travel survey data. Travel survey data include household travel survey data, (on-board) transit survey data, survey data collected from special populations such as university students or special event patrons, and visitor travel survey data. These data sets should include household-level information, person-level information, activity-trip-level information, and vehicle information. It is not necessary to collect in-home activity participation information, although such information may prove useful in extending activity-based travel models to account for in-home versus out-of-home activity engagement relationships. Geographic positioning system- (GPS)-based household travel surveys can help reduce non-response and missing data, provide accurate location and destination choice information, and shed light on route choice behavior.
- **Land Use Data.** Travel survey records need to be appended with land use data that describe the residential location of the household. Activity-travel behavior is influenced by the built environment and it is therefore essential to collect secondary data about the land use characteristics of the residential and work zones of the survey respondent. Destination choice model estimation is dependent on having land use characteristics information for all TAZs (or whatever the spatial unit may be).
- **Network Level-of-Service and Destination Accessibility Data.** Similar to land use data, network level-of-service data serves as another secondary data set that should be appended to travel survey records. The estimation of mode choice models, and the computation of accessibility measures (for example, how much retail employment can be reached/accessed within 20 minutes by automobile from a given location), call for the collection of network level-of-service data for different modes of transport that can be appended to the travel survey records.

Model validation involves ensuring that the model predictions are able to accurately replicate observed ground truth conditions in the real world. A variety of data sets can be used to test the ability of the model to replicate socioeconomic, demographic, and traffic patterns in the region. Model validation data sets include, but are not necessarily limited to these items:

- **Traffic Volumes.** A variety of traffic count and volume data may be used to validate a model. These include volumes by time of day for different corridors, screenlines, and other major arterials and facilities. Once the activity-based travel demand model is run, the output of the activity-based travel model must be passed through a traffic assignment model to obtain traffic volume predictions by time of day.
- **Census Data.** Census data include detailed socioeconomic and demographic information about the region. In addition, journey-to-work data included in the Census Transportation Planning Package can prove valuable in validating work flows predicted by the activity-based travel demand model.
- **Vehicle Registration Data.** Vehicle registration data from a state department of motor vehicles are useful for validating vehicle ownership and fleet composition models.
- **Speed Data.** Detailed highway speed data are becoming increasingly available from commercial entities. Purchasing such data may help validate the model by ensuring that the network speeds predicted by the model are reasonably close to reality.

STEP 2. Develop Synthetic Population for Model Region

The next step in the activity-based model development process is to develop a synthetic population generator. There are a variety of synthetic population generators that have been developed for use in activity-based travel demand modeling contexts. A synthetic population generator implements an algorithm (whatever that algorithm may be) to weight and expand a sample file so that the known marginal distributions of attributes of interest in the population as a whole (as reported by the census) are replicated. The synthetic population files typically include a household file and a person file with all of the attributes that may be of interest from a modeling and analysis standpoint. The synthetic population should be representative of the overall population in a region.

There are two methods for generating a future year population. In the first method, future year marginal distributions are generated for the geographic resolution of interest. For example, if a synthetic population is being generated at the level of the TAZ, then it is necessary to have distributions of household and person characteristics at the level of the TAZ for any future horizon year. Thus, there has to be a separate process to forecast aggregate future year distributions of population attributes at the zonal level. Given those future year marginal distributions and the sample file from the base year, appropriate weights can be developed and the sample file can be expanded such that the generated synthetic population closely replicates the population-wide marginal distributions of attributes of interest in the forecast year. A second method involves the development and implementation of a demographic forecasting system within a microsimulation framework. In this method, the base year synthetic population households and persons are evolved over time through a series of lifecycle evolution models to generate the future year synthetic population for any horizon year. Demographic evolution models can be constrained to ensure that the future year population meets target year control totals as specified by external data sources. The state of the art in demographic evolution modeling within a microsimulation framework is continually evolving, and such models have not yet seen widespread application in practice. At this writing, most agencies use the first method for generating future year synthetic populations.

STEP 3. Estimate Series of Model Components in Activity-Based Model System

Once the synthetic population generation step is complete, the different model components may be estimated using the data sets compiled in Step 1. A variety of discrete choice models, regression-based models, and other econometric and statistical models may be estimated to predict the behaviors of interest. It is necessary to identify the many model components that will compose the activity-based travel model system and to clearly lay out the manner in which these model components will be tied together and applied in practice. For each model component, it will be useful to identify the dependent variable and the candidate independent variables. In this way, the model can be specified in a way that is consistent with the manner in which the models will be applied. For example, if the mode choice model comes after the time-of-day choice modeling step, then time-of-day indicators may be used as explanatory variables in the mode choice model. Appropriate econometric and statistical software packages may be used to estimate the models. Goodness of fit statistics and test statistics should be examined to ensure that the model specifications are providing a reasonably acceptable fit. In addition, coefficient values and signs should be scrutinized for reasonableness and implied values of marginal effects and elasticities calculated to determine whether models are providing behaviorally intuitive sensitivity to explanatory variables.

STEP 4. Interface the Activity-Based Travel Demand Model with a Temporally Disaggregate Traffic Assignment Model

The activity-based travel demand model should be interfaced seamlessly with a traffic assignment model in this step of the process. An activity-based travel demand model provides very detailed information about activity-travel patterns of every agent in the synthetic population. This information can be fed directly into a DTA model, if one exists, for the region. As DTA models have not yet been implemented on region-wide geographic scales, many model systems in practice resort to aggregating the outputs of activity-based travel demand models into time-of-day-specific OD tables that can be assigned to appropriate modal networks using existing static traffic assignment steps. If individual trip lists or trip chains are input to a DTA model, then it is possible to fully harness the capabilities of the DTA model and obtain time-varying information about traffic volumes, speeds, and vehicle locations on the network. If the activity-based travel demand model is being interfaced with a traditional static traffic assignment model, then it is desirable to have a rich set of time-of-day categories with a view to retaining the richness of the output of activity-based travel demand models to the extent possible. If the activity-travel records output by an activity-based travel demand model are aggregated into very coarse time-of-day period categories, then the variability of travel demand and network conditions throughout the day is not captured by the model and the ability to evaluate projects that are time-varying in nature (such as variable pricing) is seriously compromised. In addition to utilizing a temporally rich and disaggregate traffic assignment process, the model system should embed appropriate feedback loops where network travel times and generalized costs are fed back into the activity-based travel demand model to simulate activity-travel patterns. This process can be repeated iteratively until the network conditions output by the traffic assignment step and the network conditions input to the activity-travel demand model are virtually identical.

One of the issues in the development of activity-based travel demand models is that it does not account for all trips in the region. The model does not include freight and truck trips, movements of goods and services, visitor trips, external trips, and any other special purpose trips outside the purview of the activity-based travel demand model. However, traffic assignment should be done with all trips loaded onto the network together. Prior to proceeding to the traffic assignment step, the OD tables aggregated from the activity-travel model outputs should be combined with OD tables produced by other steps so that the final set of OD tables sent to the traffic assignment model are comprehensive in their coverage. Alternatively, if chronologically sorted trip lists output by the activity-based travel demand model are being fed to a DTA model, then OD tables of other trips not counted by the activity-based travel demand model should be disaggregated into trip lists using appropriate smooth temporal distributions of travel. These lists can be integrated into a comprehensive trip list, sorted by departure time, and then fed into a DTA model for loading trips onto the network. This latter approach, although promising, has not yet seen widespread application in practice.

STEP 5. Calibrate and Validate Model Components and the Complete Activity-Based Model System

Following the estimation of the model components, a systematic process of model calibration and validation should be implemented. The model calibration and validation process is critical to ensuring that the model can be applied for project-level traffic forecasting and analysis. In general, the following validation procedures can be exercised:

- The synthetic population inputs can be validated against the census data.
- To validate the input work locations, the home-work distance distribution can be matched against that in the census journey-to-work data.
- To validate the vehicle ownership inputs, the census data and the department of motor vehicle estimates of automobile registrations can be used.
- Each component of the activity-travel model system can be calibrated by comparing its predictions to the observed activity-travel patterns in the household activity-travel survey.
- The commute mode choice model can be validated using the journey-to-work data.
- The entire model system can be calibrated by comparing the traffic assignment outputs with the observed traffic volumes in the study area.
- Highway traffic assignment validation can be carried out by using observed traffic volumes, while transit traffic assignment validation can be carried out by using transit boardings from an on-board transit survey and passenger counts.

It would be of value to validate each model component separately and the entire model system as a whole. If the entire model system is validated, that does not mean that each model component is valid; errors across multiple model components may cancel each other out thus yielding apparent validations at a system level. However, such a model system may not be suitable for project-level traffic analysis because the model component of particular interest for a certain project may be erroneous and yield forecasts inconsistent with behavioral response to change.

Another consideration to keep in mind is that simply replicating base year traffic conditions may not be sufficient evidence of model validity. The model should also be subject to a variety of sensitivity tests where an input or a combination of inputs is altered in a systematic manner, and the changes in outputs predicted by the model are assessed for their reasonableness. There are many studies that provide measures of elasticity, i.e., the extent to which behavior changes in response to a change in input. The outputs of the model should generally be in agreement with ranges of elasticity values reported in the literature. In addition, a sensitivity analysis of this type can also help identify ranges of input variables beyond which the activity-based model breaks down and no longer offers forecasts that are behaviorally intuitive or consistent with elasticity estimates.

STEP 6. Apply the Model to Project of Interest

The final step is the actual application of the model to the project-level traffic forecasting effort. The activity-based travel demand model is not unlike a four-step travel demand model, in that it provides estimates of travel demand assigned to a multimodal transport network. After the activity-based travel demand model is run, there may be a need to post-process the outputs and implement a traffic microsimulation model or other project-level traffic forecasting techniques to focus on the project of interest and evaluate the impacts of the project under consideration on traffic flow, queue formation and dissipation, and delays along the time axis. In the event that an activity-based travel demand model is integrated with a DTA model, it is entirely possible that no further work or post-processing would be needed. Alternatively, multiresolution modeling methods described earlier in this guidebook may be implemented, albeit with an activity-based travel model taking the place of a traditional four-step travel demand model.

8.1.6.3 Working with Outputs of Technique

The outputs of an activity-based travel demand model are similar to the household, person, and activity/trip records that are obtained from a household travel survey. For each and every person in the synthetic population, a set of trip records with full information about mode, start time and end time, purpose, and travel party composition is output by the activity-based travel model. This list of trip records can be aggregated by time of day, purpose, mode, geography, or any other dimension that may be available (socioeconomic and demographic attributes of the individuals, for example) to assess activity-travel demand for specific segments of interest. The activity-travel records output by an activity-based travel demand model may be input directly to a DTA model; alternatively, the aggregated trip tables derived from an activity-based travel demand model can be input to a traditional static traffic assignment model.

For large metropolitan areas, the output lists generated by an activity-based travel demand model can be large and appropriate computational resources with sufficient memory and data-handling capabilities should be in place. The outputs can be used to map activity-travel flows in a region, study temporal patterns of behavior, map the presence of individuals (population) in space and time by type of activity being pursued, and understand the social equity, environmental justice, and public health implications of alternative strategies and projects.

The notion of stochasticity in microsimulation models of activity-travel demand should also be considered. As every run of the activity-based travel demand model will yield slightly different results (stemming from a change in the random number seed from one run to the next), it is important to run the model a number of times to understand the stochastic variability inherent to the model system.

8.2 Method: Dynamic Traffic Assignment

8.2.1 Abstract

DTA is a method of assigning traffic in which there is explicit recognition of the time-dependent nature of the transportation network. As conditions on the network evolve over time, the shortest paths between OD pairs change depending on the departure time of the traveler. Trips are assigned to the network based on the theory that travelers minimize their travel times on time-dependent shortest paths (TDSP). DTA provides the ability to capture the dynamics of traffic flows, speeds, and vehicular movements on networks and individual corridors, particularly in response to time-varying operational strategies and pricing policies. Thus, DTA is capable of providing a high degree of temporal resolution for project-level traffic forecasts.

8.2.2 Context

Typical applications are changes in roadway geometry/capacity, HOV/HOT lane deployment, roadway pricing/tolling schemes, ITS applications, active traffic demand management (ATDM) strategies, and traveler information systems evaluation.

Geography is regional, subarea, and corridor.

Typical time horizons are short term, medium term, and long term.

Required input data for DTA models is information about travel demand between all OD pairs of interest by time of day. It would be ideal if the travel demand data were provided in the form of trip lists with exact departure time information; however, OD tables based on time-of-day period may serve as acceptable input demand data. Detailed network data are needed, with rich link and node data by time of day.

Optional input data are required for calibrating and validating the model system and applying the model to a forecast scenario. Validation data typically include traffic counts and turning movement counts by time of day on important facilities of the network. Speed data are also useful to ensure that the DTA model is able to replicate travel speeds on the network. Scenario data include all of the input data required to run the model for the forecast year or scenario of interest.

Related techniques are activity-based travel demand modeling, time-of-day modeling, incident management, and recurring and non-recurring congestion.

Advantages of DTA models include recognizing the time-dependent interaction between travel demand on the one hand and transportation network attributes on the other. DTA models are able to more realistically capture the dynamics of travel demand and route choice, as shortest paths between OD pairs continuously change in response to changing network conditions. DTA models provide rich information about the variation in traffic flows and speeds along the time axis and thus offer a higher level of temporal resolution for analyzing the impacts of operational strategies and ITS deployments on network dynamics, queue formation and dissipation, duration of congested conditions, and delays. DTA models may be considered more realistic from a behavioral standpoint as travelers are viewed as identifying shortest paths between OD pairs based on a learning process that is aided by the accumulation of experienced travel times over a period of time.

A disadvantage of DTA modeling is that the field continues to mature, and users need to have specialized training to ensure that the tools and methods are being applied and results are being interpreted and used correctly. The development and implementation of DTA models of transportation supply can be labor- and resource-intensive. Appropriate computational hardware and software systems need to be in place to ensure that the model systems can be executed within reasonable run times. While it is possible to run DTA models for small subnetworks in a computationally efficient manner, region-wide DTA applications can be computationally intensive.

No case study is included in this guidebook. However, the literature is replete with examples of DTA model applications, and users should review the literature carefully prior to embarking on DTA model development and application efforts. The Federal Highway Administration Integrated Corridor Management research enterprise has utilized mesoscopic DTA models in the evaluation of corridor management strategies (*109*).

8.2.3 Background

The four-step travel demand model includes a traffic assignment step where travel demand predicted through the preceding three steps, namely, trip generation, trip distribution, and mode choice, is assigned to the appropriate modal network so that traffic volumes on individual links can be estimated under a variety of scenarios. The traditional static traffic assignment procedures constitute an operational implementation of Wardrop's (first) principle to estimate equilibrium traffic volumes on the network. According to Wardrop's principle of user equilibrium, all used routes between any OD pair have the lowest identical travel times or generalized costs. If a traveler were to switch to an alternate (unused) route, then the traveler would experience longer travel time. In the case of DTA, the principle is extended to consider the time-dependent nature of network conditions. In the DTA case, emphasis is placed on two critical aspects—first, the travel time between any OD pair is dependent on the departure time of the trip, and, second, travelers are concerned with the experienced travel time that is realized as they traverse links on the chosen path. The experienced travel time depends on the time at which travelers reach different links because the travel time on a link will change dynamically from the instant that a traveler departs the origin to the instant that the traveler actually comes to the link in question. The experienced travel time is not a snapshot of the sum of link travel times computed at the time the trip departed, but rather a dynamic "moving sum" of link travel times where each link travel time is that actually encountered by the traveler when he or she enters the link in question. Incorporating these two critical aspects, the extended Wardrop's principle for DTA postulates that for any given OD pair and trip departure time, all used routes have identical and lowest experienced travel times. As with static traffic assignment, if a traveler were to switch to a different route, then he or she would experience a longer travel time.

Central to the notion of DTA is the concept of a TDSP. If a peak-hour assignment is being done, then every link is given a travel time for that period. Based on these link travel times, a shortest path is computed for every OD pair (in the peak hour), and every trip departing within the peak hour uses the shortest path. As congestion may contribute to an identified shortest path becoming no longer optimal, the process is repeated iteratively until all used paths have the shortest equal travel times and no other route with a shorter travel time can be found. Approaches such as the Frank-Wolfe algorithm and the method of successive averages (MSA) have been used to implement the iterative process and achieve convergence.

As with the static assignment procedures, iterative processes must be employed to reach an equilibrium solution; due to the computational burden and complexity involved in achieving equilibrium in the time-dependent dynamic situation, a relative gap measure may be used to monitor convergence. When the relative gap measure falls below a certain threshold value set by the analyst, the process is assumed to have reached convergence. The relative gap measures the difference in total travel time between the current assignment iteration and the immediately preceding assignment iteration. A formula and explanation of the conception of relative gap is provided in the section titled "Defining Quality of DTA Model Outputs" in *Dynamic Traffic Assignment: A Primer*, published by the Transportation Research Board (*110*).

DTA models generally fall under the class of mesoscopic travel models wherein the movements (position and time stamps) of individual vehicles or packets of vehicles are tracked using macroscopic speed-flow relationships as opposed to microscopic car-following and cellular automata models. However, as methods and software systems become increasingly sophisticated, the line between mesoscopic network models and microscopic traffic models is becoming increasingly fuzzy.

8.2.4 Why This Technique

An interest in DTA grew out of the recognition that traditional static traffic assignment methods are limited in their ability to accurately reflect network dynamics and traveler response to emerging policy questions and operational strategies that are inherently dynamic in nature. The focus of transportation planning and policy is increasingly shifting to an analysis of traveler behavior and response under a wide variety of scenarios in which time plays a central and critical role. Policy and technology examples include, but are not limited to:

- **Dynamic Pricing and Tolling.** Corridors and bridges may be tolled or priced such that free flow conditions are maintained at all times. Drivers interested in a high degree of travel time reliability may be willing to pay the toll in order to be assured of a free flow travel speed. A DTA model is capable of computing the time-dependent generalized travel cost accounting for the toll or price that the driver would have to pay if he or she were to choose to travel on that facility.
- **Variable Mileage-Based Fees.** Mileage-based fees are being debated as possible mechanisms to generate much needed highway revenue in the face of declining gas tax revenues. Mileage-based fees are also being seen as an effective way to manage travel demand in time and space. DTA models can be used to accurately determine how travelers will respond in the face of variable mileage-based fees and how revenue streams would be impacted under alternative configurations of such fee policies.
- **Pre-Trip and En Route Traveler Information Systems.** Travelers are increasingly being able to access information about travel conditions on the network. This information may be available to travelers pre-trip, en route, or both. DTA models are capable of reflecting changes in route choice that happen en route and the consequent changes in network conditions that result from such adaptive user behavior.
- **ITS.** In addition to traveler information systems, a range of ITS and ATDM strategies are being developed and implemented to modify traveler behavior in such a way that congestion is eased, and energy and environmental impacts of

travel are mitigated. ITS such as signal optimization and adaptive control mechanisms can impact travel times experienced by travelers, and the mechanisms (e.g., signal timing) may be impacted by the choices that travelers make as they traverse the network. DTA models, by virtue of their ability to track vehicular movements through a network and compute experienced travel times based on actual network conditions (link travel times) encountered by travelers, are able to simulate the impacts of ITS and ATDM strategy deployments at a high degree of spatial and temporal resolution.

The implementation of DTA inherently calls for a more detailed representation and coding of the transportation network. It is necessary to build a model network that is capable of supporting high-fidelity simulation of vehicular movements and trajectories.

DTA models are able to read in the individual trip records produced by an activity-based travel demand model and simulate the execution of the trips on the appropriate modal network. The full disaggregate trip information generated by an activity-based travel demand model is utilized in the assignment and simulation process of a DTA model. There is no aggregation of trip records into trip tables or OD matrices that would, by definition, result in the loss of critical and rich information about the detailed movements of people and vehicles through time and space. For example, by simulating the movements of individual travelers through the network, it is possible to determine the equity implications of different policy actions.

8.2.5 Words of Advice

Implementing DTA models should be done with care, ensuring that the agency has the necessary computational resources and network supply data in place to fully exploit the capabilities of a DTA modeling approach. It is likely that the most time will be spent in developing the appropriate network detail and in model calibration and validation in the context of DTA. It is also prudent to consider the types of applications (policy actions and scenarios and operational conditions) where the use of a DTA model would be warranted.

8.2.5.1 Disadvantages/Issues

There are essentially three key considerations in the implementation of DTA models. First, agencies considering the use of DTA models need to develop detailed network and supply side data. Additional detail required may include such items as local streets, intersection control data, signal timing data, and driveways. Second, regional DTA models can be computationally quite intensive and would require the acquisition and use of appropriate hardware/software configurations that provide efficient model run times. Third, DTA—although building on the principles of traditional static traffic assignment—calls for additional personnel, capacity building, and knowledge resources. Personnel need to be trained in the development, calibration, and validation of DTA models and the interpretation of the model results. The correct interpretation of the model results requires an understanding of the underlying methods and algorithms of the DTA model. Just as all activity-based travel demand models are not the same, all DTA models are not the same. Therefore, analysts deploying DTA tools need to be fully cognizant of the methods, behaviors, and algorithms that characterize the model being deployed to fully appreciate convergence characteristics, behavioral changes, and network dynamics output by the model system.

8.2.5.2 Possible Strategies to Mitigate/Minimize Impacts of Disadvantages/Issues

The issues identified previously can be addressed through a careful and systematic approach to the development, calibration, and validation of a DTA model for a specific application. The staff involved should be trained appropriately in DTA modeling methods, and expert consultants should be brought on board to assist in the development and deployment effort. There are many commercial and open source network maps that can be used to develop model networks with high degrees of spatial and temporal resolution. Agencies should exploit the availability of these resources in developing network and supply data for DTA modeling. In addition, it is not always necessary to code signal control and phasing schemes in the network. DTA models are often able to provide default signal timing plans and phasing schemes for intersections depending on approach volumes, turning movement counts, and the geometric configuration of the intersection. The hardware/software architecture and capabilities continue to mature at a fast pace. As such, it is not difficult for agencies to invest some resources and acquire the necessary computational hardware and software required to develop and run DTA models for a range of applications and network sizes. In any development effort, sufficient time, budget, and staff resources should be dedicated to model calibration, validation, sensitivity testing, and interpretation of results.

8.2.6 Executing the Technique

8.2.6.1 Configuration of the Technique

DTA models may be implemented in different ways and it is important to ensure that the implementation is consistent with the objectives of the planning study or application. The notion of equilibrium is a key consideration in the design and implementation of DTA models. DTA models may be configured such that they run in an iterative fashion until dynamic user equilibrium (DUE) is achieved. The time-dependent shortest path set for an OD pair can change from one iteration to the next based on the link travel times obtained through the DTA in the prior iteration. This equilibrium-based approach is quite suitable for a planning study with the objective of determining how traffic patterns will stabilize over a period of time and "settle" into an equilibrium state. For example, if an HOV lane were being converted to a HOT lane, then an equilibrium-based DTA would provide an indication of the traffic flows on the HOT lane in the steady state (i.e., after travelers have gone through a period of learning and adjustment).

On the other hand, DTA may also be run in a non-equilibrium configuration. In this configuration, the DTA model is run through a single iteration and the traffic patterns that result are examined for bottlenecks and congestion locations. This type of non-equilibrium-based approach does not necessarily mimic the learning and adjustment processes that travelers may go through in their route choice behavior. The disequilibrium based approach is quite useful in the context of analyzing an emergency evacuation scenario and other such short-term events where travelers may not have the time to go through the learning and adjustment process. In a hurricane evacuation scenario, for example, travelers will simply use their best judgment and choose an evacuation route; the conditions on the network will constantly evolve as travelers attempt to evacuate. As conditions continuously evolve, it is very useful to apply a DTA model for simulating a hurricane evacuation scenario and identify bottlenecks and congestion patterns. Based on an examination of such patterns, emergency response planners can determine the types of contra-flow lane strategies, public information campaigns, and service enterprises that are needed to best manage an evacuation scenario.

A DTA model may be hooked to either an activity-based travel demand model or the first three steps of a traditional four-step travel demand model. When hooked up with an activity-based travel demand model, all of the trip records output by the activity-based travel demand model may be input to the DTA model as a list. When hooked up with a three-step travel demand model, the DTA will accept as input OD tables by time-of-day block/period. Appropriate continuous time-of-day distributions should be input to the DTA model along with the OD tables so that trips can be disaggregated along the time axis and loaded onto the network in the DTA model.

The level of network detail is another consideration in the configuration of the DTA model. It is theoretically feasible to apply a DTA model using the standard travel demand model network; however, the network should be configured appropriately to ensure that the DTA model does not provide counter-intuitive and unreasonable results. DTA models are more effective when a network has greater levels of detail, including local and minor streets that correctly and accurately portray access points to the higher order facilities such as collectors, arterials, and freeways. The inclusion of complete information about intersection control and signal timing and phasing plans will accurately capture the travel times and delays that travelers experience as they traverse the network. Using default timing and signal plans that are embedded in the DTA software systems is a reasonable compromise in the event that such data are hard to come by. It is ideal if the configuration of the DTA model is one in which traffic is loaded at multiple points or "activity locations" along a link that is not a limited-access facility. In the traditional model networks, a centroid connector may load all traffic to a single location on a link, resulting in lumpy loadings. The coding of driveways and activity locations/parking locations, or the placement of random activity location points at regular distances on links (that are not limited-access facilities) may prove very useful in ensuring that realistic flow patterns are simulated by the DTA model.

TDSP computations need to be made as part of any DTA model. In any assignment iteration, there are likely to be many OD pairs that did not see any demand, and, hence, no TDSPs were computed for such OD pairs. For OD pairs that saw demand, TDSPs and associated travel times would be computed based on the travel times experienced by the travelers who used the paths in traveling between the OD pairs in question. However, for OD pairs with absolutely no demand, no experienced travel times are available and TDSPs may not be available. There are two configurations that are possible. In one configuration, the DTA model may be designed to compute TDSPs for *all* OD pairs at the end of each iteration regardless of whether demand existed for an OD pair. In the second configuration, TDSPs for OD pairs that had non-zero demand are computed at the end of each iteration, and TDSPs for OD pairs that had zero demand in a certain iteration are computed "on the fly," in the midst of a subsequent iteration, if demand for such OD pairs appears in a subsequent iteration. The latter situation will arise when the results of the DTA (time-dependent skims) are fed back to the travel demand model (whether four step or activity-based) and the travel demand model then generates demand between an OD pair for which it did not generate any demand in the previous iteration. When these trips are loaded onto the network, the DTA model will compute a set of TDSPs on the fly based on link travel times and assign the trips. Both configurations can be computationally demanding, and due consideration needs to be given as to which configuration is desirable for any specific application. For example, if one is dealing with a subnetwork of only a few zones, then perhaps TDSPs can be computed for all OD pairs at the end of each iteration regardless of whether demand exists or not. If one is dealing with a large network of thousands of zones, then it may be better to generate TDSPs for zero-demand OD pairs only when a subsequent iteration calls for the model to do so.

DTA models are capable of reflecting the movements of multiple traveler classes through the network. As DTA models track individual travelers and vehicles through the network, each trip can be classified based on the type of trip that is being routed. In the case of an integrated model system where a DTA model is interfaced with an activity-based travel demand model, additional information such as the type of vehicle being used and the demographic characteristics of the traveler may be known. Recognizing heterogeneity in both traveler preferences and value of time becomes possible in the DTA modeling context.

8.2.6.2 Steps of the Technique

STEP 1. Establish Study Area and Scope

The first step in the development and deployment of a traffic assignment model is to establish the study area and the geographic and temporal scope of the DTA modeling effort. The travel demand model may cover an entire region with thousands of zones and a full day of travel demand. However, it may not be necessary to include such vast coverage within the scope of the DTA model unless a specific regional DTA model is being developed. In the context of project-level forecasting, the influence area of the project can be identified. The notion of the influence area has been covered in the context of multiresolution modeling; in general, it may be appropriate to choose a larger geographic scope for DTA modeling than for microscopic traffic simulation modeling. A mesoscopic traffic model (i.e., a DTA model) is capable of providing computational efficiency for even large geographic areas and hence the geographic scope can be expanded to be conservative in terms of inclusion of network and TAZs. The scope of the study should be taken into consideration when assessing the adequacy of the travel model network for the DTA model application of interest. If, for example, the project is one which involves signal coordination and optimization, then it may be prudent to obtain detailed intersection control and signal timing plans for the intersections in the subarea network. On the other hand, if the project is dealing with an HOV to HOT lane conversion, then it may not be necessary to have exact signal control and timing plans for intersections in the network. Rather, default values embedded within the DTA model software can be used for such information, and detailed information can be gathered just for ramp meters or other control mechanisms specific to the corridor where the conversion is taking place. The scope of the study should also inform the type of sensitivity that needs to be built into the model. The model may have to be sensitive to price signals, multimodal traveler information provision, or signal control and timing plans.

STEP 2. Post-Processing Travel Demand Model Outputs for a DTA Model

Once the study is scoped and the geographic boundaries of the study area of interest are identified, the outputs of the travel demand model can be post-processed so that they are amenable to serve as input to a DTA model. The OD tables from a four-step travel demand model need to be combined with a smooth time-of-day distribution of travel demand to create a dynamic time-dependent OD demand profile that may serve as input to the DTA model. The smooth time-of-day distribution of travel demand may be obtained based on traffic counts on various corridors and subregions or based on travel surveys that can provide different time-of-day distributions for trips of different types and purposes. In order to accurately capture the heterogeneity of trips in the subarea of interest, OD tables corresponding to different trip purposes can be combined with their respective time-of-day distributions (for example, the time-of-day distribution for work trips may be very different from the time-of-day distribution for shopping trips) to create time-dependent OD tables or trip lists suitable for input to DTA models. If the model is configured to be interfaced with an activity-based travel demand model that provides trip lists to begin with, then generally no further disaggregation involving the use of time-of-day distributions of travel demand is necessary. Trip lists can be input directly to the DTA model.

STEP 3. Assemble Data Required for Model Development, Calibration, and Validation

This step is concerned with the assembly of the variety of input databases needed for DTA modeling. In addition to compiling demand data from a four-step travel demand model or an activity-based travel demand model, it is entirely possible to prepare demand data using OD table estimation techniques where traffic counts are utilized to estimate OD tables for the subarea of interest.

Network supply data are probably one of the most crucial inputs to a DTA model. Network supply data include all of the geometric configuration such as number of lanes, link lengths, and turn penalties. Such data also include all of the intersection control, signal timing, and phasing schemes at intersections where signalized control is present. Other intersections may utilize STOP or YIELD controls and should be coded as such. The network may not have to be as detailed as a network coded for a microscopic traffic simulation model because lane-changing maneuvers and car-following behavior are generally not simulated in a mesoscopic DTA model. However, the network should be detailed enough to distinguish, for example, between HOV/HOT lanes and general purpose lanes—a level of detail that is now commonly seen in travel demand model networks.

Finally, a DTA model requires that traffic volume, travel time and cost (generalized cost), and speed data be compiled. In addition, it is necessary to have information about the costs incurred in traversing various links on the network, particularly if the study involves the analysis of pricing schemes. It is best if the data are available by time of day so that the temporal dynamics of network conditions are known and the dynamics predicted by the DTA model can be compared against the actual data.

STEP 4. Configure and Develop a DTA Model

Depending on the configuration desired, an appropriate DTA modeling tool will need to be selected. All DTA modeling tools are not the same and the analyst should spend ample time and resources researching and studying the various software systems and model algorithms.

The reader should refer to the previous section on configuring the DTA modeling technique to review the various elements and make appropriate decisions regarding each element. The analyst will have to determine the type of equilibrium that will be implemented, the types of route choice and path selection behavior that will be reflected, the need for route switching and adaptive shortest path computations, and whether TDSPs are computed at the end of each iteration for all OD pairs or computed on the fly for certain OD pairs. The analyst should pay particular attention to the configuration of the feedback processes. There is an inner iterative loop within the DTA process to achieve DUE. Once DUE is achieved, then OD travel times need to be fed back to the travel demand model to ensure that travel demand is being generated in a manner consistent with network conditions. The iterative process may be considered to mimic a longer term learning process where users adjust their travel schedules and demand patterns in response to network conditions until a stable equilibrium is reached. In cases where there is an interest in explicitly incorporating induced demand effects, the feedback loops may be such that network travel times (or accessibility measures based on network travel times) influence trip generation or tour formation. A major configuration element is the establishment of convergence criteria, both for the inner DTA loop (using the notion of a relative gap) and for the outer feedback loop involving the travel demand model (using travel time convergence measures). The user will have to set appropriate tolerance levels that strike a balance between computational intensity and burden, on the one hand, and equilibration of the model system on the other. Although packages may come with their own convergence criteria values, it may be prudent to run some trials and identify an appropriate tolerance level for the application.

STEP 5. Perform Model Calibration and Validation

As the DTA model has a number of moving parts and is a complex enterprise, it is likely that the model will have to be subjected to considerable amount of calibration and validation to ensure that it is able to replicate ground truth conditions. The analyst must select a series of measures of effectiveness (MOEs) and performance measures against which the DTA model will be calibrated. This may include such measures as peak-hour traffic volumes, travel times, speeds, vehicle miles of travel, and vehicle hours of travel. For all of these measures, the analyst can choose appropriate error measures such as the root-mean-square error (RMSE) and compute the errors realized across the network or a subset of the links of the network. Appropriate criteria need to be established to determine the point at which the model would be considered adequately replicating ground conditions at the level of spatial and temporal detail required to meet study objectives.

There are a number of parameters within a DTA model that can be adjusted to calibrate the model. There may be route choice parameters that reflect the preferences of drivers for certain functional classes over others. There may be user-value-of-time functions that are critical to modeling the choice of tolled routes by travelers in multiple classes. There may be utility equations (and the associated coefficients and constants within these utility equations) that determine how travelers will choose among the *K* TDSPs available to them for an OD pair. The analyst should systematically and carefully modify these parameters and coefficients until the model is able to replicate baseline conditions within the acceptable margin of error. However, these coefficients should not be modified in ways that would be considered behaviorally inappropriate just for the sake of matching calibration data. In some cases, the calibration data may need to be revisited to ensure that they contain no errors. In other cases, some amount of error may be reasonable and acceptable in the interest of maintaining behaviorally robust models that offer sensitivity consistent with known behavioral response to operational strategies and network conditions.

Validation of a DTA model should also be done through sensitivity analysis. To be considered valid, it is necessary, but not sufficient, for the DTA model to replicate ground conditions. The validity of a DTA model hinges on its ability to reflect the type of behavioral and system sensitivity that is desired to meet the study objectives. For this reason, the DTA model should be subjected to an extensive set of sensitivity analyses where input conditions are changed and the responsiveness of the model is assessed. The sensitivity of the model should be consistent with measures of change reported in the literature and be consistent with field observations that may be available in the region where the DTA model is being applied. If the sensitivity is unreasonable or inconsistent with any available information about changes in traffic patterns in response to changes in inputs, then the model should be recalibrated and validated. Performing such a sensitivity analysis will help establish the bounds and limits of input data ranges within which the DTA model is valid, and beyond which it would be inappropriate to apply the model.

STEP 6. Apply the Model to the Project of Interest

The final step in the process is the application of the model to the scenario or project of interest. The scenario input data must be compiled. This includes coding network changes, travel cost parameters, and any other changes in network conditions that may be part of the scenario of interest. Changes in traveler preferences may also be reflected by changing weights or parameters associated with various functional classes in the network. Travel demand data for the policy scenario in question will have to be compiled and post-processed for use in the DTA model. The DTA model may be applied to a range of scenarios in this way, and the outputs studied for changes in behavior, demand, and network conditions that result from the operational strategy, pricing policy, or capacity change. The analyst should subject all results to a thorough review process to ensure that they are reasonable and would stand up to intense scrutiny.

8.2.6.3 Working with Outputs of the Technique

The DTA model provides greater levels of spatial and temporal detail than a static traffic assignment model, but less detail than a microscopic traffic simulation model. In the case of a DTA model, information on traffic volumes, travel times, speeds, and vehicular densities can be output and visualized for any time slice to see how these measures change through the course of an hour or day. Information on volumes, speeds, and travel times may be viewed and analyzed at various levels including link level, corridor level, OD path level, and network level. At the OD pair level, all of the paths between an OD pair can be analyzed to see how travelers distribute themselves across the candidate paths. At the network level, it may be possible to generate animations or other graphical displays of the simulation results to identify critical bottlenecks, congested corridors, and secondary and tertiary impacts of a policy action or operational strategy. Various DTA modeling software packages incorporate tools and visualization elements for working with outputs, thus obviating the need for users to develop their own output analysis and visualization tools.

8.3 Peak Spreading

Travel models function on the principle of forecasting future travel demand and loading that demand as traffic onto a roadway network. These models were developed primarily for transportation planning purposes. As a result, these models approach capacity as a "soft" limit making a particular route less attractive as traffic flow volume approaches capacity.

This soft limit is typically achieved through the application of a volume-delay function (VDF). A VDF returns travel time on a network link as a function of volume and capacity. The exact curve of the function changes from one VDF to another, but they all express the general trend of increasing travel time as the volume-to-capacity ratio (V/C) increases. Though the route becomes less attractive, it is possible for the model to assign additional traffic to a roadway segment in excess of capacity if no better option presents itself. Therefore, forecast volumes resulting from demand models are not capped by the number of vehicles that can occupy a given stretch of road over a given period of time.

Forecasting techniques that do not make use of travel demand models also typically face a lack of capacity constraints. Techniques such as the application of growth rates to traffic counts or conducting a trend analysis of historical traffic count data focus their scope on the data available at specific traffic count locations without reference to the roadway network. These techniques focus on extending the observed traffic data at a given location to some future year. Such forecasts are not capacity constrained and can therefore result in traffic forecasts that can surpass capacities.

The problem of trips surpassing capacity is of particular concern at the hourly and/or subhourly level of temporal resolution. Daily traffic volumes and forecasts have no practical relationship to capacity. Capacities addressed at a daily level are usually acting as a proxy for more refined levels of analysis and for planning purposes. Daily traffic forecasts are easier to develop, and daily V/C relationships have some correlation to peak-hour traffic behavior. This allows transportation planners to easily assess the state of transportation supply in their regions and to prepare regional transportation plans. Hourly forecasts are more relevant to capacity constraints. Without "hard" limits to capacity, peak-hour forecasts may be higher than realistically possible.

In practice, drivers react to congestion not just by route diversion, but also by temporal displacement. Some drivers who anticipate congested conditions may begin their journey earlier than others to avoid peak congestion. Other drivers may delay their departures to avoid congestion. In some cases, the congestion itself delays traffic to the point of keeping travelers on the road for longer periods of time. This temporal displacement is known as peak spreading (*106*).

8.3.1 Peak-Spreading Characteristics

Peak-spreading techniques constrain hourly traffic forecasts to available capacities. This provides more realistic traffic forecasts. Peak spreading also allows traffic forecasts to demonstrate prolonged congestion effects, thus giving a more temporally comprehensive understanding of the impacts of congestion.

Figure 8-2 shows light vehicle peaking characteristics of a segment of I-69 in Fort Wayne, Indiana. Notice the pronounced AM and PM peaks and the definite valley in the midday. This is a fairly typical light vehicle peaking pattern on roads that do not experience pronounced peak spreading.

In contrast, Figure 8-3 shows light vehicle peaking characteristics for a segment of I-80 in Gary, Indiana. Notice how

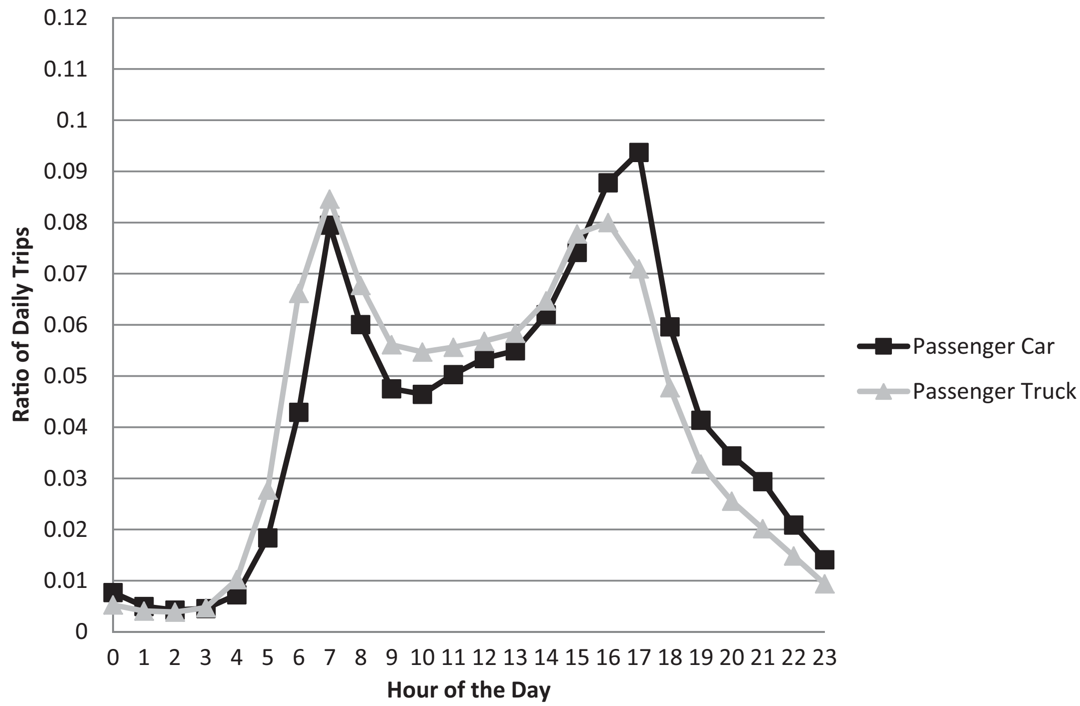


Figure 8-2. I-69, Fort Wayne, Indiana, hourly count factors, average daily counts 2007–2010.

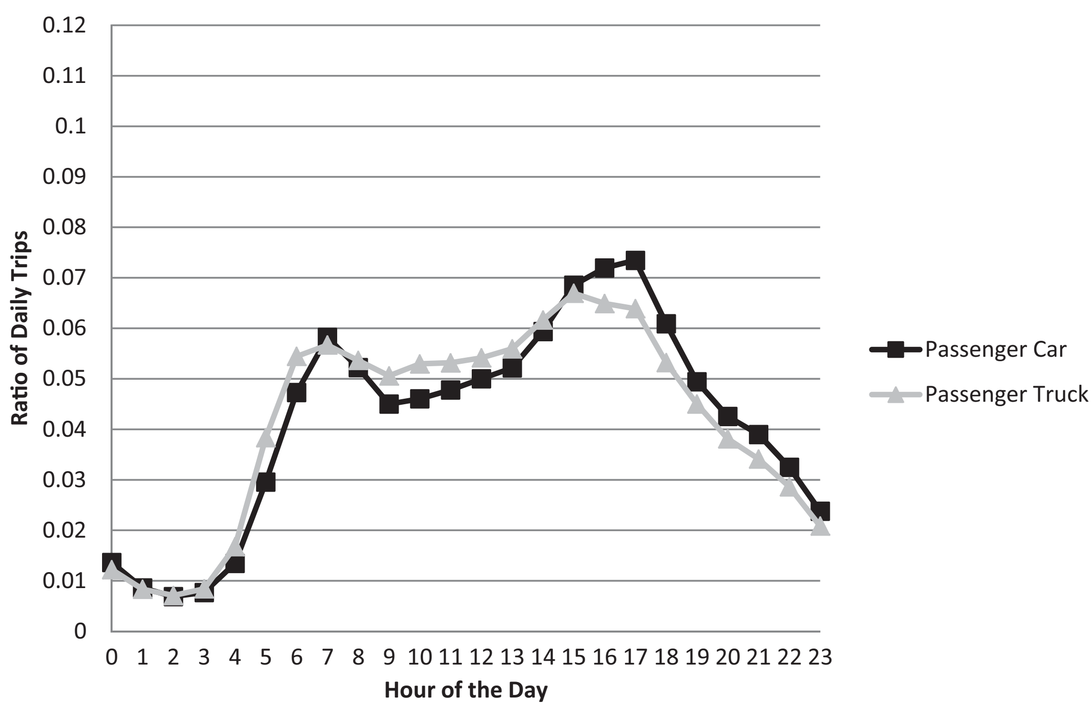


Figure 8-3. I-80, Gary, Indiana, hourly count factors, average daily counts 2010.

the AM and PM peaks are more suppressed. Also, the midday valley is not as pronounced. This pattern reflects noticeable peak-spreading behavior. Traffic is less variable throughout the day when peak spreading is present. The peak-hour volumes are less distinguished from the shoulder-hour volumes than is the case when peak spreading is not present.

8.3.2 Peak-Spreading Techniques

Techniques for applying peak spreading to traffic forecasts differ; there are link-based approaches and trip-based approaches. Link-based approaches analyze the traffic occurring in the peak hour at a given location and shift excessive traffic onto the shoulder hours on the basis of the relationship of volume to capacity. Trip-based approaches modify the trip tables of a travel demand model to reflect the shifting of trips to other times of day (*106*). The technique presented below is a link-based technique that is suitable for working with traffic forecasts developed with or without the assistance of a travel demand model.

The method described below outlines a basic approach to applying peak spreading to traffic forecasts. Steps 3 through 6 are based on a technique documented by the Ohio Department of Transportation for peak spreading with particular applications in air quality analysis (*107*). Steps 1 through 6 are the following:

1. **Establish Diurnal Distribution of Trips.** The analyst must first determine the diurnal distribution of trips before peak spreading can be applied. The analyst can develop these distributions by applying the appropriate diurnal distribution factors to daily traffic forecasts. The analyst should develop the diurnal distribution factors by analyzing historical count data. Figure 8-4 provides diurnal distribution factors based on an analysis of historical count data from around the United States. If local data are not available, the analyst should consider using the factors contained in this report.
2. **Identify Hourly Capacity.** The analyst must determine the hourly capacity for the facility for which forecasts are being developed. Service volume thresholds developed by state departments of transportation (such as the Florida Department of Transportation Quality/Level of Service Handbook) can serve as a suitable guideline for determining an appropriate capacity for peak-spreading purposes. A more detailed treatment for analyzing and identifying capacities is provided in the *Highway Capacity Manual 2010.*
3. **Determine Which Hours of Traffic Surpass Capacity.** The analyst should compare the forecast volume for each hour of the day to the capacity of the facility being analyzed. If the forecast volumes at any of these hours exceed the capacity, the analyst should note these. If all hours of traffic are at or below capacity, then the peak-spreading process ends here. Otherwise, the analyst continues on to Step 4.
4. **Identify the Heaviest Volume Hour.** Once all of the hours in which volumes exceed capacity have been identified, the analyst should determine which of these hours exceeds capacity by the greatest amount.

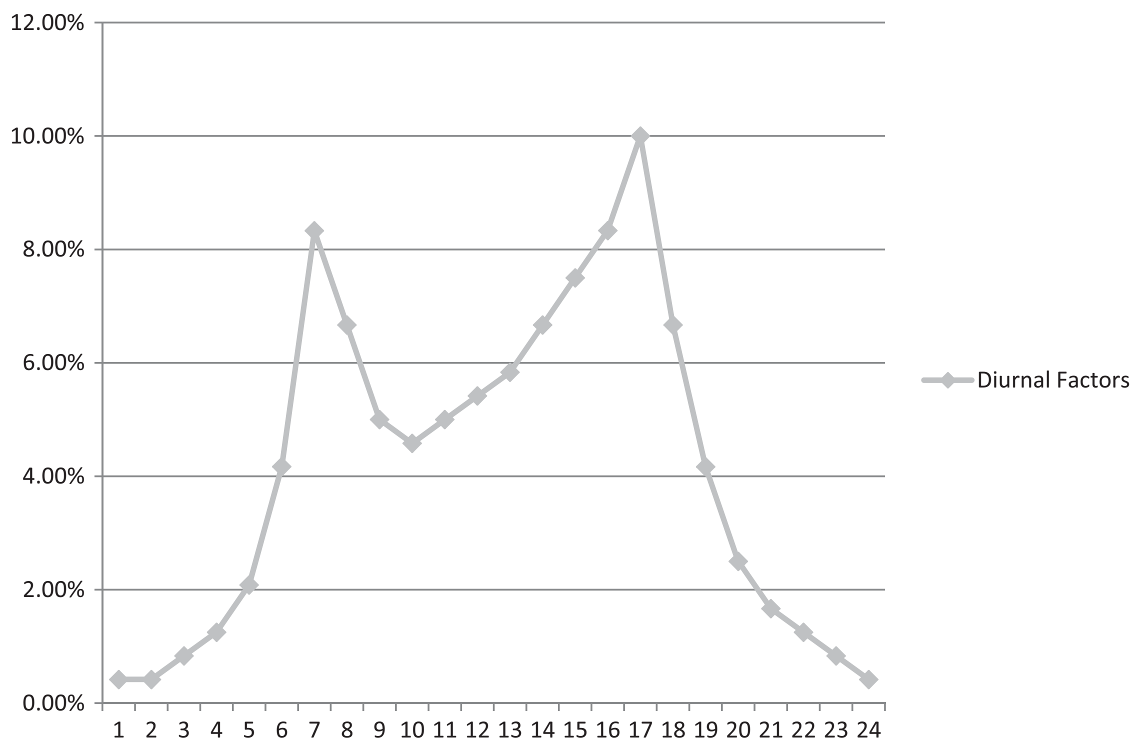


Figure 8-4. Diurnal distribution factors.

5. **Shift Over-Capacity Traffic onto Shoulder Hours.** The analyst then takes the excess volume in the highest volume hour and divides it in half. The excess volume is defined as that traffic which exceeds hourly capacity in any given hour. One half of the excess volume should be shifted onto the preceding hour and the other half of the volume should be shifted onto the subsequent hour. At this point, the hour being analyzed should have traffic at capacity.
6. **Repeat Items 3 through 5.** The analyst should return to Step 3. If there are still hours that are over capacity, the analyst must repeat Steps 3 through 5 until there are no longer any hours of the day in which forecast volumes exceed capacity.

8.3.3 Example

In this example, the facility under analysis is projected to carry a volume of 12,000 vehicles per day. Steps 1 through 9 for the example are the following:

1. The analyst identifies the appropriate diurnal distribution factors for this analysis. A chart of the factors used for this analysis is shown in Figure 8-4. When these are applied to the forecast of 12,000 vehicles a day, the analyst arrives at the distribution of trips shown in Figure 8-5. The graph in Figure 8-5 shows the number of trips plotted by hour of the day. For the sake of simplifying this example, the trips are treated as discrete bins of 50 vehicles each. As the example proceeds, the trips to be shifted during peak spreading will be shifted in 50 vehicle increments.
2. The analyst then determines what the appropriate capacity is for this particular facility. For the sake of this example, the capacity arrived at by the analyst is 1,000 vehicles per hour. This threshold is represented by the thin black line in Figure 8-6.
3. The analyst then identifies the hours in which volume exceeds capacity. In this example, the only such case is in Hour 17. With 1,200 vehicles, Hour 17 exceeds capacity by 200 vehicles. This volume is shown in Figure 8-7 as a dark column.
4. The analyst then identifies which of the over-capacity hours exceeds capacity by the most vehicles. Since in this example, only 1 hour of traffic is over capacity, Hour 17 is selected. The volume to be shifted onto the shoulders is shown in dark in Figure 8-8.
5. The analyst now moves the excess volume onto the shoulders. Since the hour to be adjusted is Hour 17, the shoulder hours are Hour 16 and Hour 18. Half of the excess volume moves into each shoulder. Of the 200 vehicles of excess

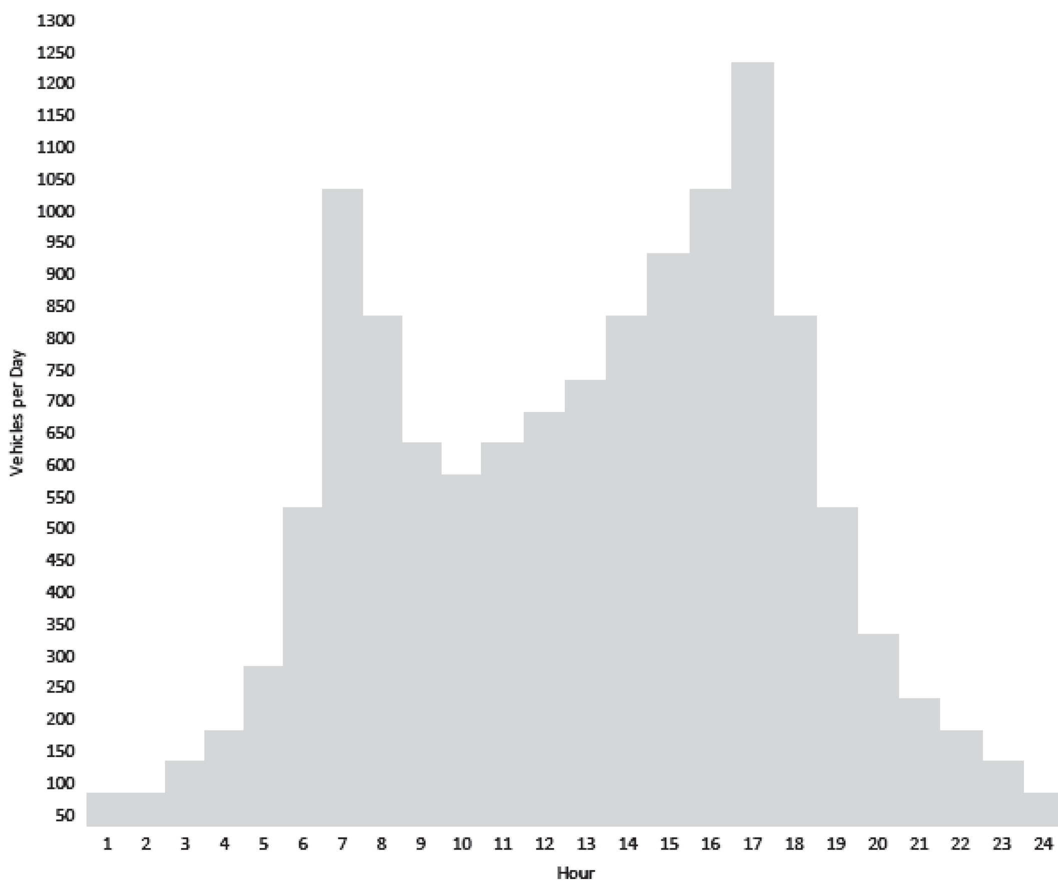


Figure 8-5. Peak-spreading example, initial traffic distribution.

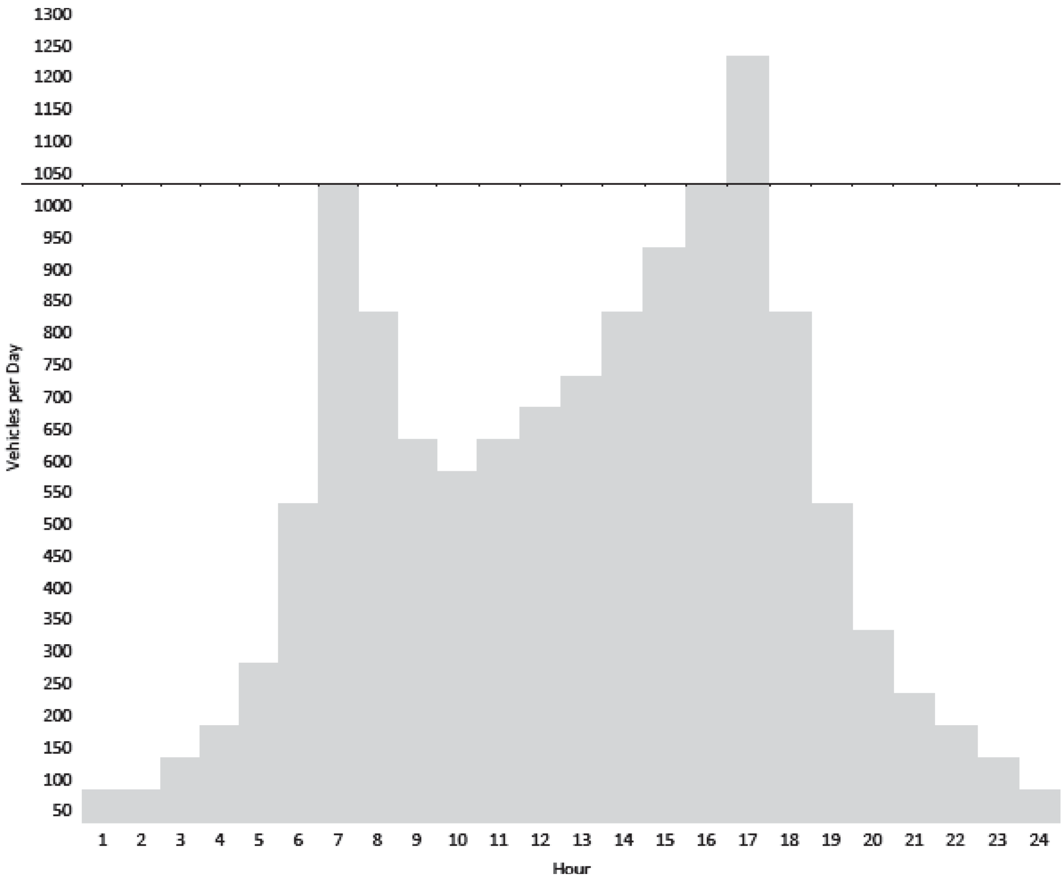


Figure 8-6. Peak-spreading example, comparison of traffic peaks to capacity.

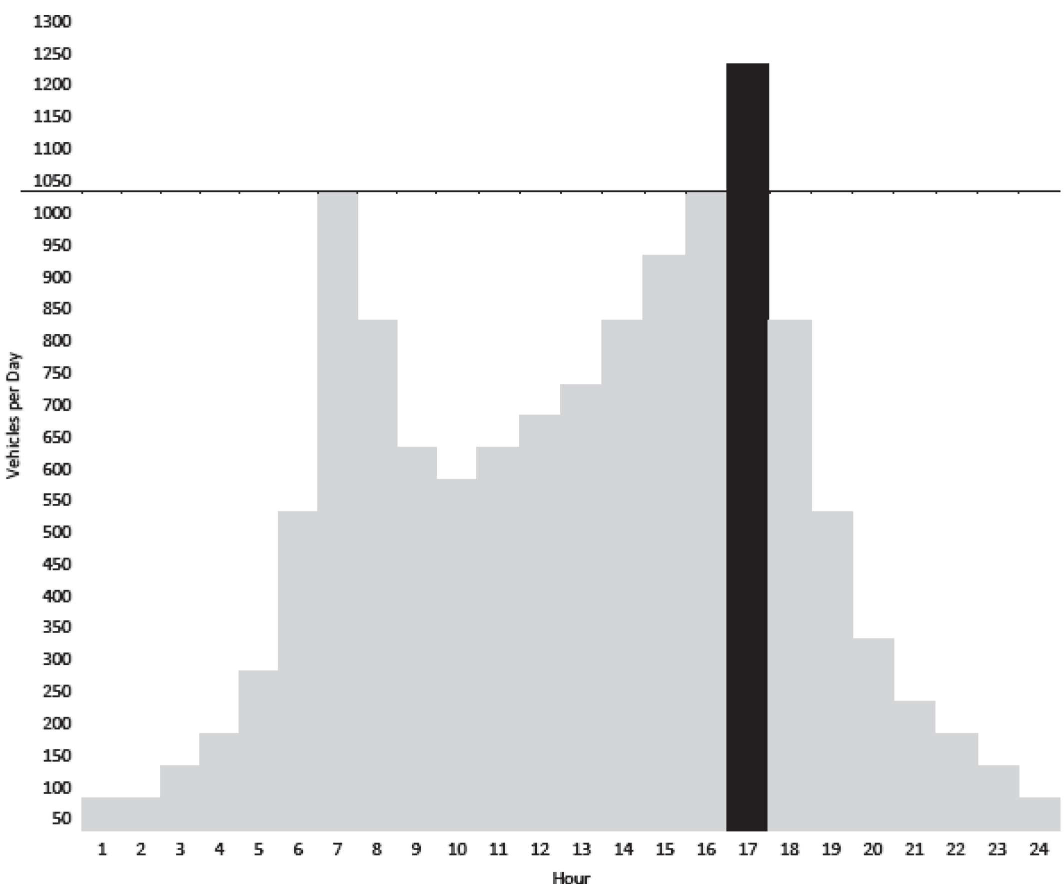


Figure 8-7. Peak-spreading example, identifying first iteration peak hour.

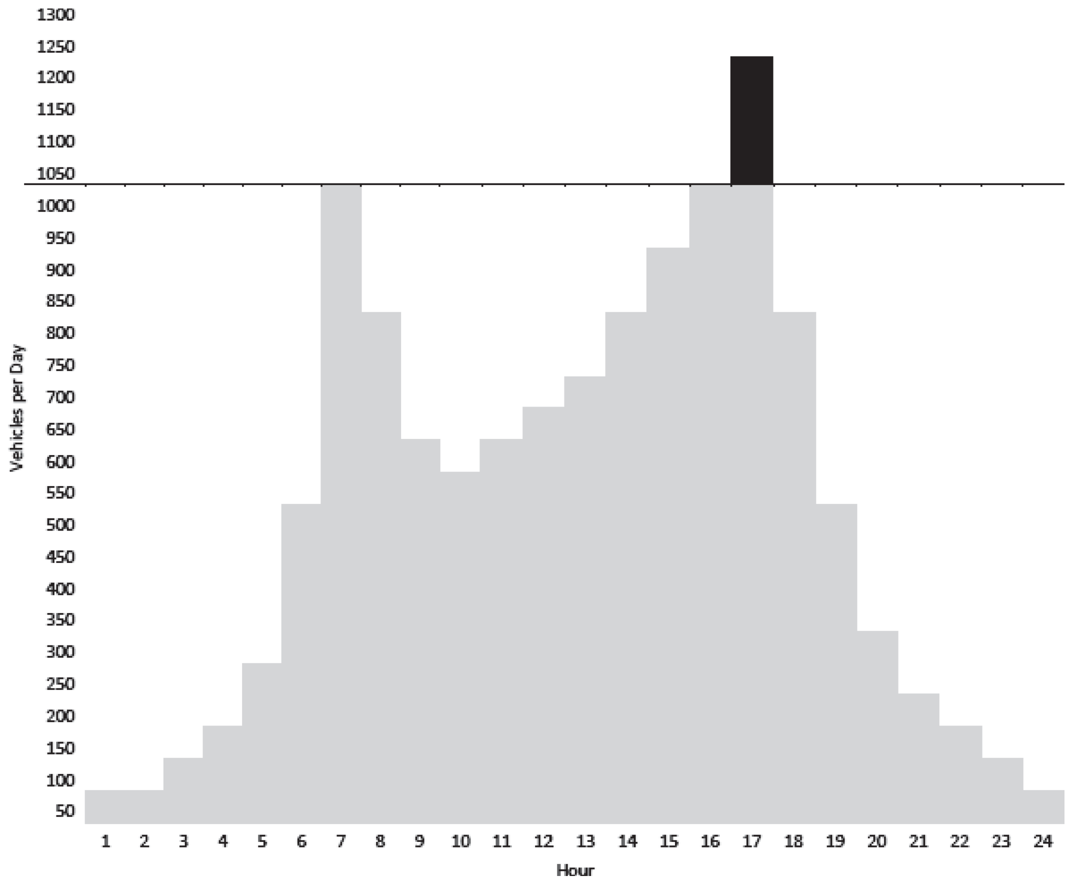


Figure 8-8. Peak-spreading example, first iteration over-capacity traffic.

volume in Hour 17, 100 vehicles are moved into Hour 16 and 100 vehicles are moved into Hour 18. The shifted volume is shown in the short dark bars in Figure 8-9. Once this adjustment has been made, there should be 1,100 vehicles in hour 16, 1,000 vehicles in Hour 17, and 900 vehicles in Hour 18.

6. Once this adjustment has been made, one iteration of the peak-spreading process has been completed. The analyst must now re-examine the volumes in each hour for excess volumes. Notice that even though Hour 17 is now at capacity, Hour 16 has gone over capacity. With a volume of 1,100 vehicles, Hour 16 exceeds capacity by 100 vehicles. This is shown with the dark bar in Figure 8-10.
7. The analyst now proceeds to continue the peak-spreading process by shifting the excess volume from Hour 16 onto the shoulders. First, the excess volume in Hour 16 is identified. The excess volume is highlighted in short dark bar in Figure 8-11.
8. The analyst now moves the excess volume onto the shoulders. This time, the hour to be adjusted is Hour 16 since that is the hour with the most excess volume. The shoulder hours are Hour 15 and Hour 17. Half of the excess volume moves into each shoulder. Of the 100 vehicles of excess volume in Hour 16, 50 vehicles are moved into Hour 15 and 50 vehicles are moved into Hour 17. The shifted volume is shown in the short dark bars in Figure 8-12.

   Once this adjustment has been made, there should be 950 vehicles in Hour 15, 1,000 vehicles in Hour 16, and 1,050 vehicles in Hour 17.
9. Once this adjustment has been made, iteration two of the peak-spreading process has been completed. The analyst must now re-examine the volumes in each hour for excess volumes. Notice that now Hour 16 is at capacity, but Hour 17 is once again over capacity. This is shown in the dark bar in Figure 8-13.

Even though Hour 17 is once again over capacity, the excess volume is now only 50 vehicles whereas at the beginning of this process the excess volume in Hour 17 was 200 vehicles. With each iteration of this technique, the excess volume will gradually spread itself out around the peak. The analyst will continue to iterate this process until all hours are at or below capacity.

Figure 8-14 shows the distribution of traffic after the process has finished iterating to its final state. Notice that instead of a sharp jump at Hour 17, there is now a smooth rounded curve encompassing Hours 15, 16, 17, and 18. Also, all hours are now at or below capacity.

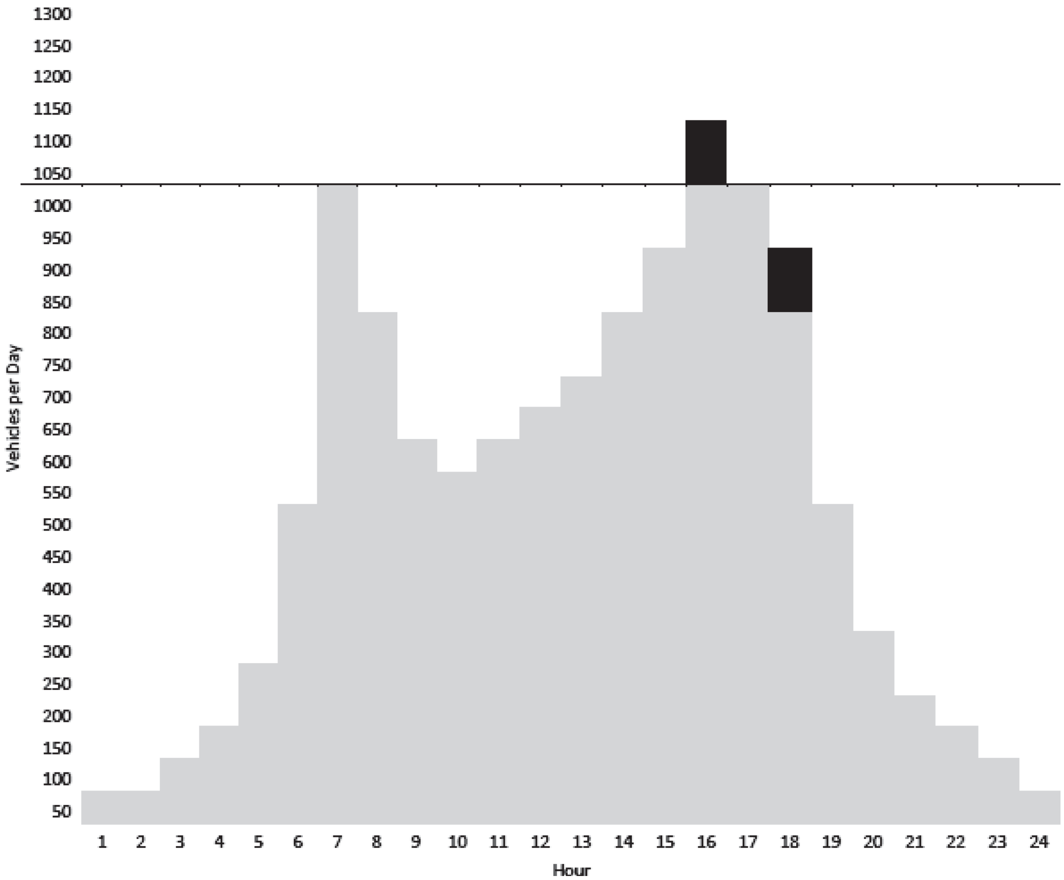


Figure 8-9. Peak-spreading example, first iteration traffic shifting.

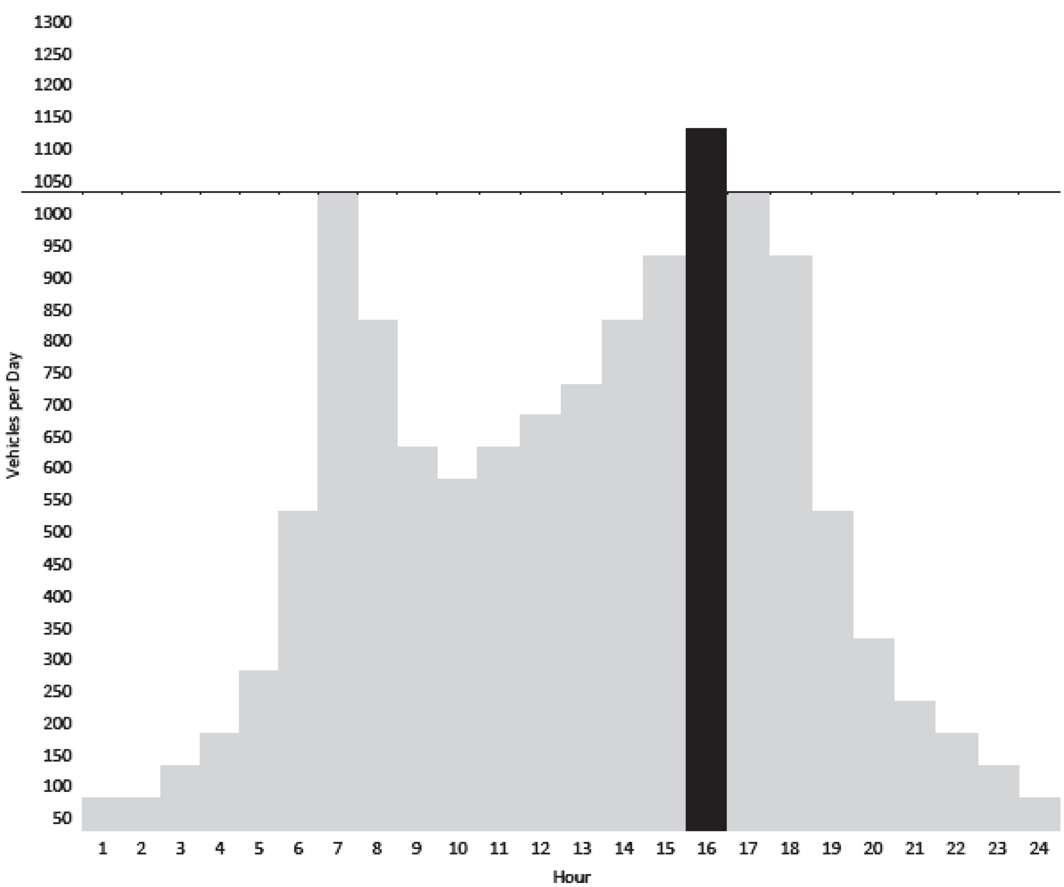


Figure 8-10. Peak-spreading example, identifying second iteration peak hour.

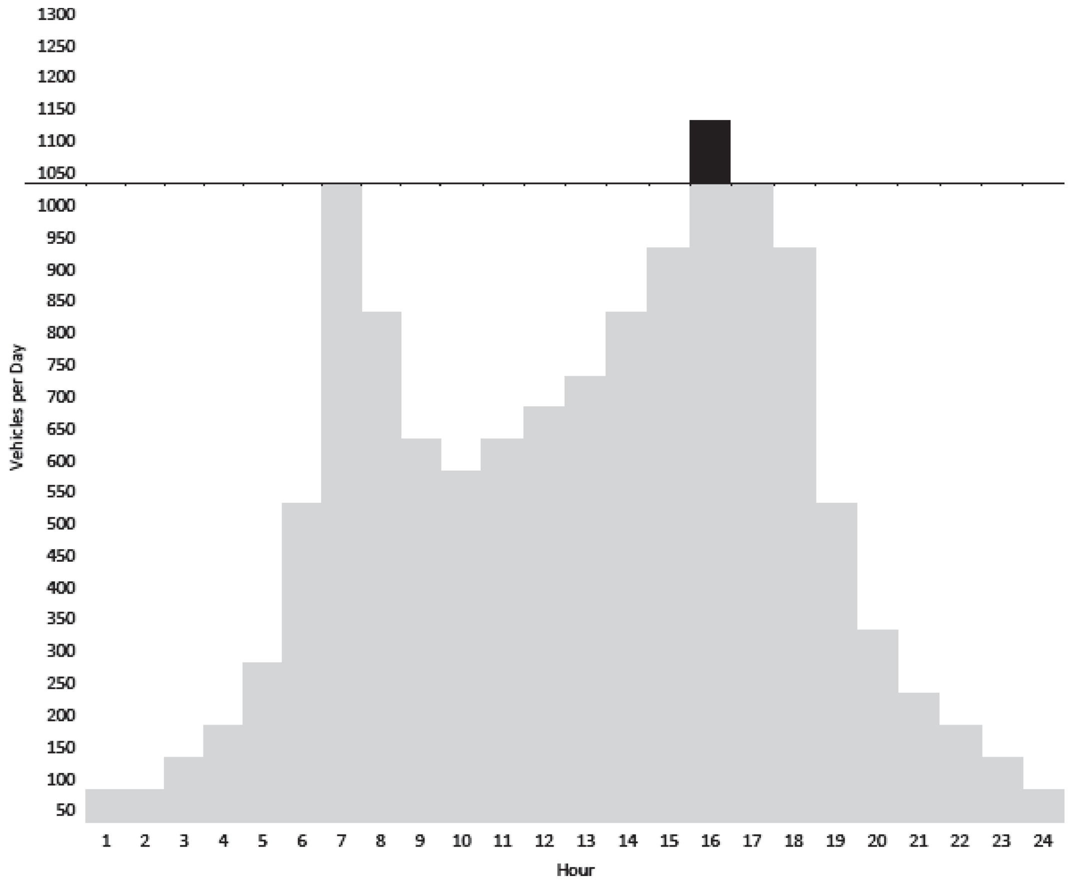


Figure 8-11. Peak-spreading example, second iteration over-capacity traffic.

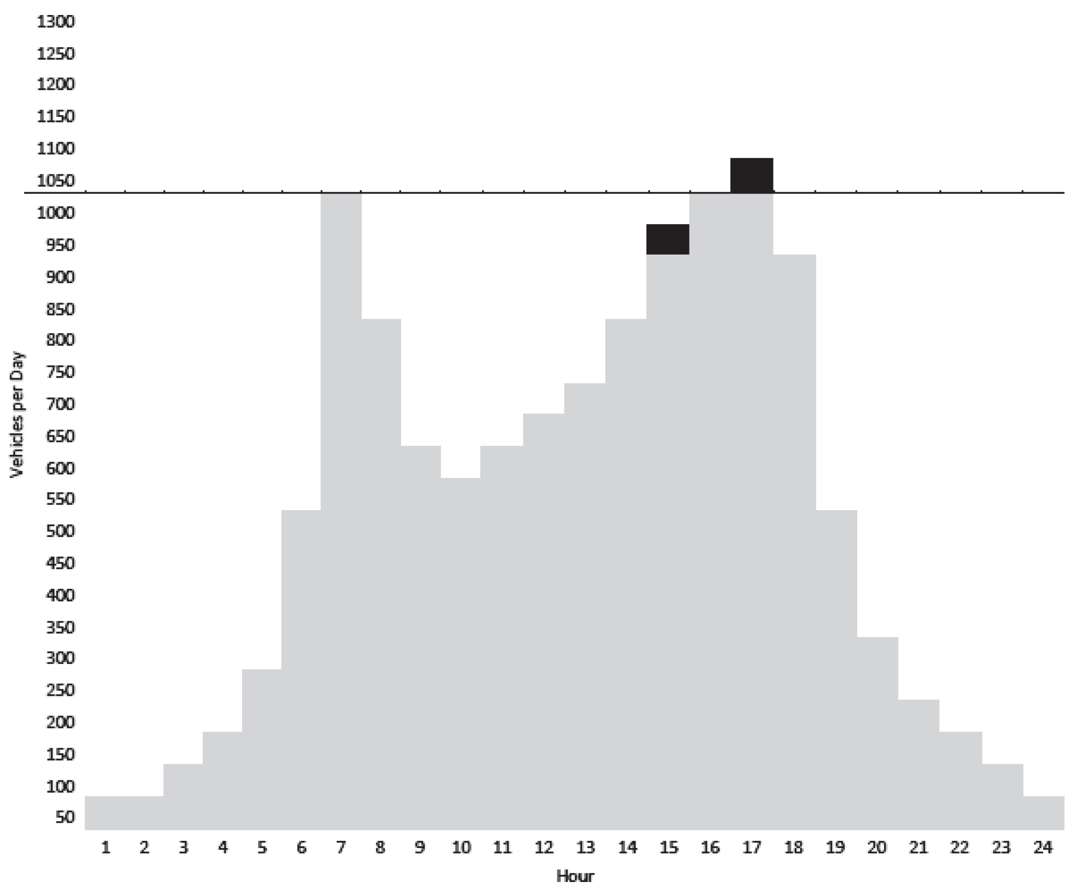


Figure 8-12. Peak-spreading example, second iteration traffic shifting.

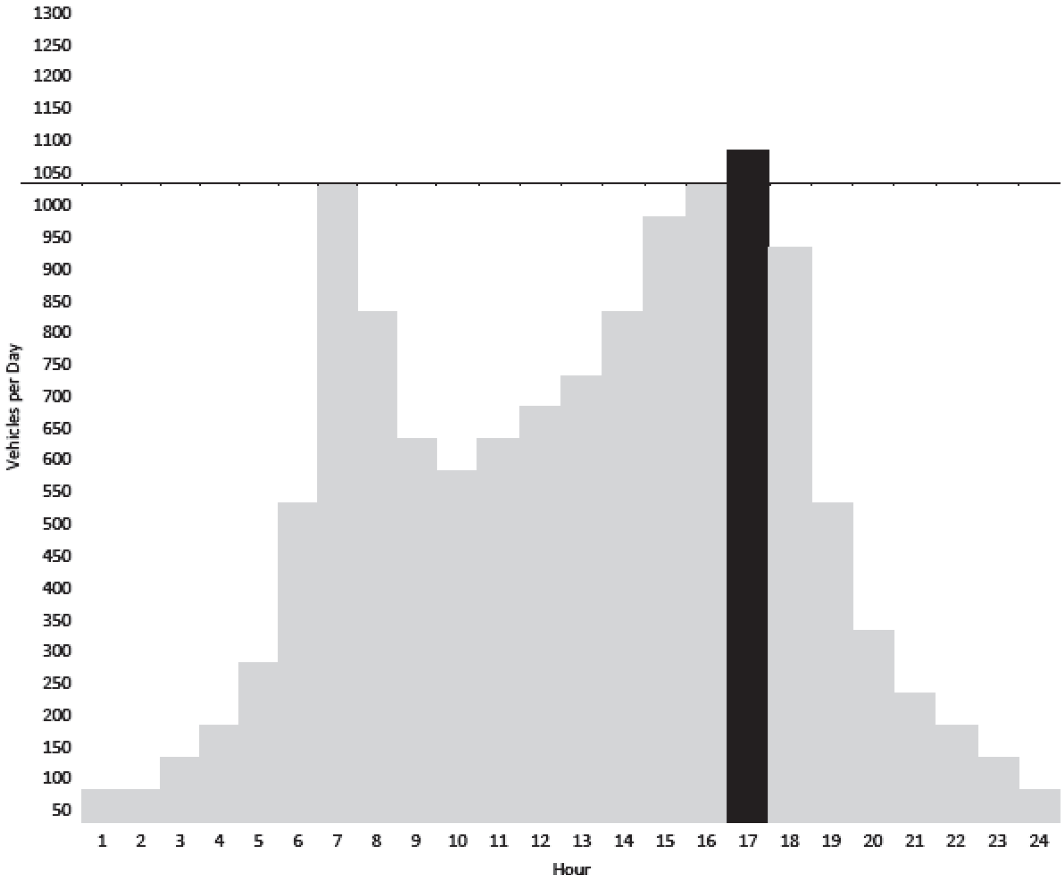


Figure 8-13. Peak-spreading example, identifying third iteration peak hour.

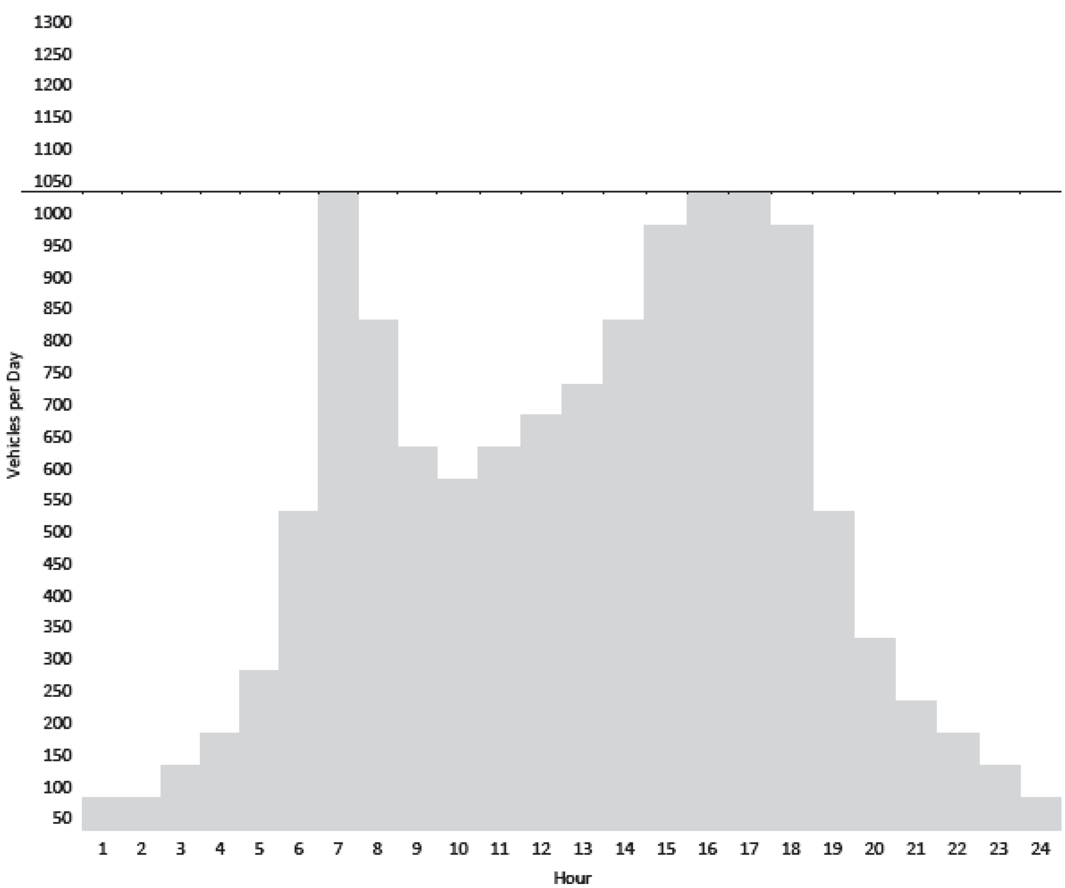


Figure 8-14. Peak-spreading example, final traffic distribution after all iterations.

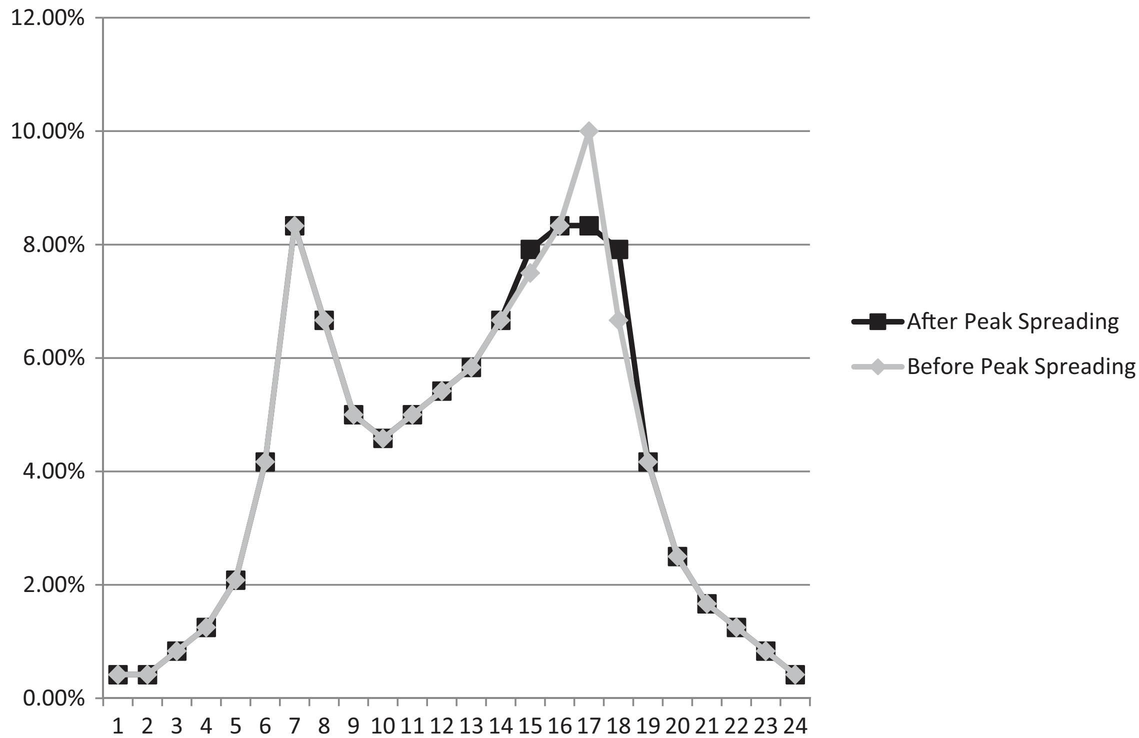


Figure 8-15. Comparison of diurnal distribution patterns.

The impact of peak spreading on the diurnal distribution of traffic can be more easily seen in Figure 8-15. This chart compares the diurnal distribution of traffic before peak spreading is applied to the diurnal distribution of traffic and after peak spreading is applied.

Though this example has been somewhat simplified, the principles demonstrated here can be applied to more complex scenarios. When preparing to apply peak spreading to traffic forecasts, the following should be kept in mind:

- This is an iterative process. A single site can be processed by hand but can be time consuming. A larger number of locations should be processed using some kind of automated procedure. Scripts appended to existing models or independently developed software for forecasts (not developed with the assistance of a model) can accomplish this.
- In some cases, the daily traffic forecasts may exceed 24 times the hourly capacity. This means that even if traffic were spread evenly throughout the day such that every hour of the day was at capacity, there would still be excess volume. This should be a relatively rare occurrence and most likely the result of using a travel demand model to develop the forecasts. The analyst should consider reviewing the traffic forecast and make any adjustments that may be necessary prior to applying a peak-spreading method.
- When using an automated process, the algorithm should have a tolerance when checking whether an hour is at or above capacity. The shifting of excess volume onto shoulder hours in an iterative fashion using the approach shown in the example results in some amount of traffic shifting back onto the original hour in highly congested situations. As a result, in highly congested situations, it may not be possible to achieve traffic at or less than capacity. The result is an infinite loop as the excess volume approaches (but never reaches) zero. A tolerance in the algorithm of some small fraction will prevent an infinite loop. Rounding the amount of traffic to the nearest whole vehicle should also work.
- When conducting the adjustments manually, the analyst should exercise professional judgment to determine when the amount of excess volume is insignificant. Insignificant excess volumes can be either ignored or shifted as a group onto one shoulder or another. For excess volume to be considered insignificant, it should be an amount that, regardless of whether or not that volume is moved onto a shoulder hour, will not alter the analyst's understanding of diurnal distribution, congestion, delay, or level of service on any given hour.

8.3.4 Vehicle Class Considerations in Peak Spreading

Peaking characteristics differ among vehicle classes. Most notably, light vehicles tend to peak in the morning and in the evening while presenting less traffic during the midday.

Heavy commercial vehicles tend to be more active throughout the midday. Peak-spreading methods that attempt to spread total traffic and use the resulting factors on vehicle class diurnal distributions will result in highly distorted peaking characteristics. This can result in a high number of trips in the overnight period with disproportionately lower trips throughout the day for some vehicle classes.

One option is to assume that certain vehicle classes are more resistant to peak spreading (e.g., heavy trucks). The other vehicle classes will be adjusted based on peak-spreading factors developed by adjusting total traffic. The resistant vehicle classes can be kept static or adjusted slightly to balance the number of vehicles among the vehicle classes. The analyst should keep an eye on the daily number of vehicles in each class. It is possible that the number of vehicles in each class may become altered while applying peak-spreading factors to the vehicle classes. Some form of iterative balancing may need to be implemented to ensure that the daily share of trips in each vehicle class remains the same after peak spreading as the daily share of trips was before peak spreading.

Another option is to shift a fixed amount of vehicles off of the peak onto the shoulder hours as opposed to shifting all of the over-capacity traffic at once. This process is more incremental. The processing time is likely to be longer using this method since the excess volume is being moved in smaller portions, resulting in more computations.

Starting with the most over-capacity hour, a fixed number of trips by vehicle class is shifted onto each shoulder. The fixed number of trips should be small to allow for greater precision. Also, the vehicle mix of the number of vehicles to be shifted should be proportionate to the vehicle mix of the trips occurring in that hour. For example, if the hour for which traffic is being shifted holds 2,000 cars, 1,000 light trucks, and 100 heavy trucks, and the hourly capacity is 2,500 vehicles per hour, the analyst could shift 20 cars, 10 light trucks, and 1 heavy truck onto each shoulder for that iteration. As each iteration passes, the mix of vehicles per hour may change, requiring that new ratios be calculated for subsequent iterations. Failing to shift traffic proportionately will result in distorted peaking characteristics for certain vehicle classes. This is because light vehicles peak during peak periods while heavy vehicle volumes are still relatively low.

This process is iterative. It focuses on a given hour of traffic while that hour is the most over capacity. When a given hour is no longer the most over capacity, the focus is shifted onto the new most over-capacity hour even if the initial hour is still over capacity. This process continues until all hours are at or below capacity. In this way, this method is similar to the method described in the example earlier in this section. The key difference is that the smaller increments of traffic that are being shifted onto the shoulder hours allow the analyst a higher level of control in the peak-spreading process. This greater precision makes it possible to spread traffic by vehicle class while not distorting the vehicle class mix of diurnal distribution curves.

8.4 Method: Pre-Assignment Time-of-Day Factoring

8.4.1 Abstract

Time-of-day (TOD) factoring is the simplest way to insert information into a forecast about how much trip making is done at various times of the day. Pre-assignment TOD factoring is performed within a model either after trips have been distributed to a destination or after trips have been split to modes, depending upon data availability, software capabilities, and the preferences of the analyst. Hourly TOD tables may be extended to DTAs by interpolation.

8.4.2 Context

Typical applications are general land use changes, new corridors/facilities, travel demand management, prioritization, benefit/cost, site impact study, air quality, road diet/cross-section modification, lane widening, equivalent single axle loads (ESALs)/load spectra, access management, tolling, and detour/diversion analysis.

Geography is site, corridor, and wide area.

Typical time horizons are short range, interim, and long range.

Required input data are urban travel model, statewide travel model, network data, and demographic data.

Related techniques are TOD choice models and post-assignment TOD factors.

An Advantage of pre-assignment TOD factoring is that it provides a quick, behaviorally correct way to factor 24-hour trip data into peak hours or peak periods.

A Disadvantage of pre-assignment TOD factoring is the need for additional analysis.

8.4.3 Background

A pre-assignment TOD table provides information necessary to convert a 24-hour production-to-attraction trip table to a single-hour (or multi-hour) OD table.

8.4.4 Why This Technique

This technique is preferred to post-assignment TOD factoring, in most cases, because it is more sensitive to trip purpose and direction of travel and less dependent on empirical variables such as highway functional class and area type. Fewer assumptions are required to forecast the directional split on a road than would be needed with post-assignment

TOD factoring. Also, pre-assignment TOD factoring allows the creation of dynamic OD tables for use in DTA.

8.4.5 Words of Advice

This technique is not sensitive to variables that affect TOD choice. However, the outputs of a TOD choice model are similar to pre-assignment TOD tables in content. It is difficult to use this technique for analyzing peak spreading.

Depending upon software capabilities, TOD tables may be varied across zones. Development sites may be able to have TOD tables that differ from the rest of the urban area. However, TOD tables cannot be easily varied by road segment or by functional class.

8.4.6 Executing the Technique

8.4.6.1 Special Data Preparation

DTAs may require OD tables for periods of time shorter than 1 hour. Hourly TOD tables may be interpolated to obtain TOD tables for shorter periods of time than 1 hour, as described in "Special Step 4," below, when subhourly tables are otherwise unavailable.

8.4.6.2 Configuration of Technique

A pre-assignment hourly TOD table can be developed either post-distribution or post-mode split. Usually, a pre-assignment TOD table refers to person trips, rather than vehicle trips. Each entry in a table contains the fraction (or percentage) of trips of a trip purpose that begins within a specific hour and goes in a specific direction. Fractions usually refer to the amount of daily traffic, although it is only important that all the fractions be consistent with the time period of the trip generation step. Two directions are possible: from the production end (production to attraction) or to the production end (attraction to production). Such tables may be built specifically for a particular urban area by analysis of home-interview surveys, or such tables may be transferred from other locales, such as those from *NCHRP Report 716*. It is not possible to build pre-assignment hourly TOD tables directly by observing traffic because it is not possible to clearly discern the direction (from production or to production), purpose, and number of passengers of vehicles within a traffic stream.

Within a trip purpose, the total of all fractions in a pre-assignment hourly TOD table must sum to exactly 1.0 (or 100%). Most tables will sum to approximately 0.5 (or 50%) within a purpose and within a direction, although this is not a strict requirement. Some published TOD tables have exactly half of trips within a single direction for the non-home-based (NHB) trip purpose, because the production and attraction ends of NHB trips are often ambiguous. Indeed, some models use exactly the same fractions for the from-production direction and for the to-production direction for the NHB purpose.

8.4.6.3 Steps of the Technique

STEP 1. Obtain Default TOD Table

It is always a good idea to obtain an already prepared TOD table. Such a table can serve as a set of default values or can guide the creation of custom tables. Table 8-1 shows a pre-assignment TOD table from *NCHRP Report 716* (*6*) for all trips, and Table 8-2 shows a pre-assignment TOD table from *NCHRP Report 716* for automobile trips. Values in these tables have been modified slightly from the original, in order to make each purpose sum to 100%, which is required to avoid losing or gaining trips across a 24-hour forecast. Since the percentages are given to five decimal places, one can expect that every hour would have at least one trip (a positive percentage). The actual percentage is certainly so small that using 0.00000% will not cause any problem.

The tables from *NCHRP Report 716* apply to an average U.S. city. If there are indications that these tables do not apply (perhaps because an urban area is very large or very small), then a separate analysis of the National Household Travel Survey (NHTS) may be required. Tables may also be adopted from similar cities. *NCHRP Report 365* gives different TOD tables for different urban area sizes, but these tables are not now recommended because of their age.

Depending upon software capabilities, it may be necessary to aggregate hours into time periods matching the forecast, such as a PM peak period.

Default tables may or may not exactly match the trip purpose definitions for the model.

STEP 2. Build a Customized TOD Table for All Traffic

TOD tables may also be built from survey data in the form of trip records. At a minimum, such data need only include the time that the trip begins, the trip purpose, the character of the origin (home, work, shop, etc.), and the expansion factor (if available). The trip mode is also required for a post-mode split table. The fractions are easily obtained from the counts of trips falling into each hour, each purpose, and each direction. Conventionally, the home is the production end for all home-based trips. For example, the direction for a home-to-shopping trip would be "from the production end," or "production to attraction," because home is the origin.

A TOD table may also be built from a TOD choice model. TOD choice models do not usually have each hour in a day as a separate alternative, so additional information would be necessary to convert choice model results to hourly fractions. Options for further refining TOD choice model outputs

Table 8-1. All trips, percentage (corrected pre-assignment TOD tables from *NCHRP Report 716*).

Begin Time	HBW P to A	A to P	HBNW P to A	A to P	HB School P to A	A to P	NHB P to A	A to P
Midnight	0.09990	0.49950	0.00000	0.29880	0.00000	0.30090	0.14985	0.14985
1:00 AM	0.00000	0.19980	0.00000	0.19920	0.00000	0.20060	0.04995	0.04995
2:00 AM	0.00000	0.09990	0.00000	0.09960	0.00000	0.10030	0.04995	0.04995
3:00 AM	0.09990	0.09990	0.00000	0.00000	0.00000	0.00000	0.04995	0.04995
4:00 AM	1.39860	0.00000	0.19920	0.00000	0.20060	0.00000	0.19980	0.19980
5:00 AM	5.19481	0.00000	0.59761	0.09960	0.70211	0.10030	0.64935	0.64935
6:00 AM	11.48851	0.09990	2.29084	0.29880	1.80542	0.30090	1.79820	1.79820
7:00 AM	14.28571	0.09990	6.97211	0.99602	4.21264	1.00301	3.94605	3.94605
8:00 AM	7.69231	0.09990	4.78088	1.29482	3.91174	1.30391	3.04695	3.04695
9:00 AM	2.79720	0.29970	3.38645	1.39442	3.61083	1.40421	2.29770	2.29770
10:00 AM	1.29870	0.29970	3.08765	1.89243	3.41023	1.90572	2.44755	2.44755
11:00 AM	1.09890	0.99900	2.49004	2.39044	2.80843	2.40722	2.89710	2.89710
Noon	1.59840	1.79820	2.29084	2.88845	2.50752	2.90873	3.39660	3.39660
1:00 PM	1.69830	1.39860	2.49004	2.68924	2.80843	2.70812	2.99700	2.99700
2:00 PM	1.69830	2.69730	2.68924	4.68127	3.00903	4.71414	3.64635	3.64635
3:00 PM	1.09890	6.19381	2.58964	5.87649	2.90873	5.91775	4.29570	4.29570
4:00 PM	0.99900	8.99101	3.18725	4.58167	3.51053	4.61384	4.09590	4.09590
5:00 PM	0.49950	10.48951	3.68526	4.88048	4.01204	4.91474	4.24575	4.24575
6:00 PM	0.29970	4.49550	4.08367	3.98406	4.61384	4.01204	3.34665	3.34665
7:00 PM	0.09990	1.89810	2.49004	3.78486	2.80843	3.81143	2.44755	2.44755
8:00 PM	0.09990	1.19880	1.09562	3.68526	1.20361	3.71113	1.74825	1.74825
9:00 PM	0.19980	1.19880	0.59761	2.49004	0.60181	2.50752	1.14885	1.14885
10:00 PM	0.29970	1.29870	0.29880	1.29482	0.30090	1.30391	0.64935	0.64935
11:00 PM	0.09990	1.39860	0.19920	0.69721	0.20060	0.70211	0.39960	0.39960

Note: P = production and A = attraction.

include survey data or default tables, as described in this step and previous steps.

STEP 3. Build Customized TOD Tables for a Site or Special Generators

The TOD characteristics of a site development rarely agree with those of the community at large. TOD tables for site developments are most often built from historical experience at similar land uses from publications such as the Institute of Transportation Engineers' (ITE's) *Trip Generation Manual*. Site impact models focus on the peak hour of the site traffic or the peak hour of the neighboring arterials. Either hour could be used, depending on local needs.

A site may consist of one or more land uses. Any given land use may or may not be consistent with a trip purpose. In ITE's *Trip Generation Manual*, each land use gives the percentage of traffic entering or leaving a site for a single hour. Judgment is necessary to aggregate land uses at a site to trip purposes for the model (home-based work [HBW], home-based, non-work [HBNW], NHB, etc.) Judgment is also necessary to determine the direction of trips (from production or to production), as these often differ from the definitions for entering and leaving. Judgment can be aided by reference to local or default (e.g., *NCHRP Report 716*) trip generation rates (*6*). When building TOD tables for a site, it is important to recognize that the percentages entering and leaving are for vehicles, not for persons. TOD tables are most typically for person trips.

Special generators, to the extent that they are handled like site developments, would follow similar logic.

SPECIAL STEP 4. Interpolation of TOD Tables to Time Periods of 1 Hour or Less

DTAs often work with time slices of less than 1 hour, such as 5, 12, 20 or 30 minutes.

Each time slice in a DTA requires its own set of OD trips. A 1-hour, production-to-attraction table may be factored into a fractional-hour OD table by using interpolated TOD factors.

The interpolation process is made slightly more complicated by the need to conserve the number of trips within an hour. The interpolation process is illustrated by an example of a 10-minute

Table 8-2. Automobile trips, percentage (corrected pre-assignment TOD tables from *NCHRP Report 716*).

Begin Time	HBW P to A	A to P	HBNW P to A	A to P	HB School P to A	A to P	NHB P to A	A to P
Midnight	0.09960	0.49801	0.00000	0.29940	0.00000	0.39880	0.09980	0.09980
1:00 AM	0.00000	0.19920	0.00000	0.19960	0.00000	0.19940	0.04990	0.04990
2:00 AM	0.00000	0.09960	0.00000	0.09980	0.00000	0.09970	0.04990	0.04990
3:00 AM	0.09960	0.19920	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
4:00 AM	1.49402	0.00000	0.19960	0.00000	0.19940	0.00000	0.19960	0.19960
5:00 AM	5.37849	0.00000	0.59880	0.09980	0.69791	0.09970	0.24950	0.24950
6:00 AM	11.65339	0.00000	1.89621	0.29940	1.69492	0.29910	0.79840	0.79840
7:00 AM	14.24303	0.09960	6.48703	0.99800	4.38684	1.09671	2.44511	2.44511
8:00 AM	7.47012	0.09960	4.59082	1.19760	3.88833	1.29611	2.54491	2.54491
9:00 AM	2.68924	0.29880	3.59281	1.39721	3.68893	1.49551	2.54491	2.54491
10:00 AM	1.29482	0.29880	3.19361	1.89621	3.38983	2.09372	3.24351	3.24351
11:00 AM	0.99602	0.99602	2.69461	2.49501	2.79163	2.59222	4.69062	4.69062
Noon	1.49402	1.79283	2.39521	3.09381	2.59222	3.09073	5.28942	5.28942
1:00 PM	1.69323	1.39442	2.69461	2.79441	2.79163	2.89133	4.34132	4.34132
2:00 PM	1.69323	2.68924	2.79441	3.99202	2.99103	3.48953	4.24152	4.24152
3:00 PM	1.09562	6.27490	2.59481	5.28942	2.79163	4.68594	4.59082	4.59082
4:00 PM	0.99602	8.86454	3.19361	4.79042	3.29013	4.88534	4.19162	4.19162
5:00 PM	0.49801	10.55777	3.69261	5.08982	3.88833	5.18445	3.69261	3.69261
6:00 PM	0.29880	4.38247	4.19162	4.09182	4.48654	4.28714	2.49501	2.49501
7:00 PM	0.19920	1.89243	2.29541	3.99202	2.49252	4.18744	1.89621	1.89621
8:00 PM	0.19920	1.19522	0.99800	3.99202	1.09671	4.28714	1.09780	1.09780
9:00 PM	0.19920	1.29482	0.49900	2.79441	0.49850	2.89133	0.69860	0.69860
10:00 PM	0.29880	1.29482	0.19960	1.39721	0.29910	1.49551	0.39920	0.39920
11:00 PM	0.19920	1.29482	0.19960	0.69860	0.19940	0.79761	0.14970	0.14970

Note: P =production and A = attraction.

time slice between 5:10 PM and 5:20 PM. Three hours are involved in this interpolation, hours beginning at 4 PM, 5 PM, and 6 PM. The hourly tables are assumed to give the TOD fraction at the midpoint of an hour, and the interpolated values are for the midpoint of the smaller time slice. All slices within the hour of the desired time slice also require interpolation as part of the calculation. The interpolated values are divided by the number of slices in the hour and then multiplied by the ratio of the whole hour factor to the sum of the time slice factors. For example, as shown in Table 8-1, the HBW "to" factors are 8.99101, 10.48951, and 4.49550 for hours beginning at 4 PM, 5 PM, and 6 PM, respectively. The midpoint of the 5:10 PM and 5:20 PM time slice is 45 minutes after 4:30 PM (the midpoint of the 4 PM hour) and 15 minutes before 5:30 PM. Thus, the unadjusted interpolated value for this time slice is

$$TOD(to,\ HBW,\ 5:10) = \frac{10}{60}\left(\frac{60-45}{60}8.99101 + \frac{45}{60}10.48951\right)$$
$$= 1.689077083$$

All the time slice factors before 5:30 PM are interpolated between 4 PM and 5 PM, and all the time slice factors after 5:30 PM are interpolated between 5 PM and 6 PM. The sum of all six interpolations is 9.57420375, but the total should be 10.48951. Thus, the underestimate for a simple interpolation is corrected by the ratio of these two values:

$$TOD(to,\ HBW,\ 5:10) = 1.689077083\frac{10.48951}{9.57420375}$$
$$= 1.862597436$$

which can be rounded to 1.86260.

8.4.6.4 Working with Outputs of Technique

The choice between post-distribution or post-mode split tables is largely governed by the way time of day is treated in subsequent steps. For example, if mode split uses data that vary by time of day, then the TOD factors should be applied before the mode split step.

Table 8-3. TOD factors derived from *NCHRP Report 716* for the 5 PM to 6 PM hour for HBW, HBNW and NHB purposes.

Begin Time	HBW P to A	A to P	HBNW P to A	A to P	NHB P to A	A to P
5:00 PM	0.49950	10.48951	3.68526	4.88048	4.24575	4.24575

Table 8-4. Production-to-attraction trip tables for three zones.

		HBW A			HBNW A			NHB A		
		Zone 1	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**
	Zone 1	20	8	18	34	20	47	22	13	24
Prod	Zone 2	40	16	30	80	38	75	13	7	10
	Zone 3	21	6	23	29	11	50	24	10	33

Table 8-5. Attraction-to-production trip tables for three zones.

		HBW P			HBNW P			NHB P		
		Zone 1	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 1**	**Zone 2**	**Zone 3**
	Zone 1	20	40	21	34	80	29	22	13	24
A	Zone 2	8	16	6	20	38	11	13	7	10
	Zone 3	18	30	23	47	75	50	24	10	33

Software may perform TOD factoring automatically. For any given hour, the process is to apply the "from" (production to attraction) factor directly to the production-to-attraction trip table and to apply the "to" (attraction to production) factor to the transpose of the production-to-attraction trip table. Thus, for any trip purpose and for hour h, it is possible to calculate the OD table, T_{ijh}^{OD}:

$$T_{ijh}^{OD} = K_h^{from} T_{ij}^{PA} + K_h^{to} T_{ji}^{PA}$$

where K_h^{from} and K_h^{to} are hourly factors (as fractions, not percentages), T_{ij}^{PA} is the original 24-hour production-to-attraction trip table, and T_{ji}^{PA} is the transpose of the 24-hour production-to-attraction trip table. The complete OD trip table for an hour is the sum of the OD tables from each purpose.

8.4.7 Illustrative Example

A community with similar characteristics to national defaults is performing a forecast for its PM peak hour, 5 PM to 6 PM. The relevant TOD factors from *NCHRP Report 716* are shown in Table 8-3.

The model has three trip purposes, HBW, HBNW, and NHB. Each trip purpose has its own production-to-attraction trip table calculated from a destination choice algorithm. The production-to-attraction trip table for the first three zones is shown in Table 8-4.

Table 8-6. OD trip table for the 5 PM to 6 PM hour.

		Destination		
		Zone 1	**Zone 2**	**Zone 3**
	Zone 1	6.98	9.98	7.48
Origin	Zone 2	6.07	5.61	4.93
	Zone 3	7.39	8.09	9.61

Notice that the NHB production-to attraction trip table is symmetric; symmetry or near symmetry is typical for the NHB trip purpose. The transpose of the PA table (logically, an attraction to production table) is shown in Table 8-5.

Each of the six trip tables (production to attraction or attraction to production) is multiplied by its corresponding factor; then the factored tables are added together to form a single OD trip table. Performing that calculation results in the OD trip table found in Table 8-6.

8.5 Method: Post-Assignment Time-of-Day Factoring

8.5.1 Abstract

Post-assignment TOD factoring is performed on the daily traffic volume produced by the traffic assignment step to generate an hourly volume used for design purposes. K and

D factors developed from historical traffic counts are used to convert the daily link volume to directional design hourly volume (DDHV). Historical counts based on an hourly factor can be used to generate input for applications that require hourly volumes. This technique is still applicable to areas without an enhanced travel demand model that generates peak-hour (or period) volumes.

8.5.2 Context

Typical applications are new corridors/facilities, travel demand management, prioritization, benefit/cost, and air quality.

Geography is site, corridor, and wide area.

Typical time horizons are short range, interim, and long range.

Required input data are urban travel model, statewide travel model, network data, demographic data, K factor or hourly factor, and directional distribution factor (D factor).

Related techniques are TOD choice models and post-assignment TOD factors.

Advantages of post-assignment TOD factoring are that it is simple, requires minimum labor and data, is able to adapt to area/facility type, and allows for link-based peak spreading.

Disadvantages of post-assignment TOD factoring are that it does not account for congested travel time during peak in trip distribution, mode choice, and assignment, and it is insensitive to localized change in demand (e.g., caused by change in land use).

8.5.3 Why This Technique

This technique offers a simple way to estimate design hourly volume (DHV) from the daily traffic volume output from a travel demand model. It requires minimum labor and data and therefore remains the most commonly used method.

8.5.4 Words of Advice

The temporal accuracy of the traffic forecast from travel demand model output has been much improved. Enhanced travel demand models with peak-hour or peak-period traffic forecasting capability have become increasingly available. For areas covered by models that can generate hourly traffic forecasts, the model output should be used. For those areas not covered by such enhanced models, the *NCHRP Report 255* procedures on post-assignment factoring can continue to be used (*1*).

8.5.4.1 Disadvantages/Issues

The daily traffic volume from a demand model is based on "daily equilibrium," which does not effectively consider the capacity constraint during the peak, especially for areas with long congested hours (*102*).

Since the hourly factor is developed from regional traffic monitoring data, this technique is not sensitive to localized change in travel demand.

8.5.4.2 Possible Strategies to Mitigate/Minimize Impacts of Disadvantages/Issues

When no significant change in land use is expected between the base and future years, the K factor and the D factor can be used in conjunction with the peak-hour volume prediction based on peak-period models because they reflect a localized pattern of traffic volumes. Otherwise, the output from the peak-period model should be used without the K and D factors.

Depending on the data availability, the post-assignment hourly factors should be developed for an urban area in different sizes, facility types, and orientation.

8.5.5 Executing the Technique

The standard method for estimating DHV is to use the K factor, which is defined as the proportion of average annual daily traffic (AADT) observed in the peak hour. Therefore, $DHV = AADT \times K$. The K factor is established using statewide or regional data by area and facility type, and this method is still applicable for those areas with a daily travel demand model.

To determine the DDHV, the directional distribution (D factor) of volume is needed. The D factor is also estimated based on regional or statewide traffic monitoring data, and it is defined as the percentage of the total, two-way DHV traveling in the peak direction. Therefore, $DDHV = DHV \times D$.

8.5.5.1 Data Preparation—K Factor and D Factor

The conventional approach is to establish the K factor as the ratio between the 30th highest hourly volume and annual average daily traffic (AADT), and this K factor is often referred to as K30. However, this approach was based on the traffic pattern observed on a rural area road in the 1950s. On heavily congested urban roads, observed peak-hour volume reflects the capacity of the section rather than the true demand for the hour. As a result, states have decided that roads in urbanized areas cannot be cost-effectively designed using a single standard K factor. For example, the Florida Department of Transportation (DOT) suggests using the standard K factors categorized by area type and population size as well as facility type, as seen in Table 8-7 (*3*).

Other K factors have been reported based on counts data, such as K50, K100, K200, and so forth, based on the 50th, 100th, and 200th highest hourly volume of a year, respectively (*103*, *78*).

The D factor is also established based on statewide data and often categorized by area type (urban versus rural) and facility type (freeway versus surface street). The practice

Table 8-7. Florida DOT standard K factor.

Area (Population) [Examples]	Facility Type	Standard K Factors * (%AADT)	Representative Time Period
Large Urbanized Areas with Core Freeways (1,000,000+) [Jacksonville, Miami]	Freeways	8.0–9.0 ***	Typical weekday peak period or hour
	Arterials & Highways	9.0 **	Typical weekday peak hour
Other Urbanized Areas (50,000+) [Tallahassee, Ft. Myers]	Freeways	9.0 **	Typical weekday peak hour
	Arterials & Highways	9.0 **	Typical weekday peak hour
Transitioning to Urbanized Areas (Uncertain) [Fringe Development Areas]	Freeways	9.0	Typical weekday peak hour
	Arterials & Highways	9.0	Typical weekday peak hour
Urban (5,000–50,000) [Lake City, Key West]	Freeways	10.5	100th highest hour of the year
	Arterials & Highways	9.0 **	Typical weekday peak hour
Rural (<5,000) [Chipley, Everglades]	Freeways	10.5	100th highest hour of the year
	Arterials	9.5 **	100th highest hour of the year
	Highways	9.5	100th highest hour of the year
*	Some smoothing of values at area boundaries/edges would be desirable.		
**	Value is 7.5% in approved multimodal transportation districts where automobile movements are de-emphasized. Essentially, this lower value represents an extensive multihour peak period rather than a peak hour.		
***	Value is 8.0% for FDOT-designated urbanized core freeways and may be either 8.5% or 9.0% for non-core freeways. Values less than 9% essentially represent a multihour peak period rather than a peak hour.		

varies from state to state. For example, Kentucky uses the average weekday peak-hour directional counts to develop D factors for each functional class (*104*). Minnesota uses the average D factor based on the 30th highest hourly volume (*105*). Florida uses the average D factor based on the 200th highest hourly volume (*3*). The analyst should refer to the local guideline on choosing the D factor.

8.5.5.2 Configuration of the Technique

The post-assignment factoring technique is fairly simple and straightforward. The DDHV can be estimated as $DDHV = AADT \times K \times D$, in which AADT represents the daily volume output from a travel demand model.

8.5.5.3 Steps of the Technique

STEP 1. Obtain Input Data

These data include the forecasted daily volume from the travel demand model and K factor and D factor established using historical counts data. It is important to locate the appropriate K factor and D factor based on the projected characteristics of the area and facility in question. The goal is to ensure that the present operation of the site groups from which the K factor and/or D factor are developed is consistent with the future operation of the project site.

STEP 2. Compute Directional Design Hourly Volume

The DDHV can be estimated using the following equation:

$$DDHV = AADT \times K \times D$$

in which AADT represents the forecasted daily traffic volume from the travel demand model.

8.5.5.4 Hourly Distribution of Traffic Volume

In other applications such as air quality analysis, hourly volumes are needed as an essential input. If counts are available for the site or corridor in question, hourly factors can be developed. Factors such as area type (urban or rural) and size (in population), facility type (i.e., freeway, arterial, or collector), and subregion (central business district [CBD] or non-CBD), and day of the week may influence the TOD distribution of volume. *NCHRP Report 255* presented a number of hourly distribution tables based on a study conducted in the 1970s (*1*). As an illustration of how much the hourly pattern has changed over the years, Figure 8-16 shows the comparison among the hourly factors (i.e., ratio of hourly volume to ADT) developed based on the automatic traffic recorder (ATR) data from several states and the factors in *NCHRP Report 255* for freeways in urban areas with more than one million in population.

There has been a significant change in peaking patterns on Interstates, especially those located in the suburbs of large metropolitan areas. Furthermore, the evening peak is much higher than the morning peak, and the midday traffic does not seem to subside after morning rush hour. This is another major shift from what was observed several decades ago. To varying extents, similar phenomena are observed on other facilities and geographic areas. Based on the ATR data, hourly volume distribution can be developed for facilities categorized by area type and size, facility type and subregion, as well as by day of the week.

For new facilities where counts do not exist, a set of hourly volume distribution tables have been developed in this research based on ATR data from permanent count stations in Florida, South Carolina, Ohio, and Texas during the period of 2007 to 2011, as well as data from Kentucky during the period of 2010 to 2011. These data are categorized by area population (smaller than 200,000, between 200,000 and 1 million, and larger than 1 million), facility type (freeway, arterials, and collectors) and location (CBD and non-CBD). In addition, weekday and weekend hourly distribution are analyzed separately. See Tables 8-8 through 8-11.

The hourly factor is defined as the average of the hourly volume to daily volume ratio for the given area, facility type and orientation, and day-of-the-week combination. For example, the volume from 7 AM to 8 AM on a typical weekday for an

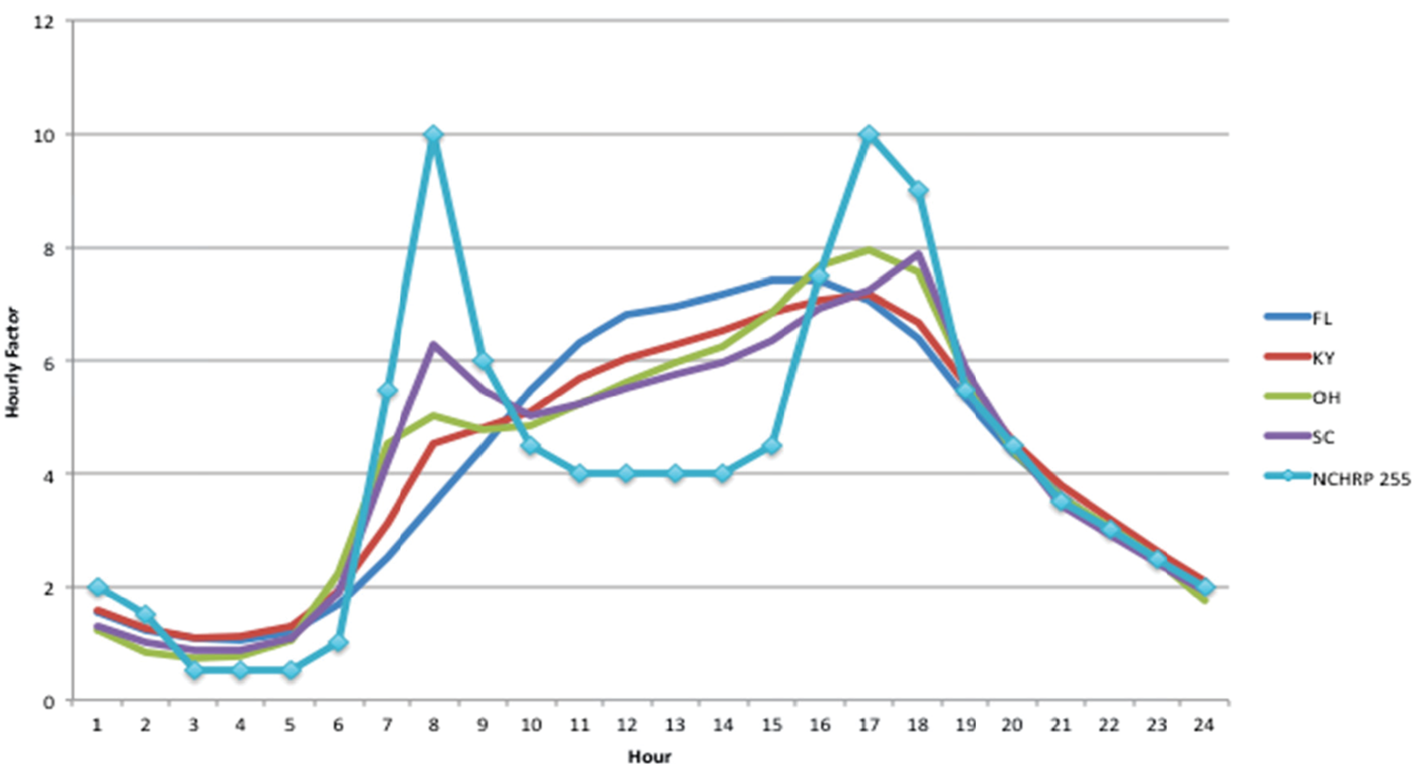


Figure 8-16. Hourly volume distribution for urban Interstates.

Table 8-8. Total traffic diurnal distribution factors by functional class: urban area, small: <200,000 population.

Hour Begins	Hour Ends	Weekday			Saturday			Sunday			Average Day		
		Interstate	Arterial	Collector	Interstate	Arterial	Collector	Interstate	Arterial	Collector	Interstate	Arterial	Collector
12:00 AM	12:59 AM	1.07	0.59	0.47	1.63	1.27	1.12	1.48	1.51	1.28	1.19	0.77	0.64
1:00 AM	1:59 AM	0.79	0.39	0.29	1.11	0.80	0.70	0.98	0.94	0.89	0.85	0.50	0.40
2:00 AM	2:59 AM	0.70	0.30	0.23	0.90	0.57	0.54	0.73	0.67	0.64	0.73	0.38	0.31
3:00 AM	3:59 AM	0.76	0.33	0.26	0.79	0.46	0.42	0.59	0.49	0.54	0.74	0.36	0.31
4:00 AM	4:59 AM	1.10	0.58	0.30	0.89	0.53	0.36	0.59	0.46	0.37	1.01	0.56	0.32
5:00 AM	5:59 AM	2.20	1.44	1.16	1.34	0.87	0.76	0.87	0.67	0.68	1.93	1.28	1.06
6:00 AM	6:59 AM	4.16	3.21	2.93	2.19	1.61	1.43	1.38	1.23	1.17	3.57	2.79	2.56
7:00 AM	7:59 AM	5.69	6.09	6.27	3.13	2.60	2.65	1.94	1.86	1.88	4.91	5.21	5.37
8:00 AM	8:59 AM	5.26	5.53	5.75	4.28	3.91	4.07	2.86	2.99	2.88	4.85	5.06	5.24
9:00 AM	9:59 AM	5.04	5.12	4.95	5.43	5.50	5.51	4.29	5.11	4.77	5.00	5.16	5.00
10:00 AM	10:59 AM	5.27	5.55	5.24	6.46	6.76	6.63	5.57	6.11	5.93	5.47	5.77	5.48
11:00 AM	11:59 AM	5.60	6.31	6.01	7.04	7.60	7.56	6.62	6.54	7.06	5.92	6.50	6.31
12:00 PM	12:59 PM	5.89	6.74	6.66	7.15	7.60	7.85	7.71	8.44	8.86	6.28	7.03	7.03
1:00 PM	1:59 PM	6.12	6.72	6.72	7.05	7.37	7.73	7.89	8.31	8.70	6.46	6.97	7.05
2:00 PM	2:59 PM	6.78	7.07	7.63	7.06	7.25	7.81	7.95	8.06	8.56	6.96	7.20	7.75
3:00 PM	3:59 PM	7.60	8.29	8.65	7.07	7.22	7.66	8.09	7.87	8.52	7.60	8.12	8.51
4:00 PM	4:59 PM	7.88	8.30	9.22	6.94	7.04	7.52	8.03	7.79	8.17	7.78	8.08	8.90
5:00 PM	5:59 PM	7.54	7.91	8.45	6.54	6.78	6.95	7.67	7.60	7.70	7.43	7.74	8.19
6:00 PM	6:59 PM	5.63	5.96	5.96	5.76	6.29	6.23	6.77	6.69	6.41	5.79	6.08	6.04
7:00 PM	7:59 PM	4.32	4.49	4.49	4.74	5.28	5.15	5.65	5.76	5.56	4.53	4.72	4.68
8:00 PM	8:59 PM	3.57	3.50	3.38	4.02	4.36	4.00	4.57	4.43	3.93	3.75	3.71	3.52
9:00 PM	9:59 PM	2.99	2.63	2.46	3.57	3.59	3.18	3.48	3.12	2.65	3.13	2.80	2.57
10:00 PM	10:59 PM	2.31	1.77	1.54	2.83	2.74	2.45	2.56	2.08	1.77	2.41	1.93	1.67
11:00 PM	11:59 PM	1.71	1.16	0.98	2.08	1.99	1.74	1.72	1.25	1.08	1.75	1.28	1.08

Table 8-9. Total traffic diurnal distribution factors by functional class: urban area, medium: 200,000–1,000,000 population.

Hour Begins	Hour Ends	Weekday				Saturday				Sunday				Average Day			
		Interstate	Arterial CBD	Arterial Other	Collector	Interstate	Arterial CBD	Arterial Other	Collector	Interstate	Arterial CBD	Arterial Other	Collector	Interstate	Arterial CBD	Arterial Other	Collector
12:00 AM	12:59 AM	0.95	0.81	0.71	0.61	1.72	1.80	1.38	1.35	1.84	2.38	1.72	1.58	1.14	1.10	0.91	0.80
1:00 AM	1:59 AM	0.65	0.47	0.46	0.36	1.13	1.17	0.87	0.83	1.20	1.54	1.09	0.97	0.77	0.66	0.58	0.48
2:00 AM	2:59 AM	0.57	0.41	0.40	0.31	0.92	1.01	0.70	0.69	0.97	1.51	0.83	0.79	0.66	0.60	0.49	0.41
3:00 AM	3:59 AM	0.61	0.31	0.46	0.34	0.76	0.62	0.59	0.56	0.70	0.76	0.62	0.62	0.64	0.39	0.49	0.39
4:00 AM	4:59 AM	0.96	0.43	0.77	0.60	0.85	0.52	0.65	0.69	0.65	0.54	0.56	0.67	0.91	0.45	0.73	0.62
5:00 AM	5:59 AM	2.10	0.98	1.80	1.32	1.31	0.74	1.03	1.01	0.92	0.64	0.82	0.91	1.87	0.91	1.59	1.23
6:00 AM	6:59 AM	4.67	2.67	4.05	3.63	2.26	1.36	1.86	2.01	1.53	1.09	1.45	1.62	4.03	2.34	3.49	3.22
7:00 AM	7:59 AM	7.17	5.90	6.40	6.70	3.34	2.37	2.91	3.26	2.13	1.76	2.16	2.55	6.16	5.02	5.49	5.83
8:00 AM	8:59 AM	6.16	5.79	5.75	6.60	4.38	3.51	3.99	4.59	3.11	2.73	3.15	3.82	5.61	5.19	5.24	6.05
9:00 AM	9:59 AM	5.13	4.96	5.18	5.60	5.26	4.75	5.16	5.72	4.45	4.18	4.68	5.37	5.07	4.85	5.12	5.59
10:00 AM	10:59 AM	5.10	5.19	5.36	5.49	6.10	5.87	6.21	6.53	5.65	5.49	5.97	6.76	5.28	5.31	5.54	5.76
11:00 AM	11:59 AM	5.37	6.22	5.76	5.92	6.74	6.79	7.02	7.07	6.53	6.43	6.64	7.19	5.67	6.32	6.02	6.20
12:00 PM	12:59 PM	5.59	7.10	6.11	6.33	7.00	7.27	7.33	7.32	7.60	7.94	8.27	8.11	5.98	7.22	6.50	6.64
1:00 PM	1:59 PM	5.78	6.95	6.25	6.40	6.94	7.33	7.34	7.22	7.75	8.25	8.33	8.02	6.14	7.14	6.62	6.68
2:00 PM	2:59 PM	6.32	6.75	6.70	6.74	6.95	7.29	7.26	7.07	7.72	8.04	8.09	7.58	6.55	6.96	6.92	6.88
3:00 PM	3:59 PM	7.22	7.18	7.46	7.44	6.99	7.24	7.24	7.17	7.74	7.80	7.88	7.42	7.25	7.25	7.47	7.41
4:00 PM	4:59 PM	7.86	7.91	8.05	7.82	6.92	7.01	7.16	6.92	7.73	7.62	7.68	7.22	7.74	7.77	7.89	7.65
5:00 PM	5:59 PM	7.97	8.27	8.14	8.18	6.62	6.68	6.90	6.63	7.36	7.14	7.33	6.80	7.74	7.95	7.89	7.84
6:00 PM	6:59 PM	5.69	6.06	6.10	6.05	5.91	6.21	6.27	5.88	6.53	6.43	6.38	6.01	5.80	6.11	6.15	6.02
7:00 PM	7:59 PM	4.10	4.72	4.42	4.33	4.77	5.49	5.20	4.91	5.45	5.50	5.37	5.05	4.33	4.89	4.62	4.47
8:00 PM	8:59 PM	3.34	3.89	3.48	3.42	4.00	4.69	4.23	4.05	4.46	4.46	4.14	4.10	3.55	4.05	3.65	3.57
9:00 PM	9:59 PM	2.88	3.18	2.82	2.71	3.68	4.22	3.71	3.55	3.51	3.48	3.09	3.10	3.04	3.34	2.96	2.85
10:00 PM	10:59 PM	2.19	2.27	2.00	1.89	3.10	3.38	2.90	2.89	2.66	2.55	2.27	2.29	2.35	2.44	2.15	2.06
11:00 PM	11:59 PM	1.61	1.57	1.36	1.24	2.34	2.67	2.07	2.08	1.82	1.74	1.46	1.49	1.72	1.73	1.47	1.37

Table 8-10. Total traffic diurnal distribution factors by functional class: urban area, large: >1,000,000 population.

Hour Begins	Hour Ends	Weekday				Saturday				Sunday				Average Day			
		Interstate	Arterial CBD	Arterial Other	Collector	Interstate	Arterial CBD	Arterial Other	Collector	Interstate	Arterial CBD	Arterial Other	Collector	Interstate	Arterial CBD	Arterial Other	Collector
12:00 AM	12:59 AM	0.96	1.22	0.78	0.59	1.95	2.55	1.70	1.54	2.32	3.27	2.24	1.95	1.22	1.61	1.07	0.84
1:00 AM	1:59 AM	0.61	0.75	0.48	0.38	1.26	1.75	1.10	0.96	1.50	2.32	1.48	1.28	0.78	1.05	0.67	0.53
2:00 AM	2:59 AM	0.51	0.58	0.37	0.30	1.00	1.38	0.83	0.71	1.20	1.81	1.11	0.95	0.64	0.81	0.52	0.41
3:00 AM	3:59 AM	0.53	0.57	0.37	0.33	0.79	1.23	0.62	0.46	0.85	1.61	0.79	0.57	0.59	0.76	0.45	0.37
4:00 AM	4:59 AM	0.85	0.79	0.61	0.59	0.83	1.10	0.59	0.50	0.73	1.29	0.64	0.47	0.83	0.89	0.61	0.56
5:00 AM	5:59 AM	2.13	1.74	1.70	1.16	1.29	1.36	0.92	0.84	0.97	1.35	0.76	0.73	1.90	1.67	1.49	1.07
6:00 AM	6:59 AM	5.11	4.23	4.17	2.72	2.30	2.16	1.72	1.65	1.63	1.92	1.25	1.34	4.40	3.75	3.53	2.44
7:00 AM	7:59 AM	7.27	6.31	6.58	5.92	3.32	3.02	2.74	3.02	2.14	2.40	1.91	2.13	6.25	5.52	5.57	5.16
8:00 AM	8:59 AM	6.61	6.24	6.08	6.05	4.33	3.90	3.95	4.39	2.93	2.94	2.99	3.23	5.95	5.61	5.46	5.58
9:00 AM	9:59 AM	5.27	5.43	5.04	5.82	5.07	4.79	5.05	5.81	4.18	4.09	4.35	4.94	5.14	5.20	4.97	5.74
10:00 AM	10:59 AM	4.86	5.18	4.96	5.78	5.76	5.42	6.03	6.62	5.44	5.28	5.67	6.15	5.03	5.20	5.18	5.93
11:00 AM	11:59 AM	5.01	5.40	5.39	6.55	6.39	5.98	6.80	7.23	6.35	5.64	6.46	6.95	5.32	5.49	5.69	6.68
12:00 PM	12:59 PM	5.20	5.72	5.81	7.08	6.73	6.35	7.20	7.40	7.16	6.33	7.87	8.39	5.59	5.85	6.22	7.26
1:00 PM	1:59 PM	5.39	5.77	5.93	6.95	6.69	6.42	7.18	7.27	7.39	6.81	8.00	8.02	5.76	5.95	6.32	7.11
2:00 PM	2:59 PM	6.02	6.07	6.31	7.20	6.75	6.43	7.11	7.07	7.47	6.91	7.87	7.80	6.26	6.19	6.58	7.25
3:00 PM	3:59 PM	7.05	6.66	7.05	7.97	6.80	6.40	7.05	7.19	7.50	6.64	7.67	7.78	7.07	6.63	7.12	7.86
4:00 PM	4:59 PM	7.78	7.07	7.85	7.94	6.70	6.22	6.89	6.92	7.52	6.42	7.56	7.61	7.63	6.91	7.69	7.79
5:00 PM	5:59 PM	7.98	7.45	8.33	7.60	6.52	6.12	6.68	6.54	7.17	6.34	7.18	7.28	7.72	7.18	7.99	7.44
6:00 PM	6:59 PM	6.11	6.12	6.52	5.66	6.04	5.92	6.16	5.96	6.52	6.28	6.40	6.25	6.14	6.10	6.46	5.77
7:00 PM	7:59 PM	4.27	4.72	4.80	4.20	4.97	5.31	5.24	4.89	5.54	5.56	5.49	5.16	4.49	4.87	4.93	4.38
8:00 PM	8:59 PM	3.37	3.77	3.88	3.29	4.14	4.55	4.45	3.97	4.69	4.76	4.56	4.12	3.60	3.96	4.02	3.45
9:00 PM	9:59 PM	2.97	3.30	3.17	2.66	3.88	4.17	3.99	3.48	3.77	3.98	3.54	3.18	3.16	3.47	3.32	2.81
10:00 PM	10:59 PM	2.41	2.77	2.28	1.97	3.61	3.94	3.37	3.12	2.96	3.44	2.54	2.30	2.61	2.97	2.45	2.14
11:00 PM	11:59 PM	1.73	2.14	1.53	1.28	2.88	3.51	2.61	2.43	2.07	2.60	1.67	1.44	1.91	2.35	1.69	1.43

Table 8-11. Total traffic diurnal distribution factors by functional class: rural area.

Hour Begins	Hour Ends	Weekday			Saturday			Sunday			Average Day		
		Interstate	Arterial	Collector	Interstate	Arterial	Collector	Interstate	Arterial	Collector	Interstate	Arterial	Collector
12:00 AM	12:59 AM	1.43	0.72	0.57	1.83	1.34	1.16	1.59	1.50	1.38	1.50	0.89	0.75
1:00 AM	1:59 AM	1.12	0.49	0.36	1.37	0.84	0.69	1.16	0.95	0.87	1.15	0.59	0.46
2:00 AM	2:59 AM	0.99	0.43	0.31	1.14	0.63	0.50	0.95	0.68	0.62	1.00	0.48	0.37
3:00 AM	3:59 AM	1.02	0.51	0.38	1.04	0.55	0.44	0.80	0.50	0.43	0.99	0.52	0.40
4:00 AM	4:59 AM	1.31	0.93	0.84	1.15	0.71	0.58	0.83	0.52	0.47	1.22	0.85	0.76
5:00 AM	5:59 AM	2.12	2.28	2.19	1.52	1.27	1.22	1.01	0.83	0.85	1.88	1.97	1.90
6:00 AM	6:59 AM	3.58	4.54	4.36	2.25	2.18	2.09	1.45	1.38	1.34	3.11	3.85	3.70
7:00 AM	7:59 AM	4.89	6.63	6.55	3.24	3.22	3.17	2.10	2.01	1.99	4.29	5.64	5.56
8:00 AM	8:59 AM	4.95	5.55	5.58	4.43	4.35	4.41	3.10	3.06	3.22	4.63	5.10	5.14
9:00 AM	9:59 AM	5.23	5.24	5.25	5.63	5.58	5.71	4.39	4.89	5.23	5.17	5.25	5.31
10:00 AM	10:59 AM	5.64	5.41	5.44	6.63	6.58	6.75	5.72	5.92	6.22	5.80	5.63	5.71
11:00 AM	11:59 AM	5.92	5.67	5.71	7.08	7.14	7.29	6.67	6.53	6.65	6.18	5.97	6.04
12:00 PM	12:59 PM	6.02	5.91	6.05	7.01	7.22	7.42	7.24	8.07	8.49	6.32	6.34	6.52
1:00 PM	1:59 PM	6.26	6.13	6.24	6.91	7.13	7.35	7.55	8.07	8.36	6.53	6.49	6.64
2:00 PM	2:59 PM	6.63	6.68	6.78	6.89	7.12	7.26	7.76	8.06	8.05	6.82	6.90	6.99
3:00 PM	3:59 PM	7.04	7.53	7.63	6.83	7.19	7.26	7.90	8.03	7.94	7.13	7.54	7.62
4:00 PM	4:59 PM	7.25	8.02	8.15	6.66	7.10	7.18	7.84	7.97	7.83	7.26	7.89	7.98
5:00 PM	5:59 PM	7.07	7.98	8.16	6.21	6.79	6.84	7.42	7.76	7.72	7.01	7.79	7.93
6:00 PM	6:59 PM	5.68	5.95	6.17	5.44	6.02	6.03	6.56	6.71	6.48	5.77	6.05	6.19
7:00 PM	7:59 PM	4.47	4.21	4.37	4.58	4.91	4.89	5.53	5.54	5.51	4.63	4.45	4.57
8:00 PM	8:59 PM	3.71	3.30	3.41	3.89	4.05	3.97	4.49	4.35	4.23	3.84	3.52	3.58
9:00 PM	9:59 PM	3.13	2.62	2.59	3.35	3.42	3.34	3.49	3.16	2.95	3.21	2.79	2.73
10:00 PM	10:59 PM	2.54	1.94	1.77	2.76	2.71	2.58	2.60	2.17	1.98	2.57	2.06	1.91
11:00 PM	11:59 PM	1.99	1.34	1.14	2.13	1.95	1.88	1.88	1.35	1.20	1.99	1.42	1.25

urban collector street located in a large urban area is approximately 5.92% of the daily traffic at the site. The hourly factor tables are presented in Tables 8-8 through 8-11.

It should be noted that the hourly factors in the tables below should not be considered as default. The appropriate use of factors from other urban areas has been a topic of much debate due to the potential disparity between the travel demand patterns at the data source area and the project in question. Factors based on local data are desirable in converting the daily volume into DHV (*110*, *112*, *113*, *114*, *115*, *116*).

8.6 Day-of-the-Week Factors and Monthly Factors

Applications including air quality conformity model, MOVES, need detailed volume distribution by day of the week and by month of the year. Using the same set of ATR data mentioned in Section 8.5 and applying the same grouping method, the day-of-the-week factor and monthly factor have been developed.

8.6.1 Day-of-the-Week Factors

Considering the fluctuation in daily traffic volume throughout a week, day-of-the-week adjustment factors are often developed from data gathered at permanent count stations. The day-of-the-week factor is defined as the ratio between the AADT and average daily volume. This enables the estimation of average daily volume for a given month and/or day of the week using the AADT output from a model. Table 8-12 shows the day-of-the-week factors for various facility types, locations, and area types. In addition to the factors for each day of the week, the combined Monday–Thursday factors (i.e., weekday factors) and Friday–Monday factors (i.e., weekend factors) are also presented.

Across all facility types and locations, Friday is the most heavily traveled day in the week, while Sunday is the least traveled day. Due to heavy commuter travel, the distinction in daily volume between weekdays and weekends is more significant on urban roads than on rural roads, especially for medium or large urban areas.

For example, Table 8-12 shows that the heaviest daily volume is generally observed on Fridays for a collector in a small urban area. If the forecasted AADT based on a travel demand model is 2,000 for such facility, its heaviest daily volume would be 2,000 ÷ 0.897 = 2,230. The peak-hour volume can then be estimated using the hourly factor for the same type of facility in the previous section.

8.6.2 Monthly Factors

Monthly factors are established to correct for bias in short-term counts that do not account for monthly (or seasonal) variation in daily traffic volume. Variation is defined as the ratio between AADT and monthly average daily volume. Table 8-13 shows the monthly factors developed from ATR data from several states mentioned previously.

Several observations can be derived from the data. First, average daily volumes are higher during the summer months (June–August) on rural freeways, while the monthly variation is less obvious on urban freeways, especially those located in medium or large urban areas. Meanwhile, lower functional class roadways such as collectors in urban areas are less traveled during the same period, particularly in June and July, than in the rest of the year. This could be the result of fewer school activities during these months.

For an illustration of the application of monthly factors, assume that a travel demand model generated a forecast of AADT of 46,000 for an arterial street located at the CBD of an urban area with a population of 300,000. According to Table 8-13, the June monthly factor is 1.033. The estimated daily volume for a typical day in June would then be 46,000 ÷ 1.033 = 44,530.

8.7 Vehicle Class Considerations

Percentage truck (and other heavy vehicles) using the roadway is the most critical factor in pavement design. Since the publication of the *Quick Response Freight Manual* (*69*) and *Quick Response Freight Manual II* (*10*), truck traffic forecasting has become more commonplace. Many metropolitan planning organization (MPO) travel demand models now have a truck module that generates future truck volumes on a link. For projects that are in the coverage of these models, forecasted truck traffic volume can directly be used.

For the projects that are not covered by a regional travel demand model with a freight component, the method described in *NCHRP Report 255* is still applicable. The procedure for predicting vehicle classification on a facility uses two major categories of data—base year and future year land uses and base year vehicle classification counts (*1*). The general steps are the following:

- **Step 1.** Select base year vehicle classification based on available data such as existing classification counts on the facility or on adjacent facilities (when the facility in question is new).
- **Step 2.** Compare base year and future land uses. Consider only land uses such as retail, industrial, and manufacturing that are expected to generate significant truck trips.

Table 8-12. Day-of-the-week factors.

		Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Mon-Thu	Weekday	Weekend
Rural	Interstate	1.079	1.090	1.032	0.985	0.875	1.041	1.060	1.046	1.012	1.051
	Arterial	1.013	1.000	0.984	0.955	0.875	1.071	1.268	0.988	0.965	1.169
	Collector	1.009	0.999	0.985	0.967	0.895	1.075	1.250	0.990	0.971	1.162
Urban - Small	Interstate	1.058	1.088	1.054	0.983	0.863	1.029	1.080	1.046	1.009	1.055
	Arterial	0.993	0.974	0.959	0.940	0.879	1.135	1.384	0.966	0.949	1.259
	Collector	0.962	0.956	0.927	0.937	0.897	1.167	1.422	0.946	0.936	1.294
Urban - Medium	Interstate	0.997	0.974	0.948	0.929	0.881	1.151	1.341	0.962	0.946	1.246
	Arterial - CBD	0.997	0.967	0.950	0.939	0.879	1.113	1.432	0.964	0.947	1.273
	Arterial - Other	1.000	0.975	0.952	0.943	0.880	1.079	1.376	0.967	0.950	1.228
	Collector	0.994	0.959	0.939	0.934	0.912	1.173	1.410	0.971	0.963	1.292
Urban - Large	Interstate	1.002	0.970	0.943	0.938	0.893	1.140	1.321	0.964	0.950	1.231
	Arterial - CBD	0.985	0.948	0.935	0.931	0.909	1.155	1.456	0.950	0.942	1.305
	Arterial - Other	0.997	0.960	0.943	0.938	0.892	1.092	1.368	0.960	0.948	1.234
	Collector	0.984	0.951	0.934	0.976	0.874	1.145	1.387	0.965	0.947	1.266

Table 8-13. Monthly factors.

		January	February	March	April	May	June	July	August	September	October	November	December
Rural	Interstate	1.144	1.103	0.985	1.002	1.005	0.946	0.935	0.985	1.054	1.011	1.002	1.056
	Arterial	1.127	1.052	0.982	0.981	0.987	0.989	1.008	0.999	1.018	0.998	1.022	1.090
	Collector	1.092	1.038	0.964	0.970	0.980	0.992	1.034	1.017	1.030	1.001	1.031	1.113
Urban - Small	Interstate	1.125	1.075	0.968	0.987	1.020	0.982	0.969	1.011	1.074	1.028	0.982	1.026
	Arterial	1.107	1.027	0.982	0.995	0.988	1.023	1.057	1.001	1.033	1.033	1.077	1.113
	Collector	1.161	1.137	0.951	0.999	1.037	0.962	1.012	0.946	0.993	1.023	1.039	1.148
Urban - Medium	Interstate	1.088	1.051	0.999	1.023	1.022	1.001	1.011	1.015	1.060	1.018	1.017	1.053
	Arterial - CBD	1.124	1.010	0.959	0.987	1.044	1.033	1.099	1.014	1.060	0.992	1.075	1.102
	Arterial - Other	1.084	1.015	0.981	1.011	1.017	1.009	1.035	1.017	1.048	1.029	1.039	1.051
	Collector	1.011	0.931	0.929	0.941	1.010	1.107	1.174	1.164	1.179	1.093	1.051	1.055
Urban - Large	Interstate	1.097	1.051	0.982	0.997	1.012	1.012	1.048	1.015	1.032	1.004	1.017	1.068
	Arterial - CBD	1.054	0.970	0.980	1.007	1.033	1.065	1.081	1.056	1.058	1.056	1.077	1.060
	Arterial - Other	1.078	1.023	0.984	0.994	0.989	0.998	1.043	1.025	1.032	1.013	1.049	1.072
	Collector	1.066	1.018	0.966	0.972	0.999	1.051	1.090	1.086	1.107	1.043	1.014	1.001

- **Step 3.** Estimate the future year vehicle classification. Analyst judgment is needed in determining whether to adjust base year classification to account for changes in land use.

Following Step 3, the analyst can use classification counts from over 400 ATR stations located in Florida, Ohio, Kentucky, and Texas developed as part of this research, to analyze the hourly, daily, and monthly volume variations for different types of vehicles and to develop the temporal distribution factors for different vehicle classes. The vehicle types considered in this research were passenger cars (FHWA Classes 1–3), single unit trucks (FHWA Classes 4–7), and combination trucks (FHWA Classes 8–15). The roadways were categorized as freeways and non-freeways (i.e., surface streets) and further stratified by their location in urban or rural area.

8.7.1 Hourly Distribution

Table 8-14 shows the hourly factors by vehicle type on each roadway category—rural freeway, rural non-freeway, urban freeway, and urban non-freeway. The hourly factor for a vehicle type is defined as the ratio between the hourly volume and the daily volume of that vehicle type. For example, in Table 8-14 (a), the single unit truck volume on a typical rural freeway segment from 10 AM to 11 AM, accounts for 6.5% of its daily volume.

Figure 8-17 shows the hourly distribution by vehicle type on freeways and Figure 8-18 shows hourly distribution by vehicle type on non-freeways. On urban freeways, passenger car volume displays two distinct peaks during a typical day, while on rural freeways there is a clear PM peak. On the other hand, compared to passenger cars, the combination truck volume has a less significant variation throughout the day on freeways in both urban and rural areas. Its hourly factors range from 0.022 to 0.057 on rural freeways, and from 0.017 to 0.061 on urban freeways. On surface streets, passenger car distribution shows a clear PM peak, while truck traffic shows a more uniformed distribution throughout the daytime business hours.

In addition to the hourly distribution of vehicles presented in Table 8-15, vehicle composition in each hour is also developed based on the same set of data.

Table 8-15 shows the hourly vehicle type composition by rural freeway, rural non-freeway, urban freeway and urban non-freeway. For example, in the early morning hours, combination trucks may account for 40% to 50% of the hourly volumes on rural freeways. From 3 AM to 4 AM, combination trucks account for 49.8% of the hourly traffic, while passenger cars account for 46.2%, and single unit trucks account for 4%. However, on urban freeways, passenger car remains the dominant vehicle type, and the highest share of the hourly volume for combination trucks occurs from 3 AM to 4 AM at 28.8%.

8.7.2 Monthly and Day-of-the-Week Distribution

The monthly and day-of-the-week factors classified by vehicle type are established to correct the daily and seasonal bias associated with short-term counts. The monthly factor is defined as the ratio between the AADT and average daily volume for the month for a given vehicle type. Due to significant variation of volume among different days of a week, the monthly distribution is developed for different days of a week. The day-of-the-week factor is defined as the ratio of AADT to the average daily volume for a vehicle type on a given day of a week. The monthly and day-of-the-week distribution of vehicle volume by vehicle type is shown in Table 8-16 for all classes of highways.

From the perspective of daily fluctuation, passenger car volume has a much smaller day-to-day variation than trucks. The range of the day-of-the-week factor for passenger cars is a lot narrower than it is for trucks. On the same facility, single unit trucks appear to have more significant variation than combination trucks in daily volume. On rural freeways, combination truck volume shows the least day-to-day variation compared to that on other facilities. This is consistent with the observation of a large share of intercity freight truck traffic on rural Interstates. Friday appears to be the most heavily traveled day for passenger cars across all facility types. Sunday is the least traveled day for all vehicle and facility types except for cars on rural freeways.

From the perspective of monthly variation, all types of vehicles seem to travel more during the summer months on rural freeways, especially passenger cars. However, this is less obvious for trucks and for all vehicle types on non-freeway facilities in a rural setting and on all roads in an urban setting. Overall, the seasonal variation of truck traffic does not appear to be significant.

Tables showing the hourly, day of week, and monthly distributions by vehicle types can be generated with ATR data collected by individual states, local agencies, or MPOs. Care should be taken to account for adequate sample sizes in each facility type and area type category.

Table 8-14. Ratio of hourly volume to daily volume by vehicle type.

(a) Rural freeway

Hour	Hourly Volume to Daily Volume Ratio		
	Car	Single Unit Truck	Combination Truck
0	0.012	0.015	0.026
1	0.008	0.013	0.023
2	0.007	0.012	0.022
3	0.006	0.012	0.022
4	0.008	0.015	0.024
5	0.014	0.022	0.027
6	0.026	0.035	0.032
7	0.039	0.043	0.037
8	0.046	0.055	0.043
9	0.052	0.062	0.049
10	0.060	0.065	0.054
11	0.065	0.067	0.057
12	0.067	0.067	0.056
13	0.070	0.069	0.057
14	0.073	0.069	0.057
15	0.077	0.068	0.057
16	0.079	0.065	0.056
17	0.075	0.058	0.053
18	0.060	0.048	0.050
19	0.047	0.040	0.047
20	0.038	0.032	0.043
21	0.031	0.027	0.040
22	0.023	0.022	0.036
23	0.017	0.018	0.031

(b) Rural non-freeway

Hour	Hourly Volume to Daily Volume Ratio		
	Car	Single Unit Truck	Combination Truck
0	0.008	0.008	0.013
1	0.005	0.007	0.013
2	0.004	0.007	0.013
3	0.005	0.009	0.015
4	0.008	0.015	0.021
5	0.021	0.027	0.030
6	0.039	0.051	0.041
7	0.054	0.061	0.050
8	0.050	0.069	0.059
9	0.053	0.071	0.067
10	0.057	0.072	0.071
11	0.060	0.073	0.072
12	0.064	0.073	0.070
13	0.066	0.073	0.068
14	0.070	0.074	0.067
15	0.077	0.075	0.064
16	0.080	0.067	0.058
17	0.079	0.053	0.050
18	0.060	0.036	0.040
19	0.044	0.026	0.032
20	0.035	0.019	0.027
21	0.028	0.015	0.023
22	0.020	0.012	0.019
23	0.014	0.009	0.016

Table 8-14. (Continued).

(c) Urban freeway

Hour	Hourly Volume to Daily Volume Ratio		
	Car	Single Unit Truck	Combination Truck
0	0.011	0.009	0.021
1	0.007	0.008	0.018
2	0.006	0.008	0.017
3	0.005	0.009	0.019
4	0.008	0.013	0.023
5	0.020	0.026	0.030
6	0.043	0.049	0.039
7	0.063	0.062	0.047
8	0.055	0.069	0.055
9	0.049	0.070	0.059
10	0.051	0.070	0.061
11	0.054	0.071	0.062
12	0.057	0.070	0.061
13	0.059	0.073	0.061
14	0.064	0.074	0.060
15	0.072	0.071	0.058
16	0.078	0.065	0.055
17	0.082	0.052	0.051
18	0.062	0.039	0.045
19	0.045	0.028	0.039
20	0.036	0.021	0.034
21	0.030	0.017	0.031
22	0.024	0.014	0.028
23	0.017	0.011	0.024

(d) Urban non-freeway

Hour	Hourly Volume to Daily Volume Ratio		
	Car	Single Unit Truck	Combination Truck
0	0.009	0.006	0.012
1	0.005	0.005	0.011
2	0.004	0.005	0.010
3	0.004	0.007	0.013
4	0.007	0.010	0.017
5	0.017	0.023	0.026
6	0.035	0.048	0.041
7	0.051	0.069	0.058
8	0.050	0.077	0.066
9	0.051	0.078	0.070
10	0.057	0.080	0.072
11	0.064	0.079	0.073
12	0.068	0.076	0.072
13	0.068	0.075	0.071
14	0.071	0.078	0.069
15	0.078	0.072	0.065
16	0.079	0.060	0.058
17	0.077	0.045	0.048
18	0.061	0.033	0.038
19	0.047	0.023	0.031
20	0.037	0.018	0.026
21	0.028	0.014	0.022
22	0.020	0.010	0.017
23	0.013	0.008	0.014

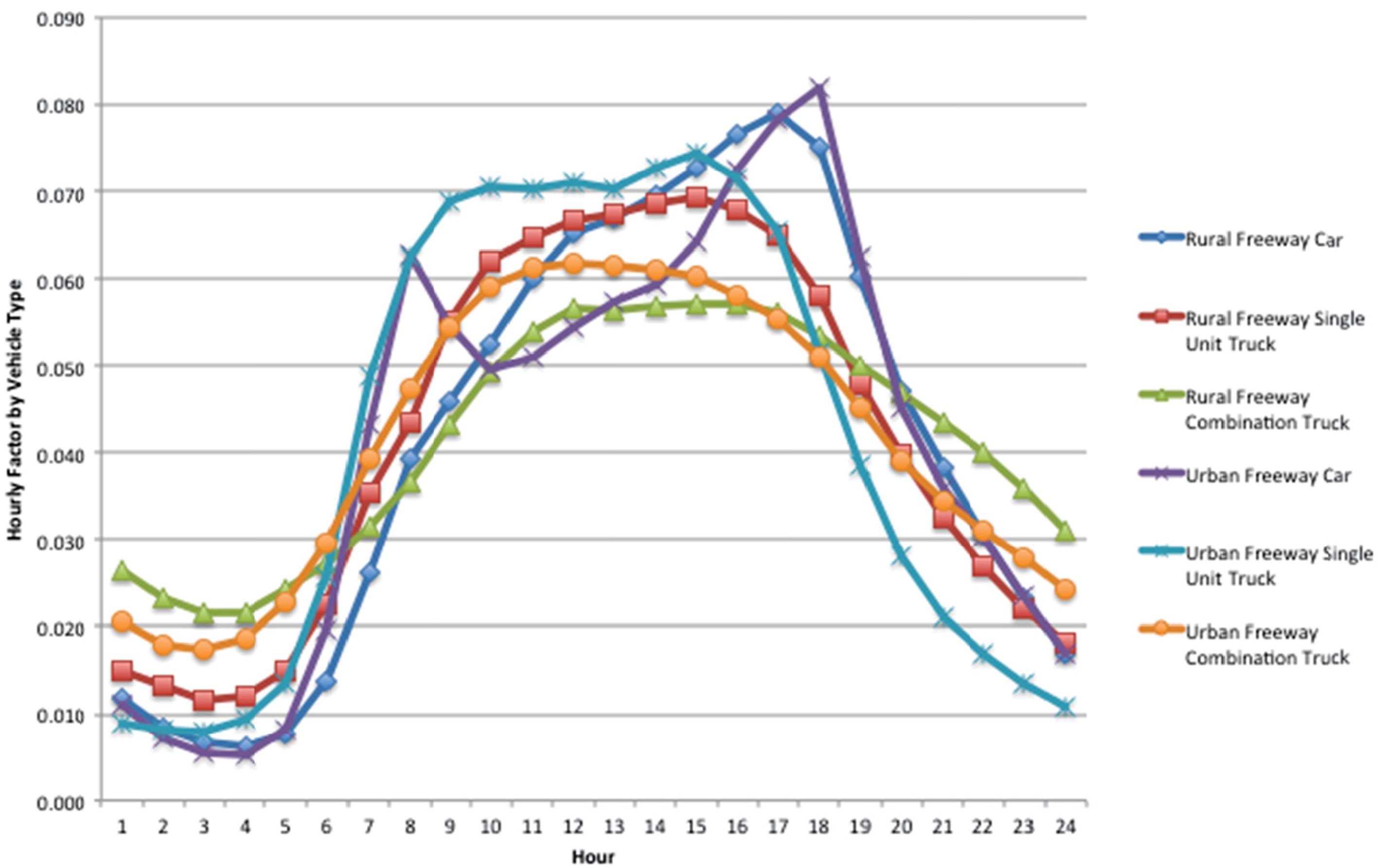


Figure 8-17. Freeway hourly factor distribution comparison.

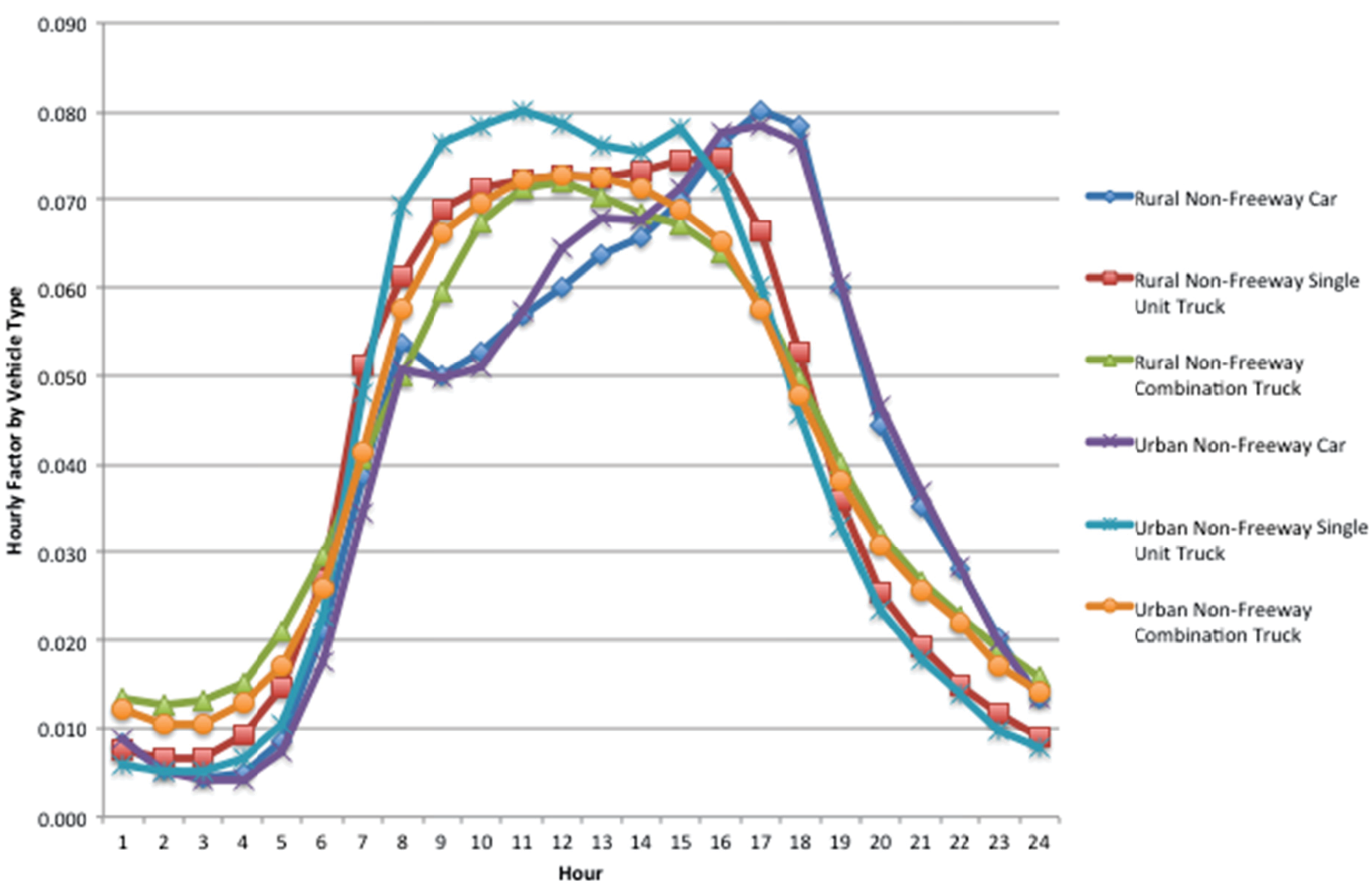


Figure 8-18. Non-freeway hourly factor distribution comparison.

Table 8-15. Vehicle composition by hour.

(a) Rural freeway

Hour	Percentage Vehicle Type by Hour		
	Car	Single Unit Truck	Combination Truck
0	0.564	0.030	0.405
1	0.515	0.035	0.450
2	0.481	0.036	0.483
3	0.462	0.040	0.498
4	0.484	0.042	0.473
5	0.582	0.041	0.377
6	0.671	0.039	0.290
7	0.716	0.034	0.250
8	0.723	0.037	0.240
9	0.728	0.037	0.236
10	0.739	0.034	0.227
11	0.746	0.032	0.222
12	0.749	0.032	0.219
13	0.754	0.031	0.215
14	0.761	0.031	0.208
15	0.769	0.029	0.202
16	0.775	0.027	0.198
17	0.772	0.025	0.203
18	0.751	0.025	0.225
19	0.723	0.025	0.252
20	0.702	0.024	0.274
21	0.676	0.024	0.300
22	0.644	0.025	0.331
23	0.609	0.027	0.363

(b) Rural non-freeway

Hour	Percentage Vehicle Type by Hour		
	Car	Single Unit Truck	Combination Truck
0	0.836	0.029	0.133
1	0.785	0.037	0.176
2	0.743	0.044	0.211
3	0.721	0.052	0.225
4	0.758	0.050	0.190
5	0.829	0.044	0.125
6	0.863	0.045	0.091
7	0.880	0.039	0.079
8	0.859	0.045	0.094
9	0.853	0.044	0.100
10	0.857	0.042	0.100
11	0.861	0.040	0.096
12	0.869	0.038	0.091
13	0.874	0.038	0.086
14	0.882	0.036	0.081
15	0.894	0.033	0.071
16	0.906	0.029	0.063
17	0.916	0.025	0.058
18	0.913	0.023	0.062
19	0.909	0.022	0.068
20	0.905	0.021	0.072
21	0.901	0.020	0.078
22	0.890	0.021	0.088
23	0.870	0.024	0.105

Table 8-15. (Continued).

(c) Urban freeway

Hour	Percentage Vehicle Type by Hour		
	Car	Single Unit Truck	Combination Truck
0	0.783	0.019	0.194
1	0.734	0.025	0.237
2	0.699	0.029	0.268
3	0.671	0.036	0.288
4	0.720	0.037	0.237
5	0.809	0.036	0.150
6	0.865	0.033	0.097
7	0.881	0.029	0.085
8	0.853	0.033	0.109
9	0.836	0.036	0.123
10	0.838	0.035	0.123
11	0.845	0.033	0.117
12	0.851	0.032	0.112
13	0.855	0.032	0.109
14	0.864	0.031	0.101
15	0.877	0.027	0.091
16	0.888	0.024	0.084
17	0.899	0.019	0.078
18	0.887	0.018	0.091
19	0.871	0.017	0.107
20	0.862	0.016	0.118
21	0.854	0.015	0.126
22	0.839	0.015	0.142
23	0.818	0.016	0.163

(d) Urban non-freeway

Hour	Percentage Vehicle Type by Hour		
	Car	Single Unit Truck	Combination Truck
0	0.931	0.017	0.052
1	0.904	0.024	0.073
2	0.884	0.028	0.089
3	0.869	0.035	0.096
4	0.893	0.032	0.075
5	0.917	0.032	0.051
6	0.929	0.033	0.038
7	0.933	0.033	0.034
8	0.925	0.036	0.040
9	0.924	0.035	0.041
10	0.929	0.033	0.039
11	0.935	0.029	0.036
12	0.938	0.028	0.034
13	0.939	0.027	0.034
14	0.943	0.026	0.031
15	0.950	0.022	0.028
16	0.956	0.019	0.025
17	0.963	0.015	0.022
18	0.962	0.014	0.023
19	0.961	0.014	0.025
20	0.960	0.013	0.027
21	0.956	0.014	0.031
22	0.951	0.014	0.035
23	0.940	0.017	0.043

Table 8-16. Day-of-the-week and monthly variation of volume by vehicle class.
(a) Rural freeway

	Month of Year	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Mon-Thu	Weekday	Weekend	Monthly
Passenger Car	January	1.359	1.509	1.446	1.295	1.013	1.103	1.140	1.399	1.238	1.122	1.266
	February	1.267	1.434	1.394	1.223	0.979	1.102	1.116	1.329	1.258	1.112	1.217
	March	1.166	1.249	1.188	1.114	0.903	0.934	0.903	1.183	1.126	0.921	1.065
	April	1.186	1.290	1.217	1.111	0.892	1.013	0.964	1.201	1.140	0.987	1.096
	May	1.047	1.260	1.230	1.077	0.851	0.941	0.933	1.153	1.093	0.939	1.049
	June	1.050	1.145	1.089	0.990	0.812	0.846	0.823	1.067	1.016	0.837	0.965
	July	0.966	1.076	1.050	0.913	0.748	0.813	0.788	0.985	0.935	0.803	0.908
	August	1.099	1.208	1.141	1.038	0.839	0.900	0.881	1.123	1.066	0.892	1.015
	September	1.086	1.310	1.313	1.169	0.913	1.024	0.994	1.219	1.158	1.009	1.116
	October	1.153	1.250	1.185	1.085	0.853	0.986	0.905	1.170	1.107	0.948	1.060
	November	1.167	1.142	0.942	1.115	0.916	0.837	0.775	1.092	1.047	0.807	0.985
	December	1.073	1.064	1.001	1.073	0.968	1.009	1.048	1.049	1.040	1.031	1.034
	Weekly	1.135	1.245	1.183	1.100	0.891	0.959	0.939	1.095	1.048	1.015	

	Month of Year	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Mon-Thu	Weekday	Weekend	Monthly
Single Unit Trucks	January	1.360	1.234	1.134	1.206	1.033	1.665	2.055	1.238	1.062	1.862	1.384
	February	1.179	1.064	1.081	0.990	1.018	1.469	1.848	1.078	1.066	1.664	1.236
	March	1.075	0.970	0.969	0.961	1.033	1.452	1.697	0.996	1.003	1.579	1.165
	April	1.035	0.963	0.916	0.946	0.938	1.400	1.647	0.966	0.961	1.524	1.121
	May	1.072	0.987	0.942	0.908	0.890	1.331	1.593	0.979	0.961	1.468	1.103
	June	0.921	0.907	0.885	0.855	0.845	1.226	1.381	0.891	0.882	1.307	1.003
	July	1.004	0.905	0.930	0.856	0.847	1.253	1.432	0.904	0.897	1.333	1.032
	August	1.004	0.984	0.938	0.918	0.915	1.327	1.489	0.962	0.953	1.410	1.082
	September	1.104	1.004	0.978	0.920	0.913	1.335	1.607	1.001	0.983	1.471	1.123
	October	0.967	0.987	0.907	0.864	0.918	1.306	1.504	0.932	0.930	1.409	1.065
	November	0.998	0.923	0.933	1.146	0.885	1.211	1.465	1.003	0.881	1.340	1.080
	December	1.079	0.987	0.892	0.971	1.002	1.614	1.834	0.945	0.962	1.731	1.197
	Weekly	1.067	0.993	0.959	0.962	0.937	1.382	1.629	0.941	0.924	1.570	

	Month of Year	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Mon-Thu	Weekday	Weekend	Monthly
Combination Trucks	January	1.253	0.989	0.841	0.908	1.061	1.415	1.551	1.002	1.026	1.486	1.146
	February	1.099	0.903	0.808	0.827	0.913	1.238	1.346	0.909	0.908	1.299	1.019
	March	1.116	0.908	0.810	0.854	1.015	1.355	1.385	0.924	0.942	1.385	1.063
	April	1.108	0.925	0.806	0.868	0.956	1.380	1.483	0.928	0.934	1.430	1.075
	May	1.145	0.969	0.833	0.859	0.955	1.325	1.503	0.953	0.954	1.420	1.084
	June	1.081	0.932	0.820	0.860	0.944	1.301	1.413	0.923	0.927	1.362	1.050
	July	1.194	0.971	0.876	0.899	0.993	1.406	1.523	0.966	0.978	1.465	1.123
	August	1.136	0.972	0.854	0.888	0.998	1.416	1.468	0.963	0.970	1.446	1.105
	September	1.170	1.017	0.874	0.880	0.971	1.389	1.543	0.984	0.981	1.466	1.120
	October	1.075	0.920	0.824	0.845	0.952	1.340	1.463	0.917	0.926	1.411	1.060
	November	1.131	0.955	0.869	1.016	1.135	1.466	1.500	0.997	1.060	1.487	1.153
	December	1.206	0.989	1.668	1.030	1.105	1.741	1.625	1.425	1.310	1.692	1.337
	Weekly	1.143	0.954	0.907	0.895	1.000	1.398	1.483	0.974	0.972	1.563	

Table 8-16. (continued)
(b) Rural non-freeway

	Month of Year	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Mon-Thu	Weekday	Weekend	Monthly
Passenger Car	January	1.136	1.148	1.123	1.103	1.047	1.275	1.452	1.127	1.112	1.365	1.183
	February	1.077	1.104	1.091	1.022	0.905	1.086	1.251	1.074	1.040	1.169	1.076
	March	1.037	1.031	1.022	0.980	0.871	1.006	1.190	1.019	0.990	1.098	1.019
	April	1.022	1.038	1.032	0.961	0.861	1.004	1.135	1.013	0.983	1.070	1.007
	May	1.040	1.040	1.026	0.970	0.848	0.998	1.159	1.017	0.984	1.079	1.012
	June	1.026	1.027	1.008	0.968	0.861	0.973	1.118	1.007	0.979	1.046	0.997
	July	0.999	0.982	0.983	0.927	0.834	0.958	1.103	0.972	0.945	1.030	0.969
	August	1.029	1.036	1.019	0.975	0.856	0.983	1.144	1.017	0.984	1.062	1.006
	September	1.072	1.041	1.042	0.978	0.851	0.991	1.172	1.033	0.998	1.082	1.021
	October	1.045	1.047	1.034	0.986	0.850	0.991	1.158	1.029	0.993	1.075	1.016
	November	1.062	1.035	0.989	1.021	0.903	1.040	1.202	1.028	1.003	1.122	1.036
	December	1.084	1.070	1.035	1.015	0.939	1.092	1.320	1.051	1.029	1.207	1.079
	Weekly	1.052	1.050	1.034	0.992	0.886	1.033	1.200	1.029	1.000	1.114	
Single Unit Trucks	Month of Year	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Mon-Thu	Weekday	Weekend	Monthly
	January	0.983	0.910	0.895	0.885	1.000	2.460	4.363	0.920	0.936	3.418	1.643
	February	0.971	0.888	0.953	0.901	0.877	2.069	3.710	0.929	0.918	2.894	1.481
	March	0.879	0.829	0.822	0.823	0.870	2.051	3.411	0.839	0.846	2.733	1.384
	April	0.799	0.768	0.771	0.761	0.827	2.277	3.185	0.775	0.785	2.743	1.341
	May	1.032	0.805	0.794	0.752	0.778	1.900	3.219	0.861	0.847	2.562	1.326
	June	0.864	0.821	0.817	0.820	0.853	1.929	3.020	0.834	0.840	2.458	1.303
	July	0.936	0.839	0.859	0.819	0.899	1.925	2.827	0.863	0.870	2.373	1.301
	August	0.874	0.843	0.873	0.821	0.846	1.948	3.337	0.855	0.853	2.627	1.363
	September	1.060	0.834	0.817	0.786	0.912	1.909	3.118	0.876	0.885	2.512	1.348
	October	0.829	0.802	0.806	0.784	0.806	1.855	2.867	0.806	0.806	2.373	1.250
	November	0.850	0.818	0.833	0.985	0.942	2.098	3.439	0.873	0.887	2.764	1.424
	December	1.032	0.978	0.927	0.945	1.039	2.442	4.247	0.976	0.989	3.345	1.659
	Weekly	0.926	0.845	0.847	0.840	0.888	2.072	3.395	0.866	0.870	2.726	
Combination Trucks	Month of Year	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Mon-Thu	Weekday	Weekend	Monthly
	January	0.995	0.912	0.871	0.891	1.051	2.519	3.428	0.920	0.947	2.978	1.524
	February	1.299	1.004	1.054	1.165	0.959	2.156	3.069	1.129	1.094	2.610	1.529
	March	0.891	0.852	0.836	0.842	0.942	2.013	2.785	0.855	0.873	2.391	1.309
	April	0.833	0.797	0.807	0.782	0.845	2.826	2.268	0.806	0.815	2.547	1.308
	May	1.016	0.839	0.820	0.808	0.876	1.878	2.435	0.874	0.874	2.148	1.239
	June	0.855	0.801	0.824	0.799	0.844	1.734	2.135	0.822	0.826	1.934	1.142
	July	0.946	0.821	0.848	0.820	0.872	1.827	2.256	0.858	0.862	2.040	1.199
	August	0.914	0.861	0.864	0.851	0.891	1.870	2.207	0.876	0.879	2.038	1.208
	September	1.023	0.813	0.806	0.772	0.854	1.702	2.300	0.857	0.859	1.986	1.181
	October	0.817	0.786	0.760	0.758	0.816	1.731	2.158	0.782	0.789	1.945	1.118
	November	0.793	0.749	0.750	0.889	0.877	1.718	2.233	0.797	0.813	1.977	1.144
	December	1.174	1.059	0.961	1.013	1.167	2.575	3.435	1.060	1.082	3.011	1.626
	Weekly	0.963	0.858	0.850	0.866	0.916	2.046	2.559	0.866	0.875	2.266	

(c) Urban freeway

	Month of Year	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Mon-Thu	Weekday	Weekend	Monthly
Passenger Car	January	1.096	1.107	1.073	1.056	0.975	1.198	1.435	1.083	1.062	1.312	1.134
	February	1.001	1.045	1.011	0.951	0.876	1.125	1.319	1.009	0.984	1.221	1.047
	March	1.017	1.009	0.996	0.974	0.906	1.091	1.261	1.000	0.982	1.176	1.036
	April	1.026	1.033	1.016	0.972	0.912	1.138	1.293	1.014	0.994	1.214	1.056
	May	1.045	1.043	1.024	0.970	0.881	1.108	1.263	1.018	0.991	1.185	1.048
	June	1.011	1.015	0.997	0.960	0.884	1.092	1.253	0.996	0.972	1.168	1.030
	July	0.967	0.958	0.968	0.911	0.861	1.065	1.212	0.955	0.936	1.137	0.992
	August	1.014	1.017	0.987	0.965	0.870	1.082	1.251	0.997	0.973	1.166	1.027
	September	1.075	1.044	1.038	0.994	0.902	1.155	1.328	1.038	1.011	1.241	1.077
	October	1.017	1.024	1.005	0.965	0.884	1.123	1.264	1.003	0.979	1.194	1.040
	November	1.009	0.983	0.938	1.014	0.926	1.114	1.232	0.987	0.975	1.172	1.031
	December	1.036	1.028	0.980	0.979	0.930	1.131	1.349	1.006	0.991	1.239	1.062
	Weekly	1.026	1.026	1.003	0.976	0.901	1.118	1.288	1.011	0.990	1.179	

	Month of Year	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Mon-Thu	Weekday	Weekend	Monthly
Single Unit Trucks	January	1.003	0.947	0.893	0.900	0.924	2.050	3.635	0.937	0.935	2.829	1.479
	February	0.886	0.871	0.848	0.824	0.821	1.790	3.103	0.864	0.856	2.441	1.306
	March	0.911	0.863	0.859	0.851	0.871	1.904	3.113	0.872	0.872	2.508	1.339
	April	0.887	0.863	0.854	0.830	0.870	1.919	3.248	0.862	0.865	2.578	1.353
	May	1.006	0.847	0.833	0.802	0.796	1.804	3.145	0.872	0.858	2.466	1.319
	June	0.864	0.843	0.848	0.824	0.824	1.796	3.058	0.844	0.840	2.402	1.294
	July	0.895	0.812	0.859	0.798	0.842	1.820	2.897	0.846	0.848	2.352	1.275
	August	0.882	0.861	0.841	0.836	0.826	1.765	2.957	0.857	0.852	2.357	1.281
	September	1.047	0.866	0.858	0.825	0.829	1.806	3.155	0.897	0.883	2.477	1.341
	October	0.866	0.843	0.831	0.812	0.823	1.768	2.904	0.837	0.834	2.337	1.264
	November	0.868	0.828	0.842	1.024	0.906	1.827	3.001	0.891	0.893	2.413	1.328
	December	1.002	0.966	0.911	0.949	0.996	2.060	3.532	0.959	0.967	2.792	1.488
	Weekly	0.926	0.868	0.857	0.856	0.861	1.859	3.146	0.879	0.875	2.508	

	Month of Year	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Mon-Thu	Weekday	Weekend	Monthly
Combination Trucks	January	1.073	0.948	0.880	0.897	0.978	1.849	2.361	0.951	0.957	2.095	1.284
	February	0.982	0.877	0.810	0.816	0.883	1.590	1.963	0.877	0.879	1.775	1.132
	March	0.996	0.862	0.824	0.856	0.940	1.670	2.031	0.885	0.896	1.849	1.168
	April	1.007	0.892	0.843	0.863	0.953	1.743	2.166	0.904	0.915	1.953	1.209
	May	1.094	0.907	0.837	0.843	0.906	1.640	2.166	0.923	0.921	1.905	1.199
	June	1.014	0.895	0.853	0.862	0.925	1.646	2.128	0.906	0.910	1.871	1.189
	July	1.030	0.882	0.855	0.853	0.926	1.626	2.037	0.908	0.915	1.828	1.173
	August	1.014	0.900	0.843	0.864	0.919	1.647	2.041	0.907	0.911	1.844	1.175
	September	1.131	0.935	0.863	0.868	0.933	1.715	2.217	0.946	0.942	1.965	1.237
	October	0.985	0.892	0.848	0.861	0.903	1.692	2.092	0.894	0.896	1.892	1.182
	November	0.981	0.867	0.838	0.992	1.018	1.729	2.023	0.919	0.939	1.875	1.207
	December	1.114	0.967	0.880	0.937	1.042	1.845	2.291	0.978	0.992	2.066	1.296
	Weekly	1.035	0.902	0.848	0.876	0.944	1.699	2.126	0.913	0.919	1.935	

Table 8-16. (continued)
(d) Urban non-freeway

	PassengerCar	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Mon-Thu	Weekday	Weekend	Monthly
Passenger Car	January	1.113	1.099	1.072	1.067	1.002	1.195	1.495	1.091	1.074	1.347	1.149
	February	1.001	1.021	0.996	0.955	0.889	1.082	1.303	0.994	0.973	1.193	1.035
	March	0.992	0.985	0.983	0.954	0.880	1.085	1.364	0.979	0.960	1.226	1.035
	April	0.995	0.988	0.978	0.944	0.876	1.060	1.274	0.976	0.957	1.167	1.016
	May	1.001	0.961	0.959	0.920	0.844	1.018	1.203	0.960	0.937	1.111	0.987
	June	0.973	0.968	0.960	0.926	0.863	1.061	1.271	0.958	0.939	1.165	1.003
	July	0.997	0.972	0.971	0.926	0.875	1.067	1.253	0.966	0.949	1.161	1.008
	August	0.991	0.993	0.979	0.951	0.878	1.077	1.287	0.977	0.957	1.181	1.022
	September	1.063	0.996	0.987	0.961	0.876	1.090	1.311	1.003	0.978	1.202	1.041
	October	1.010	1.005	0.992	0.962	0.880	1.078	1.315	0.994	0.970	1.197	1.034
	November	1.023	1.005	0.980	1.066	0.932	1.127	1.362	1.019	1.002	1.246	1.071
	December	1.057	1.063	1.012	1.019	0.989	1.167	1.412	1.038	1.029	1.291	1.103
	Weekly	1.018	1.005	0.989	0.971	0.899	1.092	1.321	0.986	0.967	1.217	

	Month of Year	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Mon-Thu	Weekday	Weekend	Monthly
Single Unit Trucks	January	1.028	0.914	0.887	0.916	0.964	2.424	5.362	0.942	0.947	3.898	1.785
	February	0.890	0.868	0.859	0.816	0.841	2.095	4.525	0.859	0.856	3.311	1.556
	March	0.878	0.843	0.898	0.834	0.830	2.031	4.110	0.864	0.857	3.074	1.489
	April	0.869	0.802	0.793	0.799	0.834	2.136	4.493	0.814	0.818	3.305	1.532
	May	0.974	0.887	0.823	0.788	0.783	1.994	3.809	0.875	0.855	2.902	1.437
	June	0.849	0.843	0.839	0.823	0.821	1.815	3.234	0.838	0.835	2.501	1.318
	July	0.897	0.818	0.859	0.795	0.835	1.905	3.554	0.843	0.843	2.728	1.380
	August	0.850	0.836	0.846	0.829	0.814	1.907	3.717	0.840	0.835	2.809	1.400
	September	0.982	0.789	0.784	0.761	0.780	1.929	3.808	0.833	0.823	2.869	1.405
	October	0.830	0.803	0.806	0.775	0.773	2.004	4.012	0.806	0.798	3.007	1.429
	November	0.855	0.811	0.848	0.987	0.890	2.149	4.552	0.878	0.881	3.350	1.585
	December	0.973	1.077	0.924	0.958	1.061	3.028	4.851	0.986	1.002	3.940	1.839
	Weekly	0.906	0.858	0.847	0.840	0.852	2.118	4.169	0.864	0.859	2.876	

	Month of Year	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Mon-Thu	Weekday	Weekend	Monthly
Combination Trucks	January	1.191	1.039	1.052	1.086	1.123	2.739	4.495	1.096	1.102	3.627	1.818
	February	1.057	0.959	0.985	0.967	0.944	2.627	3.539	0.993	0.983	3.093	1.582
	March	0.971	0.890	0.933	0.925	0.925	2.345	3.162	0.930	0.929	2.756	1.450
	April	0.943	0.849	0.833	0.811	0.830	1.845	2.773	0.861	0.856	2.310	1.269
	May	1.012	0.929	0.867	0.820	0.803	1.932	2.798	0.910	0.889	2.368	1.309
	June	0.839	0.818	0.833	0.795	0.800	1.743	2.370	0.823	0.818	2.060	1.171
	July	0.983	0.855	0.911	0.842	0.865	1.804	2.648	0.897	0.892	2.229	1.273
	August	0.994	0.908	0.928	0.906	0.872	1.923	2.850	0.937	0.923	2.388	1.340
	September	1.123	0.919	0.934	0.883	0.916	2.063	3.212	0.967	0.957	2.638	1.436
	October	1.037	0.944	0.951	0.938	0.910	2.055	2.893	0.967	0.955	2.465	1.390
	November	1.069	0.955	1.012	1.173	1.074	2.258	3.549	1.054	1.058	2.902	1.584
	December	1.263	1.301	1.139	1.201	1.321	3.091	4.408	1.230	1.249	3.757	1.960
	Weekly	1.040	0.947	0.948	0.946	0.948	2.202	3.225	0.931	0.930	2.606	

CHAPTER 9

Traffic Forecasting Methods for Special Purpose Applications

This chapter covers special purpose applications of traffic forecasting beyond the basics of traffic forecasting that are primarily based on traffic volumes. This chapter includes the following:

- Basic highway design traffic forecasting products;
- Interpolation of traffic forecasts;
- Improving the vehicle mix accuracy of forecasts or data extrapolations;
- Special needs of ESALs;
- Special needs of benefit-cost analysis;
- Special needs of toll/revenue forecasts;
- Special needs of work zone congestion: diversion and delay forecasts;
- Special needs of environmental justice; and
- Special needs of traffic impact studies.

9.1 Basic Highway Design Traffic Forecasting Products

The AASHTO Green Book (*121*), which can be considered the "Bible" of highway design, considers traffic one of the basic design controls, similar to financing, right-of-way availability, and materials. The Green Book states: "Traffic volumes can indicate the need for the improvement and directly influence the selection of geometric design features, such as number of lanes, widths, alignments and grades."

Most basic traffic forecasts contain several elements that are all traffic volume based: average daily traffic, peak-hour traffic, directional distribution, and composition of traffic. The Green Book has an excellent section on these basic elements that has guided designers for several generations (*123*, pp. 56–60).

The Green Book also gives an overview of traffic forecasting periods. It states the assumed life expectancies for right-of-way (100 years), minor drainage structures (50 years), bridges (25 to 100 years), resurfacing (10 years), and pavement structure (20 to 30 years) and further states that those assumptions are based on obsolescence. The Green Book also states that design capacity is closely linked to economics. It is too expensive to design for much more than 20 years out, which has become the default design traffic forecasting project period.

9.2 Interpolation of Traffic Forecasts

Traffic forecasts are developed with a specific target year in mind. When forecasts are prepared for specific transportation projects, multiple target years may be of interest. These include the project opening date, a final horizon approximately 20 years beyond the opening date, and a mid-year date between the project opening and the final horizon. Looking at interim year forecasts may also be of interest for long-range transportation planning and air quality analysis.

Existing forecasts may not provide traffic forecasts for the desired target year. This can be true if the analyst is

- Doing additional work for a specific project for which forecasts were previously developed for specific target years but which now require looking at interim year forecasts, or
- Working with forecasts developed from a travel demand model that was not designed to provide forecasts for the target year called for in the study that the analyst is performing.

In such cases, it will be necessary to develop forecasts for the desired target year. The simplest and easiest way to develop interim year forecasts when pre-existing forecasts are available is to interpolate. When interpolating, an analyst attempts to establish a traffic forecast using at least two previously determined data points. One of these data points is a horizon year forecast that has been established prior to interpolation. The other data point can be either an observed traffic count or a short-term traffic forecast. By analyzing the value of and the year associated with each data point, it is possible to establish a traffic forecast for any year falling between the two points. When developing traffic forecasts for *scenarios* for interim years, one should interpolate between two of the same conditions, for example, a base year build scenario and a future year build scenario. Another method that can be used is to interpolate the trip tables and then run them through the assignment process. In most cases, the results will probably be similar, but interpolating the trip tables does the theoretically proper trip assignment for the interpolated traffic. This method is more complex and time consuming and is not as popular as the interpolation between volumes method.

9.2.1 Method

The following pieces of information are needed to interpolate a traffic forecast:

- Horizon traffic forecast,
- Year of horizon traffic forecast,
- Observed traffic count or short-term traffic forecast,
- Year of observed traffic count or short-term traffic forecast, and
- Year of desired traffic forecast falling between the year of the horizon forecast and the year of the observed traffic count or short-term forecast.

The method presented below is for linear interpolation. Linear interpolation is a common method for interpolating traffic forecasts due to its ease of implementation and straightforward explanation. Linear interpolation assumes that growth is uniform across a specified interval of time.

The formula for the linear interpolation of traffic forecasts is given below:

$$Traffic_T = Traffic_B + \frac{(Year_T - Year_B)Traffic_H - (Year_T - Year_B)Traffic_B}{Year_H - Year_B}$$

where

$Traffic_T$ = Target forecast,
$Traffic_B$ = Observed traffic count or short-term forecast,
$Traffic_H$ = Horizon traffic forecast,
$Year_T$ = Target year,
$Year_B$ = Year of observed count or short-term forecast, and
$Year_H$ = Year of horizon traffic forecast.

9.2.2 Example

An analyst is attempting to establish a forecast for the year 2022. The analyst has been given the following observed traffic count from 2012 and a forecast for 2025:

- 2012 traffic count = 14,600 vehicles per day.
- 2025 forecast = 22,500 vehicles per day.

The analyst then plugs these values into the formula given above:

$$Traffic_T = 14{,}600 + \frac{(2022 - 2012)22{,}500 - (2022 - 2012)14{,}600}{(2025 - 2012)}$$

The resulting traffic forecast is:

$$Traffic_T = 20{,}677 \text{ (Rounded to 20,700)}$$

In the example above, the same technique can be used to find forecasts for any year between 2012 and 2025. Figure 9-1 plots the example above along with additional forecasts for the years 2015 and 2019.

9.3 Improving Vehicle Mix Accuracy of Forecasts or Data Extrapolations

Vehicle mix is an important consideration in the development of traffic forecasts. The vehicle mix anticipated to be traveling along a particular transportation facility has an impact on traffic operations, the durability of construction, and the longevity of the transportation project. At a minimum, being able to distinguish between automobiles and trucks in traffic forecasts can be significant in transportation planning efforts. Transportation planners may use this information to identify corridors that should be improved on the basis of promoting economic concerns that relate to goods movement. Conversely, heavy truck traffic may be seen as a nuisance on certain facilities. In these cases, vehicle mix can assist transportation planners in identifying the need for truck-only lanes and truck bypasses.

Beyond transportation planning concerns, vehicle classification data have a direct bearing on predicting the weight load that is expected to be borne by a transportation project. Wear and tear on a road is greatly influenced not just by the amount of traffic traveling along the road, but also by the kinds of vehicles that constitute that traffic. All else being equal, high-volume roadways with high shares of heavy truck traffic will wear out faster than low-volume roadways with low shares of heavy truck traffic. Thus, vehicle mix has implications for a project's design, construction, and maintenance. Vehicle mix also has an impact on air quality analysis as vehicles of different sizes and weights produce emissions at different rates.

9.3.1 Source of Forecast Vehicle Fleet Mix

Vehicle mix information for traffic forecasts can be developed from analyzing existing vehicle classification data. Existing classification data may exist for the specific facility for which a forecast is being done. If this is the case, these existing data may be used to establish the vehicle mix for the forecast

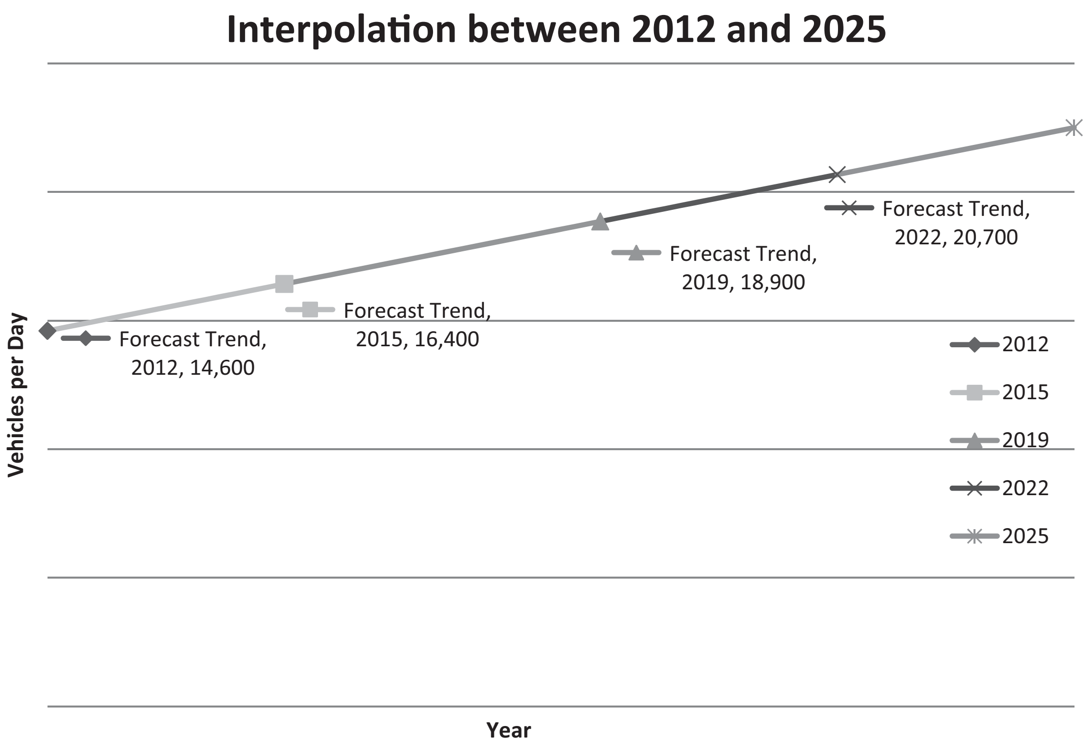


Figure 9-1. Interpolation example.

year on the same road. This is particularly true if the functional classification of the road is not expected to change significantly in the forecast year.

For example, if a forecast is being done for a segment of arterial for which vehicle classification counts already exist and the road is expected to remain an arterial in the forecast year, the existing vehicle mix may still be relevant. On the other hand, if the arterial is expected to be upgraded to a freeway in the future year, the existing vehicle mix may no longer be relevant. The analyst should use professional judgment when determining whether proposed changes to roadway characteristics for a given project would warrant using a different vehicle mix for the forecast year. A thorough understanding of the vehicle mixes for facilities in the region of the project gleaned from classification count data can assist the analyst in determining the appropriateness of any vehicle mix.

Table 9-1 shows the splits between cars and trucks by facility class for roads in Ohio. This information comes from a number of permanent automatic traffic recorder (ATR) counts and portable counts collected throughout the state in 2011 and represents statewide averages by functional class. Tables like Table 9-1 can be developed by analyzing vehicle classification counts for a given region and averaging the vehicle mix by functional class. These tables may cover an entire state, like this one from Ohio,

Table 9-1. Splits between car and truck by facility type.

Functional Class	Car	Truck
Rural Interstate	68.2%	31.8%
Rural Principal Arterial	83.0%	17.0%
Rural Minor Arterial	90.5%	9.5%
Rural Major Collector	93.2%	6.8%
Rural Minor Collector	92.0%	8.0%
Rural Local	94.7%	5.3%
Urban Interstate	87.2%	12.8%
Urban Freeway and Expressway	93.5%	6.5%
Urban Principal Arterial	93.8%	6.2%
Urban Minor Arterial	95.9%	4.1%
Urban Collector	96.4%	3.6%
Urban Local	93.1%	6.9%

Source: Ohio DOT Traffic Count Program.

Table 9-2. Average vehicle mix.

Road Type	Motorcycle	Passenger Car	Light Duty Truck	Bus	Single Unit Truck	Combination Truck
Rural Freeway	0.7%	50.6%	16.4%	0.4%	0.8%	31.1%
Rural Non-Freeway	0.2%	66.0%	22.6%	0.1%	1.1%	10.1%
Urban Freeway	0.4%	57.0%	25.4%	0.3%	0.9%	16.0%
Urban Non-Freeway	0.3%	70.3%	24.5%	0.1%	1.0%	3.8%

Source: Indiana DOT Traffic Count Program 2007—2010.

or may cover a smaller area such as a specific county. The table can be made more complex by including greater specificity in vehicle classification by distinguishing between buses, single unit trucks, and combination trucks rather than using the two-class system shown below, or tables can be made simpler by, for example, distinguishing only between freeway and non-freeway roads.

Table 9-2 shows another example of average vehicle mix. This table was developed from sample traffic count data from Indiana gathered for air quality analysis purposes. The table was developed by averaging the existing vehicle classification data from ATR sites throughout the state. In this case, the data were stratified to accommodate U.S. EPA's new mobile source emissions model, MOVES.

Tables such as Tables 9-1 and 9-2 can assist the analyst in determining whether existing classification counts for specific roads are reasonable when compared to other similar facilities and whether the existing vehicle mix data could be relevant if the functional classification of a road were to change in the forecast year. Average vehicle mixes developed from regional or statewide traffic counts can be used to establish vehicle mixes for forecasts when vehicle classification data for the proposed road do not exist.

If historical vehicle classification count data are available, then it is possible to extrapolate the historical trends for vehicle classification data. This allows the analyst to capture the changes to vehicle mix for a given road over time. Professional judgment should be used when deciding whether or not to extrapolate vehicle mix trends. Roads that experienced dramatic changes to vehicle mix in the past may not continue to see such dramatic changes in the future. The analyst should carefully consider whether the extrapolated trends result in reasonable vehicle mixes in the forecast year.

For example, a hypothetical road that in the past was upgraded from a principal arterial to an Interstate may have seen an accompanying change in heavy truck shares. This road may have had a truck share of 6% in 2000 when it was still an arterial. In 2010, after the road was upgraded, it may have a truck share of 30%. Extrapolating that trend to 2025 could result in a future year truck share of 66%. Such a high truck share would be unreasonable for this facility since the initial increase in truck share from 6% to 30% was the result of a one-time increase to the facility's functional classification and unlikely to be repeated in the future.

The decision matrix in Table 9-3 is provided to help summarize the main points of this section and to assist users of

Table 9-3. Decision matrix: Are historical counts by vehicle classification available?

Do vehicle classification counts exist for the road being forecast?		Yes	No
	Yes	It is possible to use historical count data from the road being forecast to extend the historical trend of the vehicle mixes. Roads that have historically seen increases in truck traffic over time may continue that trend. Avoid unrealistic vehicle mixes resulting from trends.	The vehicle classification data for the road being forecast can be used to provide future year vehicle mixes. Without historical vehicle classification data, future vehicle mixes will need to be kept the same as the observed data.
	No	Vehicle mixes will need to be synthesized from a statistical analysis of sites for which vehicle classification data are available. The selected sites should be similar to the road being forecast. Historical trends can be extended, but avoid unrealistic vehicle mixes resulting from trends.	Vehicle classification data will need to be synthesized from a statistical analysis of sites for which vehicle classification data are available. Sample sites should be selected based on their similarity to the forecast site. Future year vehicle mix will be the same as the observed data.

these guidelines in determining how to address vehicle classification data in their forecasts.

9.3.2 Vehicle Mix Considerations in Air Quality Analysis

Vehicle mix plays a crucial role in air quality analysis. Since different types of vehicles emit pollutants at different rates, having a vehicle mix that is as accurate and precise as possible is critical to establishing reliable emissions estimates. The current mobile source emissions model used by U.S. EPA is known as MOVES. The MOVES model looks at 13 different vehicle types (known as "source types" in MOVES) and 4 different road types. The road types used by MOVES are shown in Table 9-4. The source types used in MOVES are shown in Table 9-5.

Source types are coded using a two-digit code. The tens digit corresponds to one of six Highway Performance Monitoring System (HPMS) vehicle types: motorcycle, passenger car, light truck, bus, single unit truck, and combination truck. The ones digit further subdivides the vehicle types into MOVES source types. Unlike its predecessor, MOBILE6.2, MOVES source types are not distinguished within the vehicle types by size, weight, or fuel type. Rather, MOVES source types are distinguished by the use of the vehicle. This is most readily shown with the combination truck vehicle type. Source types 61 and 62 are both combination trucks. The difference is that 61 is the code for short-haul trucks, and 62 refers to long-haul trucks. While this distinction is relevant to the driving patterns of each of these source types and that, in turn, affects how pollutants are emitted for each, this distinction is not something that can be captured by temporary tube counters, permanent count ATRs, or manual counters.

Identifying vehicle mix according to the six HPMS vehicle types from classification count data is a rather straightforward process. These vehicle types can be directly correlated to the vehicle classifications by size, weight, and body type in most classification count programs throughout the country. The subdivision into the specific source types is a more involved process. In the MOVES manual, there is a cross walk table to convert HPMS vehicle mix data to MOVES mix data. Another option is to first calculate the vehicle mix by road type for the six vehicle types. Each vehicle type can then be subdivided into its specific source types by using the ratio of vehicle populations for those source types. MOVES also requires vehicle age distribution data, which may be developed from a variety of sources, including vehicle registration data and fleet inventories from school districts (school buses), transit agencies (transit buses), and solid waste authorities (refuse truck), among others.

The development of transportation data for MOVES is an involved topic, the detailed discussion of which is beyond the scope of this report. Additional information on this topic is being developed in a separate NCHRP research project, NCHRP Project 25-38.

Table 9-4. Road types.

Roadtypeid	Description
1	Off Network
2	Rural Restricted Access
3	Rural Unrestricted Access
4	Urban Restricted Access
5	Urban Unrestricted Access

Table 9-5. MOVES source types.

Sourcetypeid	Description
11	Motorcycles
21	Passenger Car
31	Passenger Truck
32	Light Commercial Truck
41	Intercity Bus
42	Transit Bus
43	School Bus
51	Refuse Truck
52	Single Unit Short-haul Truck
53	Single Unit Long-haul Truck
54	Motor Home
61	Combination Short-haul Truck
62	Combination Long-haul Truck

9.4 Special Needs of Equivalent Single Axle Loads

9.4.1 Abstract

A measure of traffic loading is necessary for pavement design for new construction, reconstruction, and resurfacing for both flexible and concrete pavements. The overview presented here is generic and pulls from the Florida and Kentucky equivalent single axle load (ESAL) forecasting process. This section covers the data needed to produce ESALs and gives a spreadsheet example of ESAL output for a project. It should be mentioned that some states have moved to the new Mechanistic-Empirical Pavement Design Guide (MEPDG). The end of the section gives some background on the new MEPDG process as well.

9.4.2 Context

Pavement design is an important application of traffic forecasting for all major agencies responsible for designing/maintaining pavement. Traffic forecasts for pavement design include not only traffic volumes but several other parameters. Pavement design is a very critical function since poorly designed pavement might fail early while overly conservative design might prove to be expensive. Pavement design is an excellent area in which to allow the use of ranges of results to give designers latitude.

Most pavement designs are site specific although they can stretch over the length of a corridor as well. Pavement designs typically require 20-year forecasts; however, in California, some urban high-volume freeways are designed with a 40-year pavement life, and rehabilitation jobs often use a 10-year pavement design life. Sometimes the pavement for construction detours will be designed with a 5-year design life.

9.4.3 Key Data for Pavement Design

Key data for pavement design include the following:

- Traffic volumes, both base year and future year;
- Vehicle classification, both base year and future year;
- Axles per truck, both base year and future year;
- ESALs/axle, both base year and future year;
- Directional factor, both base year and future year; and
- Lane distribution factor, both base year and future year.

The same techniques that are used elsewhere in these guidelines are used here for forecasting volumes, and the same data are used here for classifying vehicles.

A full case study will not be provided but output from the Kentucky Transportation Cabinet will be provided.

9.4.4 Steps of the Technique

STEP 1. Receive Request

ESAL forecasts are most commonly produced by state departments of transportation. It is likely that this is the case because pavement analysis and design need to be standardized and because the unique data needed for ESALs are not readily available outside large governmental agencies. ESAL forecasts are almost always produced for a 20-year period. The ESAL methodology flowchart for the Florida DOT (*3*) is shown in Figure 9-2.

STEP 2. Traffic Forecasts

Traffic forecasts of average daily traffic are made using techniques reviewed in Chapter 4. In many states, trend line analysis techniques are performed exclusively for ESAL traffic forecasts. In other areas, travel demand models are used to forecast raw volumes, then post-processed to convert to ESAL traffic forecasts. In both cases though, the base year volume and forecast year volumes use techniques already known.

STEP 3. ESAL Data

The key data items for ESALs that are different from typical traffic forecasts are derived primarily from vehicle classification counts and from weigh-in-motion (WIM) data. Information on axles per truck is derived from vehicle classification data and statewide defaults. The ESALs per axle value is produced from WIM data. The Kentucky Transportation Cabinet produces—from *Traffic Forecasting Report—2008* (*115*)—smoothed estimates of ESALs per axle (see Figure 9-3) (EALs/A is the same as ESALs/A).

The next forecasted item is the directional factor. In most cases, it is safe to assume that the ESALs are roughly equivalent in both directions. However, on some roads with heavy truck flows, the directional factor could vary from 0.5. For instance, it is not uncommon in Kentucky to have ESAL directional factors exceeding 80%.

The last forecasted item is the lane distribution factor. This is difficult to determine since it is based on the weight (or ESALs) per lane per direction. WIM data are really the only source of truck weights per lane per direction. The difficulty is that since WIM data are costly and relatively rare, statewide directional distribution defaults might have to be used. Two-lane highways are usually 50/50—with the directional caveat mentioned above. Four-lane Interstates have most of the ESALs in the right-most lanes, and six-lane highways have most of the ESALS in the right-most lane and middle lanes.

STEP 4. 20-Year ESAL Forecasts

The production of the ESAL values is almost always automated rather than using look-up tables and nomographs. The underlying ESAL equation is fairly straightforward once the annual average daily traffic (AADT) forecasts (Step 2) and ESAL parameters (Step 3) are produced. The ESAL equation and contributing equations from the Florida DOT (*78*) are shown in Figure 9-4.

STEP 5. Review/Reasonableness Checks

As with all traffic forecasts, the forecasts produced in Step 4 should be compared to historical forecasts and to forecasts on adjacent highway sections in order to have adequate confidence in the results. ESAL forecasts are another possible situation where confidence intervals might be used in order to give designers flexibility when designing the highway. For instance, the budget for a resurfacing project might not allow the growth rate projected while lesser growth might allow the project to go forward. The trade-off between forecast accuracy and available funds can then be communicated to decision-makers.

A typical ESAL product from the Kentucky Transportation Cabinet (*115*) is shown in Figure 9-5. It should be noted that Kentucky's method has many similarities to the AASHTO ESAL equations, but is not identical.

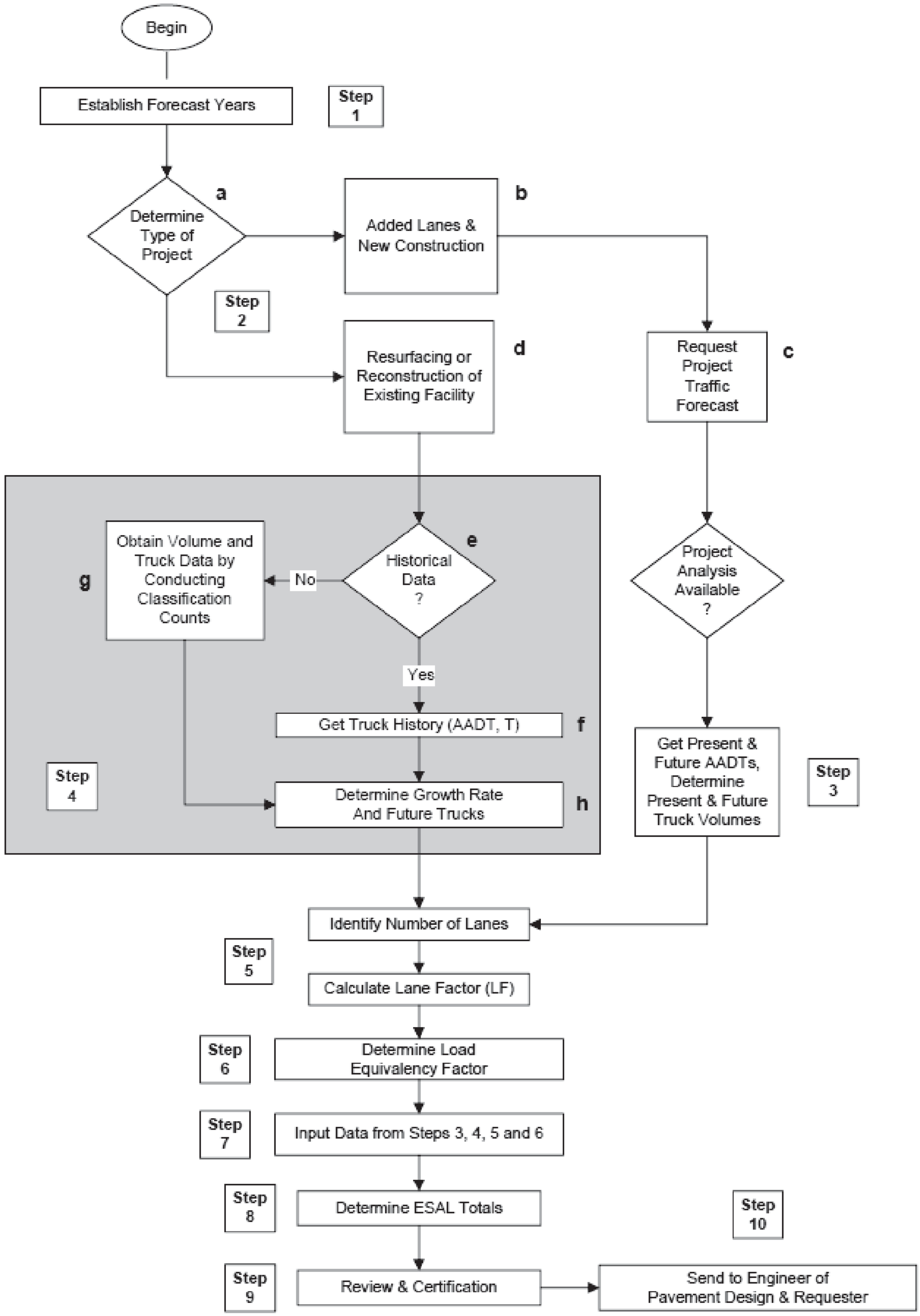


Figure 9-2. Florida ESAL methodology.

FC	FC Description	Agg. Class	ADT	T%	GR	A/T	GR	EALs/A	GR	A/CT	GR	EALs/CA	GR
1	Rural Interstate	I	35,246	29.6%	1.6%	4.6	0.1%	0.29	2.0%	4.64	0.0%	0.88	0.0%
2	Rural Principal Arterial	II	8,891	16.8%	2.0%	3.8	0.5%	0.26	1.6%	5.12	0.0%	3.30	0.0%
6	Rural Minor Arterial	II	4,787	9.9%	2.0%	3.2	0.5%	0.26	1.6%	5.12	0.0%	3.30	0.0%
7	Rural Major Collector	III	2,321	9.7%	2.0%	3.1	0.8%	0.25	1.6%	4.36	0.0%	2.70	0.0%
8	Rural Minor Collector	III	757	9.2%	2.0%	3.0	0.8%	0.25	1.6%	4.36	0.0%	2.70	0.0%
9	Rural Local	III	445	10.2%	2.0%	2.9	0.8%	0.25	1.6%	4.36	0.0%	2.70	0.0%
11	Urban Interstate	IV	84,352	14.5%	2.5%	4.3	0.9%	0.27	2.0%	4.78	0.0%	0.88	0.0%
12	Urban Freeway/Expressway	V	33,453	11.6%	2.5%	3.9	1.5%	0.30	2.0%	4.34	0.0%	3.43	0.0%
14	Urban Principal Arterial	V	20,774	8.1%	2.5%	3.7	1.5%	0.30	2.0%	4.34	0.0%	3.43	0.0%
16	Urban Minor Arterial	VI	10,588	9.0%	2.5%	3.2	1.3%	0.15	2.0%	4.47	0.0%	2.70	0.0%
17	Urban Collector	VI	4,795	7.4%	2.5%	2.9	1.3%	0.15	2.0%	4.47	0.0%	2.70	0.0%
19	Urban Local	VI	2,835	8.2%	2.5%	3.1	1.3%	0.15	2.0%	4.47	0.0%	2.70	0.0%

Notes: ADT, T%, and A/T based on traffic station information. Everything else comes from 2006 Aggregated ESAL report from Kentucky Transportation Center.

Figure 9-3. Smoothed aggregated EALs/A.

$$ESAL_D = \sum_{i=1}^{n} (AADT_i) \times (L_{Fi}) \times T_{24} \times D_F \times E_F \times 365$$

where

$ESAL_D$ = The number of accumulated 18-KIP (80-kN) ESALs in the design lane for the design z period.

i = The year for which the calculation is made. When y : 1, all the variables apply to Year 1. Some of the variables remain constant while others, such as AADT, L_F, and T_{24}, may change from year to year. Other factors may change when changes in the system occur. Such changes include parallel roads, shopping centers, truck terminals, etc.

n = The number of years the design is expected to last. (e.g., 20, 10, etc.).

$AADT_i$ = AADT for the year i.

T_{24} = Percent heavy trucks during a 24-hour period. Trucks with six tires or more are considered in the calculations.

D_F = Directional distribution factor. Use 1.0 if one-way traffic is counted or 0.5 for two-way traffic. This value is not to be confused with the directional factor (D) used for planning capacity computations.

L_F = Lane Factor, converts directional trucks to the design lane trucks. Lane factors can be adjusted to account for unique features known to the designer such as roadways with designated truck lanes.

E_F = The equivalency factor is the damage caused by one average heavy truck measured in 18-KIP (80-kN) ESALs. These factors should be provided by the planning department for each project. They will be reviewed annually and updated if needed by TranStat, based on WIM data.

Figure 9-4. Florida ESALs equation.

FORECAST OF EQUIVALENT SINGLE AXLE LOAD ACCUMULATIONS

ROUTE ID:

County	0	Date	8/26/2013
		Forecaster	Kong Ee
Road Name	Marion Bypass		
		MARS No.	0
Functional Class	16 - Urban Minor Arterial	Item No.	1-0250.01
		Route No.	US 60 Bypass
Project Description	New Highway Connecting US 60 East of Marion to US 641 South of Marion	Beg. MP	1
		End MP	2
		T.F. No.	00.081
		No. of Lanes	2
Segment Limits	segment 10 (build)	1 or 2 way	2

REFERENCES:

Previous Forecasts	94.138, 98.155, 98.076	K- Factor Value	10.0%
		K-Factor Source	A44
Traffic Volume	Traffic Modeling		
		General Comments	--
Truck Percent	station A44		--
			--
ESAL Information	1998 Aggregated ESALs		
Growth Rate	A44		

TRAFFIC PARAMETERS:

		Present Year	Growth Rate	Construction Year	Median Year	Design Year
		1998		2000	2010	2020
Volume	(AADT)	70000	2.00%	72830	88780	108200
Percent Trucks	(%T)	6.90%	1.50%	7.1%	8.2%	9.6%
Percent Trucks Hauling Coal	(%CT)	0.00%	0.00%	0.00%	0.00%	0.00%
Non-Coal Trucks:						
Axles/Truck	(A/T)	2.844	1.50%	2.930	3.400	3.946
ESALs/Axle	(ESAL/A)	0.152	0.00%	0.152	0.152	0.152
Coal Trucks:						
Axles/Truck	(A/CT)	0	0.00%	0.000	0.000	0.000
ESALs/Axle	(ESAL/CA)	0	0.00%	0.000	0.000	0.000

ESAL CALCULATIONS:

Total Median Year Daily ESALs
(AADT x (1-%T) x .005)+(AADT x %T x (A/T) x (ESAL/A))+(AADT x (%T) x (%CT) x (A/CT) x (ESAL/CA)) = 4192.229

Lane Adjustment Factor = 0.50

Design ESALs in Critical Lane
Total Median Year Daily ESALs x 365 x Number of Forecast Years x Lane Adjustment Factor = 15,302,000

Figure 9-5. 20-year ESAL estimate.

9.4.5 Mechanistic-Empirical Pavement Design Guide

The new MEPDG promulgated by AASHTO is meant to eventually replace the use of ESALs. The reasons for using MEPDG are greater flexibility and more accuracy, as explained in *Mechanistic-Empirical Pavement Analysis and Design Educational Module* (*130*). The new metrics are called load spectra.

The MEPDG requires somewhat more detailed traffic information than earlier methods such as the 1993 AASHTO *Pavement Design Guide*, which required data necessary to forecast ESALs over the life of a pavement. Certain inputs to the MEPDG relate to how trucks are designed and loaded, and these are not conveniently ascertained by project-level traffic forecasts. These particular inputs would need to come from other sources. However, the remaining traffic inputs could be assisted by a project-level forecast. These are the following:

- Truck volumes by FHWA vehicle class (4 to 13),
- Growth in truck volumes by FHWA vehicle class,
- Speed of trucks,
- Directional split of trucks,
- Fraction of trucks in the design lane,
- Monthly variation of truck volumes by FHWA vehicle class, and
- Hourly distribution of truck volumes for all classes combined.

9.5 Special Needs of Benefit-Cost Analysis

Benefit-cost analysis provides information useful to making a decision about whether or not to invest in a transportation improvement. Transportation economists consider highway investments that demonstrate a benefit-cost ratio greater than 1.0 as economically efficient. The lower the benefit-cost ratio, the less efficient the investment is, allowing for a direct comparison between different-sized projects.

Transportation benefit-cost analyses compare the monetized benefits of an investment against its costs. Benefits can include impacts to transportation system users, such as travel time savings, fuel, and other vehicle operating costs and accident costs. Benefits and costs can also include impacts to the broader society including externalities such as pollution, water quality, and greenhouse gas emissions.

Highway projects of all shapes and sizes, ranging from new high-capacity roads spanning multiple states to intersection improvements, are appropriate for benefit-cost analyses. The specific tools that are applied vary depending on the scale of the analysis. Projects could include new highways or lane additions to expressways and major arterial roads. Projects with impacts that are difficult to detect accurately in a model—including operational improvements, intersection capacity improvements (e.g., adding or extending turn lanes), and minor freeway improvements such as reconfigured interchange ramps or merge/diverge areas—are less appropriate for analysis in a travel demand model and should be conducted using simulation or highway capacity analysis techniques.

The benefit-cost analysis compares the benefits and costs of an investment against a baseline or no-build case. The build or improvement case is identical to the baseline or no-build case, except that the improvement case reflects the impact of the investment. The improvement will cause a rerouting of traffic that should benefit transportation users as a whole. Depending on the magnitude of the investment, other effects can include a shift in origin-destination (OD) patterns, induced/disinduced travel, shifts in mode of travel, and shifts in departure time choice. Most benefit-cost analyses account for reroutings only, and this assumption simplifies the analysis.

Comparing project benefits and costs is a powerful tool in a transportation investment decision-making framework. However, there is a broader set of impacts that is difficult to monetize but also important to consider. This set includes externalities such as noise and quality of life, mobility considerations such as changes in connectivity and access, and the potential change in the general attractiveness of a community or neighborhood.

9.5.1 Changes in Vehicle Miles Traveled and Vehicle Hours of Travel

The changes in travel time and vehicle hours of travel (VHT) produced by a transportation improvement are the two most significant factors in the estimation of benefits in a benefit-cost analysis. Transportation improvements can shorten trips by providing a more direct route to a destination or a faster trip to a destination along the same route. It is not unusual for an improvement to increase travel distances or vehicle miles traveled (VMT), while decreasing travel times, or VHT. In such cases, travelers will divert to longer distance routes if it means saving enough time to justify the change in route.

9.5.2 Locally Significant Transportation Improvements

Local transportation improvements that are not expected to create major reroutings of trips and that will not be evaluated within a travel demand model can be evaluated for their VHT/VMT change from base case conditions in a straightforward manner. The change in travel time can be evaluated as the following:

$$T_j = \Sigma(P_{bj} - P_{ij}) * VOT_j$$

where

T_j = Monetized travel time impacts for trip purpose j;
P_{bj}, P_{ij} = Base (no build) and improvement (build) case person hours of travel for trip purpose j, and
VOT_j = Hourly value of time for trip purpose j.

This difference is annualized and summed over the useful life of the project, which is typically 20 years.

For local improvement projects, it may be reasonable to assume that there is no rerouting of travel from other routes or general increase in trip-making. However, a more accurate assessment might assume that some traffic diversion from other routes or increase in trip-making to take advantage of an improvement's travel times savings would occur. The following expression is used by the Federal Highway Administration in highway needs analysis to account for the increase in demand from a reduction in travel costs: "improvements that increase capacity/reduce travel times." For use of this expression, refer to Section 10.3 of this report, which discusses the use of elasticities.

The resulting volumes will decrease slightly the prospective benefits of a transportation improvement. However, this approach provides a more realistic assessment in accounting for the potential of travelers to "fill" new capacity and reroute their travel in order to save travel time.

9.5.3 Regionally Significant Transportation Improvements

Travel demand models, and network assignment models in particular, are the tool of choice to analyze the impacts of larger scale highway improvements. Most highway network assignment models are designed to achieve travel time equilibrium, which means that travelers from an origin to a destination cannot improve their travel time by taking a different path. The equilibrium process iteratively assigns traffic to shortest paths between origins and destinations, until a state of equilibrium is achieved to an acceptable degree. Attaining a state of equilibrium for the base case and improvement case scenarios is a prerequisite for meaningful and reliable user benefit analysis. This means that, for benefit-cost analysis, the traffic assignment process should be allowed to run long enough to achieve an acceptable degree of equilibrium.

Traffic assignments that have not reached a state of equilibrium can produce illogical results. For example, significant changes in traffic volumes that are far beyond the expected impact shed of the improvement project can arise between the base and improvement case. Volumes on feasible alternative paths with small travel time differences can oscillate from one traffic assignment iteration to the next, resulting in significant link volume differences in locations near the improvement project between the base case and improvement scenarios.

One commonly used statistical measure of traffic assignment convergence is the relative gap. Relative gap measures the percent difference in total generalized costs (or just travel time) between costs generated from an all-or-nothing assignment and those generated by the equilibrium-weighted volumes for a given iteration. Lower values signify higher levels of equilibrium and more reliable results. Most software packages supply a relative gap statistic to gauge the quality of the equilibrium traffic assignment.

Achieving true equilibrium may require hundreds or thousands of traffic assignment iterations and is thus impractical for most applications. More efficient traffic assignment algorithms and continued improvements in computer processor speeds will continue to reduce these running times.

While the literature on assignment convergence cites 0.01% as a desirable relative gap, the United Kingdom's Transport Analysis Guidance recommends that the relative gap (expressed as a percentage) be at least 10 times the percent difference in the total user benefits between the base and the improvement case.

9.5.4 Values of Time and Travel Markets

The U.S. Department of Transportation provides general guidance on the selection of appropriate values of travel time for benefit-cost analysis. The base hourly wage rates must be discounted by a traveler's "willingness to pay" to save travel time. Suggested factors are shown in Table 9-6. On-the-clock travel refers to working time spent in a vehicle.

Table 9-6. Value of time.

Market Value of Time	
Commute	**40–50% of Wage Rate**
Personal Travel	**30–40% of Wage Rate**
On-the-Clock Travel	**100% of Wage Rate**

9.5.5 Streams of Benefits and Costs

While transportation impact analyses capture conditions at a point in time, benefit-cost analysis should estimate benefits and costs over the lifetime of the prospective project. The total costs and benefits can be summed over the (typically 20-year) analysis period and compared.

In most applications, information about traffic volumes on a year-by-year basis will not be available. A simple way to estimate the year-by-year traffic impacts is to conduct separate analyses at the end points of the project lifetime (year 1 and year 20) and to interpolate the results for the intervening years.

9.5.6 Discounting Benefits and Costs

Transportation spending for highway improvements and the benefits that accrue from that spending occur at different times over a project's lifetime. In benefit-cost analysis, dollar values are expressed in comparable terms by converting their year-by-year values into a present value. To express future sums in present value, the potential "interest accrued" from a future dollar value is extracted to arrive at an expression of current value. As an example, the present value of $100 earned 10 years from now would be $67.56, at a 4.0% discount rate. This discounting of future benefits is unrelated to inflation. Long-lived transportation investments such as bridges generally have lower discount rates than roads. The U.S. Office of Management and Budget publishes recommended discount rates for public-sector investment analysis.

The example shown in Figure 9-6 illustrates an application of the discounted benefit-cost comparison. The traffic impacts of a $42.5 million dollar project expected to be completed by 2020 are evaluated with a travel demand model for the years 2020 and 2035. The user benefits that are estimated from those 2 years (the change in travel times between base case and improvement case, multiplied by the value of time) are interpolated for the years between 2020 and 2035 and extrapolated from 2035 to 2040 (benefits were assumed to decline beyond 2035). A discount rate of 4.0% is applied to the benefits and the capital costs (no operating costs were assumed) and summed across the 20-year period. Discounted

Year	VHT Estimate (Mill/Yr)	Discount Year Factor	Modeled User Benefits ($000)	Benefit Stream ($000)	Capital Costs ($000)	Discounted Benefits ($000)	Discounted Costs ($000)
2010	562						
2011	572						
2012	581	1.0000					
2013	591	0.9615					
2014	600	0.9246					
2015	610	0.8890					
2016	619	0.8548					
2017	629	0.8219					
2018	639	0.7903					
2019	648	0.7599					
2020	***658***	***0.7307***	***$ 2,250***	***$ 2,250***	***$42,500***	***$ 1,644***	***$ 31,054***
2021	667	0.7026		$ 2,288		$ 1,607	
2022	677	0.6756		$ 2,325		$ 1,571	
2023	686	0.6496		$ 2,363		$ 1,535	
2024	696	0.6246		$ 2,400		$ 1,499	
2025	705	0.6006		$ 2,438		$ 1,464	
2026	715	0.5775		$ 2,475		$ 1,429	
2027	725	0.5553		$ 2,513		$ 1,395	
2028	734	0.5339		$ 2,550		$ 1,361	
2029	744	0.5134		$ 2,588		$ 1,328	
2030	753	0.4936		$ 2,625		$ 1,296	
2031	763	0.4746		$ 2,663		$ 1,264	
2032	772	0.4564		$ 2,700		$ 1,232	
2033	782	0.4388		$ 2,738		$ 1,201	
2034	792	0.4220		$ 2,775		$ 1,171	
2035	***801.15***	***0.4057***	***$ 2,813***	***$ 2,813***		***$ 1,141***	
2036		0.3901		*$ 2,531*		*$ 987*	
2037		0.3751		*$ 2,278*		*$ 855*	
2038		0.3607		*$ 2,050*		*$ 740*	
2039		0.3468		*$ 1,845*		*$ 640*	
2040		0.3335		*$ 1,661*		*$ 554*	
Total			***$ 5,063***	***$ 50,866***	***$42,500***	***$ 25,914***	***$ 31,054***

Figure 9-6. Example benefit/cost stream.

costs exceed benefits ($31,053 versus $25,914) implying that constructing the project as configured is not justified from on transportation efficiency grounds.

9.6 Special Needs of Toll/ Revenue Forecasts

Strategies for incorporating tolls in travel demand modeling include generalized cost approaches, logit-based toll diversion approaches, and mode choice approaches. These are described below.

9.6.1 Generalized Cost

The most basic approaches to toll modeling with a travel demand model use a method of converting costs and time into a common unit, such as minutes or dollars, and assigning traffic using a function to minimize the impedance throughout the network. The traffic assignment model assigns traffic to a toll road built as part of a shortest impedance path calculation and considers a composite of a traveler's value of time, vehicle operating cost, and toll cost. The toll may be identified as an attribute of the highway network, and unique values of time may be established for each trip purpose (e.g., home-based work) or vehicle class (e.g., truck) in the model. This approach is relatively easy to implement and is used in general planning and or sketch-planning applications.

9.6.2 Logit-Based Toll Diversion

Toll choice models are commonly used in toll-feasibility studies. This approach splits each OD automobile travel pair into toll users and non-toll users, based on an application of a binomial logit model that compares the weighted time and cost of the highway toll and non-toll travel options. The weights (coefficients) for the model application may be estimated from a stated preference survey, in which potential toll users indicate which hypothetical combinations of trip times and costs would prompt them to use the toll facility in a real-life situation. Toll route choice makes extensive use of the network path-building process in determining the feasible set of origins and destinations that may use a toll facility (through select link and select zone features), as well as the travel times and costs associated with using or not using the facility. Once the choice model splits automobile trips into the toll and non-toll segments, the assignment model assigns each to their proper network.

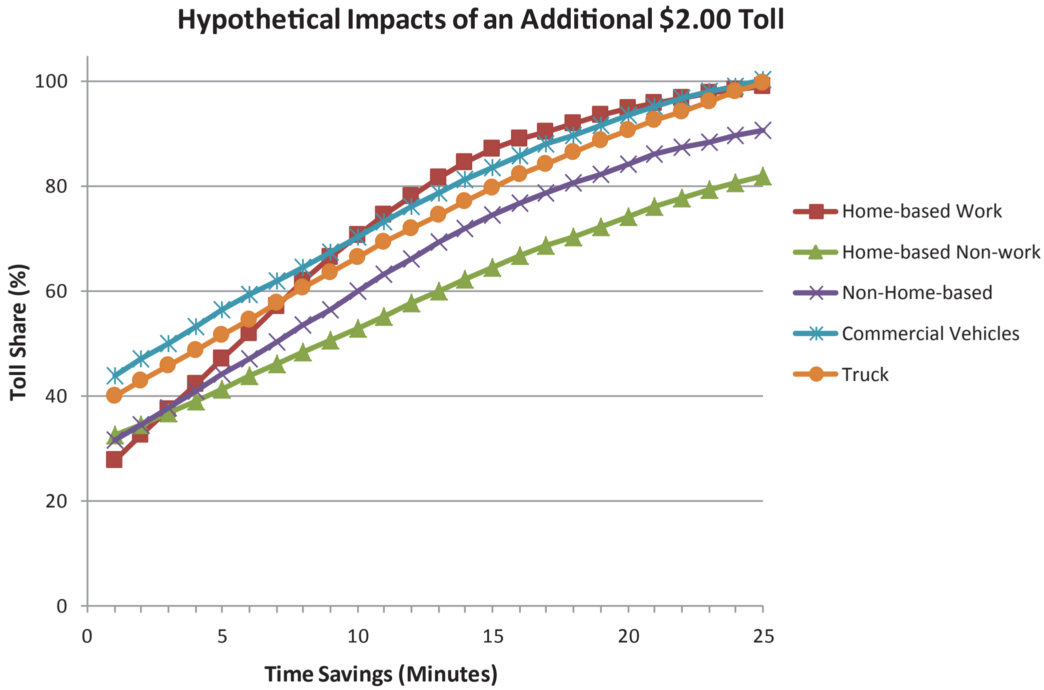


Figure 9-7. Sample toll diversion curve.

The relationship between independent variables and toll share can be described graphically in a toll diversion curve. Figure 9-7 presents a hypothetical curve showing the relationship between travel time savings and toll share, assuming a toll increase of $2.00.

Investment-grade analyses collect a great deal of information about travelers in a potential toll corridor. OD travel surveys capture the travel shed of potential toll facility and provide baseline information against which the travel demand model network assignment can be validated. These surveys can also provide critical market segment information, such as income, occupation, and attitudinal information. Such information helps determine potential users' value of time, sensitivity to travel time reliability, and ability to shift travel out of the peak. Additionally, speed, volume, and delay data on a potential toll route and on competing routes will provide base condition information for traffic model calibration and validation. Collecting sufficient data for network assignment validation is important in order to produce reasonable estimates of toll use and to understand the potential for vehicle diversion onto parallel and nearby non-tolled roads.

9.6.3 Mode Choice Approaches

Some advanced approaches also consider toll options at the mode choice level, which allows analysts to reflect the impacts of policy variables, consumer preferences, and a more accurate representation of the trade-offs among vehicle occupancy, public transportation choice, and toll choice. As an example, a choice-based model can reflect the differences in traveler preferences due to factors such as reliability and convenience, while a path-based evaluation cannot. More advanced extensions of toll modeling that may become part of standard practice in the years ahead include incorporating dynamic traffic assignments (DTAs), which are more capable of capturing the impacts of variable pricing and incorporating different distributions of values of time for different user groups.

9.7 Special Needs of Work Zones: Diversion and Delay Forecasts

In recent years, travel models have become more important to the preparation work zone transportation management plans (TMPs). Any travel modeling done for the project itself may or may not be applicable to a TMP, given the different outputs that are sought. Modeling of a project would have been performed to aid the design of the project itself and to select among various alternatives.

Modeling for a work zone focuses entirely on the immediate impacts of construction activities and on the impacts of any road or lane closures associated with the construction schedule.

Work zones are often categorized as being short term or long term. Short-term work zones last only a few hours to a few days, with drivers being dependent upon publically provided advice on delays, detours, and diversion options. Long-term work zones are in place long enough for many drivers to obtain first-hand knowledge of the work zone's impacts and for drivers to make their own informed route choice decisions.

Work zone impacts can range from being minor, such as a late-night lane closure on a road segment with ample capacity, to being severe, such as a full freeway closure over a weekend. Impacts can include substantial queuing and delays on the highway under construction; blocking of off-ramps due to queues; increased traffic volumes and delays on nearby streets due to detoured and diverted traffic; various environmental impacts; various community impacts; and driver confusion, frustration, and loss of productivity. A well-written and executed TMP can mitigate these impacts, but for many projects impacts can remain at unpleasantly high levels, in spite of an agency's best efforts. A travel model is capable of forecasting traffic volumes in and around a work zone, and these traffic volumes can serve as inputs to a traffic microsimulation or a traffic operations model for determining potential delays and queues, if the travel model does not have sufficient capability itself. This type of analysis can aid in determining ramp closures for traffic mitigation purposes, signal timings, and advisories, among other strategies. This type of analysis may be accomplished by a regional travel model or by a DTA.

Forecasts for work zones, where mitigation strategies do not include transit, are mainly concerned with the assignment of traffic, as the demand patterns are almost always assumed to be the same as before construction. Thus, being able to correctly forecast drivers' route choices is critical.

9.7.1 Regional Modeling

Most regional models are straightforward in their approach to traffic assignment for work zones. Drivers are routed on the shortest path of impedance, such that Wardrop's first equilibrium principle is satisfied. Feedback to trip distribution is unnecessary, because destination choice can be assumed constant. Many regional models are multiclass, so that trucks can have different impedances from automobiles. Regional models that are dependent on volume-delay functions (VDFs) for impedances have limited ability to accurately predict delays under highly congested situations. Regional models are static, so they have limited ability to respond to traffic peaks. Regional models have been used for work zones with some success, given these limitations. Regional models are particularly helpful when impacts are widespread, such as might be seen from a multiple-lane closure on a busy urban freeway.

9.7.2 Specialized Work Zone Modeling with Dynamic Traffic Assignment and/or Microsimulation

DTAs are well suited for work zone studies. Newer DTA software products are designed to handle highly congested traffic conditions and are adept at calculating impedances considering traffic controls at nodes. DTAs can be equilibrium traffic assignments according to Wardrop's first principle, and they can be multiclass. DTAs are especially good at handling traffic peaks. DTAs are naturally good at estimating queue lengths, which are of critical importance to many strategies in a TMP.

DTA software requires as input a dynamic OD table. This table can be adapted from a regional model or built synthetically by matching traffic counts.

If a DTA is being custom created for a particular work zone, then the network needs to cover the highway with the construction (from well upstream of the work zone to well downstream) and all conceivable diversion routes. A zone structure, similar in principle to a regional model's zone structure (traffic analysis zones [TAZs] and external stations), is necessary to correctly represent full trips from their true origins to their true destinations (or good approximations thereof). Very large construction projects may require very large networks. Networks should be similar in their functional classes to a regional model.

It is good to assume that traffic in and near long-term work zones in urban areas reaches something approximating equilibrium conditions after several days. Drivers will obtain very good information about delays on their own, over time. Initial impacts of work zones may be severe or minor depending upon how much publicity is given to the construction, and these transient impacts are difficult to predict.

Studies have shown a tendency for occasional drivers to stay on their original route through a work zone, rather than divert. If the work zone has a large percentage of occasional drivers, then it may be necessary to use advanced methods suitable for rural work zones (see Section 9.7.3). A small number of occasional drivers can be absorbed by the equilibrium process.

9.7.3 Considerations for Short-Term and Rural Work Zones

Traffic in and around rural and short-term work zones is much more difficult to forecast than traffic in and around long-term work zones. There has been comparatively little research on this subject, so only very general guidelines can be given. These guidelines are an outcome of a series of work zone traffic studies and models developed for the Wisconsin DOT and are the following:

- Many of the same methods for long-term urban work zones apply to short-term and rural work zones, as well. DTA should be capable of equilibrium and multiclass; however, the results will not necessarily satisfy Wardrop's first principle. There is a need for a dynamic OD table. Delays should be calculated from high-quality traffic theory such as that found in the HCM2010 (*21*). Networks need to cover large portions of trips that would have passed through the work zones.

- Many drivers passing through rural and short-term work zones have poor information as to delays and alternative routes, in spite of the best efforts of the agency.
- There are strong biases toward staying on originally planned paths. That is, there is a positive impedance component for all alternative routes.

Drivers can be categorized into those who would never divert, regardless of delays; those who would always divert, regardless of the lack of delays; and those who make an informed choice. Eventually, all of these drivers will fall into one of two kinds of users—those that stay on their original route (many of them passing through the work zone) and those who always divert from the work zone. Within a multiclass traffic assignment, diverting drivers are prohibited from passing through the work zone; all other drivers may pass through the work zone, although some of these remaining drivers may have already chosen to avoid the highway with the work zone for a variety of reasons unrelated to the work zone itself.

Thus, a dynamic OD table must theoretically be split into twice as many vehicle classes than would be needed for a long-term urban work zone. This split can be accomplished either within the DTA software or externally, depending upon the capabilities of the software. There is a preference for splitting the OD table within the DTA software so that the split can reflect the feedback of impedances from a fully loaded network. It should be noted that the splitting of drivers who never intended to use the highway with the work zone should not appreciably affect the results, so there is no need to identify these drivers ahead of time.

There are numerous choice theories that could be used to create the splits, but a simple binary logit model should be adequate for most situations. The choice model is applied only to those drivers who are open to a choice between staying on or leaving the highway with the work zone. Other drivers should be given to one of the vehicle classes by rule. In general, the probability that a choosing driver stays on the original route between Zone i and Zone j is the following:

$$p_{ij}^{orig} = f(t_{ij}, \tau_{ij}, b_{ij})$$

where f() is a suitable choice function (such as logit), b_{ij} is an original-route bias constant, t_{ij} is the impedance (e.g., travel time) with the work zone, and τ_{ij} is the expected impedance under normal conditions. The original-route bias constant should depend upon whether the work zone is urban or rural and long term or short term. The original-route bias constant is also dependent on the amount and quality of information available to drivers. Bias constants of about 20 minutes have been observed for long-term, rural freeway work zones in Wisconsin.

9.8 Special Needs of Environmental Justice

The recipients of federal-aid highway funds have been required to certify, and the U.S. DOT must ensure, nondiscrimination under Title VI of the Civil Rights Act of 1964 and many other laws, regulations, and policies. In 1997, the U.S. DOT issued its *DOT Order to Address Environmental Justice in Minority Populations and Low-Income Populations* to summarize and expand upon the requirements of Executive Order 12898 on Environmental Justice (EJ). Federal agencies are required to make EJ a part of their mission by identifying and addressing disproportionately high and adverse effects of its programs andpolicies on minority and low-income populations.

Large highway projects have the potential to cause disproportionate impacts to EJ populations. Travel demand models are often used as a means to identify these impacts. Travel demand models can relay graphically the low-income and minority populations and their relationship to the transportation project. However, EJ analysis is not simply calculating measures; it is intended to be a comparative analysis measuring impacts of build versus no-build relative to current and forecasted conditions.

EJ analysis helps agencies address both potential positive and negative effects of projects to assist in developing effective environmental justice approaches that involve affected communities throughout a project's development.

Data needs for addressing environmental justice include project-specific data, demographic data, and public comment. Project-specific data on roadway attributes, transit attributes, alignments, and so forth, are required to initially determine the impacts of the improvement on the region compared to a "no-build" scenario. These data can be obtained from the local agency. Demographic data are required to determine the locations of low-income and minority populations sensitive to disproportionately high and adverse impacts. Demographic data can be obtained from a recently updated travel demand model at the TAZ level of aggregation or from the U.S. Census at the block group level of aggregation. Public comment is needed to understand the key themes and potential adverse effects of populations in the region. These comments can be obtained from public meetings and various conversations with local community representatives and stakeholders.

Some of the measures used to identify the transportation effects of the plan alternatives include the following:

- Vehicle trips by time of day;
- Average trip length distributions in time and distance;
- Vehicle miles and hours traveled;
- Roadway speeds and delay;
- Mode share for work, non-work, and all trips;
- Accessibility to transit service and frequency;

- Accessibility to non-motorized (walking and bicycling) facilities;
- Proximity to jobs, schools, health care, and so forth; and
- Right-of-way impacts/displacement.

The measures used in the analysis depend on the analysis approach. A common approach is to measure benefits of the transportation project based on accessibility. Other approaches include travel time savings. Additionally, the appropriate measure should be based on the type of transportation project. A new roadway facility differs from a transit project, which differs from a toll facility.

9.9 Special Needs of Traffic Impact Studies

Traffic impact studies generally follow the standard three-step process of trip generation, trip distribution, and traffic assignment. Because traffic impact studies characteristically involve only automobile trips, the mode split step is usually ignored. These steps are then followed by an analysis step in which the impacts of the proposed development or planned land use change are identified and quantified. It is for this analysis that traffic forecasts are required. The Institute of Transportation Engineers' *Trip Generation Manual* (the current version is the 9th edition) (*108*) has become the standard reference for estimating trip generation associated with various land use types. The *Trip Generation Manual* presents weighted average trip rates from studies conducted throughout the United States and Canada since the 1960s, but it also encourages users to supplement the data with local data collected at similar sites. However, the additional sources listed in Section 3.6.5 should also be considered, where appropriate. Regional travel models also may provide an option for trip generation based on local data. Depending on the type of model (i.e. three-step versus four-step), an adjustment for mode choice may be needed.

Trip distribution is an important step in traffic impact studies. Distribution of project trips is commonly performed manually, based on existing traffic volumes, manual gravity distribution, or using engineering judgment. Travel demand models also can be used to distribute site-generated trips, using either additional population and/or employment associated with the proposed development or by treating the proposed development as a special generator. Windowing or focusing of travel demand models is very effective for distribution and assignment of site-generated trips.

Some commercial travel demand model software packages allow the assignment of multiple OD matrices, so site-generated trips can be managed in a separate OD matrix. Caution must be exercised when using a travel demand model for assigning site-generated trips as a distinction must be made among primary trips (trips made for the specific purpose of visiting the generator), pass-by trips (trips made as intermediate stops to the generator on the way from an origin to a primary trip destination), and diverted linked trips (trips attracted from roadways within the vicinity of the generator but requiring a diversion to gain access to the site).

There are other aspects of conducting traffic impact studies that could be discussed but that are beyond the scope of these guidelines. These include items such as the following:

- Assessing the severity of impacts,
- Accounting for programmed transportation improvements, and
- Determination of and/or responsibility for mitigation of such impacts.

Finally, a good number of state departments of transportation have manuals to guide the performance of such reviews, as well as many county, city, or municipalities that may have their own locally adopted guidelines, or preferred methods, for regulating the analyses that are performed.

CHAPTER 10

Tools Other Than Travel Models

This chapter examines methods other than travel models to develop project-level traffic forecasts. It presents various options in step-by-step procedures that include the method's background, the context of the technique, words of advice, disadvantages/issues of the method, strategies to minimize the impacts of the disadvantages/issues, execution steps of the method, and illustrative examples.

10.1 Method: Time Series of Traffic Volume Data

10.1.1 Abstract

When results from a travel forecasting model are unavailable, it is often possible to forecast near-term traffic volumes by extrapolating upon historic trends. Time-series models estimate traffic volumes as a function of time and, perhaps, a small set of explanatory variables. Time-series models can adjust for seasonal and daily variations in traffic, where those variations follow regular patterns. There are a variety of methods, including growth factors, linear trend lines, exponential smoothing, moving averages, and auto regression. Each of these methods has advantages and disadvantages, depending upon data availability.

10.1.2 Context

Typical applications are lane widening, road diet/cross-section modification, site impact study, benefit/cost, and ESALs/load spectra.

Geography is site.

Typical time horizons are short range and interim.

Required input data are historic traffic volumes.

Optional input data are historic explanatory variables such as population, employment, and gross domestic product.

Advantages of time-series methods are that they are quicker and less data intensive that travel forecasting models. They can be customized to a specific location.

A disadvantage of time-series methods is that they assume that prior trends will continue into the future. It is difficult to introduce causality in some cases. It is difficult to test policy options with time-series methods. Time-series methods cannot be applied to situations where there is expected to be substantial rerouting of traffic or where anything new is happening for which there is no precedent.

Case study is Case Study #5 - Blue Water Bridge.

10.1.3 Background

Time-series methods isolate a single road or a single direction on a road. A statistical model, consisting of a single equation, is custom built where traffic volume (or period-to-period changes in traffic volume) is the dependent variable.

Independent variables can include time (expressed as days, months, or years from an arbitrary starting point), earlier traffic volumes, demographic variables, economic variables, and other relevant variables that vary over time.

The two most often used time-series methods by departments of transportation are growth factors and linear trend analysis.

Growth factor methods estimate a growth rate, r, from historical data and then extrapolate upon the last known traffic volume, T_0, to find a traffic volume in some future period, n periods hence,

$$T_n = T_0 (1 + r)^n$$

where T_n is the future year volume. A period is most often a year for traffic applications. Growth factor methods are of limited use and will not be described further.

Linear trend methods estimate a period-to-period increment over a prior period volume. Since linear trend models are fitted statistically, the prior period is arbitrary,

$$T_n = an + b$$

In this case, n is the number of periods from the arbitrary starting point of the analysis, a is the period-to-period increment of traffic volume, and b is the estimated volume for the arbitrary starting period.

Growth factor and linear trend methods are elementary. Much more sophisticated time-series methods, particularly those of the ARIMA (autoregressive, integrated, moving average) family of methods can bring added realism to the analysis (*123*). For example, a very elementary autoregressive model might look like this:

$$T_n = aT_{n-1} + b$$

where T_{n-1} is the traffic volume one period earlier.

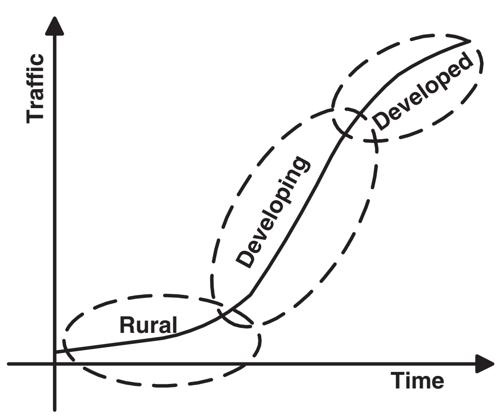
There are a number of associated techniques for enhancing time-series analysis. A moving average is a way of smoothing out either statistical variation or periodic variation in a series. A typical byproduct of applying moving averages to a periodic time series is a set of "seasonal" adjustment factors. Box-Cox transformations are often applied to time-series data to diminish the possibility that episodes of high variation do not unduly influence the coefficients.

10.1.4 Why This Technique

Time-series methods are applications of statistics, usually extensions of linear regression analysis. Time-series models can incorporate trends in explanatory variables, as well as trends in the volume data. Spatial factors can be included, such as the traffic volume on a nearby road. Software packages for doing the estimation are readily available. Adequate time-series models can be built with spreadsheets.

10.1.5 Words of Advice

Unless there is strong evidence of accelerating growth or accelerating decline in traffic, it is best to assume that growth is linear. Figure 10-1, from the *Guidebook on Statewide Travel Forecasting* (*25*), shows stages of traffic growth that are typical for many urbanizing areas. Early development trends, when the area is mostly rural, might suggest an accelerating growth, but the growth rates slow in later years when land becomes filled. A model that assumes growth will continue to accelerate might overestimate the amount of traffic, depending upon the stage of development at the time the analysis is done.



Source: *Guidebook on Statewide Travel Forecasting* (25).

Figure 10-1. Stages of development.

Although time-series models are not suitable for policy analysis, it is useful if economic trends are included, since existing forecasts of the local economy can be readily available. A good understanding of statistics is necessary for the more advanced methods.

It is best to avoid fishing expeditions when choosing explanatory variables. Explanatory variables should have a logical relationship to the amount of traffic, so irrelevant variables should be discarded immediately. Do not choose variables simply because they have a significant correlation with traffic volume.

10.1.5.1 Disadvantages/Issues

Time-series methods have no variables for driver behavior. Many typical policy questions (such as pricing, modal options, and capacity expansions) cannot be handled. Time-series models are insensitive to small-scale changes in development patterns.

Time-series models are not usually transferable from one location to another, although independent variables that are significant at one location might also be significant at a nearby location.

10.1.5.2 Possible Strategies to Mitigate/Minimize Impacts of Disadvantages/Issues

The analyst needs to be cognizant of the limitations of this method. A fresh time-series model must be estimated for each road segment.

10.1.6 Executing the Technique

10.1.6.1 Special Data Preparation

The only required data items are the traffic volumes for the road (in one or both directions) and the years (or other suitable time periods) for which the data were collected.

Optional data include time series of demographic and economic data that are thought to be correlated with volume. Other events (such as spikes in fuel prices, holidays, special events, natural disasters, and effective dates of laws and treaties) should be expressed as a set of time series. Time-series data have three general forms: trends, impulses, and steps, as shown in Figure 10-2.

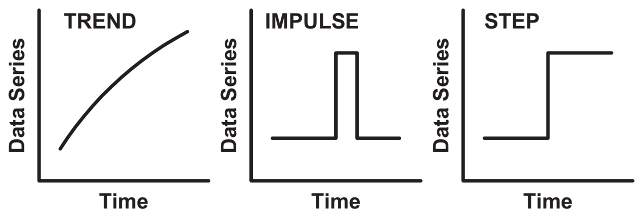


Figure 10-2. General forms of data series.

All data items need to be coordinated. That is, they must be referenced to the same starting date and there must be complete data in all of the time series for all dates for which there is volume data. In some cases, it may be necessary to interpolate within a time series to fill in missing data items.

10.1.6.2 Configuration of the Technique

The reference date for the analysis could be the first period (e.g., year) of the data or an arbitrary date somewhat earlier than the first period. It is undesirable to use the full year (e.g., 2005) explicitly as an independent variable, because this practice can result in nonsensical estimates for year zero.

If autoregression of volume data is being considered and the technique is being implemented on a spreadsheet, then it will be necessary to repeat the volume data series at various "lags." Autoregression uses a time series to estimate itself. For example, traffic volume for June in some future year might be predicted, partially, from traffic volume for June in the immediately previous year. So to create such a regression, monthly traffic volumes would need to be incorporated as an independent variable, but offset by 12 months. Since traffic volumes follow fairly regular patterns, a good set of lags is generally obvious; however, textbooks on time-series analysis give guidelines for choosing lags based on "autocorrelations" and "partial autocorrelations," which are statistics provided by specialized time-series software and are helpful when the properties of a time series are unknown. Some studies of traffic have shown the desirability of doubling the lag to give greater statistical strength to the model.

For example, it may be helpful to use as independent variables monthly traffic volumes lagged at 24 months and monthly traffic volumes lagged at 12 months.

Software specifically designed for time-series analysis will create the lags with internal logic, rather than physically shifting data around.

Trends are expressed in natural units such as vehicles, dollars, and people. Steps and impulses are expressed as dummy (0,1) variables. Dummy variables have the value of 1 when something is happening and a value of 0 otherwise. Transients (lasting, but diminishing, effects of impulses and steps) are typically ignored.

Software suitable for the envisioned analysis must be obtained. This discussion will be limited to those methods that can be readily implemented within spreadsheet software.

10.1.6.3 Steps of the Technique

STEP 1. Obtain Data Series and Associated Data

While time-series models can be built with only a few data points, strong models require many data points over many years. Monthly or daily traffic volumes can be accommodated and will improve the quality of estimated coefficients. Data about explanatory variables should be obtained as well. Since traffic levels are known to be related to population, employment, and other economic factors, an effort should be made to obtain data on regional totals of these types of variables. Other data worth obtaining are dates of major events that could have affected traffic levels. It is important to avoid explanatory data that cannot be reliably forecast.

Explanatory variables should always make intuitive sense. Care should be taken to not include pairs of explanatory variables that are essentially measuring the same thing. For example, employment and gross domestic product for a region would likely be highly correlated, and having both variables in the model would not be better than having just one of these variables.

Identify any natural periodic variation in the traffic volume data. Traffic in most locations varies regularly by hour across a weekday, by day across a week, and by month across a year. These regular patterns of variation readily suggest how moving averages should be created or how lags should be introduced.

Descriptive information about the site and development trends will assist the process of choosing the model structure.

Gaps can occur in a data series. For data series without periodic variation, missing data items should be filled in with linear interpolation between adjacent periods. For a data series with periodic variation, interpolation should be made between similar periods. For example, a missing data item from June 2005 should be interpolated from June 2004 and June 2006, rather than from May 2005 and July 2005.

All data series must be placed on the same timeline.

STEP 2. Choose and Configure a Method

Choose a method or combination of methods to analyze the time series. There are two classes of time-series models that are recommended for project-level travel forecasting under most circumstances:

- Linear trend models with optional explanatory variables, central moving averaging, and Box-Cox transformation; and
- Autoregressive models with optional explanatory variables and Box-Cox transformation.

Central moving averaging removes periodic variation in a time-series, so the remaining data series reflects only long-term trends. Box-Cox transformations create more consistent variation throughout the data series.

A linear trend model estimates this equation, statistically:

$$T_n = an + b_0 + b_1x_1 + b_2x_2 + \cdots + \varepsilon_n$$

where b_0, b_1, and b_2 are estimated coefficients and x_1 and x_2 are explanatory variables. ε_n is the error in year n, and it is required to form an equality, but it is always set to zero when doing any forecast.

An autoregressive (AR) model estimates this equation, statistically:

$$T_n = a_1T_{n-1} + a_pT_{n-p} + a_qT_{n-q} + \cdots + b_0 + b_1x_1 + b_2x_2 + \cdots + \varepsilon_n$$

where a is an estimated coefficient, T_{n-1} is the traffic volume one period earlier (lag = 1), T_{n-p} is the traffic volume p periods earlier, and T_{n-q} is the traffic volume q periods earlier. The lags (p, q and any others) should be selected to match internal properties of the traffic-volume time series and to increase the quality of the statistical fit. There may be several lags.

Choice of model structure should also be made considering local factors, such as stage of development. The ARIMA family allows for models that are much more complicated than autoregression, and while these models could be explored in special cases, experience suggests that autoregression is sufficient for estimating traffic volumes. Textbooks on time-series models should be consulted for a full explanation of ARIMA.

Analysts who perform time-series analysis often mix and match parts of the ARIMA acronym to describe their model. A pure autoregressive model would be designated as AR. An autoregressive model with explanatory variables would be designated as ARX, as described here. A similar model with a spatial component or a seasonal component would be SAR or SARX. Many other combinations are possible. In addition, numbers are often added after the name of the technique in parentheses to indicate the "order" of the model. A full ARIMA model would have three numbers to indicate the "order" of the AR, I, and MA parts, respectively.

An AR model, as described here, would have just a single number indicating the number of lags in the model. So an AR model with two lags will often be described as being AR(2), regardless of the size of the lags.

STEP 3. Smooth and/or Transform Data Series

Linear trend models sometimes use time series that are smoothed to remove periodic variation before estimation. This is accomplished by averaging all data items within about one-half period ahead and within about one-half period behind. The total number of items within the average should equal the number of periods in the cycle. (The number of periods ahead and the number of periods behind cannot be kept exactly equal when there is an even number of periods in the cycle.) For example, a smoothed traffic volume for January 2005 could be found by averaging July 2004 through June 2005.

In order to later recover the cyclical patterns after smoothing, it is necessary to calculate seasonal adjustment factors. Seasonal adjustment factors are the average of the ratios of the original series and the smoothed series for all similar periods in the cycle.

A time series may be transformed to remove uneven variation, which is referred to as "heteroscedasticity." Variations in traffic volumes tend to increase when overall traffic levels increase. In places where traffic is growing over time, linear regressions will inadvertently place more weight on parts of the data series with the most variation, usually the latest parts. It is considered good practice to plot the time series, usually after any smoothing, to identify any heteroscedasticity. If a problem is perceived, then it may be necessary to apply a Box-Cox transformation to the series to reduce heteroscedasticity. A Box-Cox transformation is accomplished by applying one of these two equations to the data:

$$T_\beta = \frac{T^\beta - 1}{\beta}, \quad \beta > 0$$

or

$$T_\beta = \ln T, \quad \beta = 0$$

depending upon the value of β selected. In these equations, T is the original data, and T_β is the transformed data. Values of β of 0 (logarithmic transformation) or 0.5 have natural interpretations, so they should be tried first. A rule of thumb is that a good value of β has been selected when all thirds (earliest, middle, and latest) of the transformed data series have approximately the same standard deviation.

Estimates must be later untransformed by inverting these equations with the same value of β. That is,

$$T = (1 + \beta T_\beta)^{1/\beta}, \quad \beta > 0$$

or

$$T = e^{T_\beta}, \quad \beta = 0$$

depending upon the original choice of β.

STEP 4. Estimate the Model

Different statistical software packages have different ways of configuring the analysis. This discussion assumes that the analysis will be performed with a spreadsheet containing a multivariate linear regression tool.

Time series are usually ordered with earliest dates first. Each variable gets its own column and each time period gets its own row. Building lagged variables on a spreadsheet is accomplished by repeating the independent variable, but shifting it downward (later) by the number of rows suggested by the lag.

The usual guidelines for building linear regression models apply. Variables should be included when their coefficients are significantly different from zero with 95% confidence according to the t-test. The signs and magnitude of the coefficients of the explanatory variables should be reasonable.

It is especially important to inspect the coefficients for the correct sign. An expected sign is often an indication of multicollinearity, that is, two independent variables being highly correlated with each other. Such cases require special attention to determine whether both variables are necessary within the model.

An "autocorrelation" is the Pearson correlation coefficient of the independent variable with itself at a given lag. It is sometimes useful to inspect a variety of autocorrelations to determine which lags might be worth testing in the equation.

The estimated time series should be plotted against the actual time series to determine whether there are any further issues. Discrepancies early in the time series are not as problematic as discrepancies in more recent periods. If there are no serious discrepancies, or if discrepancies are simply anomalous, then the model is ready. Otherwise, there may be a need to restructure and re-estimate the model.

It is useful to make note of the standard error of the estimate, as given by the statistical software. This standard error will allow the analyst to place confidence bounds on any forecasts that are made with the statistical model. This report recommends that confidence bounds be set according to the "probable error," that is the range in which forecasted traffic levels fall 50% of the time. The relationship between the probable error and the standard error, assuming a normal distribution, is the following:

$$E_{50} = 0.6745s$$

where E_{50} is the probable error, and s is the standard error of the estimate.

STEP 5. Special Steps in Applying the Model

If the time series has been transformed before estimation, then the estimated equation will forecast a transformed traffic volume. This transformation must be reversed by inverting the appropriate Box-Cox equation, as described in Step 3.

If the time series has been subjected to a central moving average to remove periodic variation, then "seasonal" adjustment factors should be applied to the forecast. Autoregressive models should already have had their seasonality captured by the coefficients of the lagged variables.

10.1.6.4 Working with Outputs of Technique

A traffic forecast requires that all inputs be separately forecast for the future period. Existing economic and population forecasts can be interpolated between their forecast years, if necessary, so that they correctly match the year of the traffic forecast. The error term and the dummy variable values for any unusual, nonrecurring events are all set to zero.

Trend models can directly calculate traffic volumes for the forecast time period. However, with autoregressive models, there needs to be a separate forecast for every time period beyond the last period with full data, because all the lags must be calculated before the forecast can be completed.

Some agencies have a policy to enforce a minimum growth rate, say 0.5% per year, regardless of the results of the statistical analysis. Such a policy seemed prudent during periods of growth in freight traffic, growth in population, growth in automobile ownership rates, urban decentralization, and affordable gasoline prices. However, after several decades of a nearly continuous increase, overall traffic in the United States remained relatively constant, on average, between 2005 and 2012. Enforcing an arbitrary minimum growth rate should be done only when the analyst is satisfied that long-term growth trends will continue well into the future.

10.1.7 Illustrative Example

Table 10-1 shows the last 3 years of ferry boat traffic data assembled by Savage (*124*).

It can be seen that traffic is increasing each year, but there is considerable month-to-month variation. Traffic peaks in August, and there is comparatively little traffic during the cold months of November to April.

An equation for ferry traffic can be estimated in many different ways. For this example, traffic for August of Year 4 for this example (8 months after the last data point) was forecasted with a linear trend model with a central moving average and an autoregressive model.

Table 10-1. Ferry traffic data.

Month	Year 1	Year 2	Year 3
January	2,848	2,465	3,464
February	2,502	2,555	3,095
March	2,814	3,446	4,035
April	4,350	4,797	5,295
May	5,656	6,059	6,790
June	7,623	8,440	9,286
July	9,263	10,819	11,294
August	9,949	11,904	11,672
September	7,680	8,949	9,221
October	6,147	6,896	7,000
November	4,737	5,322	5,605
December	4,665	5,040	5,241

Table 10-2. Central moving averages.

Month	Year 1	Year 2	Year 3
January		5,850	6,741
February		5,980	6,781
March		6,143	6,762
April		6,249	6,784
May		6,311	6,793
June		6,360	6,816
July	5,686	6,391	6,833
August	5,654	6,474	
September	5,659	6,519	
October	5,711	6,568	
November	5,749	6,610	
December	5,782	6,671	

Table 10-3. Seasonal adjustment factors.

Month	Factor
January	0.467600
February	0.441848
March	0.578860
April	0.774094
May	0.979826
June	1.344698
July	1.660945
August	1.799115
September	1.364957
October	1.063083
November	0.814597
December	0.781164

10.1.7.1 Linear Trend Model

Table 10-2 contains the central moving averages for the illustrative example, computed from the current month, all 6 months behind and all 5 months later.

Table 10-3 contains the seasonal adjustment factors.

The smoothed data series is plotted in Figure 10-3. Note that only 25 months of data remain.

The plot revealed that there is almost a linear trend and that there was no need to transform the data series to eliminate heteroscedasticity. June of Year 1 is taken to be period 0 and the following equation was estimated:

$$T_n = 57.5n + 5567$$

where n is the number of periods from June of Year 1, an arbitrarily selected period. The adjusted R-square for this model is 95.1%, and the t-score for the period is 21.7, which indicates significance at the 95% confidence level. The standard error of the estimate is 95.47 vehicles.

August of Year 4 is 38 months after June of Year 1. So the traffic forecast for August of Year 4 is the following:

$$T_{39} = (57.5 * 38 + 5567) * 1.80 = 13{,}954$$

after applying the seasonal adjustment factor (rounded to 1.80) for August. The probable error is:

$$E_{50} = 0.6745 * 95.47 * 1.80 = 115.9$$

noting that the standard error of the estimate applies to the smoothed data series before applying the seasonal adjust-

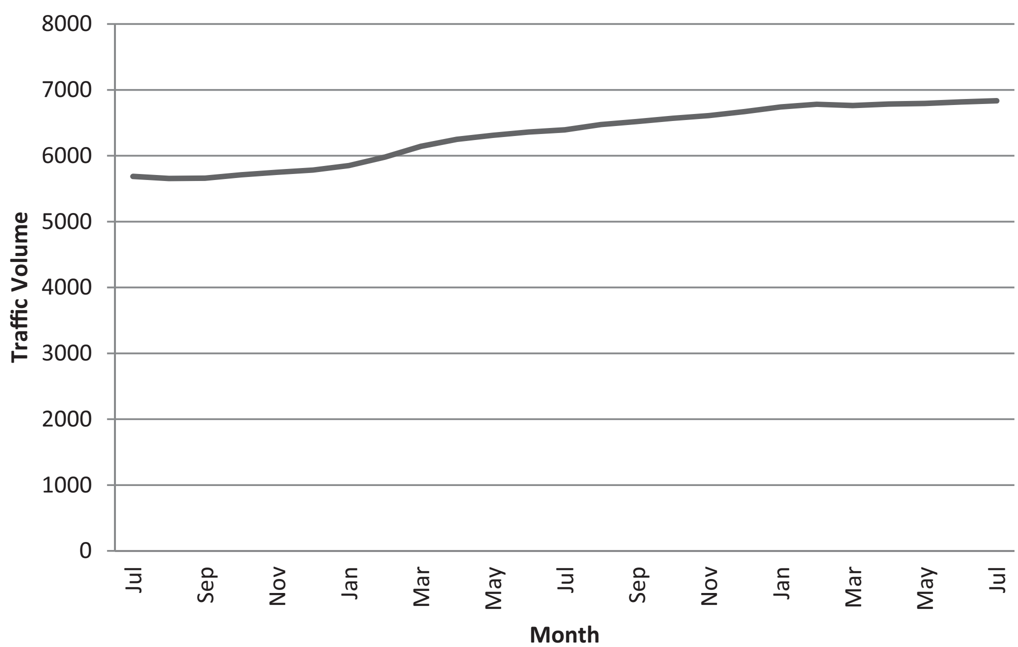


Figure 10-3. Plot of smoothed ferry traffic.

ment factor. So it can be said that the forecasted traffic is 13,954 ± 116 vehicles per month.

10.1.7.2 Autoregressive Model

It is clear by visual inspection of the time series that the natural lags of an autoregressive model might be 1 and 12. So for example, August in Year 4 would be forecast with information from July of Year 4 and August of Year 3. Consideration of additional lags should wait until after these two lags have been tried.

The traffic data series was neither smoothed nor transformed for this model. Creating the lags meant losing 12 of the data points. The remaining data were for Years 2 and 3, only. Table 10-4 shows how the data look for the last 6 months of Year 3. Note that all of the numbers in Table 10-4 can be found somewhere on Table 10-1.

The regression of traffic with its two lags resulted in the following AR(2) model:

$$T_n = 0.022 * T_{n-1} + 1.029 * T_{n-12} + 249$$

with an adjusted R-square of 96.9%. The t-scores for the lag at 1 and the constant were not significant, so the model needed to be re-estimated, first by eliminating the lag at 1. This gave an AR (*123*) model:

$$T_n = 1.049 * T_{n-12} + 275$$

with an adjusted R-square also of 97.0%. The constant was still not significant, so eliminating the constant gave the following:

$$T_n = 1.087 * T_{n-12}$$

with an adjusted R-square of 95.2%. The t-score for T_{n-12} was 68.6, which was excellent. This model is actually a form of growth factor model, applied to traffic 12 months earlier, with a growth rate of 8.7% each year. The standard error of the estimate is 513.9 vehicles.

Forecasting with an autoregressive model usually requires computing forecasts for every period leading up to the desired period, because the lag at 1 period needs to be computed period by period. However, in this case, there is no lag at 1, so only the traffic level from the previous August, which is already known, was needed. So the forecast was the following:

$$T_n = 1.087 * 11{,}672 = 12{,}687$$

The probable error is then the following:

$$E_{50} = 0.6745 * 513.9 = 346.6$$

The forecast should be reported as 12,687 ± 347 vehicles. Note that the linear trend model and the autoregressive model give different forecasts by more than 1,000 trips; this is probably because August of Year 3 has lower traffic than August of Year 2, which is affecting the two models in different ways.

A full-scale application of time-series methods is provided in Case Study #5 (see Section 11.5) of truck traffic across the Blue Water Bridge in southeast Michigan.

Table 10-4. Sample of ferry traffic data with lags.

Month	Traffic, Original	Traffic Lagged by 1	Traffic Lagged by 12
July	11,294	9,286	10,819
August	11,672	11,294	11,904
September	9,221	11,672	8,949
October	7,000	9,221	6,896
November	5,605	7,000	5,322
December	5,241	5,605	5,040

10.2 Sketch-Planning Technique: Manual Gravity Model

One form of sketch-level planning performed by the Kentucky Transportation Cabinet is the manual gravity diversion methodology. (It is a "gravity" diversion in that trips are diverted to the new route based on its attractiveness, expressed as a distance and travel time advantage over the existing route.) Details of this procedure can be referenced in *Traffic Forecast Special Report—Manual Gravity Diversion Methodology* (*72*). The basis for this methodology is to determine travel patterns and traffic diversion to new facilities in areas where travel demand models do not exist. The procedures are built on *NCHRP Report 387: Planning Techniques to Estimate Speed and Service Volumes for Planning Applications* (*73*, pp. 79–84) and research by the California Department of Transportation (DOT).

The data inputs required to perform a manual gravity diversion for a new facility include the following:

- Traffic control data (posted speed, signal information, segment lengths, etc.),
- Physical characteristics (number of lanes, lane widths, turn bays, directional factors, etc.),
- Traffic characteristics (growth rate, K factor, peak-hour factor, truck percentage, etc.),
- Base year no-build average daily traffic (ADT) volumes,
- Future year no-build ADT volumes, and
- ADT turning movements at major intersections.

There are five steps involved in performing a manual gravity diversion to determine the traffic volume diverted to a new facility. These five steps are presented in the remainder of this section. The five steps are the following:

1. Estimate free flow speed.
2. Calculate roadway capacity.
3. Generate the no-build traffic forecast.
4. Estimate congested travel speed.
5. Apply California DOT deviation curves.

STEP 1. Estimate Free Flow Speed

The recommended method for estimating free flow speed (in units of miles per hour) is to obtain a field measurement under light traffic conditions. However, when field measurements are unavailable, the Kentucky Transportation Cabinet report suggests using one of two equations to estimate free flow speed, one for facilities without signals and one for signalized facilities.

For facilities without signals:

Free Flow Speed (Sf) = 0.88 * Sp + 14, for speed limit (Sp) > 50 mph

Free Flow Speed (Sf) = 0.79 * Sp + 12, for speed limit (Sp) < 50 mph

For signalized facilities:

Free Flow Speed (Sf) = L / [L/Smb + N * (D/3600)]

where

L = length of facility (miles);
N = number of signalized intersections on length, L, of facility;
Smb = 0.79 * Sp + 12 = midblock free flow speed (mph); and
D = DF * 0.5 * C $(1 - g/C)^2$ = average delay per signal (seconds)

where

D = total signal delay per vehicle (sec);
g = effective green time (sec); and
C = cycle length (sec).

If signal timing data are not available, the following defaults can be used:

C = 120 sec,
g/C = 0.45,
DF = 0.6 for coordinated signals with highly favorable progression, 0.9 for uncoordinated actuated signals, 0.9 for coordinated signals with favorable progression, 1.0 for uncoordinated fixed time signals, and 1.2 for coordinated signals with unfavorable progression.

STEP 2. Calculate Roadway Capacity

The Kentucky Transportation Cabinet report offers capacity equations for three major facility types based on *NCHRP Report 387* and simplified *Highway Capacity Manual* (HCM) methods—freeways, two-lane unsignalized roads, and signalized arterials.

The capacity equation for freeways is the following:

*Capacity (vph) = Ideal Cap * N * Fhv * PHF*

where

Ideal Cap = 2,400 (pcphl) for freeways with 70+ mph FFS, otherwise 2,300 (pcphl).
N = number of through lanes.
Fhv = heavy vehicle adjustment factor—
= 1.00 / (1.00 + 0.5 * HV) for level terrain,
= 1.00 / (1.00 + 2.0 * HV) for rolling terrain, and
= 1.00 / (1.00 + 5.0 * HV) for mountainous terrain.
HV = proportion of heavy vehicles (if unknown, use 0.05 as default).
PHF = peak-hour factor (ratio of the peak 15-minute flow rate to the average hourly flow rate). If unknown, use default of 0.90.

The capacity equation for two-lane unsignalized roads is the following:

*Capacity (vph) = Ideal Cap * N * Fw * Fhv * PHF * Fdir * Fnopass*

where

Ideal Cap = 1,600 (pcphl) for all two-lane rural roads.
N = number of lanes.
Fw = lane width and lateral clearance factor = 1 + (W – 12)/30. W is the lane width in feet. If W is unknown, use 0.8 if there are narrow lanes (<12 feet) and/or narrow shoulders (<3 feet); otherwise use 1.0.
Fhv = heavy vehicle adjustment factor—
= 1.00 / (1.00 + 1.0 * HV) for level terrain,
= 1.00 / (1.00 + 4.0 * HV) for rolling terrain, and
= 1.00 / (1.00 + 11.0 * HV) for mountainous terrain.
HV = proportion of heavy vehicles. If unknown, use 0.02 as default.
PHF = peak-hour factor (ratio of the peak 15-minute flow rate to the average hourly flow rate). If unknown, use default of 0.90.
Fdir = directional adjustment factor = 0.71 * 0.58 * (1 – peak direction proportion). If unknown, use 0.55 as default peak direction proportion.

Fnopass = no-passing zone factor—
= 1.00 for level terrain,
= 0.97 – 0.07 * (*NoPass*) for rolling terrain, and
= 0.91 – 0.13 * (*NoPass*) for mountainous terrain.

NoPass is the proportion of length of the facility for which passing is prohibited. If unknown, use 0.6 for rolling terrain and 0.8 for mountainous terrain.

The capacity equation for signalized arterials is the following:

$$Capacity\ (vph) = Ideal\ Sat * N * Fw * Fhv * PHF * Fpark * Fbay * FCBD * g/C$$

where

Ideal Sat = 1,900 = ideal saturation flow rate (vehicles per lane per hour green).
N = number of lanes.
Fw = lane width and lateral clearance factor = 1 + (W – 12) / 30. W is the lane width in feet. If W is unknown, use 0.8 if there are narrow lanes (<12 feet) and/or narrow shoulders (<3 feet); otherwise use 1.0.
Fhv = heavy vehicle adjustment factor = 1.00 / (1.00 + 1.0 * HV) for level terrain.
HV = proportion of heavy vehicles. If unknown, use 0.02 as default.
PHF = peak-hour factor (ratio of the peak 15-minute flow rate to the average hourly flow rate). If unknown, use default of 0.90.
Fpark = on-street parking adjustment factor = 0.9 if on-street parking is present and parking time limit is ≤1 hour, otherwise 1.0.
Fbay = left turn bay adjustment factor = 1.1 if exclusive left-turn lanes are present or if streets are one way streets, otherwise 1.0.
FCBD = central business district (CBD) adjustment factor = 0.9 if located in CBD, otherwise 1.0.
g/C = ratio of effective green time per cycle. If no data are available, use defaults—
= 0.4 if protected left-turn phase is present and
= 0.45 if protected left-turn phase is not present.

STEP 3. Generate the No-Build Traffic Forecast

The no-build traffic forecast consists of ADT traffic volumes and turning movement volumes at major intersections for both the base year and design year. Base year ADT volumes are commonly estimated from observed traffic counts and historical count data. Historical growth rates based on socioeconomic trends and linear regression or other regression analysis of historical count data can be applied to the base year traffic volumes to determine future year traffic volumes. For turning movement volumes, the Kentucky Transportation Cabinet report recommends using observed turning movement counts or using approach ADT volumes and a turning movement program such as *turns.bat* and checking for reasonableness.

STEP 4. Estimate Congested Travel Speed

Using the Bureau of Public Roads (BPR) equation, the analyst can estimated the congested travel speeds for each roadway segment in the base year and design year. The following BPR equation is recommended by the Kentucky Transportation Cabinet report:

$$S = Sf/[1 + a * (v/c)^b]$$

where

S = congested speed (mph);
Sf = free flow speed (mph);
v = generalized hourly volume (vph) = ADT * 0.10 (default K factor);
c = segment capacity (vph);
a = 0.05 for facilities with signals spaced 2 miles apart or less, otherwise 0.2; and
b = 10.

The modified BPR curve from the Kentucky Transportation Cabinet report is presented graphically in Figure 10-4. This curve shows the relationship between the volume-to-capacity ratio and congested speed. The relationship established in the modified BPR curve is based on a maximum v/c ratio of 1.25; beyond this point, the modified BPR equation relationship is no longer valid.

STEP 5. Apply California DOT Deviation Curves

The final step in the Kentucky Transportation Cabinet manual gravity diversion methodology is to apply the California DOT deviation curves to origin-destination (OD) volumes to produce base year and design year volumes on the new facility. The steps involved in this application include the following:

1. Determine the volume of traffic moving between a given OD pair:
   a. Start with the ADT at the origin and reducing it by the percentage of through trips from the estimated turning movements until the destination is reached.
   b. The volume moving between the OD pair may also be reduced to account for changes in the ADT along the segment due to local destinations.
   c. The procedure is repeated in the opposite direction (starting at the destination), and the two resultant volumes are averaged to determine an approximate volume of traffic moving between the given OD pair.

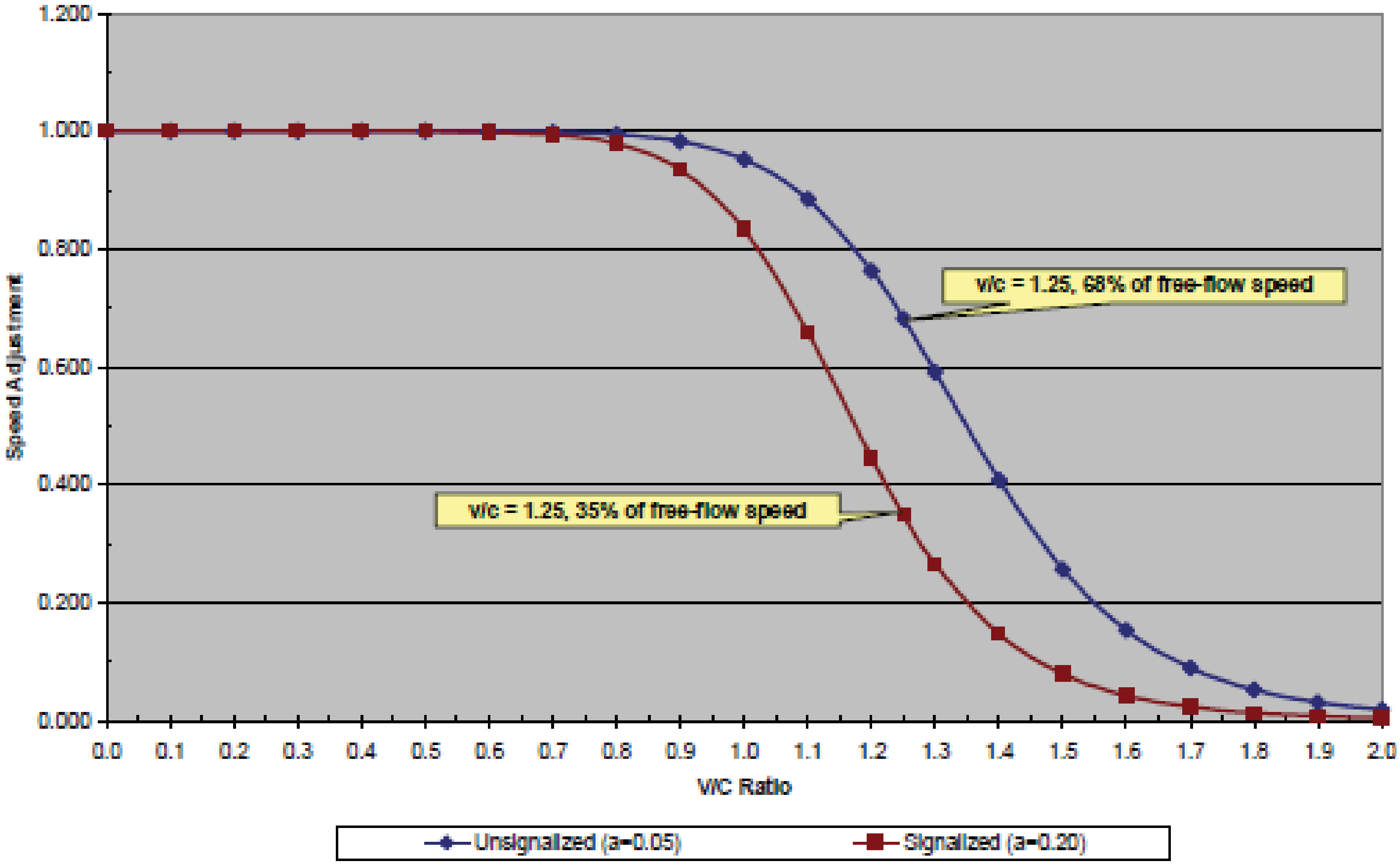


Figure 10-4. Modified BPR curve.

2. Determine the distance between the OD pair using the existing route (de) and the best available route (db) using the new facility:

   Distance saved, $\Delta d = d_b - d_e$

3. Determine the congested travel times between the OD pair using the congested travel time of the existing route (t_e) and the best available route (t_b) using the new facility:

   Time saved, $\Delta t = t_b - t_e$

4. Calculate the percentage (P) of diverted traffic using the California DOT deviation equation:

   $P = 50 + 50 * (\Delta d + 0.5 * \Delta t)/\text{SQRT}\ [(\Delta d - 0.5 * \Delta t)^2 + 4.5]$

5. Multiply the OD volume by P and assign this volume to the bypass; assign the balance to the existing route.
6. Repeat Steps 1–5 for every OD pair that may use the new bypass facility.
7. For the design year analysis, increase the volume assigned to the new facility by 20% to account for observed trends in induced traffic on a new facility. This volume increase is generally observed in the through trips rather than any in-town traffic that may use the facility.

The manual method is based on link distance and travel time accounting for congestion and uses recent count data and estimates of turning movements to determine travel patterns and the percentage of through trips. This manual method approach is compared to *NCHRP Report 365* procedures developed by D. G. Modlin, Jr., and the report provides guidance on appropriate uses for each of the methods.

10.3 Elasticity Methods

10.3.1 Abstract

An elasticity is the fractional change in an output divided by the fractional change in an input. When a travel demand model is not available to cover a specific change by a project to a traffic system, then it may be necessary to use an elasticity to estimate the effect of that change. Elasticities can also be used to validate the results of a travel demand model, and elasticities can be used to extrapolate the results of a travel demand model to situations not originally covered by the travel demand model. Normally, elasticities are derived empirically by observing the effects of system changes locally or elsewhere. Many elasticities are available in the transportation literature.

10.3.2 Context

Typical applications are travel demand management, benefit/cost, and tolling.

Geography is small area.

Typical time horizons are short range, interim, and long range.

Required input data are recent mainline counts and recent intersection counts.

Optional input data varies.

Advantages of elasticity methods are that they are very quick and inexpensive; good for "back-of-the-envelope" assessments, and a large inventory of elasticities exists, covering a wide variety of system changes.

Disadvantages of elasticity methods are that they are simplistic, and it is often difficult to verify the reliability of a borrowed elasticity.

10.3.3 Background

Elasticity methods are among the simplest of forecasting models. An elasticity is a fractional change of an output divided by a fractional change of an input. An elasticity is sometimes called a "sensitivity." An elasticity should theoretically exist at a single point of an input and an output; however, as a practical matter, an elasticity is most often computed from before and after states of a system, so it is necessary to involve at least two points of inputs and outputs. Transportation planners have been most comfortable with using the "midpoint arc" elasticity (see *TCRP Report 95*, *Chapter 1*), η:

$$\eta = \frac{\Delta Q/[(Q_1 + Q_2)/2]}{\Delta P/[(P_1 + P_2)/2]}$$

where P is an input and Q is an output for two states of the system: "1" (before) and "2" (after).

Other formulations exist. However, *TCRP Report 95* emphasizes the "log arc" elasticity:

$$\eta = \frac{\Delta log Q}{\Delta log P}$$

Nonetheless, given small changes in input, these two formulas will yield approximately the same results.

Economists use elasticities extensively to describe the relationships between the price of a good (P) and the amount of sales (or demand) of a good (Q). Since price is almost always inversely related to sales, the "price elasticity of demand" is almost always a negative number. Economists often omit the minus sign when specifically talking about price elasticities, as this inverse relationship is generally understood. A good is said to be "elastic" if the price elasticity is substantially greater than one (excluding the minus sign) and is said to be "inelastic" if the price elasticity is substantially less than one. A price elasticity of exactly one is revenue neutral; that is, total sales in monetary units will be constant regardless of change in price. Of course, elasticities can be used to describe many processes other than the effect of price changes on sales, and in those cases the sign attached to the elasticity is left intact.

Once an elasticity has been ascertained and deemed to be applicable and reliable, then the forecasted output (Q_2) can be readily computed from the forecasted input (P_2), the current output (Q_1), and the current input (P_1).

A "cross-elasticity" tells how much the sales for one good would change if there were a change in price of another good, usually a competitive product. For example, there are many analysts in the freight industry who are keenly interested in the cross-elasticities between railroads and trucks, that is, the percent increase in railroad shipments given a 1% increase in truck price.

10.3.4 Why This Technique

Elasticity methods can be applied very quickly, if there has already been sufficient research to establish the elasticity value to a reasonable degree of accuracy.

Elasticities are available for many situations that would be difficult to assess with a travel demand model.

10.3.5 Words of Advice

Finding local data to establish an elasticity is often difficult or impossible, so there is a strong temptation to borrow an elasticity from elsewhere. It is critically important to verify that the circumstances of the borrowed elasticity are sufficiently similar to what should be experienced in the forecast.

10.3.5.1 Disadvantages/Issues

Not every system change has a well-established elasticity. Elasticity methods can be simple summaries of complex, multivariate events. There are disagreements between studies of the same elasticity. A constant elasticity demand function exists only in theory, so it is important to confine system changes to a narrow range, when possible.

10.3.5.2 Possible Strategies to Mitigate/Minimize Impacts of Disadvantages/Issues

The analyst needs to be willing to recommend other forecasting methods, if good elasticities cannot be calculated or borrowed.

10.3.6 Executing the Technique

10.3.6.1 Special Data Preparation

An elasticity may be obtained by comparing before and after conditions when there is a change in a fundamental property of the system, by doing a statistical analysis of a time series, or by adopting a value from another location. There are different ways to compute an elasticity from the same data, so when adopting an elasticity from another location it is important to understand how that elasticity was originally calculated.

10.3.6.2 Obtaining an Existing Elasticity

Elasticities may be borrowed from elsewhere. The most extensive compendium of elasticity values for transportation planning is *TCRP Report 95: Traveler Response to Transportation System Changes Handbook* (*38*), which describes a variety of situations in which there was a behavioral impact. *TCRP Report 95* includes 19 chapters, each of which is a separate publication covering a specific topic:

- Chapter 1: Introduction,
- Chapter 2: HOV Facilities,
- Chapter 3: Park-and-Ride/Pool,
- Chapter 4: Busways, BRT, and Express Bus (planned),
- Chapter 5: Vanpools and Buspools,
- Chapter 6: Demand-Responsive/ADA,
- Chapter 7: Light Rail Transit (planned),
- Chapter 8: Commuter Rail (planned),
- Chapter 9: Transit Scheduling and Frequency,
- Chapter 10: Bus Routing and Coverage,
- Chapter 11: Transit Information and Promotion,
- Chapter 12: Transit Pricing and Fares,
- Chapter 13: Parking Pricing and Fees,
- Chapter 14: Road Value Pricing,
- Chapter 15: Land Use and Site Design,
- Chapter 16: Bicycle and Pedestrian Facilities,
- Chapter 17: Transit-Oriented Development,
- Chapter 18: Parking Management and Supply, and
- Chapter 19: Employer and Institutional TDM Strategies.

10.3.6.3 Computing an Elasticity from Local Before/After Data

If the current planning situation mirrors an historical event, then that event may be mined for an elasticity. Many of the elasticities reported in *TCRP Report 95* were obtained in this way, that is, by direct application of the definition of log arc elasticity. For example, in 1998, Lee County, Florida, implemented a reduction of tolls on a bridge during off-peak periods for certain drivers with discount passes to encourage them to shift away from congested peak periods (*127*, *128*). A toll was originally \$0.50 per trip, and it was effectively reduced by 50% to \$0.25 per trip. There were a number of measurable behavioral effects. Among those drivers with passes, there was a 17.8% increase in the number of trips during the pre-AM peak period. For the sake of clarity, assume that there were 1,000 drivers originally making the trip during the pre-AM period and 1,178 drivers making the same trip after the decrease in tolls. The log arc elasticity was

$$\eta = \frac{\Delta logQ}{\Delta logP} = \frac{log(1178) - log(1000)}{log(0.25) - log(0.5)} = -0.236$$

It is most convenient when the changes in travel behavior are observed through counting passengers or vehicles. However, ascertaining complex reactions to system changes might require a survey.

10.3.6.4 Computing an Elasticity from a Time Series

Sometimes elasticities may be obtained from linear regression of time series data with one or more explanatory variables. Consider a simple case of price (P) and demand (Q), for instance, transit fare versus transit ridership, over an extended period of time.

Since a demand function with a constant elasticity throughout takes the form,

$$Q = AP^{\eta}$$

the simple linear regression equation,

$$log(Q) = alog(P) + b$$

will yield a value of the coefficient, a, that can be interpreted as an elasticity and the constant, b, which is arbitrary. So for the transit fare example, log(Q) is the logarithm of ridership and log(P) is the logarithm of fare. There are many variables affecting transit ridership, so a multivariate analysis would likely be necessary to isolate the effects of fare by itself.

It is also worth noting that this equation cannot be used when any input (fare, in this case) is zero, because log(0) is undefined. So an elasticity cannot be derived for systems that went to free transit, such as Chapel Hill, North Carolina, did in 2002.

For example, consider the case of the Belle Urban System (BUS) in Racine, Wisconsin. BUS saw substantial fare increases and ridership decreases in the first decade of the 21st century. Table 10-5 summarizes these trends.

It is also worth noting that BUS has maintained about the same level of service (LOS) during their period of time, as indicated by the maximum number of vehicles used in any given day. Transit systems, when faced with budget woes, will

Table 10-5. Transit data for Belle Urban System (BUS).

Year	Revenue	Unlinked Trips	Consumer Price Index	Revenue per Trip Adjusted	Number Vehicles	Ln Trips	Ln Revenue	Ln Vehicles
2002	$941,710	1,812,512	180.1	$0.29	38	14.410	–1.243	3.638
2003	$994,578	1,566,459	183.9	$0.35	36	14.264	–1.063	3.584
2004	$938,220	1,498,667	189.4	$0.33	35	14.220	–1.107	3.555
2005	$885,105	1,520,634	195.4	$0.30	36	14.235	–1.211	3.584
2006	$942,522	1,534,114	203.5	$0.30	40	14.243	–1.198	3.689
2007	$1,117,316	1,476,489	208.3	$0.36	33	14.205	–1.013	3.497
2008	$1,126,692	1,516,149	220	$0.34	33	14.232	–1.085	3.497
2009	$1,113,796	1,428,438	215.4	$0.36	33	14.172	–1.016	3.497
2010	$1,227,922	1,455,028	218	$0.39	35	14.191	–0.949	3.555

Note: Ln = natural logarithm.

consider cutting service as well as increasing fares, so it is important to control for any service cuts. The Federal Transit Administration provides data on total system revenues and total unlinked trips. The remaining data are derived. This analysis used natural logarithms (Ln), although any logarithmic transformation would have worked. Revenue per unlinked trip is adjusted for the Consumer Price Index to remove effects of inflation.

LnTrips was the dependent variable and LnRevenue and LnVehicles were independent variables in the regression analysis; however, LnVehicles proved insignificant. The following regression equation was obtained with an adjusted R-square of 0.43:

$$LnTrips = -0.484 LnRevenue + 13.71$$

which is entirely reasonable. The elasticity is –0.484, which is the desired answer, and the constant (13.71) is irrelevant. This elasticity should be applied as if it were a log arc elasticity.

10.3.6.5 Steps of the Technique

STEP 1. Obtain Baseline Data and Anticipated Changes

Baseline data may be actual or forecast. Baseline data consist of a known output, typically a level of traffic, and a known input, typically a price or LOS variable. These data are required for each segment of output, if segmentation is desired.

STEP 2. Select or Compute an Elasticity

Follow one of the three options, described earlier, for obtaining elasticity values. If there are multiple segments of travelers with differing sensitivities to the input variable, then an effort should be made to obtain an elasticity for each segment.

STEP 3. Apply the Elasticity

The elasticity should be applied to the best estimate of the output before the system change is made. Using log arc elasticity, the state of the output afterward, Q_2, may be found from:

$$Q_2 = log^{-1}\left[\eta\left(logP_2 - logP_1\right) + logQ_1\right]$$

where η is the elasticity, Q_1 is the original output, P_1 is the original input, and P_2 is the afterward output. If natural logarithms are used, then the inverse log is the exponential function, e^x, and if base 10 logarithms are used, then the inverse log is a power of 10, 10^x.

It is important to segment the population of travelers into those people who are affected by the system change and those who are not.

When different segments of the population of travelers will react more strongly or less strongly to the system change, then different elasticities should be applied to each segment, if those elasticities are available. This segmentation is especially important for price elasticities because people of high income are usually less sensitive to price changes than people of low income.

If there are multiple types of changes, such as price and LOS, then elasticities are needed for all types. The cumulative effect of multiple types of changes is found by applying the effects of each change successively.

Consider a bus route that has a fare arc elasticity of –0.30 (the value from the well-known Simpson-Curtin rule of thumb), a frequency-of-service arc elasticity of 0.5 (see Chapter 9 of *TCRP Report 95* for typical values), and 5,000 riders per day. A proposal is made to reduce service from four buses per hour to three buses per hour and to increase fares from $1.50 to $1.75.

The effect of the change in service is

$$Q_2 = log^{-1}\left[0.5\left(\log(3) - \log(4)\right) + \log(5{,}000)\right] = 4{,}330$$

And the additional effect of the change in fare is

$$Q_2 = log^{-1}\left[-0.30\left(\log(1.75) - \log(1.50)\right) + \log(4{,}330)\right] \\ = 4{,}134$$

The order of the calculations (that is, fare first or service first) does not matter.

10.3.6.6 Working with Outputs of the Technique

If the elasticity is being used to validate a travel demand model, then the travel demand model needs to be run for an identical situation.

Every application of elasticity should be checked for reasonableness.

10.4 Using the Highway Capacity Manual in Project-Level Traffic Forecasting

10.4.1 Pre-Processing and Post-Processing Using the Highway Capacity Manual

Since its introduction in 1950, the *Highway Capacity Manual* (HCM) has been the fundamental reference document of methods and procedures used to evaluate the surface transportation system. The HCM2010, the fifth edition of the manual (*21*), was significantly revised to incorporate the latest research on highway capacity and quality of service. The HCM2010 continues the evolution of the document while keeping in step with present times and the needs of its users. The HCM2010 is organized into four volumes, described below.

10.4.1.1 Volume 1. Concepts

Volume 1 includes the basic information with which an analyst should be familiar before performing capacity or quality of service analyses. The volume includes definitions of parameters that are fundamental to traffic forecasting, such as free flow speed, capacity, and delay.

10.4.1.2 Volume 2. Uninterrupted Flow

This volume contains the methodological chapters related to the analysis of uninterrupted flow transportation system elements. These include methods for the analysis of basic freeway segments and freeway facilities, freeway weaving segments, freeway merge and diverge segments (i.e., entrance and exit ramps), multilane highways, and two-lane highways.

10.4.1.3 Volume 3. Interrupted Flow

Volume 3 contains all of the methodological chapters for the analysis of interrupted flow elements of the transportation system. These include methods for analyzing urban street segments and urban street facilities, which are composed of two or more urban street segments. The chapters include methods for pedestrian and bicycle travel modes, as well as public transit material specific to multimodal analyses. A separate chapter is provided for the analysis of off-street pedestrian and bicycle facilities. Volume 3 also contains chapters for the analysis of signalized intersections, two-way stop-controlled (TWSC) intersections, all-way stop-controlled (AWSC) intersections, roundabouts, and interchange ramp terminals.

Volumes 1 through 3 are provided in both three-ring binder and electronic formats in order to facilitate interim updates to the manual as new research becomes available.

10.4.1.4 Volume 4. Applications Guide

Volume 4 is an electronic-only volume that can be located on the Internet at www.hcm2010.org. It is organized into four main components:

- Supplemental chapters that include more detailed descriptions of certain computational methods,
- Example applications of alternative tools for situations that are not addressed by methods contained in Volumes 2 or 3,
- Additional example problems and results of calculations, and
- New chapters that have been developed since publication of the manual but that have not been adopted yet as enhancements to the methods contained in Volumes 2 or 3.

Volume 4 includes a technical reference library that contains a selection of papers, technical reports, or other documents that provide support and background information for methods in the HCM2010.

With respect to project-level traffic forecasting, there are methods in the HCM2010 prior to processing, as well as facility evaluation after the forecasts have been produced. The methods and/or results can be implemented within a travel demand model or external to the model through the use of manual methods or other computational engines.

10.4.2 HCM2010 Parameters Related to Project-Level Traffic Forecasting

Other sections of these guidelines provide information and analytical methods for dealing with variations in travel demand. Volume 1 in the HCM2010 provides additional information on variations in traffic demand that may be useful in the absence of actual data or computational methods. This includes information on seasonal and monthly variations in traffic demand, daily and hourly variations, peak hour and analysis hour, spatial distributions (directional and lane distributions), and travel time variability. These are provided for automobile, bicycle, pedestrian, and transit modes of travel.

Other parameters defined in the HCM2010 that are specific to pre-processing and post-processing applications related to project-level traffic forecasting include the following:

- **Average Travel Speed.** This is a traffic stream measure based on the travel time observed on a known length of street or highway; it is the length of the segment divided by the average travel time of all vehicles traversing the segment, including delay time associated with stops. When projected or observed traffic demand approaches or exceeds capacity, the average travel speed represents congested speeds that are typically used in travel demand models.
- **Free Flow Speed.** This is a fundamental segment (link) attribute used in travel demand models and/or computational methods used to develop traffic forecasts. It is the average speed of vehicles on a given street or highway segment measured under low-flow conditions.
- **Capacity.** This is the maximum sustainable hourly flow rate at which persons or vehicles reasonably can be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, environmental, traffic, and control conditions.
- **Delay.** In general, delay is the difference in travel time between travel at free flow speed and average travel speed. Specifically, there are several different types of delay:
  - Control Delay. For interrupted flow facilities, control delay is the delay brought about by the presence of a traffic control device (such as a traffic signal or STOP sign).
  - Geometric Delay. This delay is attributable to geometric features causing vehicles to reduce their speed in negotiating a system element (e.g., delay caused by vehicles slowing to make a sharp turn at an intersection).
  - Incident Delay. This is additional travel time experienced due to an incident (compared to the condition where no incident occurred).
  - Traffic Delay. This delay results from the interaction of vehicles (particularly under congested conditions), causing drivers to reduce their speed below free flow speed.
  - Total Delay. This is the sum of control, geometric, incident, and traffic delay.

10.4.2.1 Planning and Preliminary Engineering Applications of the HCM2010 and Their Use in Project-Level Traffic Forecasting

Historically, the HCM has been applied at the operational and design levels of analysis, where most or all of the input values are known and based on observed data. Since the 2000 edition of the manual and particularly with HCM2010, applications for planning and preliminary engineering have been introduced. In principle, the computational methods are the same whether they are applied at the operational, design, or planning and preliminary engineering levels of analysis, but the degree to which default values (and sometimes simplifying assumptions are used) differs.

In planning and preliminary engineering analyses, the analyst applies the HCM2010 methods by using default values for some or nearly all of the method inputs. The results are less accurate than the operational or design analyses, but the use of default values reduces the amount of time and personnel resources needed to perform the analyses. In traffic forecasting, not all of the methodological inputs may be known (e.g., future directional traffic split) and therefore must be assumed or predicted in the absence of actual measurement.

Generalized service volume tables are sometimes used in planning and preliminary engineering analyses to provide a "ballpark" estimate of capacity based on assumed or default inputs to the various computational methods. Either as a pre-processing input estimate of street or highway segment capacity or as a post-processing estimate of LOS, generalized service volume tables can be constructed for general facility types having common characteristics. Multiple sets of service volume tables can be constructed by varying input parameters to reflect characteristic changes like area types (urban, developing, or rural) or facility types (freeways, multilane highways, two-lane highways, or arterials) so that, while still general, more specific estimates of capacity and LOS can be developed.

Traffic models and modelers historically have used some form of speed-flow relationships to estimate travel speed as a function of traffic volume or volume-to-capacity ratio. The BPR equation served as the standard for many years as a simple way to predict speed as a function of volume-to-capacity ratio. The standard BPR curve form is the following:

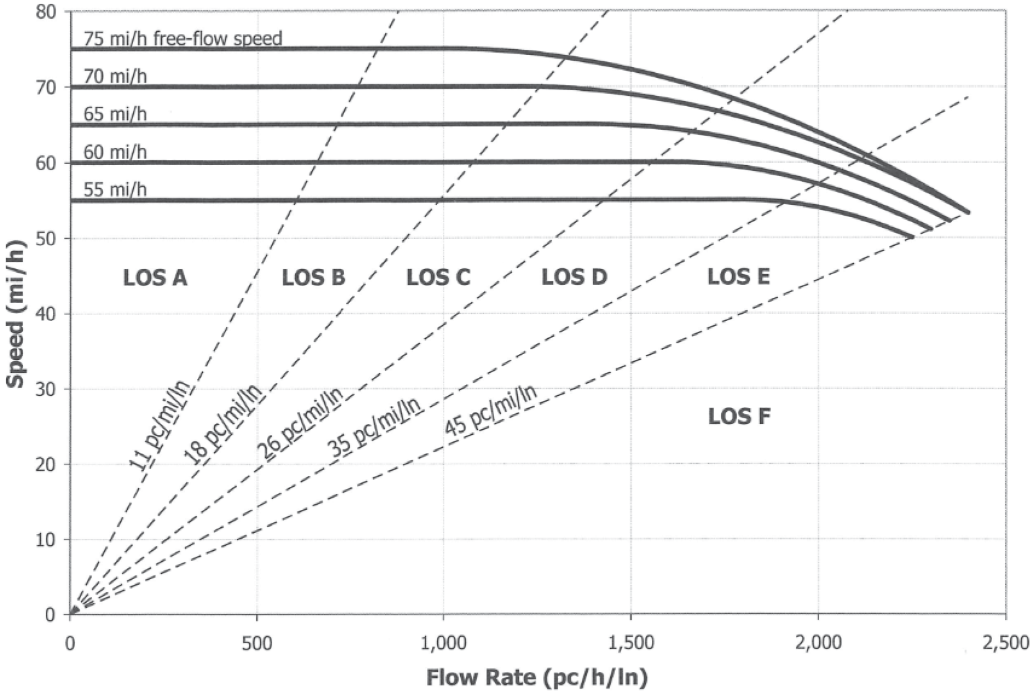
$$s = \frac{s_f}{1 + a\left(\frac{v}{c}\right)^b}$$

where

s = predicted mean speed,
s_f = free flow speed,
v = volume,
c = practical capacity,
a = 0.15, and
b = 4.

In this application, practical capacity was defined as 80% of capacity, and free flow speed was defined as 1.15 times the speed at the practical capacity.

Other modelers developed variations of the basic BPR equation.



Source: HCM2010, Exhibit 11-6 (*21*).

Figure 10-5. Speed-flow curves for basic freeway segments.

The 1994 update to the 1985 edition of the HCM introduced a refined set of speed-flow relationships for basic freeway sections where average passenger car speed is a function of traffic flow rate. This set of curves was developed through research under NCHRP Project 3-45.

The curves were further revised to include a 75-mph curve for basic freeway segments, as included in the 2000 and 2010 versions of the HCM. The curves as presented in the HCM2010 are shown in Figure 10-5.

10.4.2.2 HCM2010 Computational Methods

The HCM2010 provides computational methods for estimating parameters commonly associated with project-level traffic forecasting for different transportation system facility types:

- Basic freeway segments,
- Freeway weaving segments,
- Freeway merge and diverge segments,
- Freeway facilities,
- Multilane highways,
- Two-lane highways, and
- Urban street segments and facilities (including signalized intersections, TWSC intersections, AWSC intersections, and roundabouts).

Detailed discussions on the methods associated with each of these are presented in the HCM2010. A brief discussion of the application of these methods in pre-processing and post-processing applications associated with project-level traffic forecasting is provided in the Section 10.4.3.

10.4.3 Basic Freeway Segments

Free flow speed is estimated as the base speed with adjustments for lane width, right-side lateral clearance, and total ramp density (in ramps per mile). In the absence of field measurements, a base speed of 75 mph is assumed. Factors for adjustments to base speed are discussed in Chapter 11 of the HCM2010.

Capacity is determined to be a function of the computed free flow speed as shown in Table 10-6.

Density, the measure upon which LOS is based, is estimated according to the following equation:

$$D = \frac{v_p}{S}$$

where

D = density (passenger car [pc]/mile [mi]/lane [ln]),
V_p = demand flow rate (pc/hour[h]/ln), and
S = mean speed of traffic stream under base conditions (mph).

Table 10-6. Capacity for computed free flow speed.

Free Flow Speed (miles per hour)	Capacity (passenger car/hour/lane)
75	2,400
70	2,400
65	2,350
60	2,300
55	2,250

10.4.4 Freeway Weaving Segments

Freeway weaving segment capacity is determined to occur at that point where breakdown of the segment occurs and is controlled by one of two conditions:

- When the average density of the segment reaches 43 pc)/mi/ln; or
- When the total weaving demand flow rate exceeds 2,400 pc/h for two lanes or 3,500 pc/h for three lanes.

Guidance for determining which case is expected to occur is provided in Chapter 12 of the HCM2010.

At the core of the method is the estimation of average speeds for weaving and non-weaving vehicles. The methods for estimating both of these are provided in this HCM2010 chapter.

The estimated weaving speed is determined to be a function of lane-changing rates, whose methods are also provided in the chapter.

As with basic freeway segments, LOS is a function of density.

10.4.5 Freeway Merge and Diverge Segments

Within the context of a travel demand model, freeway merge and diverge segments (i.e., ramp-freeway junctions) constitute a very small portion of the network, yet can have a significant impact on traffic assignments, particularly when these segments are operating at or over capacity. Thus, it is important to provide reasonable capacity estimates. With the exception of major freeway-to-freeway interchanges, ramp segment lengths are characteristically short; thus, associated ramp travel times and corresponding speeds are less significant in the assignment process than capacity estimates.

Methods for estimating the capacity of ramp-freeway junctions are a function of ramp flow rates and the capacity of the freeway immediately downstream of an on-ramp or immediately upstream of an off-ramp. Capacity estimates for ramp-freeway junctions, high-speed ramp junctions on multilane highways and collector-distributor roadways, and ramp roadways are provided in Chapter 13 of the HCM2010. Methods for estimating density in ramp influence areas are based on the ramp flow rate, flow rate on the freeway, and length of the ramp influence area. Equations for estimating speed at ramp junctions and in the outer lanes of the freeway are provided in Chapter 13 of the HCM2010 as well.

LOS for freeway merge and diverge segments is based on density, for which equations are provided in this HCM2010 chapter.

10.4.6 Freeway Facilities

This methodology provides for an integrated analysis of a freeway facility composed of connected segments. It builds upon the procedural methods for basic freeway segments, freeway weaving segments, and freeway merge and diverge segments. The methodology adds the ability to consider linked segments over a number of time periods and also adds the ability to analyze operations when oversaturation exists on one or more segments of the defined facility.

The methodology and its limitations are discussed in Chapter 10 of the HCM2010. The process is difficult and time consuming, thus it is best executed through the use of software like FREEVAL-2010, the computational engine that was developed to implement the methodology. As it exists, the methodology cannot be used in planning, preliminary engineering, and design applications. The HCM2010 does provide guidance on the use of generalized service volume tables for freeways within the freeway facilities context.

10.4.7 Multilane Highways

The methods for estimating speed and capacity on multilane highways is similar to those for basic freeway segments. The methods are described in Chapter 14 of the HCM 2010.

The free flow speed is estimated to be the base free flow speed with adjustments for lane width, lateral clearance, median type, and access point density. Estimates for base free flow speed are a function of the posted speed limit (e.g. see Tables 10-7 and 10-8).

Capacity is a function of free flow speed.

LOS for multilane highways is defined on the basis of density, which is computed as the demand flow rate divided by

Table 10-7. Base free flow speeds.

Posted Speed Limit	BFFS
≥ 50 mph	Posted Speed + 5 mph
< 50 mph	Posted Speed + 7 mph

Table 10-8. Capacity for free flow speeds.

Free Flow Speed (miles per hour)	Capacity (passenger car/hour/lane)
60	2,200
55	2,100
50	2,000
45	1,900

the average speed. Average speed as a function of free flow speed and flow rate is obtained from the speed-flow curves under base conditions, as shown in Figure 10-6. LOS is a function of free flow speed and estimated density.

10.4.8 Two-Lane Highways

Especially in models that encompass rural areas, two-lane highways can constitute a significant portion of the total model network. Though traffic volumes on two-lane highways are relatively low when compared to other facility types within the network, providing accurate estimates of free flow speed and capacity are nonetheless important, particularly with model calibration.

Similar to other uninterrupted flow methods in the HCM2010, free flow speed is estimated by making adjustments to an assumed or measured base free flow speed. Specifically, those adjustments are for lane and shoulder width and for access point density. The HCM2010 method groups two-lane highways into three classes:

- Class I—major intercity routes, primary connectors of major traffic generators, daily commuter routes, or major links in state or national highway networks where motorists expect to travel at relatively high speeds.
- Class II—access routes, scenic or recreational routes, or routes passing through rugged terrain where motorists do not expect to travel at relatively high speeds.
- Class III—highways serving transitioning or moderately developed areas, often accompanied by reduced speed limits.

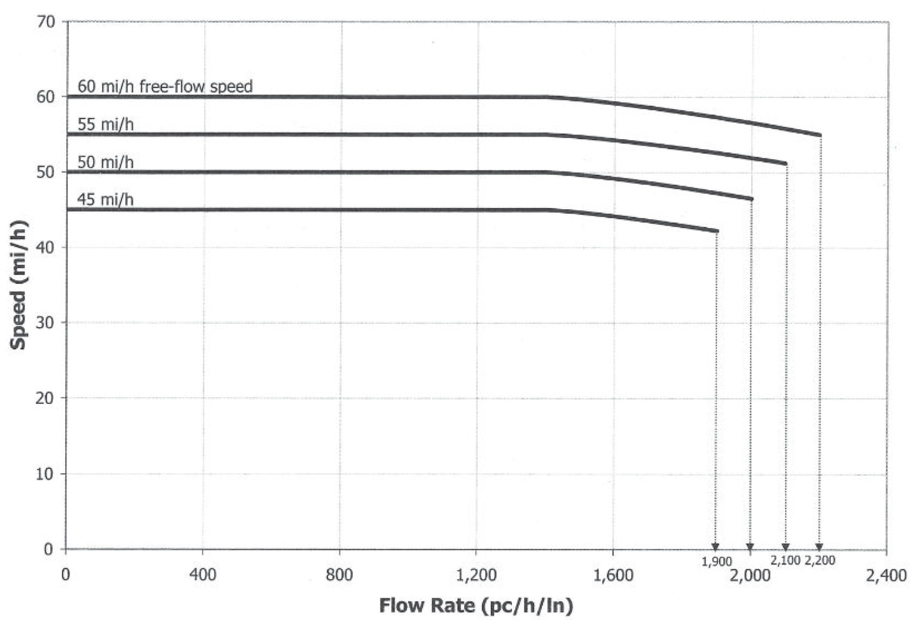
Based on classification, the method (which is documented in Chapter 15 of the HCM2010) provides guidance on estimating the base free flow speed.

Capacity of a two-lane highway is 1,700 pc/h in one direction under base conditions, with a limit of 3,200 pc/h total for both directions.

When the capacity of 1,700 pc/h is reached in one direction, the opposing flow directional capacity is 1,500 pc/h due to interactions between directional flows.

Three measures of effectiveness determine LOS for two-lane highways, based on the classification:

- For Class I highways, LOS is based on average travel speed and the percent time spent following (PTSF), which is the



Note: Maximum densities for LOS E occur at a *v/c* ratio of 1.00. These are 40, 41, 43, and 45 pc/mi/ln for FFSs of 60, 55, 50, and 45 mi/h, respectively.

Source: HCM2010, Exhibit 14-2 (*21*).

Figure 10-6. Speed-flow curves for basic freeway segments.

percentage of time that vehicles must travel in platoons due to the inability to pass slower vehicles;
- For Class II highways, LOS is based on PTSF; and
- For Class III highways, LOS is based on the percent of free flow speed (PFFS), which represents the ability of vehicles to travel at or near the posted speed limit.

10.4.9 Urban Street Segments and Facilities

The HCM2010, for the purpose of analysis, separates an urban street into individual elements that are physically adjacent to each other and operate as a single entity. Within an urban street system, there are two primary elements: points and links. A point represents the boundary between links and is usually represented by an intersection. A link joins two points and represents a length of roadway. An urban street segment is defined by a link and its two boundary points, while an urban street facility is a collection of contiguous segments and typically is functionally classified as an urban arterial or collector street.

Computational methods in the HCM2010 for elements that compose urban streets are provided in the following chapters:

- Chapter 16. Urban Street Facilities
- Chapter 17. Urban Street Segments
- Chapter 18. Signalized Intersections
- Chapter 19. Two-Way Stop-Controlled Intersections
- Chapter 20. All-Way Stop-Controlled Intersections
- Chapter 21. Roundabouts
- Chapter 22. Interchange Ramp Terminals

At the urban street segment level of analysis, free flow speed is estimated as the base free flow speed with an adjustment for signal spacing. Base free flow speed is computed by assuming a constant speed (with guidance for estimating or measuring provided) and adjusting for street cross-section and access point density.

For urban streets, capacity represents the maximum number of vehicles that can discharge from a queue per hour. Segment capacity typically is determined by the points that define a segment; that is, the intersections or ramp junctions that define the segment ends and control the flow entering and exiting the segment. With one exception, depending on the type of control at the intersection, segment capacity is computed using the appropriate procedures in Chapters 18 to 22 of the HCM2010. The one exception is Chapter 19, Two-Way Stop-Controlled Intersections, for which there is no procedure for estimating capacity of the uncontrolled through movement. If the case exists where such an intersection is needed in a travel demand model, a method to estimate this capacity is provided in Chapter 17.

For automobiles, LOS for urban street segments is based on travel speed as a percentage of free flow speed and those thresholds are provided in Chapter 17. An exception is if the volume-to-capacity ratio is greater than 1.0; if that is the case, regardless of the ratio of travel speed to free flow speed, the LOS is F.

Several signalized intersection analysis tools can be found in *TRR Circular 212* (*132*).

10.5 Stitching a Model Together

Stitching travel demand models together is a common practice for efficiently developing regional or even statewide models that combine one or more urban areas with rural areas. This forms a larger study area, enabling evaluation of expanding urban areas, new developments in more urban areas, and intercity facilities such as rail, interstates, and so forth.

A major effort involved in stitching together models to form a regional or statewide model is the data-gathering process. It is critical to gather the existing model files developed for the study area such as existing metropolitan planning organization (MPO) travel demand models and any geographic information system (GIS) files available for those areas outside the existing model study areas. The GIS data include highway networks and attributes, traffic analysis zone (TAZ) systems and attributes, traffic count data, and so forth. Other important information includes survey data from local or national sources if re-estimation of trip rates, trip distributions, or mode shares is necessary.

Another major effort involved in stitching together models to form a regional or statewide model is syncing up the local models and GIS files. There are several considerations when stitching together a variety of data sources:

- Geographic
  - Do any models overlap in study area?
  - Do the highway network geometries align? Do the networks have consistent roadway attributes?
  - Do the TAZ system geometries align? Do the zones have consistent land use attributes?
  - How to convert the external station to internal study area links? How to create new external stations at the edge of the model study area and determine the external-to-external trip movements?
- Methodology
  - Do the models have common trip purposes?
  - Do the models have common components (mode choice, time of day, commercial vehicle, feedback, etc.)?
  - Do the models have the same base and forecast years?
- Model Development
  - Are the trip generation models the same type (regression/cross classification)?
  - Are the trip distribution models the same (gravity/destination choice)?

– Are the mode choice models the same (logit/factored trip table) and do the models include transit components?
– Should the MPO model components be maintained for those areas or should the same components and methodology be used for the entire study area?
– Should the MPO model parameters (trip rates, distribution factors, mode shares, time of day factors, volume-delay functions, etc.) be maintained or re-estimated for the model study area?

These considerations are necessary and time consuming at the start of the model development. However, using existing travel demand models and other data sources as well as GIS procedures and scripting to develop a travel demand model is easier than developing a model from scratch.

10.6 Simplified Highway Forecasting Tool

10.6.1 Abstract

These guidelines have provided tools for a wide variety of users including designers, planners, and operational analysts. Frequently, there is a need for traffic forecasting products for lower risk projects such as resurfacing projects, culverts, bridge deck repairs, noise wall panel replacement, slip repairs, and other similar projects. The Ohio Department of Transportation's Modeling and Forecasting Section has devised an innovative tool for producing these low-risk, lower effort traffic forecasts, the Simplified Highway Forecasting Tool (SHIFT) (*133*).

10.6.2 Context

This tool is designed for use on Ohio state highways for forecasting needs that are low risk and require a very quick turnaround in production time. The tool is totally automated and produces high-quality reports that are automatically sent to a central repository of traffic forecasts.

10.6.3 Background

Many large agencies have a heavy workload and need innovative ways of handling traffic forecast needs without using limited staff resources. This technique was developed for those scenarios. Ohio's traffic forecasting is normally accomplished using traffic forecasters/modelers in the Central Office. This new technique allows decentralized (Districts) staff to make certain traffic forecasts.

10.6.4 Why This Technique

This technique saves significant time and money without sacrificing quality.

10.6.5 Words of Advice

Other agencies considering a technique like this should strongly consider all of the associated caveats and not use it for larger projects, such as those involving the addition of new roads, lanes, ramps, or interchanges.

The Ohio Department of Transportation gives the following limitations:

- There is no attempt to provide consistency between previous forecasts or adjacent segments.
- The tool provides forecast only on state mainline roads—no ramps or local roads.
- It cannot provide turning movements.

10.6.6 Executing the Technique

10.6.6.1 Special Data Preparation

Data needs are small and include county, route, and log (milepoint). If the user has new traffic count information beyond the historical database, it can be used optionally.

10.6.6.2 Configuration of the Technique

The computer program uses linear regression to make the traffic forecast, and it has six internal methods to accomplish this:

1. Use all available counts.
2. Use Method 1 but drop the count with the highest residual error.
3. The oldest count is dropped if there are at least four counts.
4. Use Method 3 along with dropping the erroneous count and have five remaining counts.
5. Drop the oldest two counts if there are at least five remaining counts.
6. Use Method 5 along with dropping erroneous counts with five remaining counts.

The program also makes *NCHRP Report 255* adjustments if data from travel demand models are available.

Finally, growth rates are capped at 3% per year for cars and 4% per year for trucks.

10.6.6.3 Steps of the Technique

STEP 1. Select the Location

The computerized tool allows the location selection via mapping or data entry.

STEP 2. Traffic Forecast Form

Basic information such as description, opening year, and design year is inputted.

Simplified HIghway Forecasting Tool (SHIFT)
Design Designation

Ver 1.0 7-10-12 7/19/2012 2:29:08 PM mbyram
CMS DB Version June 4, 2012 Page 1 of 2

RIC 00071 7.14 - 10.68

2015 ADT:	43,000
2035 ADT:	53,000
K:	0.10
2035 DHV:	5,300
D:	0.53
T24:	0.29
TD:	0.15

```
DEFINITIONS
ADT: Average Daily Traffic
  K: Design Hour Factor
DHV: Desighn Hour Traffic
     DHV = K*ADT
  D: Peak Direction Factor
T24: Daily Trucks Fraction
 TD: Design Hour Truck Fraction
```

VARIABILITY INFORMATION

	CMS* Run Year	ADT MIN / MAX	
Regression Method	2040	9,113 / 79,848	95% CONFIDENCE LEVEL
NCHRP ADJ Method		53,705 / 57,223	

Figure 10-7. Simplified highway forecasting tool report.

STEP 3. The Newer Counts Form

This form allows counts to be keyed in or imported from a spreadsheet. After using the count processing button, the following metrics are produced:

- ADT,
- Hourly design volumes, and
- Directional factors.

It should be noted that the form will apply the Ohio Department of Transportation's seasonal adjustment factors automatically.

STEP 4. The Design Designation Report

After entering the new count information, the design designation report can be produced. This is a standard two-page report containing traffic forecasting details. The second page of the report is shown in Figure 10-7.

10.6.6.4 Working with Output from the Technique

Traffic forecasts produced by this technique use a rounding convention. Users are encouraged to save the forecast report for their records.

CHAPTER 11

Case Studies

This chapter presents both real-world and theoretical examples of project-level traffic forecasting applications. A suburban arterial, a "network window" approach for a small area in a much larger metropolitan area, a small city application, an high-occupancy vehicle (HOV) to high-occupancy toll (HOT) lane conversion using an activity-based model in a large metropolitan area, a time-series analysis of truck traffic at an international bridge crossing, and blending a regional travel forecasting model with a traffic microsimulation approach for a microsimulation of a large portion of a metropolitan area's freeway system are presented as case study applications.

11.1 Case Study #1—Suburban Arterial

11.1.1 Project Description

The city of Somerset in South Central Kentucky lies at the crossroads to many things, including transportation and recreation. Located in Pulaski County, this city is larger than its population of 11,200 implies.

Situated 75 miles south of Lexington along US 27, Somerset was a stopping place between Lexington and Knoxville, Tennessee prior to the construction of Interstate 75. It remains a popular tourist destination today. Lake Cumberland, a 65,530-acre impoundment maintained by the Army Corps of Engineers, is located just southwest of Somerset and attracts more than 4 million visitors annually. Most of those visitors arrive by private automobile.

US 27 bypasses the downtown area of Somerset to the west. Within the immediate vicinity, this principal arterial carries 25,000 to 33,000 vehicles per day. Built originally as a bypass of downtown, the four-lane arterial is the backbone of a fully developed, mixed land use corridor that includes commercial and retail development, health care facilities, a community college, and residential areas. The community's regional airport also is located near US 27. In addition to providing accessibility to Lake Cumberland, US 27 is a heavily traveled commuter route and also serves as a parallel north-south alternative to I-75. Just north of the downtown area, US 27 intersects with KY 80, which joins together the Louie B. Nunn Parkway and the Hal Rogers Parkway to provide east-west mobility across the southern portion of Kentucky.

Traffic along US 27 is composed of a mix of commuters, tourists (many hauling boats or campers), shoppers, and truck drivers. The Kentucky Transportation Cabinet maintains a closed-loop system of 32 traffic signals along a 5-mile section of US 27, including three intersections along KY 80 just east of US 27. An area map is shown in Figure 11-1.

Land use changes, recreational traffic, truck movements, and commuter traffic, apply continuous pressure to KYTC to maintain mobility, manage access, and improve safety along the corridor. This case study demonstrates the role of project-level traffic forecasts in the application of traffic analyses to identify operational and geometric improvements typically associated with urban and suburban arterials.

11.1.2 Available Data/Resources

Several data types and tools were available for the analyses illustrated by this case study. They include the following:

- Roadway geometry;
- Traffic control data, including signal timing plans;
- Peak-hour intersection turning movement count at major intersections;
- A county-level, 24-hour travel demand model; and
- Development information for a (hypothetical) proposed commercial development in the corridor.

11.1.3 Techniques

Techniques are the following:

- Refining Directional Splits from Travel Models,
- Refining Turning Movement Outputs of Travel Models,

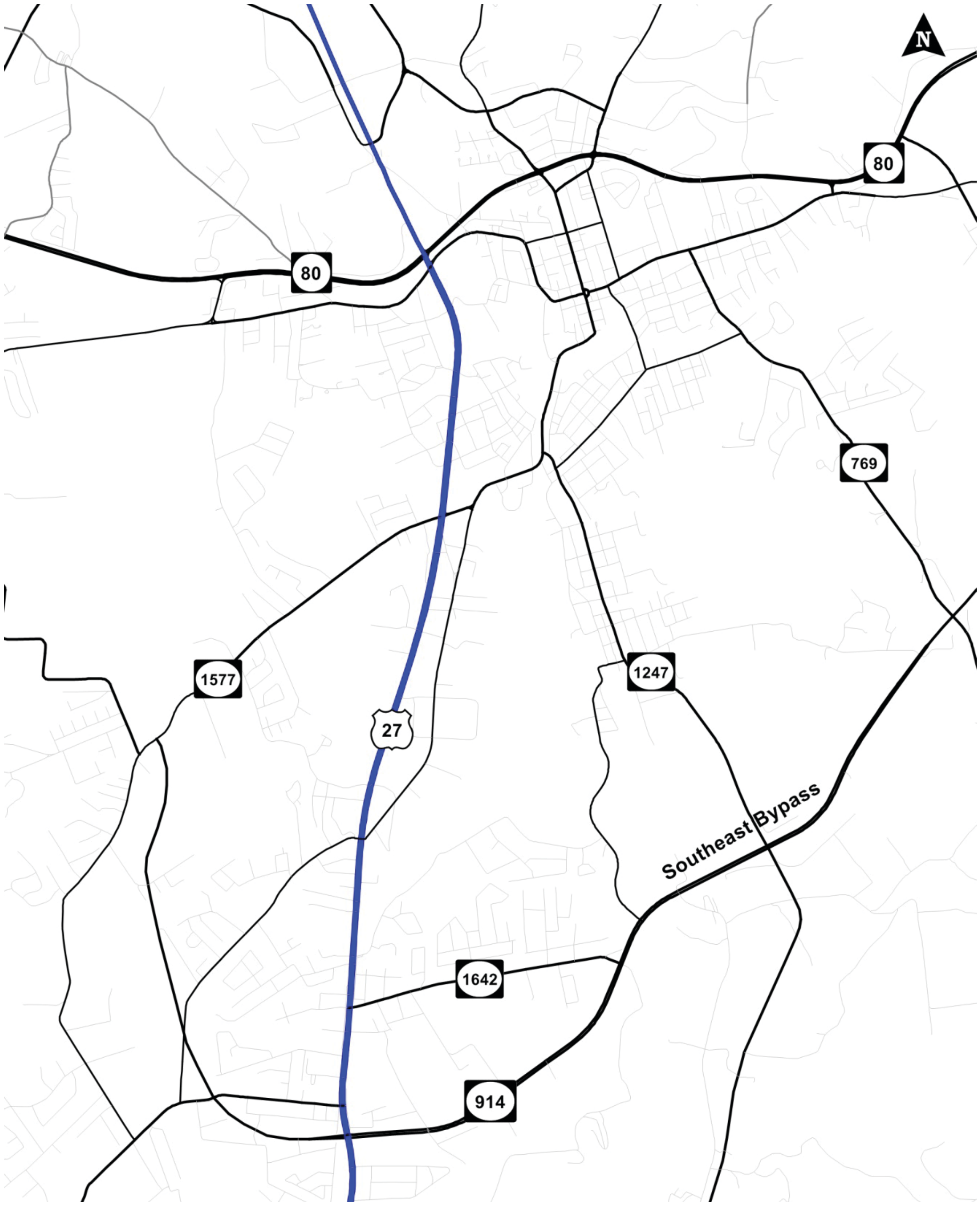


Figure 11-1. Area map of Somerset, Kentucky.

- Selecting Link/Zone Analysis, and
- Windowing and Model Refinements with Origin-Destination (OD) Matrix Estimation.

11.1.4 Applications—Case Study Projects

Applications are the following:

- Estimating Directional Distribution, D, using a Travel Demand Model;
- Developing Intersection Turning Movement Forecasts Using Travel Model Output;
- Using Select Link Analysis to Distribute Site Traffic in a Traffic Impact Study; and
- Using Windowing with Synthetic OD Table Estimation to Develop Turning Movement Forecasts at Multiple Locations.

11.1.5 Estimating Future Year Directional Distribution, D

Traffic moves efficiently along US 27 as a result of access management and good traffic signal progression. To maintain good progression in the future while adequately serving side street demand associated with various retail, business,

Table 11-1. Summary of mainline directional volumes obtained for peak-hour traffic counts.

Traffic Counts (veh/hour)

Analysis Period	Southbound	Northbound	D
AM Peak	930	560	0.62
PM Peak	900	1,250	0.58

and residential areas, it will be necessary to develop intersection turning movement forecasts that will reflect anticipated conditions for which assessments of the current traffic signal system can be made. An important component of the turning movement forecasts is the directional distribution, D.

A county-wide travel demand model is available for use. The model was calibrated to a base year 2008, and the forecast year is 2030. It is a basic three-step, 24-hour travel model. This exercise within the case study demonstrates the refinement of directional splits from a traffic model for use in development of future turning movement forecasts.

For a segment of US 27 immediately south of the KY 80 intersection, mainline directional volumes obtained from peak-hour traffic counts are summarized in Table 11-1.

The travel demand model was used in the estimation of a future D. Base year and future home-based-work (HBW) productions and attractions were assigned to the network, representing peak-period home-to-work travel. The assigned productions and attractions from the 24-hour model represent the relative portion of work travel during the AM peak; the PM peak direction is just the reverse of the AM peak direction. A summary of the 2008 base year and 2030 future year P's and A's for HBW trips is shown in Table 11-2.

As a reasonableness check, the estimated D from the base year model output should be within 10% of the D computed from the counts in order to use the predicted home-to-work travel model as a reasonable source for predicting future directional distribution. Although the model-estimated D falls outside that range, it is consistent with the D computed from the counts. The travel demand model uses HBW trip generation rates from *NCHRP Report 365.* While the overall model was calibrated to within acceptable limits, the trip purpose components of the model were not calibrated individually. Given the multitude of land uses in the corridor, it was determined that it was reasonable to use the estimated D from the travel demand model for use in developing a future year D for traffic forecasts.

Using the count data and D estimates from the travel demand model, the future year D was estimated as follows:

$$D_F = D_B \times \frac{WT_F}{WT_B}$$

where

D_F = future year traffic directional distribution,
D_B = base year traffic directional distribution,
WT_F = future year work trip directional distribution, and
WT_B = base year work trip directional distribution.

For the AM peak:

$$D_F = 0.62 \times \frac{0.81}{0.79} = 0.64$$

A similar calculation for the PM peak yields an estimated D = 0.59.

11.1.6 Developing an Intersection Turning Movement Forecast Using Travel Model Output

The intersection of US 27 with KY 80 is heavily traveled. Of particular interest is the westbound-to-southbound, left-turn movement, especially during the AM peak. The current configuration of the westbound approach is a left-turn lane, a combined left-turn/through lane, a through lane, and a channelized right-turn lane. Because of this configuration, split signal phasing is presently implemented for the eastbound and westbound approaches, i.e., all westbound lanes move concurrently, followed by all eastbound lanes. While functional and safe, the split phasing scheme is not as efficient as a typical lead-left phasing scheme or a "lead/lag" left-turn

Table 11-2. Summary of 2008 base year and 2030 future year productions and attractions for HBW trips.

Traffic Counts (veh/hour)

Analysis Period	Southbound	Northbound	D
AM Peak	7,675	1,982	0.79
PM Peak	8,910	2,146	0.81

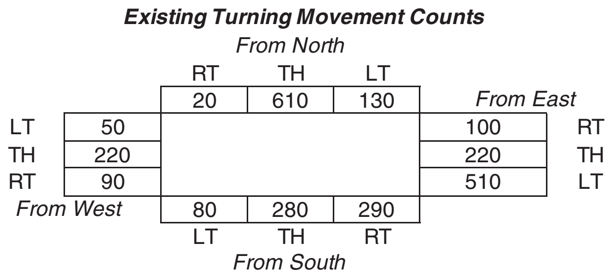


Figure 11-2. Summary of AM peak-hour turning movement counts.

scheme. A summary of AM peak-hour turning movement counts for the intersection is provided in Figure 11-2.

The construction of a western bypass, which is nearing completion, is shown in Figure 11-3. The completion of the new western bypass is likely to have an effect on future turning movements at this intersection, the Kentucky Transportation Cabinet is faced with some important questions when considering improvements to the most heavily traveled intersection in the community:

1. How will traffic movements through this intersection change, in comparison to existing movements, with the completion of the new western bypass?
2. What is the most cost-effective solution for addressing the heavy westbound left-turn movement? Can it be satisfactorily addressed with signal timing modifications or are geometric improvements needed, even with the construction of the western bypass?

The county-level travel demand model is available for use in forecasting future intersection turning movements. Its usefulness in developing forecasts is limited, however, because it is a 24-hour model. Also, choosing the best technique is important. A comparison of turning movement forecasts was made using two different techniques: the ratio method and the directional iterative method. In the ratio procedure,

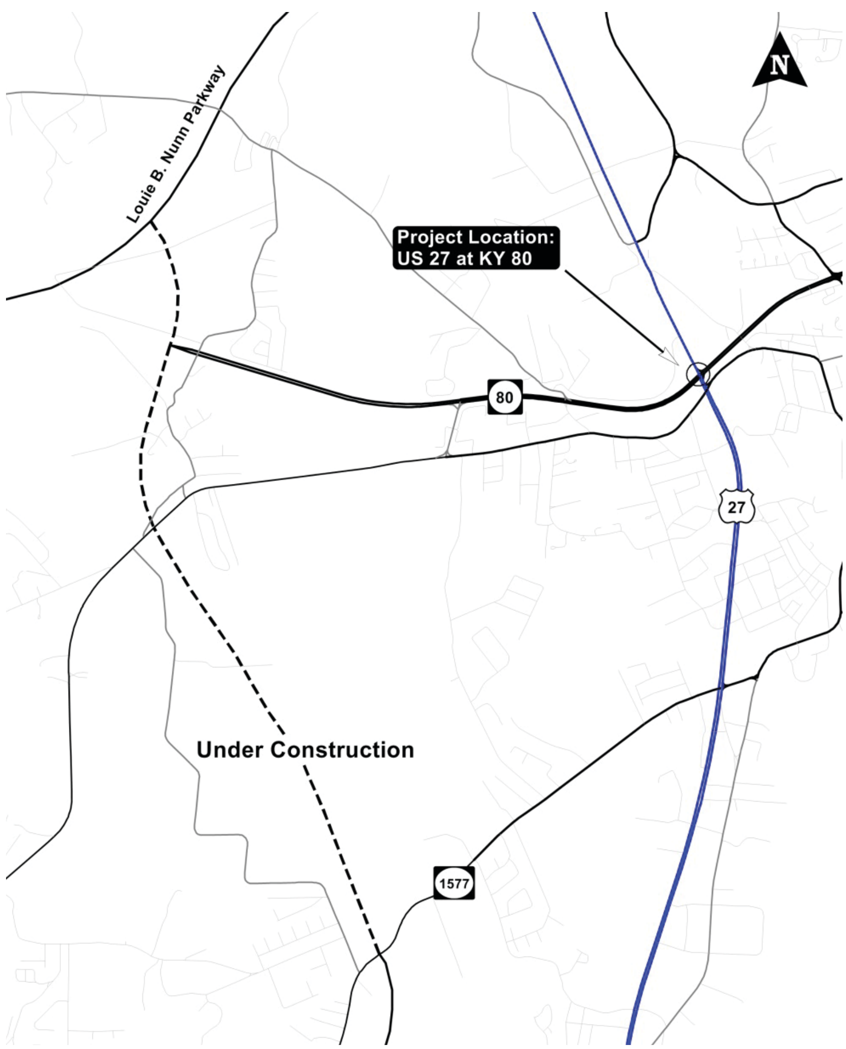


Figure 11-3. Completion of western bypass.

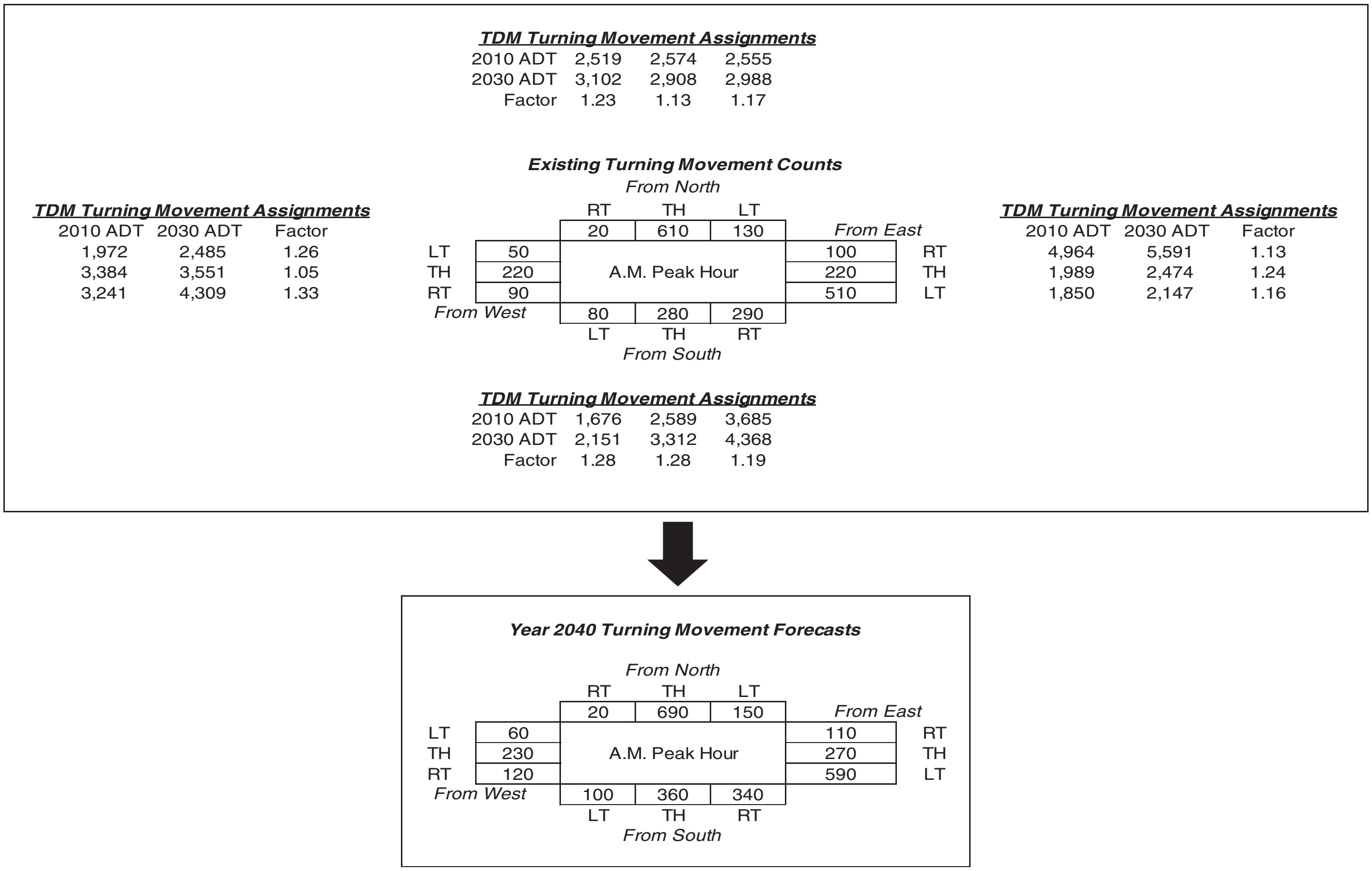


Figure 11-4. Turning movement forecasts using the ratio method.

existing turning movement volumes are multiplied by the ratio of the future year travel demand model turning volume divided by the base year travel demand model turning volume. The calculations and results are shown in Figure 11-4.

As a check, turning movement forecasts also were estimated using the directional iterative method. Based on 24-hour traffic count data, a K factor of 0.075 was applied to the Year 2040 assigned daily traffic volumes for the intersection approach links. Directional splits (i.e., D factors) were computed by assigning HBW productions and attractions to the model network, as described in Section 6.4. The estimated peak-hour approach and departure volumes were input into the procedure along with the existing turning movement volumes, and the results are shown in Figure 11-5.

The forecasted inflows and outflows are within ±10% of the summed turning movements, so it was determined that an acceptable level of convergence was reached using the iterative method.

Comparing the results from the two methods, it can be seen that the biggest differences are related to turning movements to and from the south, especially the westbound left turn. This volume is predicted to increase using the ratio method, which would indicate the need for widening to create a second exclusive left-turn lane. However, using the iterative method, the volume actually is predicted to decrease. So which method is more applicable here?

The completion of the western bypass is included in the future travel demand model as it was applied using both procedures. Using the ratio method, traffic growth (from the base year 2010 to the year 2040) estimated by the travel demand model was applied to existing turning movements. By its application, the directional distribution is assumed to be the same for both the base year and the forecast year. The change in directional distribution as it is affected by the completion of the bypass, particularly for the south and west legs of the intersection, is included using the iterative method. Because of this, it can be concluded that the estimates produced using the iterative method are most likely to occur. More importantly, it can be concluded that intersection improvements for the westbound approach would not be needed.

11.1.7 Using Select Link Analysis to Distribute Site Traffic in a Traffic Impact Study

To the west of US 27 lies a "big box" discount store, just to the south of KY 1577. This is located in traffic

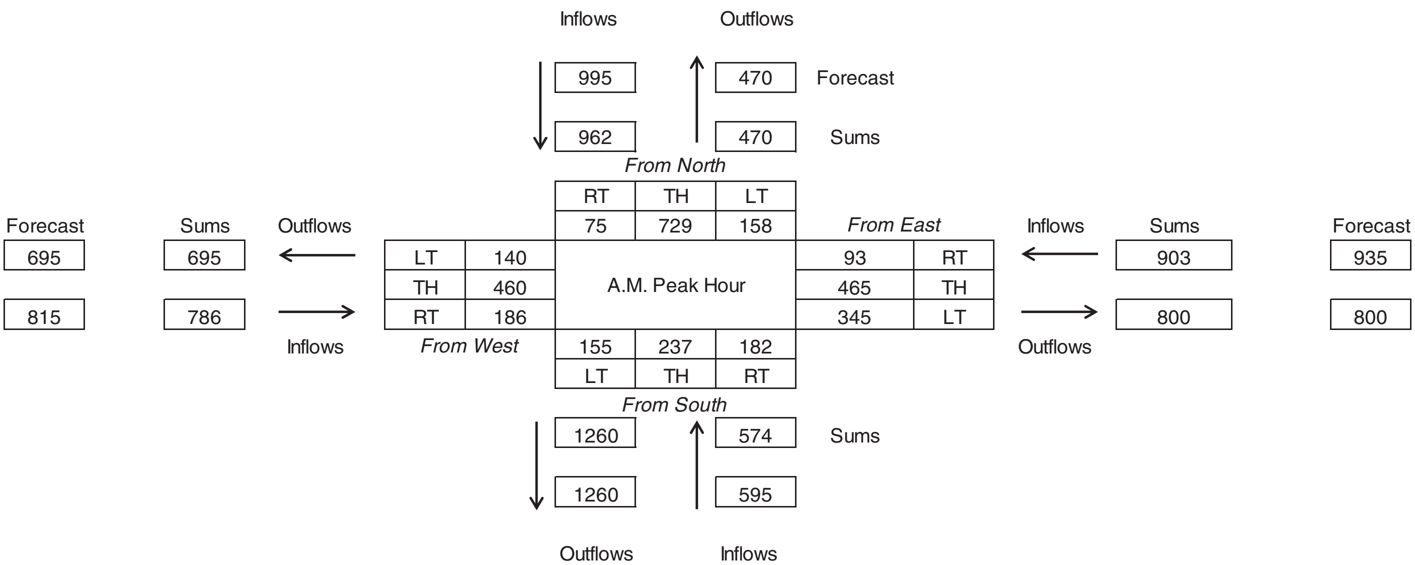


Figure 11-5. Turning movement forecasts using iterative method.

analysis zone (TAZ) 174 in the travel demand model (see Figure 11-6).

A proposed (hypothetical) development in this zone would create 1,350 additional jobs, including retail and service jobs. Primary access to the development would be to and from US 27, with secondary access to/from KY 1577, which connects with the new western bypass west of the site.

In conducting a traffic impact study for the development, it is important to estimate the distribution of the estimated site-generated traffic for the following purposes:

- Determining design requirements for the site access road from KY 1577 and
- Determining intersection modifications and adjustment to signal timing plans needed at the main access with US 27.

Estimated site-generated traffic will be developed using conventional methods such as those contained in the Institute of Transportation Engineers' (ITE's) *Trip Generation Manual.* It is common practice to distribute site-generated traffic in proportion to existing traffic volumes on the adjacent roadway network. If that approach were taken here, it is likely that site traffic to and from KY 1577 would be underestimated, especially with the completion of the new bypass west of the site.

In this case study, the travel demand model was used to estimate the distribution of project site traffic that would be generated by the proposed development. Two future year model scenarios were developed—one with the additional employment figures associated with the proposed development and one without. For each scenario, a model assignment was executed and a select link analysis was performed. The results are summarized in Table 11-3.

The "Difference (Δ)" column in Table 11-3 represents the additional daily trip ends associated with the proposed development. It should be pointed out that the 952 total additional trips should be used only for the distribution of site traffic; the actual site traffic forecasts discussed previously would most likely be more accurate and include projected peak-hour traffic volumes.

11.1.8 Using Windowing with Synthetic OD Table Estimation to Develop Turning Movement Forecasts at Multiple Locations

In all, there are 32 signals as part of a coordinated system along US 27 (including two signals on KY 80). The Kentucky Transportation Cabinet has recognized that it is impractical to provide coordination and progression along the entire system. As part of a signal retiming and optimization process, the Kentucky Transportation Cabinet will focus on developing coordinated plans for the 11 signals along the northern section of US 27.

Due to financial constraints on the project, the decision was made to collect intersection turning movement counts at the six busiest intersections along the section. For the remaining five intersections, turning movements were estimated for use in the signal timing optimization process.

For this portion of the case study, the windowing with synthetic OD table estimation technique described in Section 7.2 of these guidelines was used. The technique employs OD table estimation from intersection turning movement counts. For those intersections where counts did not exist, side street approach and departure volumes were estimated using estimates from ITE's *Trip Generation Manual*, based on

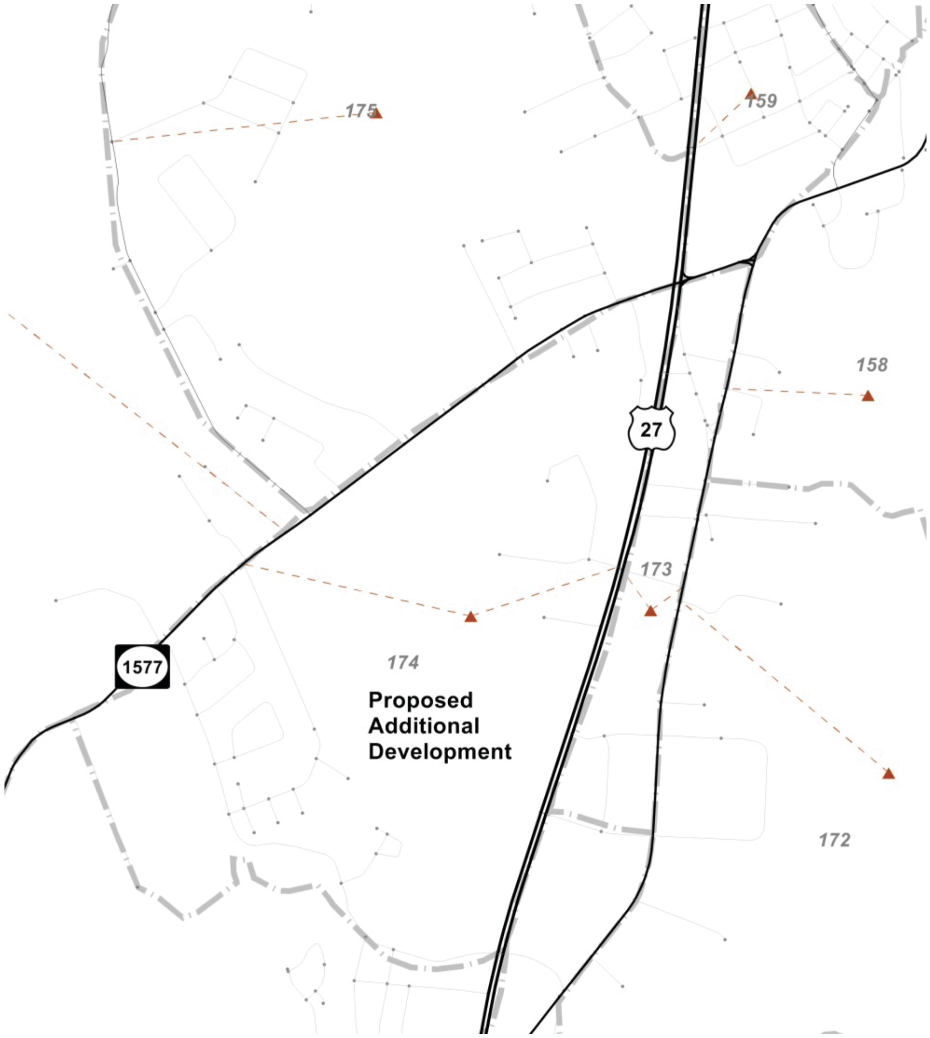


Figure 11-6. Proposed development within the travel demand network and TAZ structure.

Table 11-3. Traffic assignment results with and without additional development.

Approach/Departure	*Future Year Average Daily Trip Ends* Without Additional Development	With Additional Development	Difference (Δ)	Distribution (%)
US 27 to/from the South	771	873	102	**11%**
US 27 to/from the North	1,619	2,061	442	**46%**
KY 1577 to/from the Southwest	1,000	1,363	363	**38%**
KY 1577 to/from the Northeast	469	514	45	**5%**
Totals	3,859	4,811	952	**100%**

the estimated number of residences served by the cross street or the type and size of development (if the side street was an access drive to the development). Those intersections for which turning movement counts were collected and those for which approach and departure volumes were estimated are noted in Figure 11-7. For this case study, intersection turning movement volumes were estimated for the weekday PM peak hour.

The first step in the process was to create the subarea network, to include all of the external stations and centroids to be used in the traffic assignment process. For this application, the network was windowed from the travel demand model network. The windowed network was modified so that no centroids from the travel demand model were used; all non-intersection nodes were treated as external stations. External links were populated with approach and departure volumes—either actual volumes derived from the intersection turning movement counts or estimated approach departure volumes, as described previously.

The next step involved balancing the approach and departure volumes. Travel modeling software was used for this purpose and the resulting table of balanced approach and departure volumes are shown in Table 11-4.

The third step involved the development of an OD seed table. As discussed in Section 7.2, the seed OD table can be

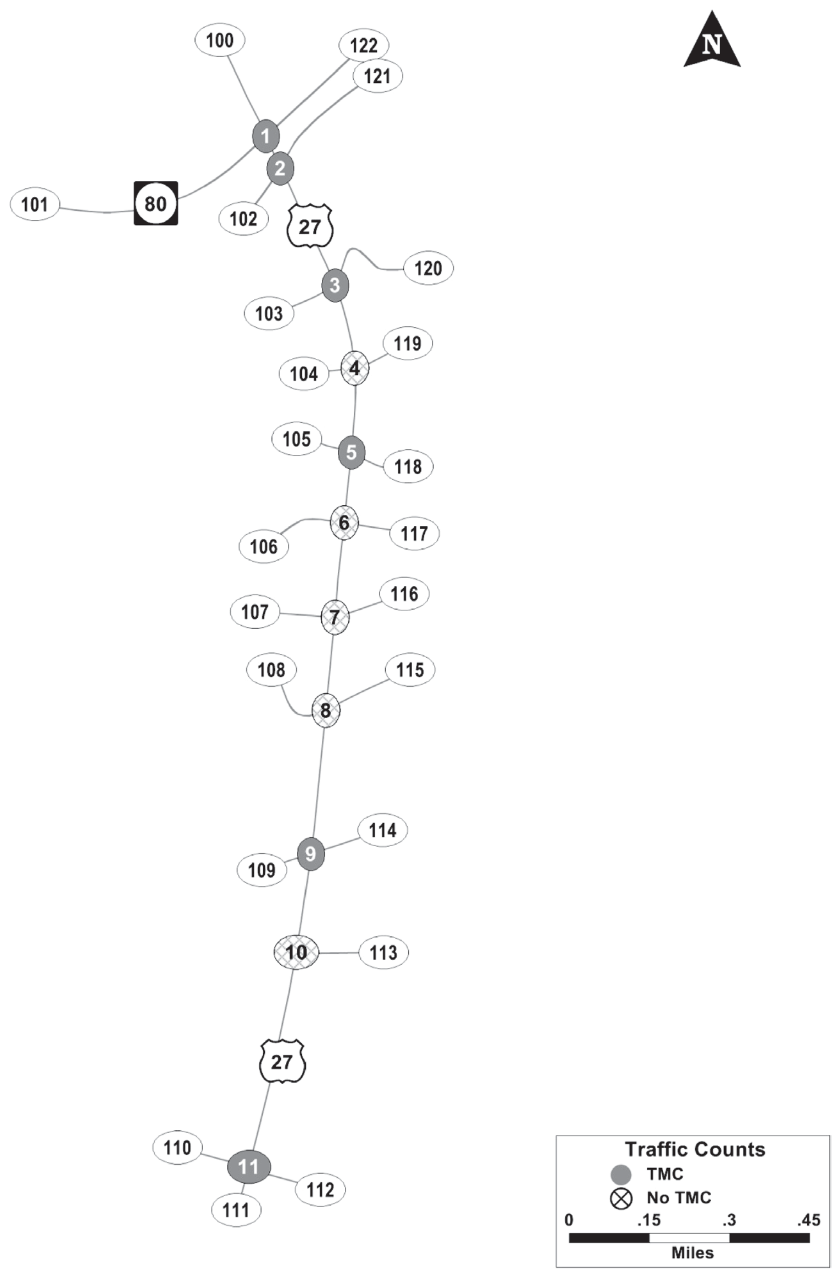


Figure 11-7. Windowed subarea network.

Table 11-4. Balanced approach and departure volumes.

Node	Approach	Departure
100	653	924
101	320	523
102	797	424
103	208	297
104	68	67
105	292	419
106	77	75
107	11	10
108	53	48
109	350	514
110	623	327
111	911	903
112	164	281
113	52	29
114	387	227
115	53	95
116	11	10
117	84	86
118	209	164
119	148	114
120	174	183
121	346	378
122	1,004	896
Totals	6,992	6,992

developed from cordon survey data or from assumptions of driver behavior over short distances. No cordon survey data were available for this application, so the table was developed based on assumptions of driver behavior. Because the windowed area is small, it was determined that using external traffic only would suffice, and the network was constructed such that all movements are external-to-external (E-E) trips. Thus, it was necessary to develop only one OD table.

Constructing the seed OD table was a two-part process. The first part involved the creation of an impedance matrix for all OD pairs. The following assumptions were made:

- All destinations are roughly accessible from all origins, so the probability of arriving at a given destination is virtually insensitive to typical impedance measures like distance or travel time.
- At any intersection, through movements have the highest probability of occurrence. This was validated by examining the turning movement counts where they were available.
- Traffic movements passing through the entire corridor had the highest probability overall (between Nodes 100 and 111 for US 27 and between Nodes 101 and 122 for KY 80). In other words, the probability that a driver would pass through any given intersection was higher than the probability that the driver would make a turn.
- The only information to suggest that one destination was superior to another was the traffic volume on the intersection departure leg. That is, those intersections with the highest volumes "attracted" the most trips in the seed OD table estimation process.
- As a matter of probability, drivers preferred destinations that could be reached with fewer turns, and right turns were more likely than left turns.
- Drivers were most likely to make zero, one, or two turns within the windowed area network; trips with three or more turns were ignored. In most cases, right turns are more likely than left turns. However, because access management controls have been implemented along this section of US 27, left turns and right turns have equal probability. This was confirmed by examining the left- and right-turning volumes from the counts collected at six of the intersections.

Within the travel forecasting software, a doubly constrained gravity model with an exponential friction factor was used:

$$T_{ij} = X_i Y_j O_i D_j exp(-\beta t_{ij})$$

where T_{ij} is the seed-matrix traffic from origin I to destination j, where X_i was chosen such that:

$$\sum_j T_{ij} = O_i$$

where Y_j was chosen such that:

$$\sum_i T_{ij} = D_j$$

where exp() is the exponential function, O_i is the number of vehicles originating at entry point i, D_j is the number of vehicles with destinations at exit point j, and t_{ij} is the smallest number of turns between origin I and destination j.

An impedance matrix was created and a unit value for each was set at 7 (see the discussion on selecting impedance values in Section 7.2).

Also, it was assumed that the probability of zero-turn trips was twice as likely as a one-turn trip and that a one-turn trip was twice as likely as a two-turn trip. Again, no more than two turns were assumed for any trip. A friction factor matrix was constructed using the probabilities of zero-, one- and two-turn trips passing at each intersection (cell). The impedance matrix and friction matrix were used to estimate the seed OD table. The seed OD table was then assigned to the network and the assigned turning volumes were compared to the observed turning movement counts. The results of this comparison are shown in Figure 11-8.

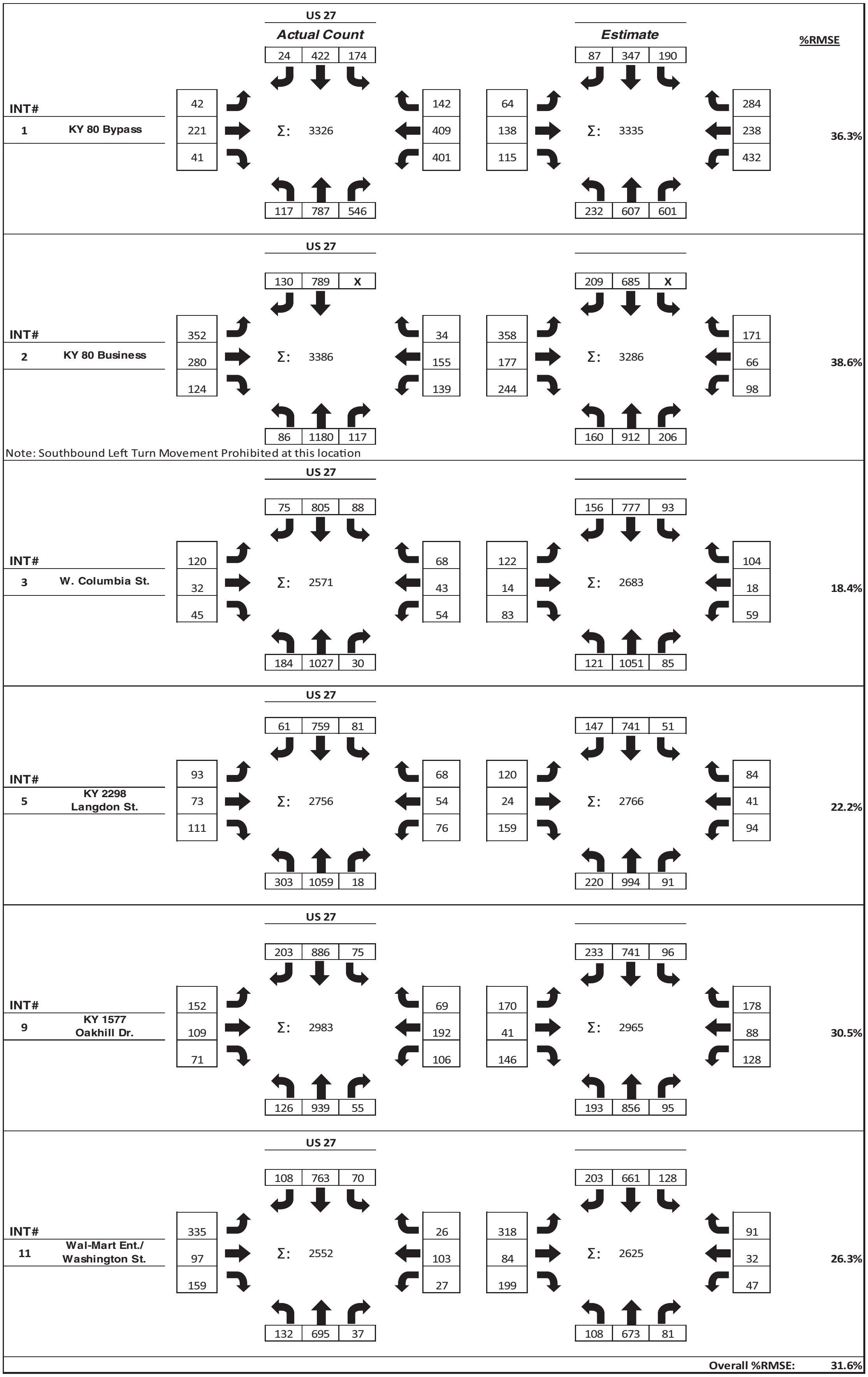


Figure 11-8. Comparison of assigned seed OD table movements to turning movement counts.

The calculated root-mean-square (RMS) error for all of the estimated turning movements was 31.6% of the mean traffic count. For the development of traffic signal timing plans through the use of optimization software, the argument could be made that this was sufficient given the variability among the counts themselves and given that the comparison between estimated and actual through movement was less than the overall RMS error. However, further refinement to the impedance values through trial and error would produce an overall lower RMS error and a closer match between the estimates and ground counts. Regardless, use of OD table estimation to produce turning movement forecasts for those minor intersections where counts are not available offers an acceptable option.

11.2 Case Study #2—Network Window

The "network window" case study illustrates the construction of a custom network for small area applications. A "network window" covers only a small portion of a much larger metropolitan area.

11.2.1 Study Area Description

The study area (see Figure 11-9) is located in the southern portion of the City of Milwaukee, approximately 6 miles south of the Milwaukee central business district. Milwaukee's Mitchell International Airport is located just east of the study area. Besides several major arterials, this window contains sections of I-43/894 (locally called the Airport Freeway), I-94 (locally called the North-South Freeway) and the Airport Spur. The window contains a major freeway interchange, the Mitchell Interchange, and a separate interchange to the Airport Spur. As is typical for a Midwestern city, most arterials run on north-south or east-west lines. This portion of the City of Milwaukee contains a wide variety of land uses, ranging from low-density residential to heavy industrial.

I-94 is officially an east-west highway, but within the window, I-94 runs essentially north-south. Traffic traveling to the north (toward downtown Milwaukee) is officially "westbound," and traffic traveling to the south (toward Chicago) is officially "eastbound."

I-43/894 runs east-west within the window. This road is used by drivers to bypass downtown Milwaukee and to travel to Beloit, Lake Geneva, and other cities to the southwest of the Milwaukee metropolitan area.

Arterial and freeway construction work, along with concerns about freeway incident management have necessitated the recent installation of an integrated traffic control system that covers most of the window. Freeway reconstruction is currently underway from the Illinois border (well south of Milwaukee) to a point north of the Mitchell Interchange.

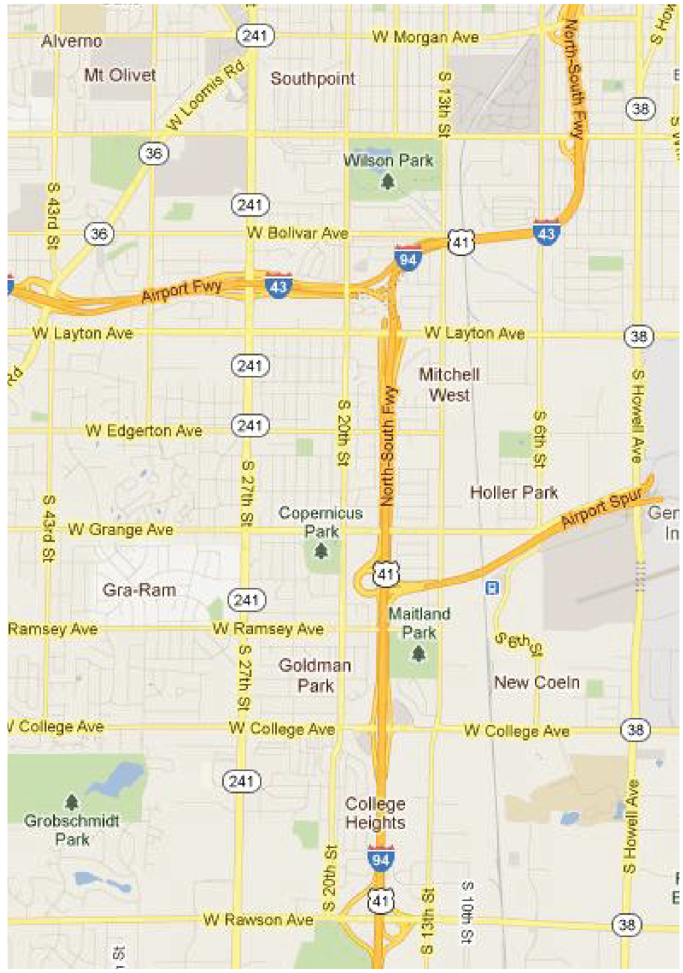


Figure 11-9. Study area.

The model was constructed principally to understand work zone detouring and diversion during reconstruction of the Mitchell Interchange and Airport Spur Interchanges. Of particular concern are complete long-term closures of on- and off-ramps in the area. Because delays might be excessive at signalized intersections, all signal delays are calculated according to operational analysis procedures from the *Highway Capacity Manual* within the traffic assignment step.

The window had been cut out of the larger metropolitan area, and it is approximately 5 miles by 4 miles in dimension. There are 91 traffic signals or signed intersections at arterial intersections. Each traffic-controlled intersection was individually inspected to obtain the correct lane geometry. Because signal timings are expected to change as a way of mitigating traffic impact, signal timing was simulated, not given as an input.

The time period of analysis is a single hour, 4:30 to 5:30 PM, on an average weekday. An OD table was created for this hour by matching traffic counts on many of the arterial and freeway segments. There was only one vehicle class and only one trip purpose.

Alternatives, consisting of one or more ramp closures along with one or more lane closures, can be evaluated for their impacts on the local traffic system. Beyond its intended purpose, this model could be used for traffic impact studies, lane widening, intelligent transportation systems (ITS), and signal control improvements.

11.2.2 Available Data/Resources

The analyst had a number of data items to assist in building the model, beyond maps and photographic images from online sources:

- PM peak-hour traffic counts were obtained from a database maintained by the Wisconsin Department of Transportation (WisDOT).
- A floating car speed study was performed during the 4:30 to 5:30 PM peak hour, covering most major arterial streets in the window.
- Speeds were available from a geographic positioning system (GPS) navigation equipment vendor for many of the streets in the window for all times of the day and for all days of the week.
- Selected arterial intersections had fairly recent TMCs.

Most importantly, there was an absence of information available to create a seed OD table. There was no lead time or budget for a vehicle re-identification study, and the OD table from the regional model maintained by the metropolitan planning organization (MPO) used inconsistent geography and was considered too coarse for this small window.

11.2.3 Techniques

This case study illustrates how to perform subarea windowing, OD matrix estimation in the absence of an empirical seed OD table, and signal timing within the traffic assignment step. Traffic volumes are estimated using user-optimal equilibrium traffic assignment, which is considered appropriate for long-term urban work zones.

11.2.4 Case Study Project

I-94 work zone construction on I-94 West (looks northbound on the map) just north of the Airport Spur will require closing one lane. Because of the potentially short weaving section between the two interchanges, the plan also calls for closing the westbound-to-westbound (looks westbound-to-northbound on the map) ramp of the Airport Spur interchange (Alternative A) with I-94. Furthermore, there are worries about too much traffic through the work zone, so the traffic engineers are also considering closing the westbound ramp (looks northbound on the map) at College Avenue (Alternative B). The airport represents a rather large obstacle to travel, so any diversion from the airport (for which the only exit is the Airport Spur) or from College Avenue would most certainly be seen within the window.

11.2.5 Network

The network was drawn to closely match the arterial roadway configuration in the area. A zone system, corresponding to the one used by the local MPO, was defined for the window to handle the small amount of locally generated traffic. Demographic data (employment and households) were borrowed for these zones. Special-generator centroids were drawn at all places where roads entered or exited from the window. These special-generator centroids were given productions (for entering traffic) and attractions (for exiting traffic). The network is shown in Figure 11-10. For this network, two-way streets are the thicker lines, one-way streets are the thinner lines, traffic-controlled intersections are squares, and centroids are dots or houses. The method of traffic assignment did not use centroid connectors; vehicles from many automatically created subzones are loaded at the nearest intersection.

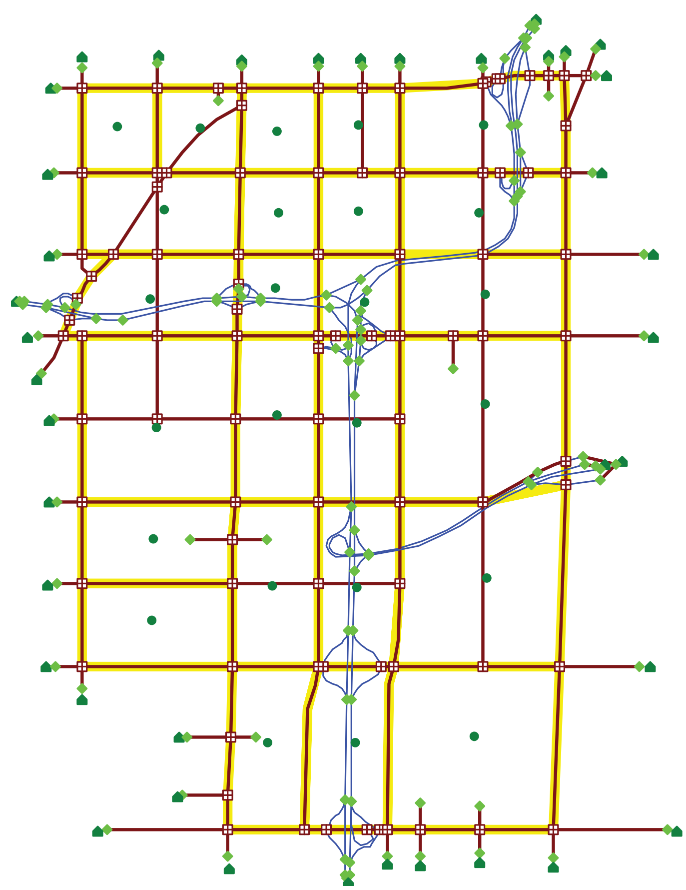


Figure 11-10. Milwaukee/Mitchell window network.

11.2.6 Special Data Preparation Steps

The seed OD table was created by a gravity model with impedances as a function of the minimum number of turns between an origin and a destination. Historic traffic counts indicated that there were fewer left turns than right turns. However, naturally occurring left-turn delays at traffic-controlled intersections during the OD table estimation process would tend to discourage left turns, relative to right turns. Thus, all turn impedances were set to exactly 10 minutes, as a start. A friction factor table was created by trial and error, resulting in these friction factors:

- No turns = 80,
- One turn = 40,
- Two turns = 20,
- Three turns = 10, and
- Four or more turns = 0.

Each additional turn exactly halves the likelihood of that particular trip, and no trip with four or more turns within the window is permitted. (A very similar result could have been obtained had an negative exponential friction factor function been used in the gravity model with a coefficient of 0.07 and a turn penalty of 10 minutes.) The final OD table was created by matching peak-hour directional traffic counts using the whole-table least-squares method. Parameters of the OD table estimation process were set so that there would be about a 10% RMS deviation between forecasted volumes and traffic counts. The average count was 1,018 vehicles per hour and the RMS deviation was 98 vehicles per hour. Any closer fit would have been within the error of a traffic count, itself. After re-assigning the estimated OD table to the network, there were 7% left turns and 11% right turns, on average, at traffic-controlled intersections, which was considered acceptable. The assignment of the final OD table was compared with traffic counts, link-by-link, and no issues were discovered. Delays on the network were compared with floating car runs, and they were also found to be acceptable.

11.2.7 I-94 Work Zone Evaluation of Alternatives

Alternatives A and B can be evaluated alone, against each other, or against the base case. The analyst did not create a do-nothing alternative, because safety concerns required that at least the ramp between the Airport Spur and I-94 be closed. For both Alternatives A and B, one link of eastbound I-94 was reduced from three lanes to two lanes, and the capacity of each lane was reduced from about 2,100 vehicles per hour per lane to 1,800 vehicles per hour per lane, as is typical for freeway work zones in the Milwaukee metropolitan area. Traffic assignments were performed using 20 iterations of method of successive averages (MSA) to achieve equilibrium conditions.

A comparison of the alternatives and the base case can be seen in Table 11-5.

The freeway is operating below capacity in the base case, but the work zone will not have anywhere near enough capacity to handle normal traffic volumes. Both Alternatives A and B caused traffic to shift from the freeways to the arterials; however, not enough volume was shifted to completely avoid queuing. Alternative B, by closing an upstream on-ramp, did just slightly better, perhaps because almost half of this on-ramp's traffic would try to avoid I-94, with the work zone in place. The impact on the arterials was negligible. Average arterial speeds on the network dropped only about 0.2 mph. An inspection of delays at signalized intersections for both Alternatives A and B showed additional delays would average at most a few seconds for any given vehicle at any given approach. The difference between Alternative A and Alternative B in terms of user cost, as indicated by vehicle hours of travel (VHT), is also negligible.

Table 11-5. Comparison of base case and Alternatives A and B.

	Base Case	Alternative A	Alternative B
I-94 Capacity N of Airport Spur	6,400 vehicles per hour (VPH)	3,600 VPH	3,600 VPH
Assigned Volume on I-94	5,630 VPH	4,133 VPH	4,064 VPH
Assigned Volume, College Ave On-Ramp	1,013 VPH	593 VPH	0 VPH
Freeway—vehicle miles traveled (VMT)	82,919 veh-miles	79,381 veh-miles	79,327 veh-miles
Arterial VMT	66,008 veh-miles	70,266 veh-miles	70,756 veh-miles
Average Major Arterial Speed	26.12 mph	25.91 mph	25.90 mph
Total System—vehicle hours of travel (VHT)	4,879 veh-hours	5,087 veh-hours	5,085 veh-hours

11.2.8 Full Weekend Closure of I-43/894 Evaluation

WisDOT needed to install a new culvert across I-43/894 between 27th Street and the Mitchell Interchange. A decision was made to completely close the freeway in both directions from late Friday night to early Monday morning. There was insufficient lead time to build a new model for weekend traffic; the few traffic counts for weekends were limited entirely to automatic traffic recorder (ATR) sites; and some of those ATRs were inoperative or unreliable due to construction on I-94. The Milwaukee/Mitchell window was used to evaluate a peak Saturday hour by scaling the weekday PM OD table. Because there was only a single reliable ATR site in the vicinity, and traffic at that site may have been affected by construction activity on I-94, a decision was made to use time-of-day and day-of-week factors from Chapter 8 of these guidelines.

Because the full closure is a short-term work zone, there will not be enough driver experience to establish anything close to equilibrium conditions without intervention by WisDOT. Nonetheless, an equilibrium traffic assignment would provide insight for determining whether there is enough capacity in the system to avoid gridlock and to indicate a potential pattern of detours that could lead to an acceptable outcome.

The overall setup of the model was the same as for the I-94 work zones, but the OD table was scaled by 70% to approximate the smaller amount of traffic on the Saturday 2 PM peak hour for large city (>1,000,000 population) Interstate highways. The 70% figure was obtained from Chapter 8 by combining the ratio of time-of-day factors between a weekday at 5 to 6 PM and a Saturday at 2 to 3 PM with the ratio of a Wednesday day-of-week factor and a Saturday day-of-week factor. There was only one alternative (A, full closure), which is compared with the base case (no closure).

Figure 11-11 shows part of a band width plot of Alternative A, Full Closure. It can be seen that most eastbound traffic is exiting I-43/894 at 27th St., just ahead of the closure, although a significant amount of traffic is choosing to exit at Loomis Rd., one interchange farther west. A select link analysis on the 27th St. eastbound off ramp shows that most of the exiting drivers find their way back to the freeway system at one of the two closest on-ramps. Eastbound traffic (looks southbound) on I-94 intending to travel westbound on I-43/894, exits mostly at Howard Avenue and Layton Avenue.

Of greatest concern is the effect of the diversion on traffic-controlled intersections, so a before and after comparison of delays and signalization would be most revealing. It is important to reiterate that the green splits in the simulation are adaptive (not fixed), that is, they adjust to the amount of traffic. Therefore, delays are substantially lower than would be seen if the signal timing were to remain unchanged. Table 11-6

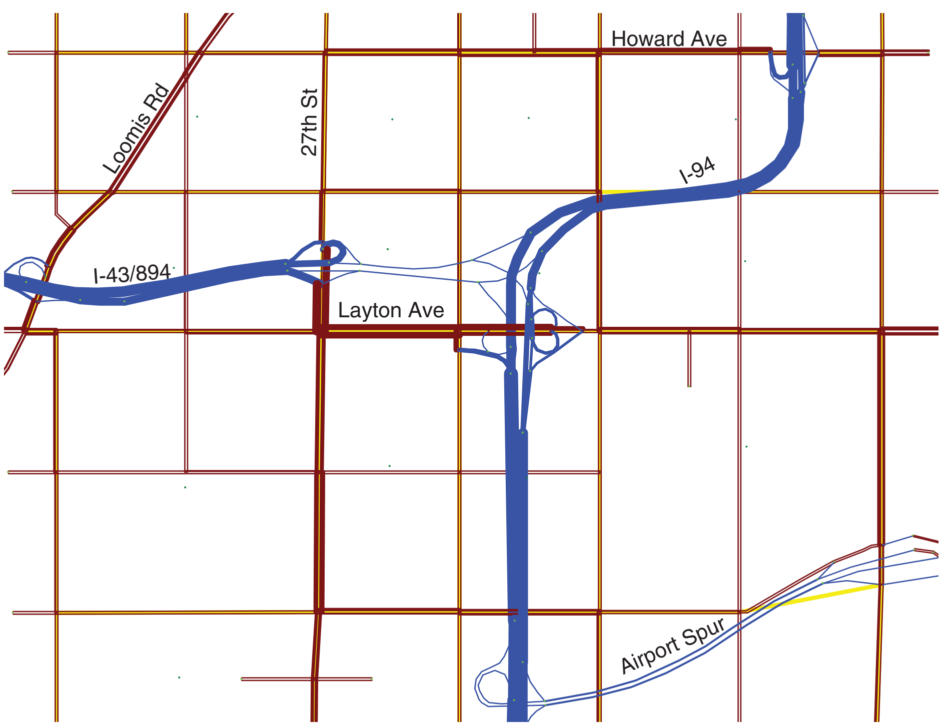


Figure 11-11. Forecasted equilibrium traffic volumes in the window after a full weekend closure of I-43/894.

Table 11-6. Before and after delays.

	Base Case Delay (seconds)	Alternative A Delay (seconds)
27th St. EB Off Ramp at 27th St.	17	43
27th St. NB at EB Off Ramp	11	27
27th St. SB at EB Off Ramp	24	10
27th St. NB at Layton Rd.	15	26
27th St. SB at Layton Rd.	14	98
Layton Rd. EB at 27th St.	14	23
Layton Rd. WB at 27th St.	15	28

Note: EB = eastbound, NB = northbound, SB =southbound, WB = westbound.

shows the before and after delays for the intersection of the 27th St. off ramp, and the intersection of 27th St. and Layton, which is the worst case.

The volume-to-capacity ratio for the 27th St. eastbound off ramp is just about 1.0 for Alternative A, so queuing should be expected there, at least intermittently, under the best of circumstances. Total vehicle hours for Alternative A was just 3,515 hours in comparison with 2,900 hours for the base.

A few other intersections will require only minor tweaking to best adapt to equilibrium traffic conditions. Overall, the plan for a full freeway closure has some negative traffic impacts, as well as the expected increase in user costs, but these impacts could be mostly manageable with changes to signalization and a well-thought-out detour plan.

Since this Alternative A represents a short-term closure during a period of time in which there will be many inexperienced drivers on the road, it will be necessary to develop a set of recommended detour routes along with a public information campaign to encourage drivers to find the same paths to minimize their travel times that they naturally would if they had perfect information.

On the other hand, leaving drivers entirely to their own devices could create chaos on the traffic system. During the weekend, most drivers in Milwaukee do not expect to encounter any serious delays when they travel. An all-or-nothing traffic assignment of the same OD table to Alternative A's network (i.e., an assignment where all drivers are assumed to act independently of all other drivers), resulted in many intersection approaches having volume-to-capacity ratios well in excess of 1, implying long queues throughout the window. Average intersection delays could be as high as 4 minutes at one location, with total vehicle hours in the system climbing to 4,106 hours.

11.3 Case Study #3—Small City

The "small city" case study is performed using the Charleston Area Transportation Study (CHATS) travel demand model.

11.3.1 Study Area Description

Charleston is a coastal city located in South Carolina. The three-county metropolitan statistical area includes Charleston, Berkeley, and Dorchester Counties. The area had an approximate population of 572,000 in 2003 and 664,600 in 2010 (U.S. Census estimate); approximately 78% of this population is in the urban area. The area has heavy tourism activity and heavy freight traffic generated from the Port of Charleston. There are two major Interstates, I-26 and I-526, that run into the city. A location map of Charleston, South Carolina, is shown in Figure 11-12. An image of the CHATS MPO study area is shown in Figure 11-13.

11.3.2 Charleston Area Transportation Study Travel Demand Model

The CHATS MPO, staffed by the Berkeley Charleston Dorchester Council of Governments (BCDCOG) is responsible for developing, maintaining, and updating the regional transportation model and provided the CHATS travel demand model for use in this case study. The purpose of the CHATS model is to be used as a planning tool that will assist in the analysis of the transportation system in the Charleston area, including analysis of a concurrent Long-Range Transportation Plan (LRTP). The CHATS model is used to obtain accurate representation of traffic volumes, operating speeds, and vehicle trips on major roadways.

The official CHATS model has a base year of 2003, updated using 2000 decennial census data, and a forecast year of 2030, updated using local planning information and growth rates. The model is a traditional four-step travel demand model, including daily automobile assignment with truck preload. This model does not include time-of-day or feedback components. The study area consists of 628 zones and 14 external stations.

11.3.3 Case Study Project

The project analyzed in this case study is a new alignment project of Carolina Bay Drive/Wildcat Way/Sanders Road

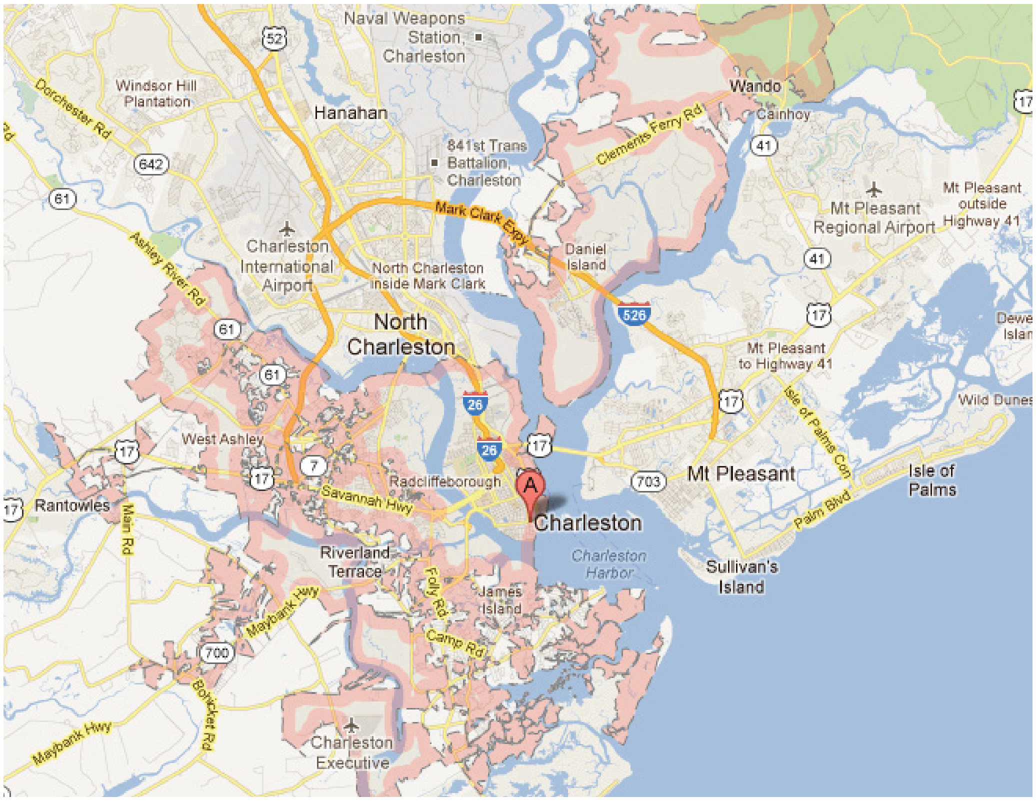
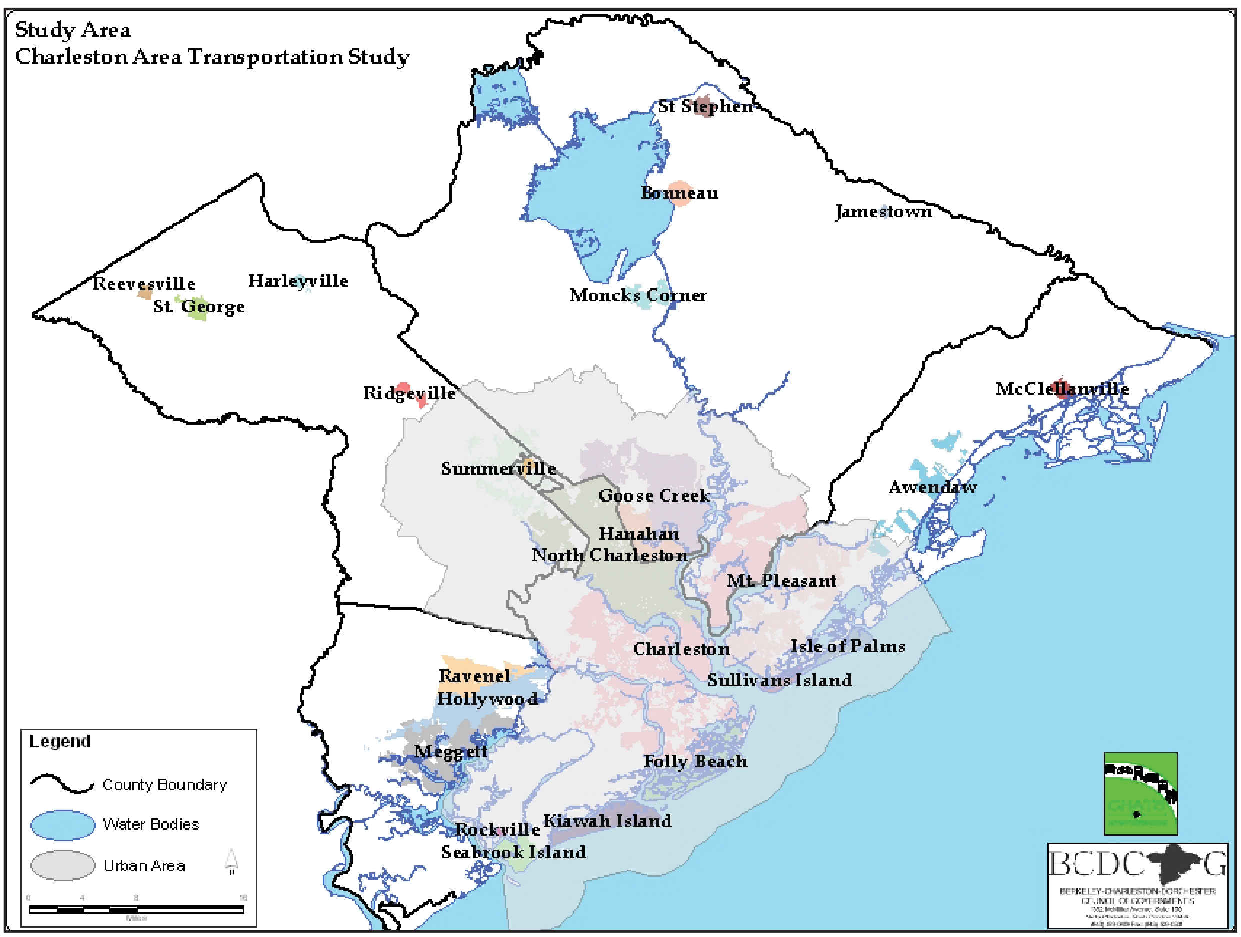


Figure 11-12. Region of Charleston, South Carolina.



Source: Berkeley Charleston Dorchester Council of Governments.

Figure 11-13. CHATS MPO study area.

between Glenn McConnell Parkway and Savannah Highway (US 17), west of downtown Charleston. These roadways are two-lane collector roadway facilities and represent about 3.6 miles of new roadway construction providing access to major arterial roadways for a new residential development. These new alignments are shown in Figure 11-14. This project is evaluated as part of the "Existing plus Committed" (E+C) scenario in Year 2030. This scenario is referred to as the "Build" scenario in this case study. The 2030 E+C scenario without Carolina Bay Drive/Wildcat Way/Sanders Road between Glenn McConnell Parkway and Savannah Highway (US 17) is referred to as the "No-Build" scenario.

The roadway network attributes of lanes, speed, facility type, median, and so forth were updated for the project links. No changes were made to the TAZ or demographic data.

11.3.4 Spatial Analysis Technique

Select link analysis on the case study project was performed to show the spatial impacts of the new construction project on the existing highway networks. The link evaluated in the select link analysis is on Glenn McConnell Parkway southeast of the new construction project. This link is evaluated to identify the shift in traffic on Glenn McConnell Parkway and Bees Ferry Road due to the new construction project.

Figure 11-15 shows a flow map of the select link volumes for the "No-Build" scenario. The selected link is shown in darker gray near the center of the figure. Approximately 86,000 vehicles per day are estimated in 2030 for the selected link on Glenn McConnell Parkway in the "No-Build" scenario. A summary of estimated average daily traffic (ADT) volumes is provided in Table 11-7.

Figure 11-16 shows a flow map of the select link volumes for the "Build" scenario. The selected link is shown in darker gray near the center of the figure. This map looks very similar to the "No-Build" scenario map with some minor changes. Traffic accessing Carolina Bay Drive and Wildcat Way also utilize the selected link on Glenn McConnell Parkway. Unlike the "No-Build" scenario, there is no traffic access to both Bolton's Landing and the selected link on Glenn McConnell Parkway. A summary of estimated ADT volumes is provided in Table 11-8.

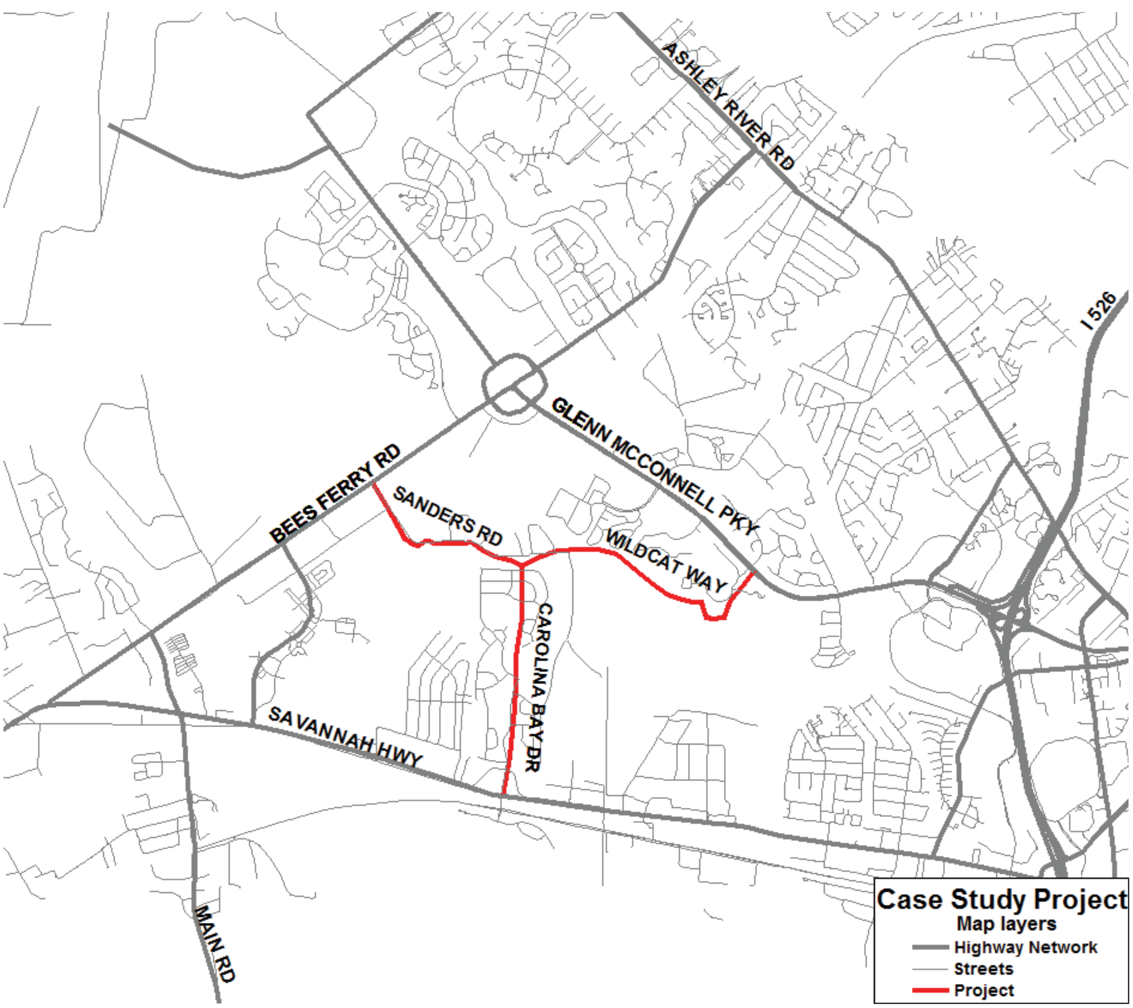


Figure 11-14. Case study—new construction project.

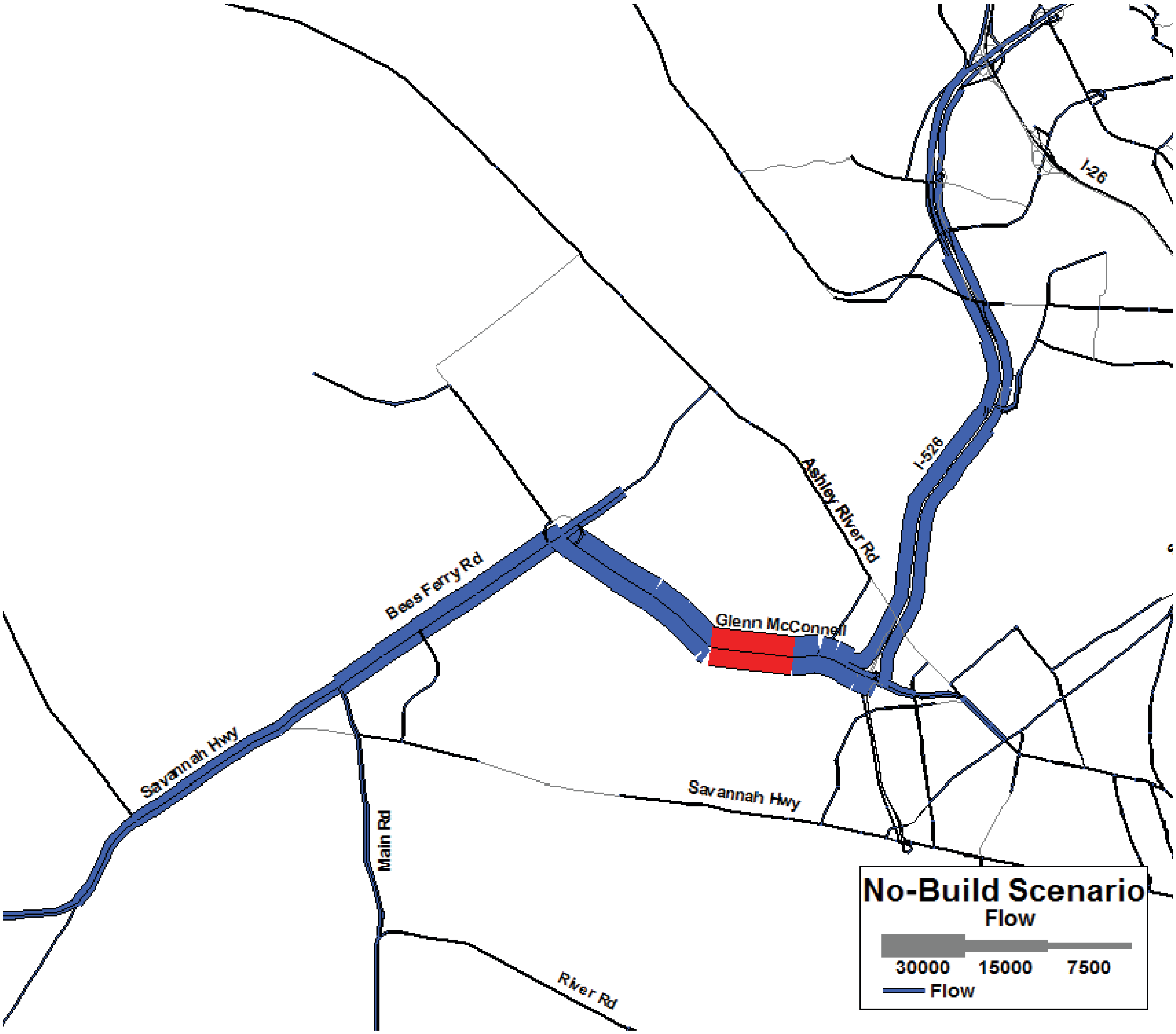


Figure 11-15. "No-Build" scenario select link flow map.

Table 11-7. "No-Build" scenario select link volumes.

Road Name	Segment Description	2030 "No-Build" ADT
Glenn McConnell Parkway	Between Selected Link and I-526	82,800
Glenn McConnell Parkway	Selected Link	54,900
Glenn McConnell Parkway	Between Selected Link and Bees Ferry Road	48,900
Bees Ferry	Between US 17 and Glenn McConnell	37,500
Bees Ferry	Between Ashley River Rd and Glenn McConnell	23,000
Savannah Hwy (US 17)	Between Bees Ferry and Carolina Bay Dr	42,300
Savannah Hwy (US 17)	Between Carolina Bay Dr and I-526	42,300
Carolina Bay Drive	Between US 17 and Wildcat Way	n/a

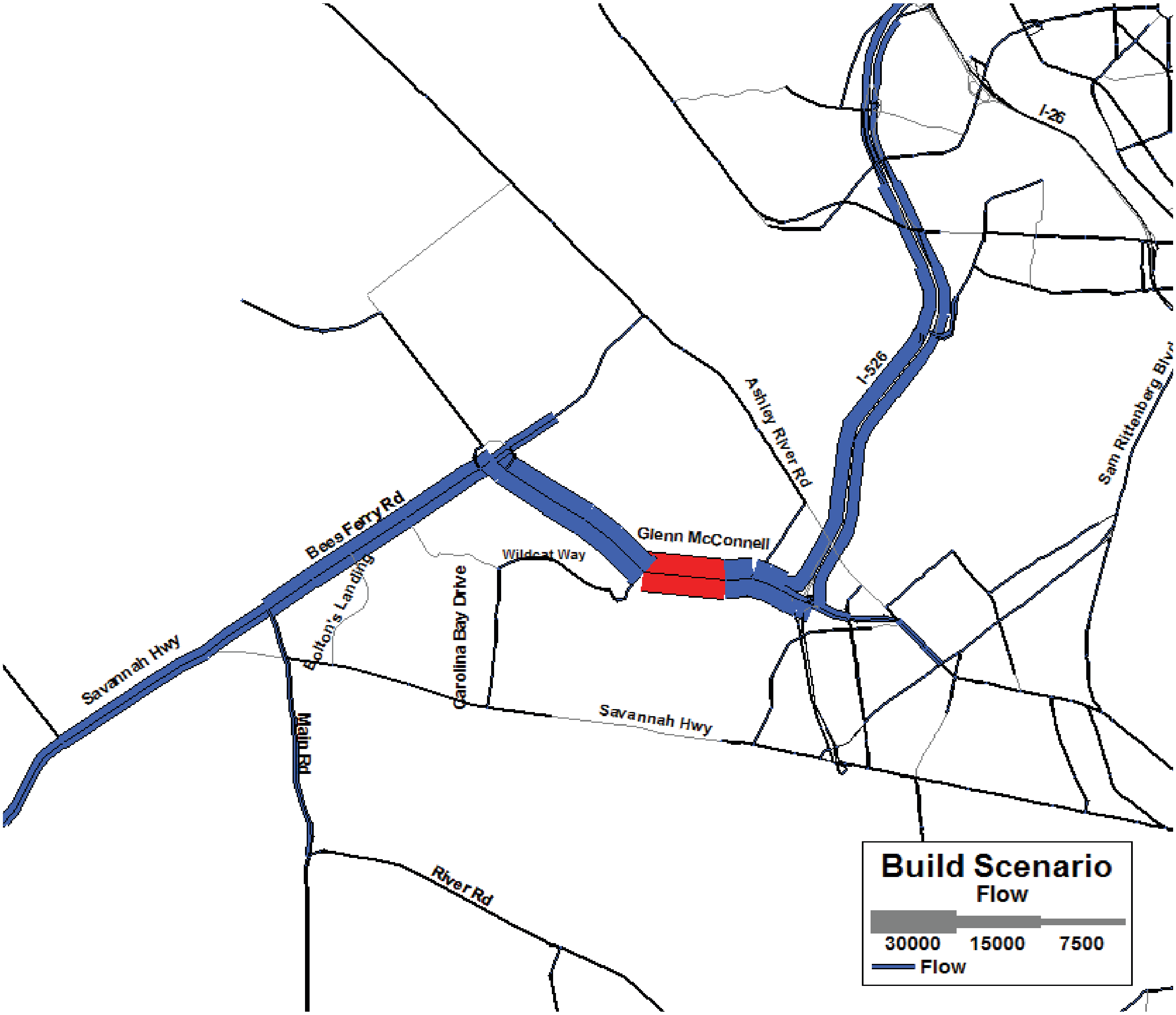


Figure 11-16. "Build" scenario select link flow map.

Table 11-8. "Build" scenario select link volumes.

Road Name	Segment Description	2030 "Build" ADT
Glenn McConnell Parkway	Between Selected Link and I-526	83,700
Glenn McConnell Parkway	Selected Link	56,500
Glenn McConnell Parkway	Between Selected Link and Bees Ferry Road	48,000
Bees Ferry	Between US 17 and Glenn McConnell	36,800
Bees Ferry	Between Ashley River Rd and Glenn McConnell	22,900
Savannah Hwy (US 17)	Between Bees Ferry and Carolina Bay Dr	40,200
Savannah Hwy (US 17)	Between Carolina Bay Dr and I-526	40,700
Carolina Bay Drive	Between US 17 and Wildcat Way	3,000

Figure 11-17 shows the difference in volume between the "Build" and "No-Build" select link volumes. This figure reflects variations of flows traversing the selected link on Glenn McConnell Parkway that can be expected with construction of the proposed project. There is a drop in volume northwest of the new construction projects on roadways such as Bees Berry Road, Glenn McConnell Parkway, Savannah Highway, Main Road, and Bolton's Landing. This implies that with the new roadway projects traffic traveling along Glenn McConnell Parkway to and from Bees Ferry Road and to the north is diverting to use the new roadway projects. This also implies that with the new roadway projects an additional 1,700 (rounded) vehicles per day will be induced on Glenn McConnell Parkway.

Overall, the difference in roadway ADT volumes is summarized in Table 11-9. From these statistics, the largest drop in daily traffic is on Savannah Highway (US 17). What this suggests is that without the new construction project, the local traffic from that zone was directly loading onto Savannah Highway. However, with the new construction project, the traffic is loading onto Carolina Bay Drive and accessing Glenn McConnell instead of accessing Savannah Highway. Thus, the new construction project diverts 1,600 to 2,000 vehicles per day from Savannah Highway to Glenn McConnell Parkway.

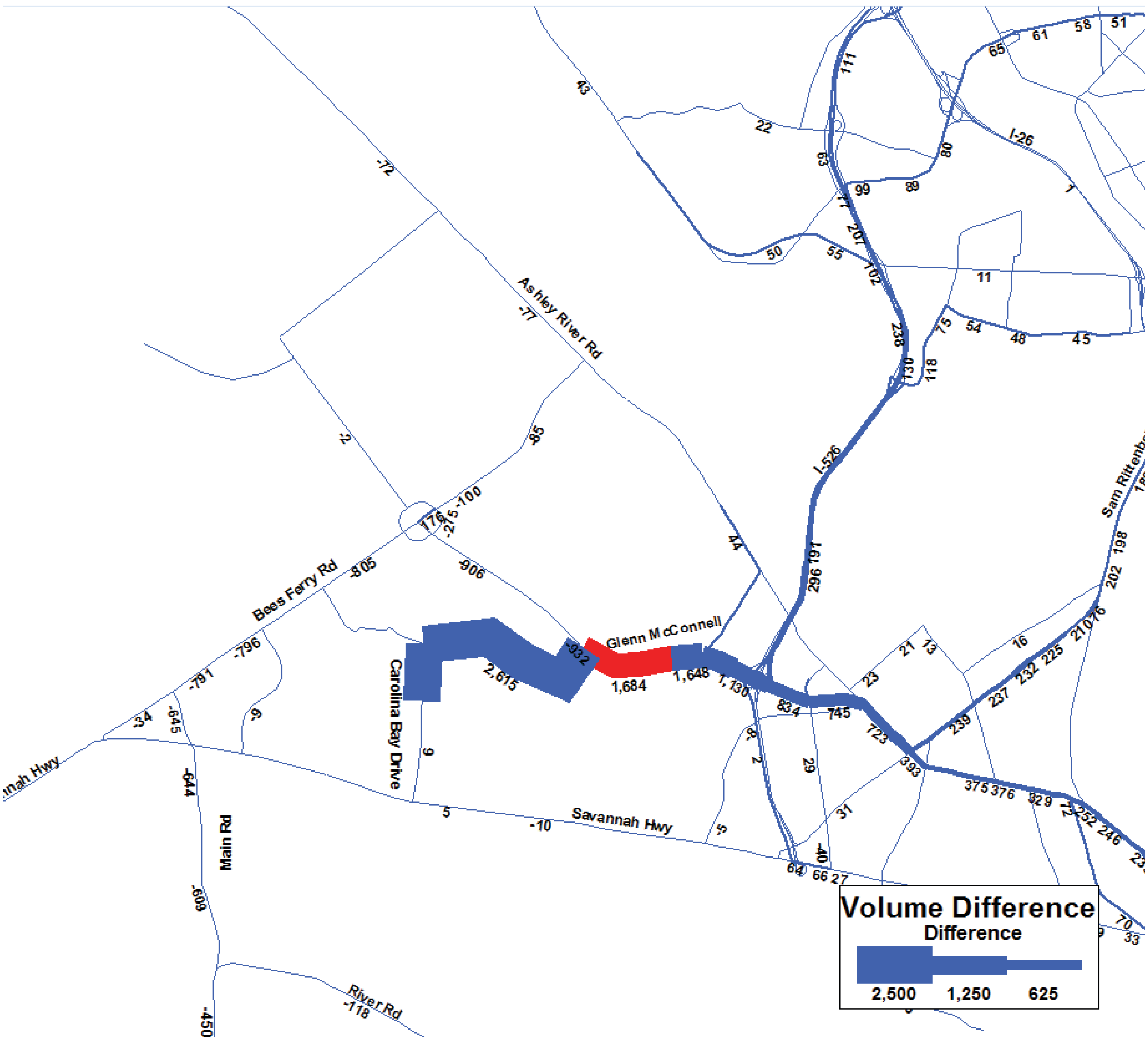


Figure 11-17. Difference in select link volumes.

Table 11-9. "Build" scenario select link volumes.

Road Name	Segment Description	2030 "No-Build" ADT	2030 "Build" ADT	Difference
Glenn McConnell Parkway	Between Selected Link and I-526	82,800	83,700	900
Glenn McConnell Parkway	Selected Link	54,900	56,500	1,600
Glenn McConnell Parkway	Between Selected Link and Bees Ferry Road	48,900	48,000	(900)
Bees Ferry	Between US 17 and Glenn McConnell	37,500	36,800	(700)
Bees Ferry	Between Ashley River Rd and Glenn McConnell	23,000	22,900	(100)
Savannah Hwy (US 17)	Between Bees Ferry and Carolina Bay	42,300	40,200	(2,100)
Savannah Hwy (US 17)	Between Carolina Bay and I-526	42,300	40,700	(1,600)

For comparison, analysis of the new construction project as the selected link can be conducted to evaluate the spatial distribution of the new roadway project users. Figure 11-18 shows graphically the behavior of traffic traversing the new roadway project, where the new roadway project selected link is shown in darker gray near the left-center of the figure. The ADT estimated by the model for the new roadway project is 3,000 vehicles per day in 2030. It can be noted that most of these 3,000 vehicles using the new roadway facility are traveling to and from downtown using Glenn McConnell Parkway and St. Andrews Boulevard and they are traveling to and from North Charleston and Mt. Pleasant using the Glenn McConnell Parkway and I-526.

This analysis can be further verified using the OD matrix output from the select link procedure. The OD matrix is another tool to analyze the impacts of the new construction project being studied.

11.3.5 Temporal Analysis Technique

The CHATS travel demand model is a daily model. For design purposes, peak-hour volumes are necessary to analyze the impact of critical congested travel periods. In this case study, design hourly volumes are obtained by post-assignment time-of-day factoring of the daily traffic volumes estimated by the CHATS travel demand model. This technique is commonly used due to its simple nature and minimal labor and data requirements.

The requirement for estimating directional design hourly volume (DDHV) is to use the K factor, which defines the proportion of ADT in the peak hour, and the D factor, which defines the directional distribution of two-way traffic in the peak direction of travel. The DDHV can be estimated as $DDHV = ADT \times K \times D$, where ADT represents the daily volume output from the CHATS travel demand model. Additional details on the DDHV and associated parameters can be found in Section 8.5 of this report.

Typically, the K and D factors are estimated based on regional or statewide historical traffic count data and they vary by facility type and area type/size. For the purposes of this case study, the following parameter values were used:

- K factor of 9%,
- D factor of 60% in the peak direction (60/40 direction split for the AM and PM peak periods), and
- ADT of 3,000 vehicles per day for the new roadway project on Carolina Bay Drive.

Using the equation $DDHV = ADT \times K \times D$, the DDHV for the new roadway project on Carolina Bay Drive is $DDHV = 3{,}000 \times 0.09 \times 0.60 = 162$ peak-hour vehicles in the peak direction.

More specific hourly volumes may be necessary for forecasting traffic on the new roadway project. For example, based on the study area characteristics, the peak AM and PM periods may have significantly different design hour volumes—the evening peak is usually much higher than the morning peak. Hourly volume distributions can be utilized for facilities characterized by area type/size, facility type, and day of the week. Chapter 8 of this report provides hourly factors based on ATR data from permanent count stations from various states over a 5-year period. These factors are a reliable source when localized data are not available, but the forecaster should be aware of the lack of sensitivity to localized change in travel demand.

The hourly distribution factors from Chapter 8 of this report are used to factor the ADT estimated for Carolina Bay

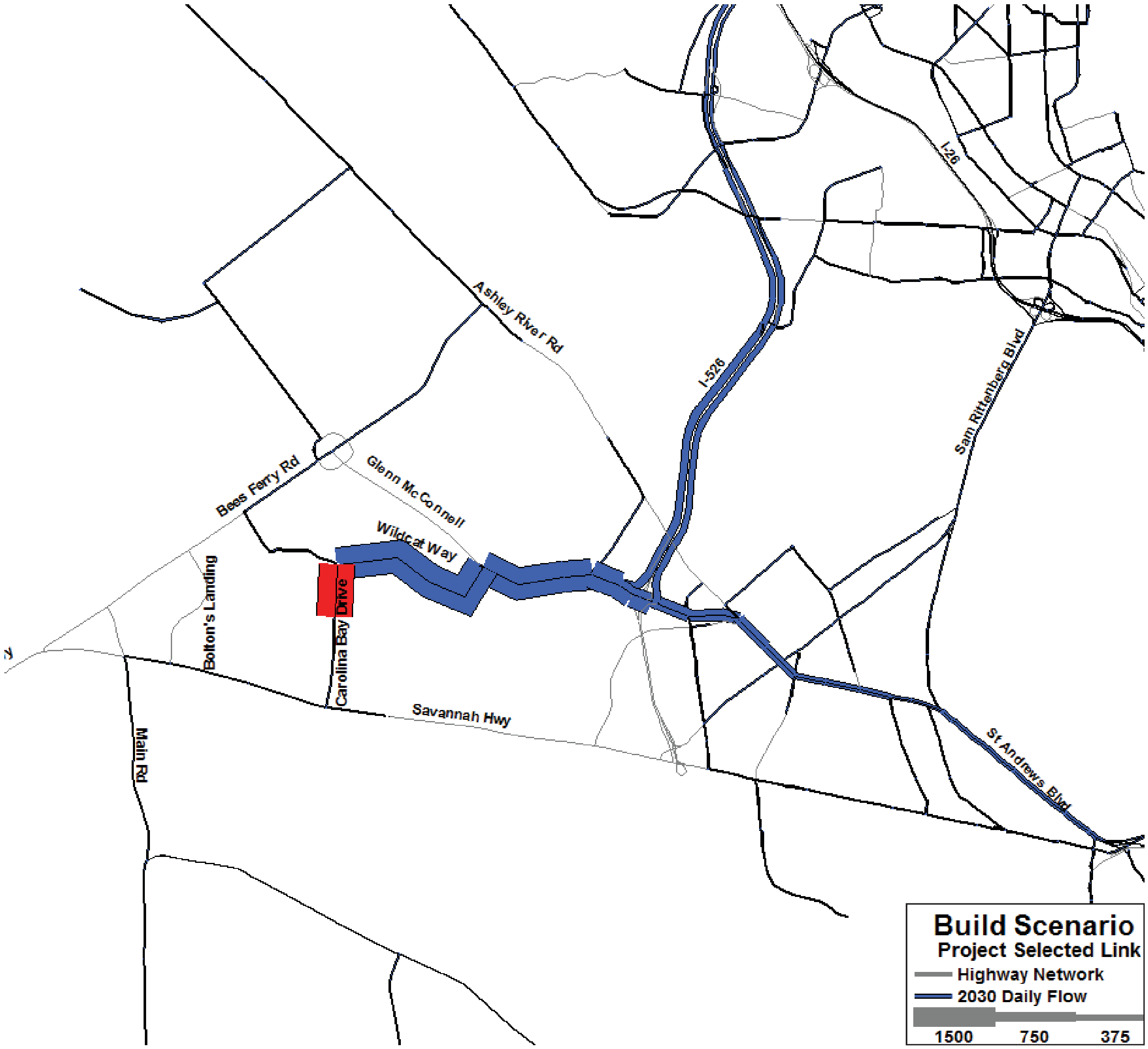


Figure 11-18. "Build" scenario—new project select link flow map.

Drive by time of day. The following data are used for the purposes of this case study:

- Study area size—small urban area,
- Roadway facility type—collector,
- Day of week—average day,
- AM peak hour—8:00–9:00,
- PM peak hour—5:00–6:00, and
- Table 8-8. Urban Area, Small: <200,000 Population.

Based on these input data, the hourly factors for the AM and PM peak hours from the "Urban Area, Small: <200,000 Population" table presented in Chapter 8 of this report are 5.24% and 8.19%, respectively. These hourly factors are applied to the ADT for Carolina Bay Drive to get the AM and PM hourly volume:

AM Volume (8:00–9:00) = 3,000 ∗ 0.0524 = 157 vehicles.
PM Volume (5:00–6:00) = 3,000 ∗ 0.0819 = 246 vehicles.

The directional peak-hour volumes can be determined by applying the D factor to the hourly volumes:

Directional AM Volume (8:00–9:00) = 3,000 ∗ 0.0524 ∗ 0.60 = 94 vehicles.
Directional PM Volume (5:00–6:00) = 3,000 ∗ 0.0819 ∗ 0.60 = 147 vehicles.

11.4 Case Study #4—Activity-Based Model Application for Project-Level Traffic Forecasting/ Analysis: HOV to HOT Lane Conversion

11.4.1 Introduction

This case study demonstrates the development and application of an activity-based travel demand model for project-level traffic forecasting and analysis. The specific project is an HOV to HOT lane conversion scenario in the Atlanta metropolitan area. The Atlanta Regional Commission (ARC), the metropolitan planning organization for Atlanta, has developed a state-of-the-practice, activity-based travel demand model system. This model system simulates activity-travel patterns for a synthetic population of the Atlanta region under a wide range of policy and network scenarios. This section provides a summary of the application with a view to illustrating the use of the activity-based travel demand model for a corridor-level project analysis. Complete details about the study effort can be found in the project report (*129*).

The configuration of the model adopted by ARC combines an activity-based travel demand model with a time-of-day, period-based traditional static traffic assignment procedure. The modeling process does not incorporate a mesoscopic dynamic traffic assignment (DTA) or microscopic traffic simulation model within the scope of this case study. Appropriate iterative feedback loops are in place such that skims from the time-of-day-based traffic assignment are fed back into the activity-based travel demand model. Through a series of nested logit models linked together through the use of logsums (accessibility measures), any change in skim values affects all activity-travel choices including tour generation and formation, destination choice, mode choice, and time-of-day choice.

11.4.2 Scenario

The scenario considered in the application of the activity-based travel model is the conversion of an HOV lane to a HOT lane that single-occupancy vehicles (SOVs) and HOV2 vehicles would be allowed to use for a fee. The HOV2HOT scenario consists of converting the HOV lanes on I-75, I-85, and GA 400 (north of I-285) corridors to HOT lanes. While SOVs and HOV2 vehicles would pay a fee, HOV3+ vehicles might not have to pay, depending on the policy. Facilities are priced in cents per mile and the price varies by time of day. Figure 11-19 shows two schematics of the network; the schematic on the right shows link IDs.

Table 11-10 shows the basic attributes of the corridors including the pricing scheme for the different vehicle occupancy levels.

A set of initial toll costs were used to determine traffic on the various links of the network including the freeway corridors in question. The intent of the pricing scheme is to set toll levels so that uncongested conditions are maintained on the links at all times. This requires flow to remain below 1,600 vphpl. The initial toll costs, shown in Table 11-11, were applied and the activity-based travel model yielded flows that exceeded 1,600 vphpl. The pricing levels were selectively increased, and the activity-based travel model was run multiple times at incrementally higher pricing levels, until all HOT lane links had flows in the uncongested regime. Table 11-11 shows the final set of costs for the activity-based travel model.

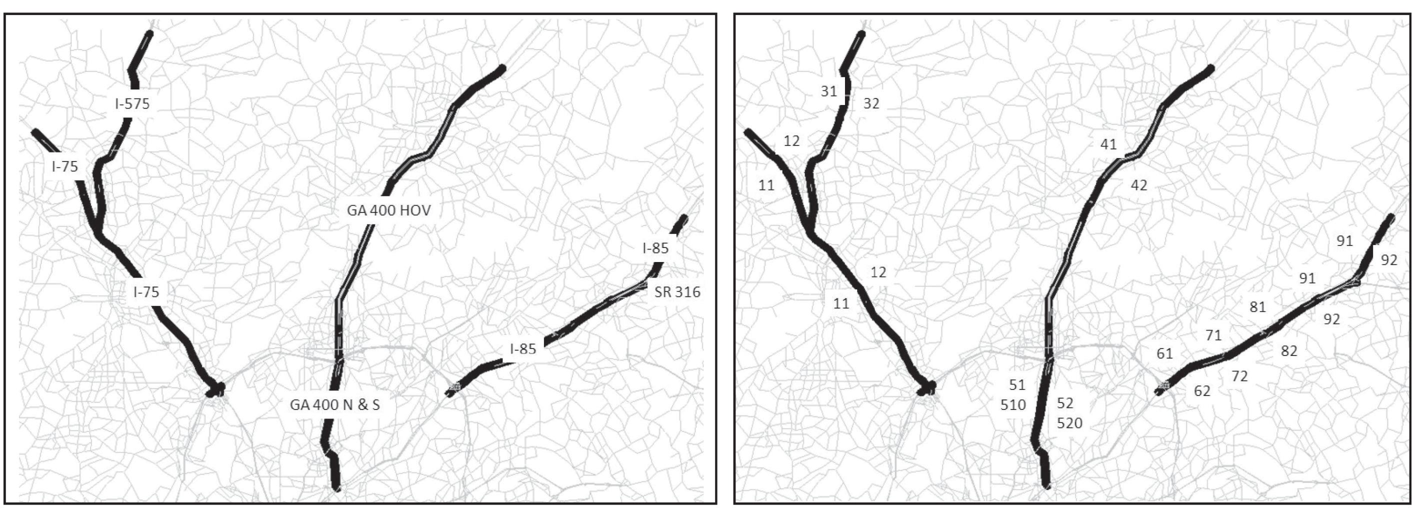


Figure 11-19. Corridors for HOV2HOT conversion scenario in Atlanta.

Table 11-10. Basic HOT facility characteristics.

	User Class				HOT Lanes By Direction				General Purpose Lanes by Direction			
Facility	SOV	HOV2	HOV3	Trucks	AM	MD	PM	NT	AM	MD	PM	NT
I-75	Pay	Pay	Free	Not Allowed	2 (SB only)	2 (NB only)	2 (NB only)	2 (NB only)	6	6	6	6
GA 400 North of I-285	Pay	Pay	Pay	Not Allowed	2	2	2	2	4	4	4	4
I-85	Pay	Pay	Free	Not Allowed	1	1	1	1	6	6	6	6

Note: HOT = high-occupancy toll, SOV = single-occupancy vehicle, HOV = high occupancy vehicle, MD = Midday, NT = nighttime, SB = southbound, NB = northbound.

11.4.3 Running the Activity-Based Travel Demand Model

Running the activity-based travel demand model required the generation of a synthetic population for the entire region of Atlanta. The synthetic population is generated using the population synthesizer embedded in the ARC activity-based travel model system. Using data from the census and locally generated forecasts, ARC generated a 2005 and 2030 synthetic population for the region. Appropriate checks and comparisons were performed to ensure that the 2005 population replicated the actual population characteristics. Changes in population characteristics between 2005 and 2030 were also examined to ensure that the 2030 synthetic population was a reasonable forecast of the population of the region. Table 11-12 shows the basic numbers for the synthetic populations for the 2 years.

Table 11-11. Pricing structure for toll lanes.

Initial Costs (cents/mi)						ABM Final Costs (cents/mi)			
TOLLID	**TOLLAM**	**TOLLMD**	**TOLLPM**	**TOLLNT**	**FIXED**	**TOLLAM**	**TOLLMD**	**TOLLPM**	**TOLLNT**
11	15	5	10	5	0	75	5	10	5
12	5	5	15	5	0	5	10	30	5
21	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0
31	30	5	10	5	0	30	5	10	5
32	5	5	40	5	0	5	5	40	5
41	15	5	30	5	0	30	5	30	5
42	5	5	44	5	0	10	5	44	5
51	50	50	50	50	**1**	50	50	50	50
52	50	50	50	50	**1**	50	50	50	50
61	40	25	20	10	0	80	25	40	10
62	20	25	40	10	0	40	25	80	10
71	40	25	20	10	0	80	25	40	10
72	20	25	40	10	0	40	25	80	10
81	40	25	20	10	0	80	25	40	10
82	20	25	40	10	0	40	25	80	10
91	40	25	20	10	0	40	25	20	10
92	20	25	40	10	0	20	25	40	10
510	0	0	0	0	1	0	0	0	0
520	0	0	0	0	1	0	0	0	0

Increased Relative to the Initial Costs

Note: MD = midday, NT = nighttime, ABM = activity-based model.

Table 11-12. Synthesized populations.

Year	Households	Persons	Workers (Full Time + Part Time)
2005	1,768,645	4,696,894	2,318,741
2030	2,689,464	6,901,699	3,550,976
Percent Change	52%	47%	53%

Figure 11-20 shows the patterns of population change in the region predicted by the population synthesizer. It can be seen that much of the growth occurs in outlying areas while the central areas show more modest growth over the 25-year time period.

The activity-based travel model was applied to the synthetic population. The synthetic population was not altered across corridor pricing scenarios. Regardless of the HOV2HOT lane conversion scenario, the synthetic population for the 2030 horizon year was assumed fixed. Thus, the synthetic population generator was run only once while the rest of the activity-based travel model was run repeatedly for various pricing levels.

The activity-based travel demand model was run in its entirety and ARC compared the results of the activity-based travel demand model with results from a trip-based model that included a toll post-processor. Results were considerably different, suggesting that the activity-based model may be capturing behavioral aspects and sensitivity that the trip-based model is not able to capture. Complete details of the comparison can be found in the project report (*129*).

The case study includes a number of results that illustrate the output provided by an activity-based travel demand model system. These are briefly highlighted in the next sections.

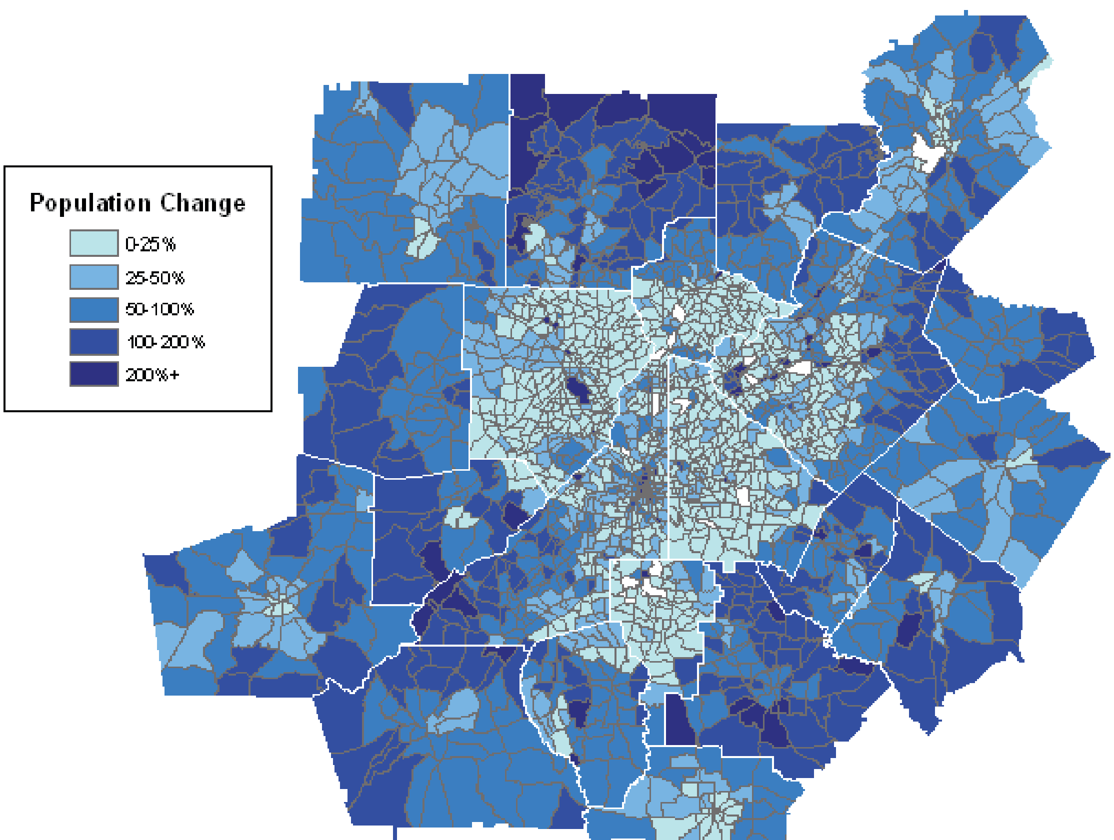


Figure 11-20. Population change 2005–2030 as predicted by the synthetic population generator.

Table 11-13. Managed lanes model results.

	ABM					
	Managed Lanes			General Purpose		
AM	I-75	GA 400 HOV	I-85	I-75	GA 400 HOV	I-85
FROM NODE	47216	12348	10702	4814	4958	5263
TO NODE	47213	12139	10703	4817	9401	5264
SOV	7437	7758	2183	26828	10227	25060
HOV2	1220	1489	654	2519	1120	2966
HOV3	2950	507	1898	16	362	163
COM	0	0	0	2886	1642	2945
MTK	0	0	0	1345	749	1846
HTK	0	0	0	3011	621	3516
AM CAPACITY	3300	3200	1600	9900	6400	9950
TIME_1	0.68	0.89	0.35	1.56	0.84	0.95
SPEED	58	55	61	58	55	61
CGSTSPD	41	46	52	19	42	19
VC_1	0.87	0.76	0.73	1.01	0.61	1.02
LOS	E	D	D	F	C	F

Notes: ABM = activity-based model, COM = commercial vehicles, MTK = medium trucks, HTK = heavy trucks, and VC_1 = volume-to-capacity ratio.

11.4.4 Managed Lanes Results

The activity-based travel model system was applied by ARC to evaluate link attributes under the managed lane scheme. Table 11-13 presents an overview of the results depicting selected link attributes for the managed lanes and the general purpose lanes.

From Table 11-13, it can be seen that there is considerable demand among SOV drivers for the use of managed lanes, particularly on I-75 and I-85. The pricing levels had to be increased substantially to push SOV drivers out of the managed lanes and provide enough capacity for HOV2 and HOV3+ vehicles while maintaining uncongested conditions. Commercial and other trucks are not allowed to use managed lanes. It can be seen that the managed lanes maintain congested speed values considerably higher than those in the general purpose lanes. The exception is GA 400, where HOV3+ vehicles are required to pay toll as well and, hence, the demand for managed lane use among these vehicles is low.

The assignment results for the corridors in question from the activity-based travel model application provide rich information about the number of trips by time period that fall into various travel time savings bins. Figure 11-21 shows the AM toll trips by minutes saved. In this figure, it can be seen that the number of drive-alone vehicle trips in the AM period with substantial time savings is quite large. The

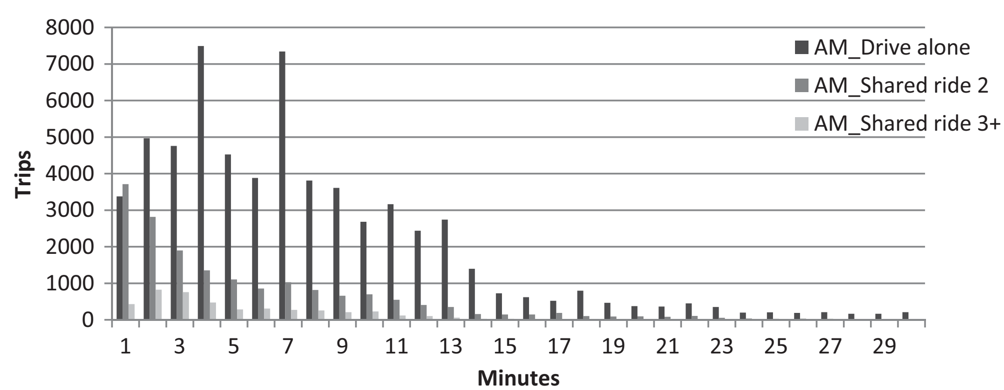


Figure 11-21. AM toll trips by minutes saved.

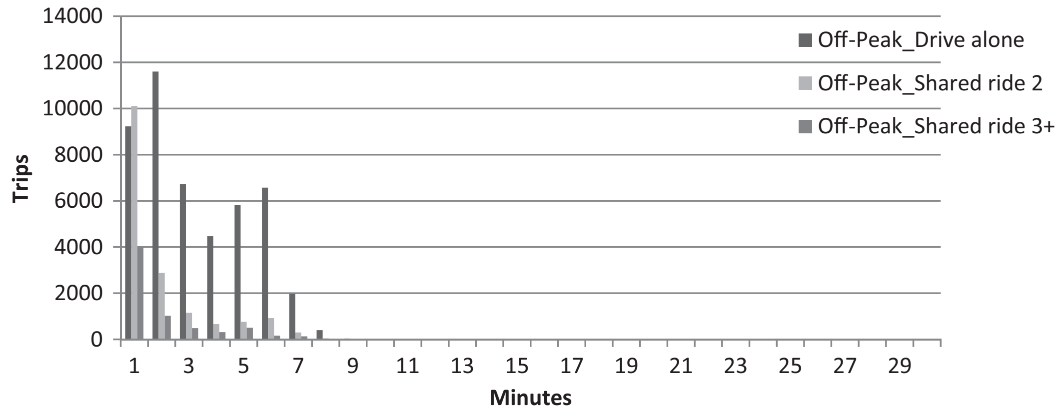
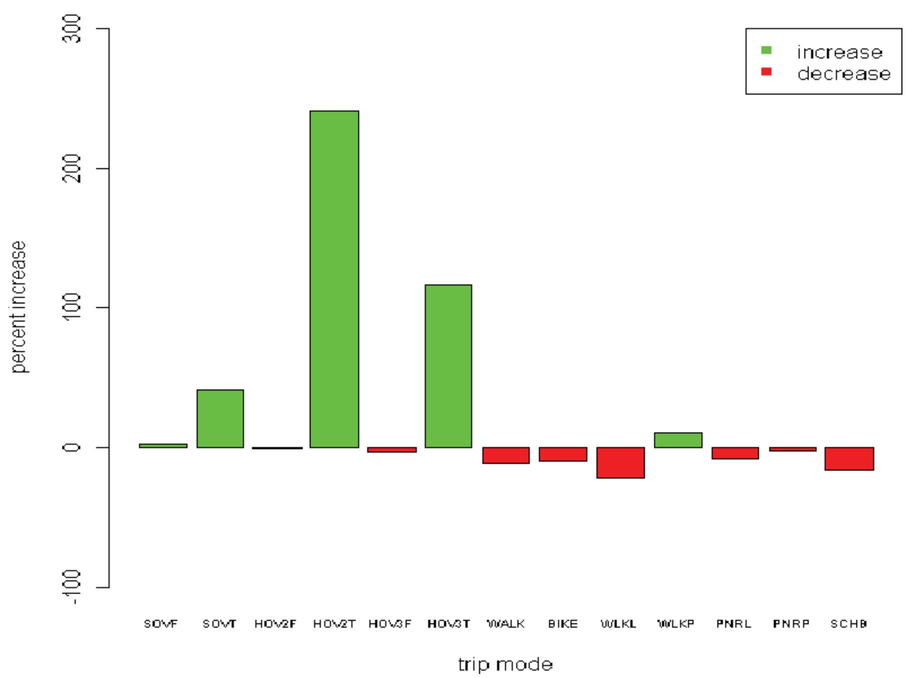


Figure 11-22. Off-peak toll trips by minutes saved.

trend seen among shared-ride trips is largely a downward pattern, suggesting that shared trips were probably enjoying uncongested travel times even in the AM peak period before the HOV lanes were converted to HOT lanes. Thus, after the conversion to HOT lanes, these trips do not realize appreciable benefits; the distribution of shared-ride trips by minutes of time saved shows smaller travel time savings than the distribution for drive-alone trips. Figure 11-22 shows the number of trips by minutes saved for off-peak trips. As expected, the distributions are all skewed substantially toward small travel time savings, consistent with the notion that uncongested travel times in the off-peak period and corresponding travel times in the toll scenario are quite close in magnitude to one another.

An examination of model outputs shows that the activity-based travel demand model yields link volumes that largely stay under the 1,600 vphpl threshold within the AM and PM peak periods. As mentioned earlier, the pricing structure is modified with incremental increases in the toll cost so that the volumes assigned by the model do not exceed the 1,600 vphpl threshold needed to maintain level of service (LOS) C conditions.

The activity-based travel demand model effectively captures changes in mode shares as a result of the pricing scheme. Figure 11-23 shows the change in mode shares as a result of



Notes. SOVF = Single-occupant vehicle free, SOVT = SOV toll, HOV#F = HOV free, HOV#T = HOV toll, WLKL = Walk to local transit, WLKP = Walk to premium transit, PNRL = Park and ride to local transit, PNRP = Park and ride to premium transit, SCHB = School bus.

Figure 11-23. Change in trip mode share relative to base year.

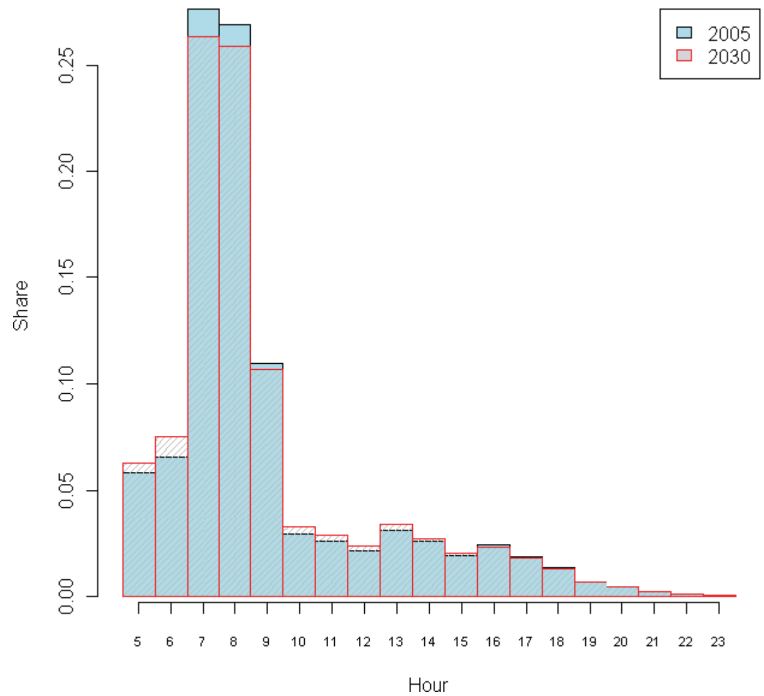


Figure 11-24. Distribution of work trip departure time from home.

the tolling strategy (over the 25-year forecast period). As expected, there are substantial increases in the shares of toll modes and decreases in the shares of other modes such as walk, bicycle, and transit (except for walk-access premium transit). It appears that the improvement in operating conditions on the priced facilities contributed to higher mode shares for the toll modes even though the out-of-pocket cost attribute increases between the non-toll and the toll scenario.

Another important attribute of interest for which activity-based travel demand models are able to offer detailed information is the time-of-day choice. Figure 11-24 shows the change in time-of-day distributions for work trips between the 2005 and 2030 scenarios. The figure shows the phenomenon of peak spreading in the forecast year, presumably due to increases in congestion in the horizon year. The study report provides similar comparisons for non-work trips. Comparisons are presented for both departure time and home arrival time. The activity-based travel demand model suggests that individuals will arrive home later in the forecast year, once again due to increases in congestion and longer travel times (figure not shown here).

11.4.5 Summary

This case study has demonstrated that a comprehensive activity-based travel model system can be effectively interfaced with a traditional traffic assignment procedure to obtain link volumes and performance measures for any time-of-day slice. In this particular case study, it was not necessary to further model scenarios using a DTA or microscopic traffic simulation model.

11.5 Case Study #5—Time-Series Analysis of the Blue Water Bridge

11.5.1 Background and Data

The Blue Water Bridge (the Bridge) is an international border crossing between the U.S. state of Michigan and Ontario, Canada. The Bridge spans the northernmost point of the St. Claire River, just as it meets the southern portion of Lake Huron (see Figure 11-25). The St. Claire River and the Detroit River together separate southeast Michigan from southern Ontario. The Blue Water Bridge has the city of Port Huron, Michigan, on its west end and the city of Sarnia, Ontario, on its east end. The issue of the importance of the Bridge to international commerce has been in the forefront of transportation planning for the region in recent years because of interest in reconstructing the inspection plazas and adjoining roadways on both the U.S. and Canadian sides. The toll and inspection plaza on the U.S. side is shown in Figure 11-26. Additional interest has been focused on the Bridge due to the planning and environmental clearance of a second bridge across the Detroit River between the cities of Detroit, Michigan, and Windsor, Ontario, not far from the privately owned Ambassador Bridge. Although the Blue Water Bridge

Figure 11-25. Blue Water Bridge location map.

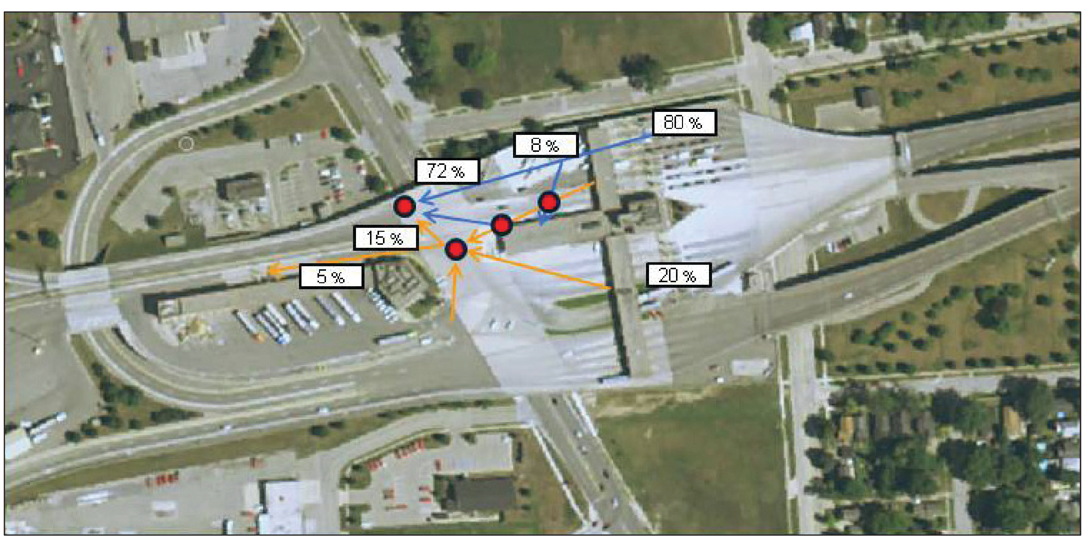


Figure 11-26. Configuration and traffic movement percentages: U.S. Plaza (east is to the right side of the graphic).

is somewhat distant from the city of Detroit, its location is ideal for shipping from most other parts of Michigan and many points west, such as into the heart of southern Ontario, including the Toronto metropolitan area. I-94 and I-69 meet just west of the Bridge, and they connect to Ontario Highway 402, also known in Canada as the King's Highway. The Bridge is the second busiest border crossing between the U.S. and Canada; the busiest crossing is the Ambassador Bridge.

The Bridge originally opened in 1938 and was expanded to three lanes in each direction in 1999. Traffic on the Bridge has steadily increased over the last three decades. Total automobile traffic is approximately 1,860,000 vehicles per year and total truck traffic is approximately 670,000 per year (according to 2012 data). Automobiles pay a toll of $3 per trip and trucks pay $3.25 per axle per trip. Truck traffic has been declining in recent years.

Of greatest interest to commerce is the amount of truck traffic on the Blue Water Bridge. The Blue Water Bridge is essentially a single two-way link in a traffic network. Thus, a time-series forecast of truck traffic on the Blue Water Bridge would follow very similar methods as a time-series forecast of any other highway link. However, for the sake of clarity, this case study only employs methods that can be performed with a spreadsheet program such as MS Excel. More sophisticated, but not necessarily better, time-series methods can be found within specialized statistical software packages.

The case study forecasted the amount of truck traffic in October 2020, using a time-series forecast of truck traffic on the Blue Water Bridge. The steps in the time series are listed below. A time-series forecast can use historical data on traffic volumes as well as historical data on the economy and population. In this example, these historical data series were collected for each month from January 1984 until December 2010:

- Eastbound monthly truck volumes on the Bridge,
- Westbound monthly truck volumes on the bridge,
- U.S. gross domestic product (GDP),
- U.S. price of all grades of motor vehicle fuel,
- Michigan population,
- Ontario population,
- Effective date of the North American Free Trade Agreement (NAFTA), and
- Date of the 9/11 attacks.

The two population data series were interpolated from yearly statistics.

Figures 11-27 and 11-28 show the eastbound and westbound traffic, respectively.

A number of observations can be made from the data series. The two data series are almost identical, the data series are steadily increasing over time, and the data series seem to be exhibiting a cyclic pattern; however, this pattern is not simple. An inspection of the full data series (not shown) also shows that the month-to-month variations increase over time, and there is a very slight dip in truck traffic for a few months following September 2001. The remaining analysis will concentrate on westbound truck traffic.

Figures 11-29 through 11-32 are X-Y data plots of westbound truck traffic (Y) against each of the four continuous explanatory variables (X).

The scatterplots all show a positive correlation of an explanatory variable and westbound truck traffic, but the correlation with fuel price is weak. There is an almost linear relationship between Michigan population and truck traffic, likely because Michigan population is strongly correlated with the size of the Michigan economy. Both U.S. GDP and Ontario population correlate strongly and positively in early

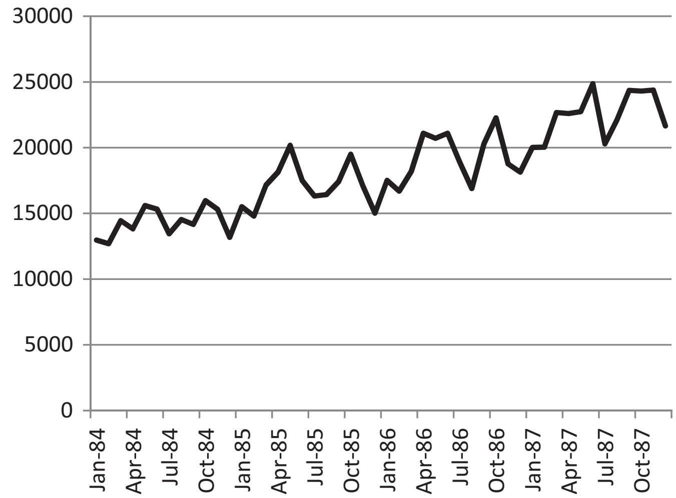


Figure 11-27. Eastbound truck traffic on the Blue Water Bridge 1984–1987.

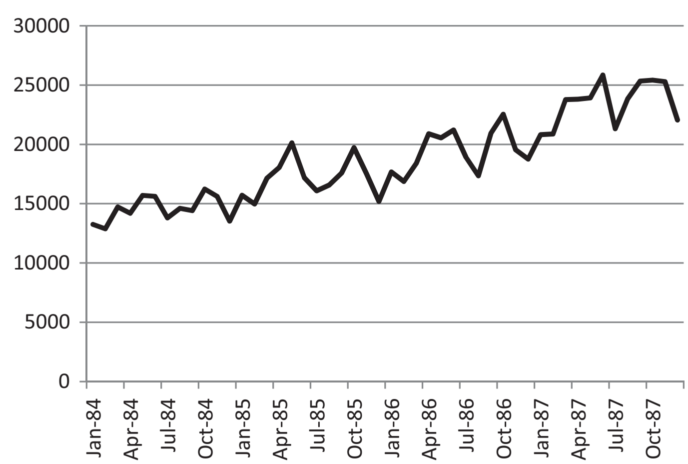


Figure 11-28. Westbound truck traffic on the Blue Water Bridge 1984–1987.

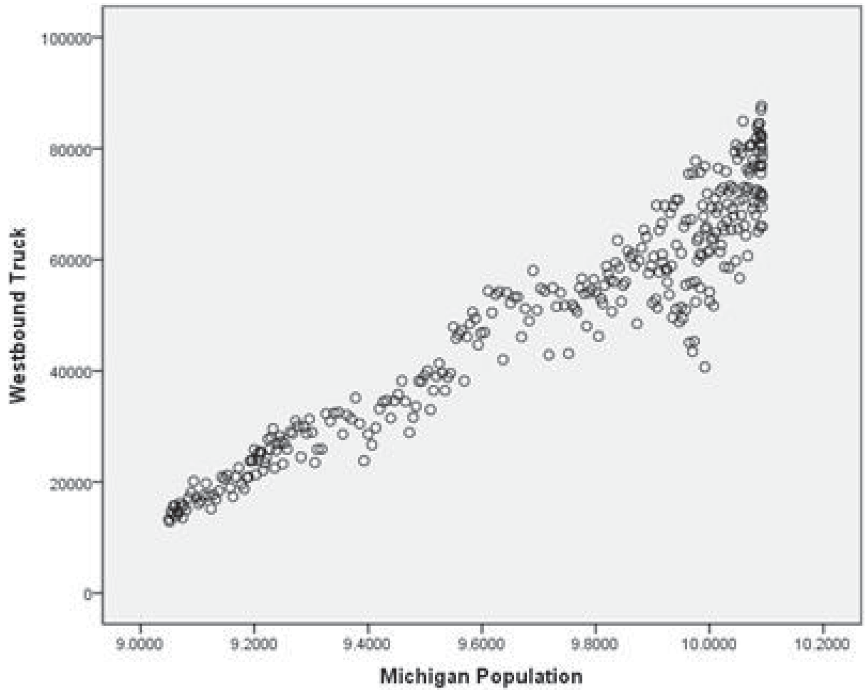


Figure 11-29. Scatterplot of westbound truck traffic and Michigan population.

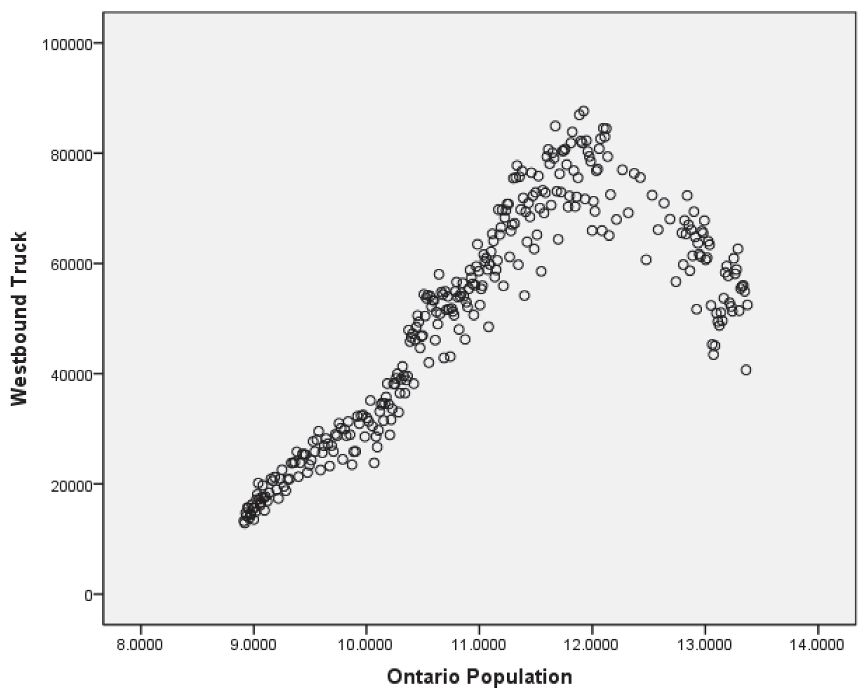


Figure 11-30. Scatterplot of westbound truck traffic and Ontario population.

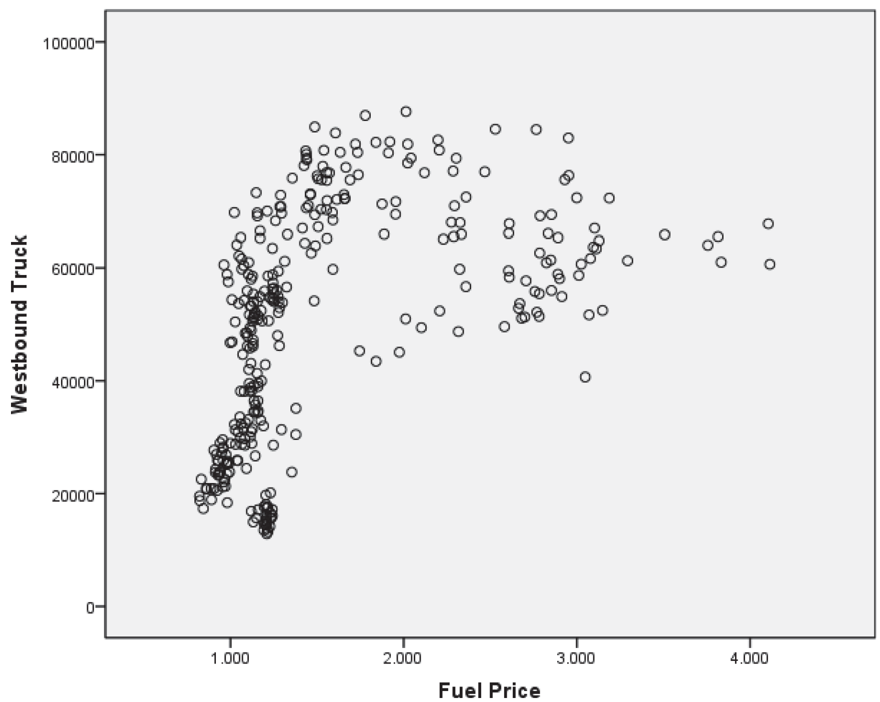


Figure 11-31. Scatterplot of westbound truck traffic and fuel price.

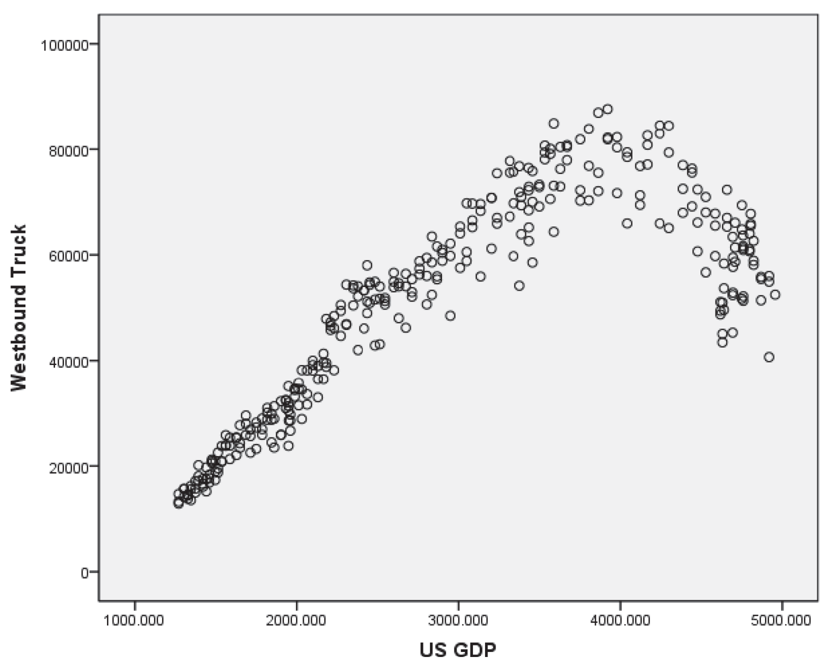


Figure 11-32. Scatterplot of westbound truck traffic and U.S. GDP.

years, but in the later years appear to correlate negatively instead of positively.

NAFTA and the attacks of 9/11 can be handled as dummy (0, 1) variables. NAFTA's effective date was January 1, 1994, so a data series can be created with all zeros before 1994 and all ones from 1994 onward. The 9/11 data series contains all zeros, except for the months of September, October, and November 2001.

11.5.2 Analysis: Central Moving Average

A quality trend analysis can depend upon the smoothness of a data series. Cyclic variations in a data series can be temporarily removed by a technique called "central moving average." This technique calculates multiplicative "seasonal" adjustment factors that can be applied later to any forecasts from the smoothed data. A central moving average is illustrated by the screenshot in Figure 11-33.

D9 =SUM(B3:B14)/12

	A	B	C	D	E
1		Truck		Moving Average	
2		Westbound	Eastbound	Westbound	Eastbound
3	Jan-84	13253	12968		
4	Feb-84	12878	12689		
5	Mar-84	14716	14444		
6	Apr-84	14186	13820		
7	May-84	15699	15596		
8	Jun-84	15619	15323		
9	Jul-84	13799	13448	14544	14287
10	Aug-84	14612	14539	14749	14499
11	Sep-84	14411	14165	14923	14674
12	Oct-84	16232	15964	15126	14900
13	Nov-84	15603	15308	15449	15260
14	Dec-84	13525	13177	15818	15642
15	Jan-85	15706	15513	15950	15822

Figure 11-33. Illustration of central moving average for monthly truck traffic.

The portion of the two data series shown in Figure 11-33 is from the earliest months. The first central moving average is from July 1984. That average comes from the 12 months from January 1984 to December 1984. The second central moving average, August 1984, comes from the 12 months from February 1984 to January 1985. A central moving average can be used to remove any well-established periodic variations from a data series. The extent to which the westbound traffic has been smoothed can be seen in Figure 11-34, where the black line is the central moving average and the gray line is the original data.

To later restore periodic variations to a forecast on smoothed data, it is necessary to calculate seasonal adjustment factors. A seasonal adjustment factor is the average of the data series for a period (a month, in this case) divided by the average of the smoothed data series for the same period. Figure 11-35 shows the seasonal adjustment factors for westbound and eastbound truck traffic. Seasonal adjustment factors are greater than one when the month tends to have larger truck volumes, and factors are less than one for months when truck traffic is relatively small.

11.5.3 Analysis: Linear Trend Line on Smoothed Data

Linear trend line analysis is the most elementary of time-series methods, and it is a technique in wide use by departments of transportation. Linear trend lines can be easily estimated on spreadsheets, either by built-in bivariate regression func-

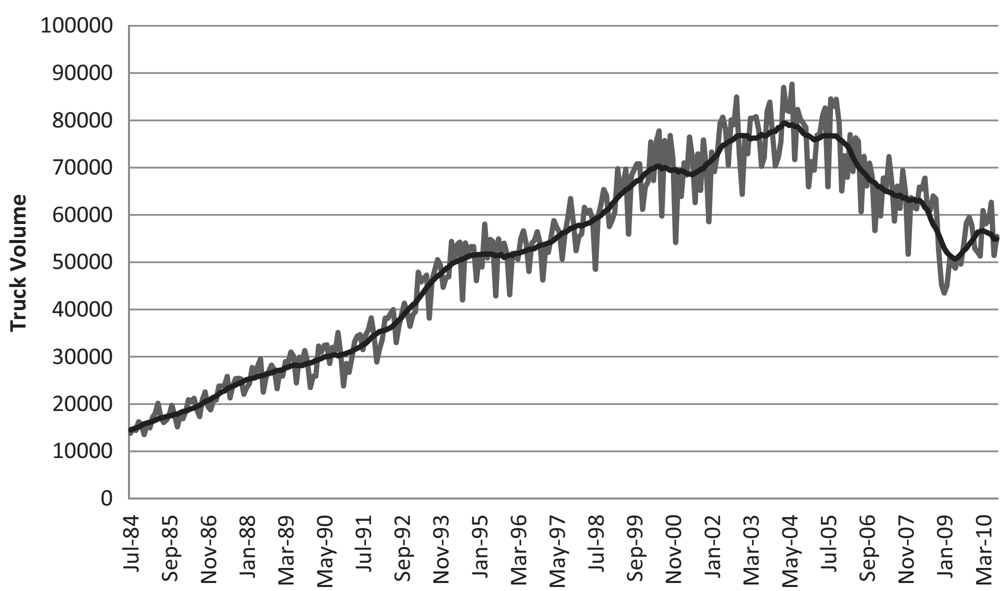


Figure 11-34. Central moving average of westbound truck traffic.

Month	Mean of Truck Volume Westbound	Eastbound	Mean of Moving Average Westbound	Eastbound	Seasonal Adjustment Factor Westbound	Eastbound
Jan	47598	43333	50923	47456	0.9347	0.9131
Feb	46702	43269	51043	47612	0.9150	0.9088
Mar	52219	48566	51174	47778	1.0204	1.0165
Apr	51219	47691	51307	47948	0.9983	0.9946
May	53322	49808	51434	48114	1.0367	1.0352
Jun	53390	50476	51560	48272	1.0355	1.0457
Jul	45114	42391	50097	46466	0.9005	0.9123
Aug	51872	49466	50221	46615	1.0329	1.0612
Sep	51958	49114	50344	46764	1.0320	1.0502
Oct	54683	51480	50493	46940	1.0830	1.0967
Nov	51412	48216	50633	47110	1.0154	1.0235
Dec	43788	41711	50772	47276	0.8624	0.8823

Figure 11-35. Computation of seasonal adjustment factors.

tions or by statistical add-ins. Statistical add-ins are recommended because they provide statistics on goodness of fit, such as t-scores and R-square statistics. Linear trend lines do not use explanatory variables, except for time, which is usually expressed as the number of periods from the beginning of the data series. For the Blue Water Bridge, the beginning of the smoothed data series is July 1984. A simple regression analysis results in this equation:

$$T_n = 230n + 14291$$

where n is the number of months, starting at July 1984. Truck traffic is increasing by 230 vehicles per month each month, on average.

There is at least one obvious problem with the linear trend line. An inspection of Figure 11-34 reveals that truck traffic has declined in recent years, so the long-term upward trend might not extrapolate well into the future. Perhaps the inclusion of explanatory variables would give a better forecast. Therefore, linear trend analysis will not be explored further.

11.5.4 Analysis: Linear Regression with Explanatory Variables

A linear regression can contain explanatory variables, with or without time as a variable. Since the Blue Water Bridge truck volumes are highly correlated with Michigan population, and Michigan population is mostly increasing with time, it is likely that time can be excluded as a variable. The statistical analysis add-ins that come with Excel do not do stepwise linear regression, so the analyst must decide which variables should be included. The following sets of explanatory variables are tried:

- Model 1: Michigan population (millions);
- Model 2: Michigan population, Ontario population (millions);
- Model 3: Michigan population, U.S. GDP (billions $);
- Model 4: Michigan population, U.S. GDP, NAFTA, 9/11 attacks; and
- Model 5: Michigan population, fuel price ($).

These are not all the possible combinations of explanatory variables, but there are enough combinations to draw conclusions as to the best model. Regressions are trying to explain the smoothed, westbound monthly truck volumes. The results are summarized on Table 11-14, showing coefficients, t-scores (in parentheses), and adjusted R-square values.

Table 11-14. Results of linear regressions on smoothed westbound truck volumes with explanatory variables.

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Intercept	−497049 (−76.3)	−611522 (−87.6)	−626205 (−59.1)	−656705 (−42.5)	−535639 (−79.7)
Michigan Population	56430.84 (84.1)	74601.87 (75.9)	71275.3 (60.0)	74603.82 (43.7)	60995.06 (84.2)
Ontario Population		−5627.15 (−20.6)			
U.S. GDP			−5.08066 (−13.9)	−5.1932 (−14.3)	
NAFTA				−2315.04 (−2.6)	
9/11 Attacks				−1204.54 (−0.6)	
Fuel Price					−3711.76 (−10.4)
R-Square	0.957632	0.982063	0.973846	0.974284	0.968541

It is important to inspect variables for the logically correct sign as well as having a significant t-score. The Michigan population has the correct sign in all models, but incorrect signs are observed for the Ontario population, U.S. GDP, and NAFTA. 9/11 attacks has the correct sign, but it has a weak t-score. R-squares are excellent and of similar size across all models. Taking everything into consideration, Model 5 is most likely to give the best results.

In order to forecast with any of these equations, it is necessary to forecast each of the explanatory variables in the equation. A reasonable forecast for NAFTA is that it will continue, so its series has a value of one for all future periods. A reasonable forecast for the 9/11 attacks is that there will not be another attack of this magnitude, so its series has a value of zero for all future periods. The forecast for Michigan population can come from commercial or governmental sources, or it could be estimated by a linear trend line. A trend line (separate analysis, not shown) gives a Michigan population in October 2020 of 10.6825 million, despite recent population loses. There are many possibilities for fuel price; for this analysis, a $4 fuel price is assumed.

The estimated westbound truck traffic for October 2020 from Model 5 is 101,094 trucks per month, using smoothed data. Applying the seasonal adjustment factor for October of 1.0830 brings the final estimate to 109,484 trucks per month.

The placing of confidence limits on this estimate requires consideration of both the standard error of the truck forecast (3,481 trucks) and the standard error of the Michigan population forecast (0.123549 millions of people). The standard error of the Michigan population forecast is amplified by its coefficient (60995.06) in the truck forecast, for a total standard error of the population term of 7,536 trucks. Conservatively adding the two sources of error as if they were independent and applying a 50% confidence limit results in a tolerance of about ±5,600 trucks, assuming there are no unforeseen events.

11.5.5 Autoregressive Integrated Moving Average (ARIMA)

ARIMA models do not require external smoothing because careful selection of terms can allow for close tracking of seasonal variations and can allow for some smoothing of period-to-period variations. However, ARIMA models can benefit from transformations to reduce heteroscedasticity. A quick inspection of Figure 11-34 reveals that there is more variation later in the series than earlier. A Box-Cox transformation can even up much of this variation, but there is a need to select the β parameter. One way to determine β is to try several different values and then see how well standard deviations vary across time. Table 11-15 shows the standard deviations of the transformed series with four different values of β as well as the original series. Standard deviations in each case are computed for the earliest through latest sixths of the whole, unsmoothed westbound truck traffic series. Table 11-15 indicates that β = 0.5 gives the most uniform results. A β = 0.5 value is chosen for the rest of the analysis, as illustrated in Figure 11-36.

Table 11-15. Standard deviations of sixths of the westbound truck data series after transformation.

	Original	0.7	0.6	0.5	0.4
First	4242.26	217.06	80.65	29.98	11.15
Second	5159.87	227.74	80.54	28.49	10.08
Third	4783.81	185.88	62.97	21.34	7.23
Fourth	7377.83	265.20	87.55	28.91	9.55
Fifth	6811.98	236.23	77.05	25.14	8.20
Sixth	7275.84	273.32	91.57	30.69	10.28

11.5.6 Autoregressive Model

Software designed specifically to do ARIMA will provide autocorrelation and partial autocorrelation statistics that can aid model design. However, spreadsheets can only provide autocorrelations and, even then, only awkwardly. If ARIMA is conducted on a spreadsheet, then a trial-and-error process is likely to provide adequate results. Spreadsheets can do either autoregressive or integrated models, but spreadsheets cannot do models with moving average terms. Fortunately, good models of highway traffic are usually easy to construct. Autoregressive models forecast the data series directly, and simple integrated models forecast period-to-period differences. Figure 11-37 shows the period-to-period differences for the transformed data series. Figure 11-37 shows a substantial amount of period-to-period variation, much of it looking random, but some of it likely being cyclical. One would suspect that a regular pattern repeats every 12 months, so an AR(2) model with lags at 1 month and 12 months has a good chance of explaining much of the variation in the transformed data series.

An AR(2) model is fairly easy to estimate on a spreadsheet by putting the data series in one column and its lags in additional columns. Lags are created by shifting the data series down by a desired number of rows, one row per amount of lag. This equation was therefore estimated:

$$T_n = 0.38144 * T_{n-1} + 0.56038 * T_{n-12} + 30.957$$

with all t-scores being significant, an adjusted R-square of 0.962, and a standard error (transformed) of 17.69. The model is entirely empirical. Even though the series was unsmoothed, the overall goodness of fit was about the same as seen with the linear regression models in the previous analysis. A forecast with this model would require an intermediate forecast

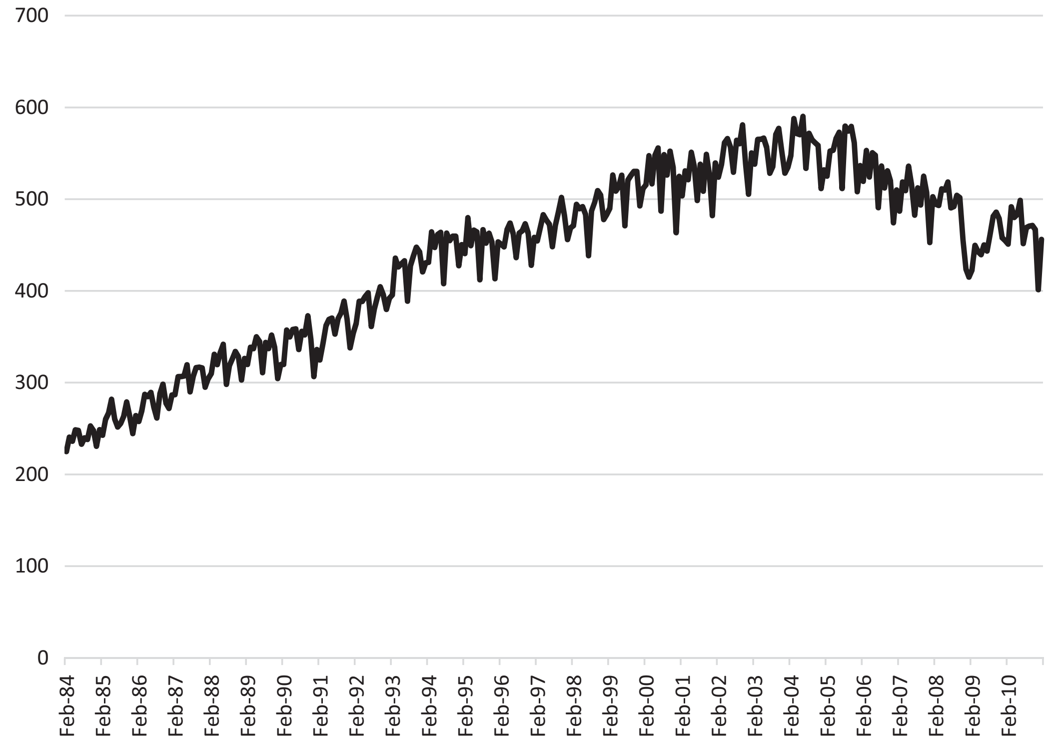


Figure 11-36. Transformed data series (β = 0.5) of westbound monthly truck volumes.

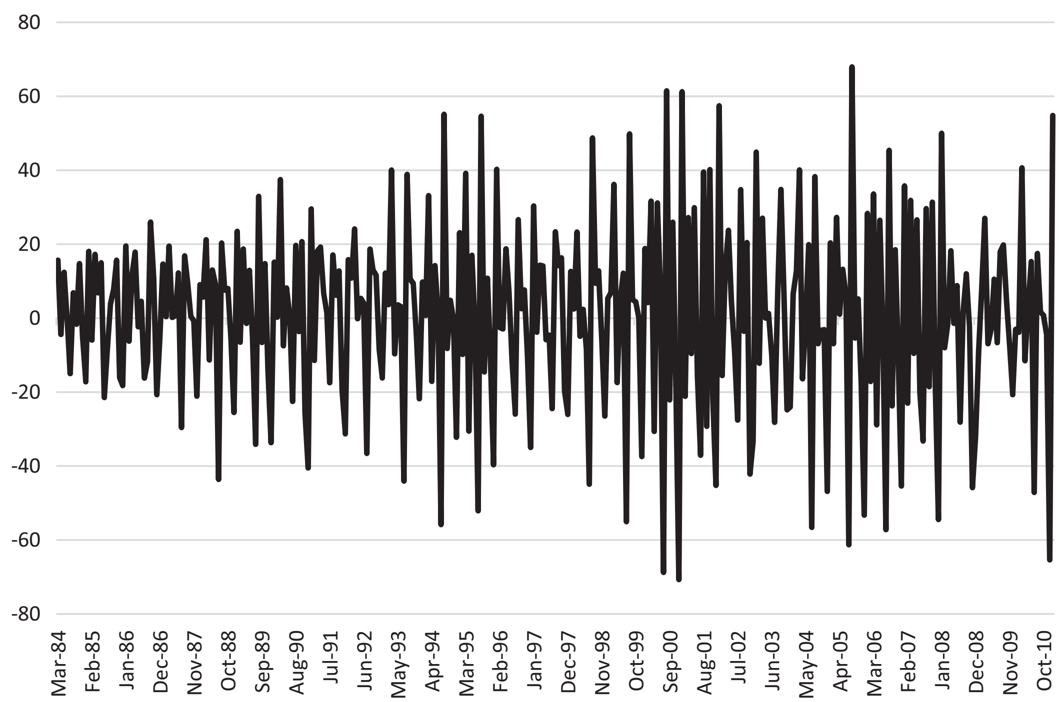


Figure 11-37. Month-to-month variation in the transformed truck volume data series.

of every month between the last data point and the desired future month. Since this model is forecasting a transformed variable, the forecast will need to be untransformed before being reported or used. Because of the strong results, there is no need to consider additional lags.

11.5.7 Autoregression with Explanatory Variables

Autoregression can be combined with explanatory variables to create models that are less dependent on current trends and can reflect changing demographics and economics. For clarity, AR models with explanatory variables (sometimes referred to as ARX models) should not be transformed. For example, a model with lags at 1 and 12 with Michigan population (M) and fuel price (F) as explanatory variables would look like:

$$T_n = 0.21655 * T_{n-1} + 0.58674 * T_{n-12} + 13{,}329 * M - 4{,}153 * F - 112{,}154$$

with M in units of millions of people, F in units of dollars, and all forms of T in units of trucks per month. All t-scores are significant, and all coefficients have the correct sign. The adjusted R-square is 0.962, and the standard error of the estimate is 3,733.

11.5.8 Discussion

Many of the models fit the truck volume data series very well. For the Blue Water Bridge analysis, Model 5 (linear regression) slightly outperforms the ARX model. Since Model 5 also has fewer empirical elements, it should be chosen for forecasting purposes.

Two other explanatory variables, not available, would likely have given interesting results: Michigan GDP and the difference in truck tolls between the Ambassador Bridge and the Blue Water Bridge.

None of the models are capable of correctly predicting the effects of a second bridge across the Detroit River, especially if the second bridge toll charges are lower than those of the Ambassador Bridge.

Please note that all data were obtained from publicly available sources.

11.6 Case Study #6—Blending a Regional Travel Forecasting Model with a Traffic Microsimulation

The use of a blended model can be illustrated by a previous application of three software packages to the freeway system for the Portland, Oregon, metropolitan area. One package performs macroscopic travel forecasting, another package performs DTA, and the third package performs a traffic microsimulation. This case study concentrates on how the packages were interfaced rather than the individual specifics of each package. The case study further illustrates some of the difficulties encountered when transferring outputs of a regional travel forecasting model to a traffic microsimulation model.

11.6.1 Study Area Description

The study area is Portland, Oregon, where there was a need for a traffic microsimulation of a large portion of its freeway system (shown in Figure 11-38). Roads included in the microsimulation were I-5, I-205, I-405, I-84, and OR-217.

11.6.2 Techniques

This case study describes the creation of a dynamic OD table that could be conveniently fed into the traffic microsimulation and satisfy the requirement of good agreement with short-duration traffic counts. Original static OD tables were obtained from the regional planning model and then they were passed through two separate refinement steps.

The freeway network used for refinements, which corresponds closely to the network for the microsimulation, is seen in Figure 11-39. The network was drawn to closely match the freeway roadway configuration in the area. Only short segments of arterial streets were included to provide access to the freeway.

The original static OD tables were obtained from the regional travel forecasting model for the Portland metropolitan area (Metro). Provided OD tables were originally divided into vehicle classes, but all classes were combined during the refinement steps. One OD table was for a 2-hour AM period and the second OD table was for a 2-hour PM period. As expected, the quality of fit to ground counts of these OD tables was below requirements for a microsimulation. Figure 11-40 shows the quality of fit of one of the original 2-hour OD tables assigned to the freeway network.

Average RMS error was 51%, which is well above what is acceptable for a microsimulation and also well above the expected error of a ground count. It should be noted that this RMS error could have been lower for the full regional network, which contained many arterials as well as freeways. In addition, the zone system for the regional model did not correspond to the zone system for the microsimulation. The need for refinement was obvious.

11.6.3 Refinement Steps

11.6.3.1 Refinement Step #1: Refine 2-Hour Static Origin-Destination Tables

The first step in the refinement process was to improve upon the performance of the 2-hour static OD tables.

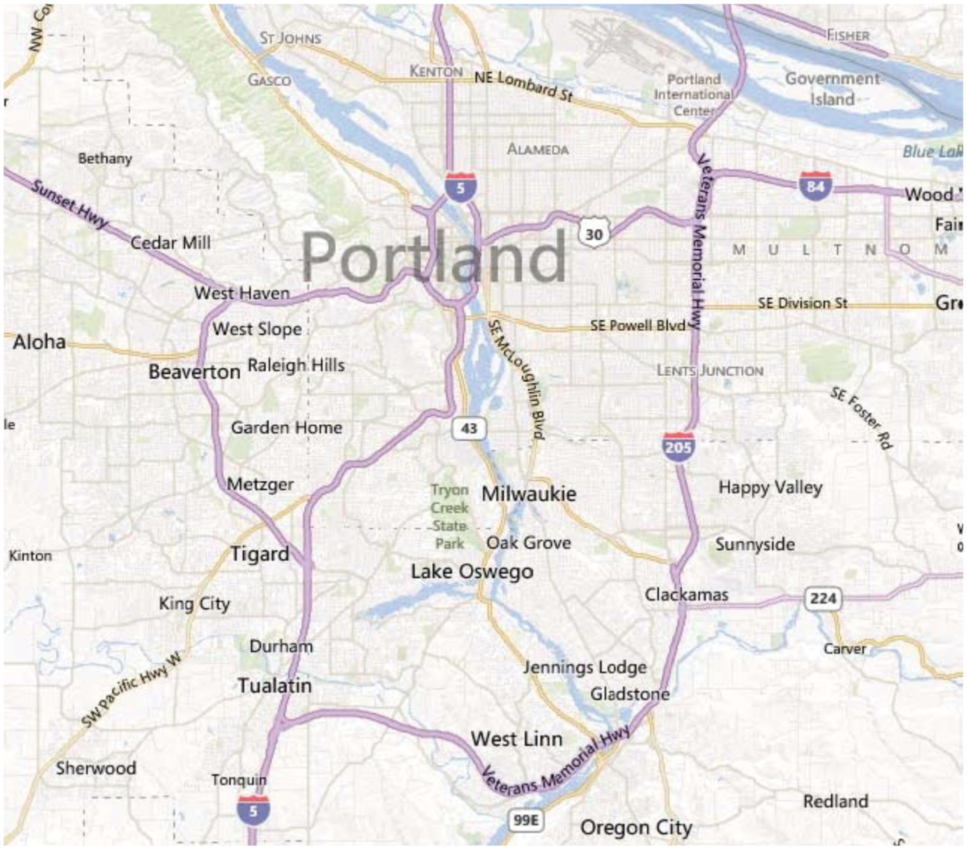


Figure 11-38. Approximate area covered by the freeways in the microsimulation.

Figure 11-39. Portland freeway refinement network.

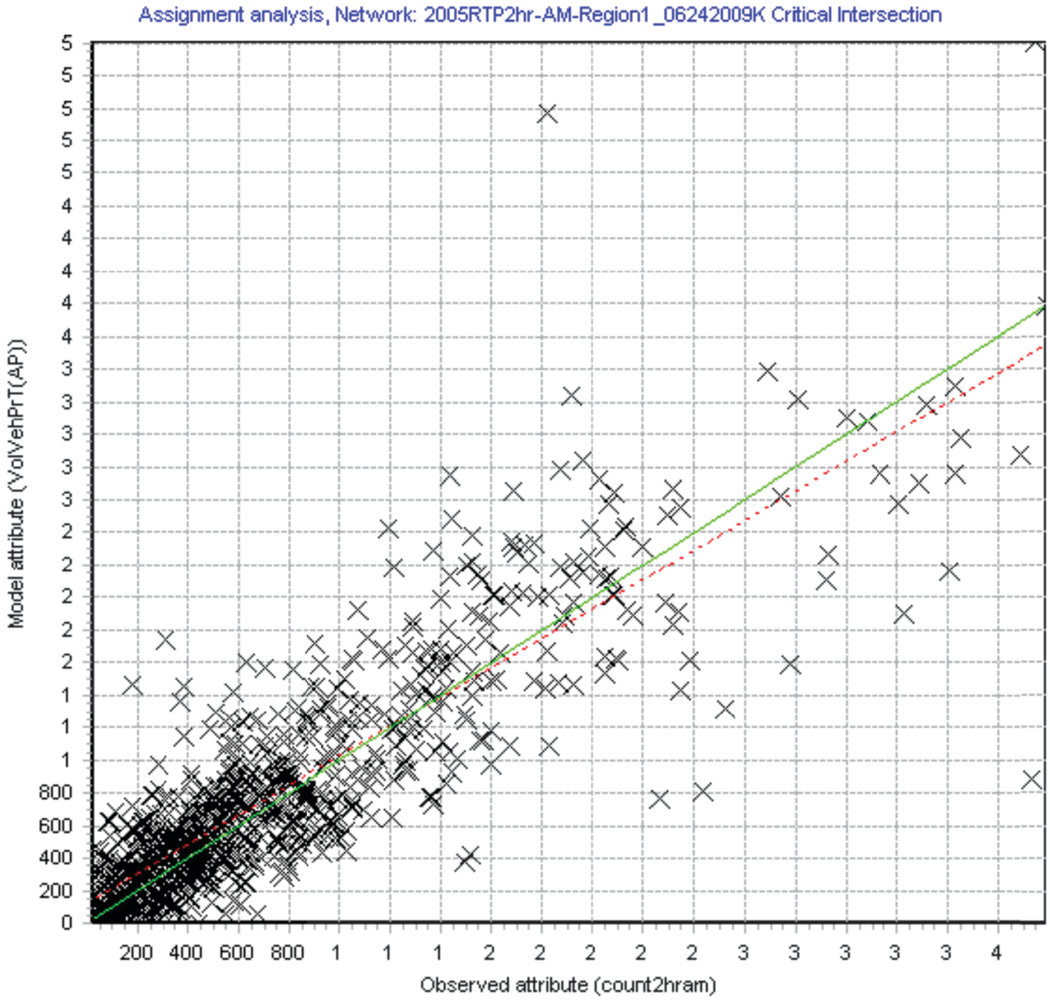


Figure 11-40. Comparison of assigned volumes to ground counts for the original 2-hour AM OD table.

Mainline and ramp traffic counts were obtained from Portland State University's Portland Transportation Archive Listing (PORTAL). In addition, many turning movement counts at intersections were obtained specifically for this project. A proprietary OD table estimation tool was selected. During the estimation process, several counts were determined to be inconsistent with the rest of the counts and were discarded. A single, vehicle-class estimation improved the fit to ground counts, as seen in Figure 11-41.

RMS error improved to 21% for the AM 2-hour period and 17% for the PM 2-hour period. These RMS errors are approaching the level of error in the ground counts, themselves, so there was no need to improve the static tables any further.

11.6.3.2 Refinement Step #2. Create Multihour Dynamic Origin-Destination Tables

The refined 2-hour static OD tables needed to be converted to 4- and 5-hour dynamic OD tables: 6 to 10 AM and 2 to 7 PM. The first part of this step required the factoring up of the 2-hour tables to their respective 4- and 5-hour tables. A separate, single scale factor was used for each, as determined by the traffic counts.

Each time slice for the dynamic tables was 15 minutes in duration, so a dynamic OD table was required to span the 4- and 5-hour periods in 15-minute increments. The factoring down of the longer time periods into 15-minute increments was accomplished within the DTA software separately for each freeway. Counts for each of the five freeways were used to find a factor for the "territory" around each freeway. This factoring by territory was enabled by unique features in the proprietary software that was adopted, but the process was analogous to using select link analysis to apply segment factors to the OD table. AM factors varied from about 4% to almost 8%, and PM factors varied in a tight range from about 4% to 5.5%. Then the traffic was assigned using a dynamic user-equilibrium (DUE) traffic assignment program to obtain dynamic path flows and dynamic link flows. The outputs served as inputs to the microsimulation model.

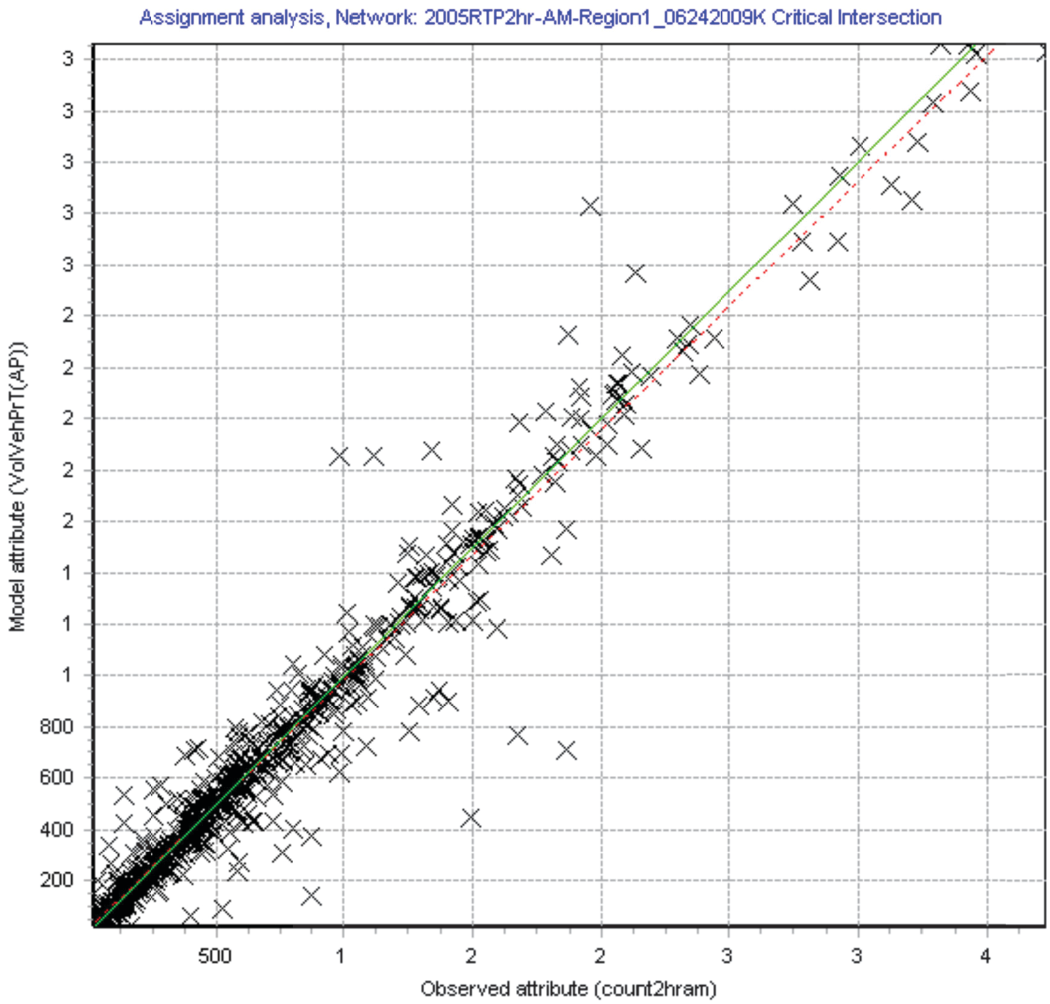


Figure 11-41. Comparison of assigned volumes to ground counts for the refined 2-hour AM OD table.

11.6.3.3 Discussion

There are several important lessons from this case study. First, regional models can create OD tables which assign relatively poorly to subnetworks. Unless the regional model has been designed and calibrated for project-level forecasting, refinement of the OD tables will likely be necessary. Thus, an automatic interface, without refinement, between a regional travel forecasting model and a microsimulation could be quite disappointing. The situation is further aggravated by any inconsistencies in zones between the two types of models.

Second, microsimulations are inherently dynamic and regional travel forecasting models are largely static. Peaking characteristics within short time increments must be considered. A DTA model has the potential of correctly representing those peaking characteristics and likely has better delay relationships.

Third, it is critical that an analyst be cognizant of any problems that can arise. For example, mistakes in archived traffic counts can distort results. Mistakes can stem from inadequate counting technology, incorrect geocoding, missing data items, and various technical glitches. A refinement step is good way to identify incorrect counts, because a refinement step, if executed well, tends to smooth out variations in traffic, making it easier to identify outliers.

Third, although the two-step procedure adopted by the modeling team was effective, there were numerous opportunities for things to go wrong. A more solid approach would have been to perform a full dynamic OD table estimation from traffic counts within the DTA software with a “bilevel” algorithm.

11.6.3.4 Acknowledgment

This case study was performed in 2009 by PTV America for the Oregon Department of Transportation(*131*). All graphics were supplied by PTV America.

References and Bibliography

1. Pedersen, N. J., and D. R. Samdahl. *NCHRP Report 255: Highway Traffic Data for Urbanized Area Project Planning and Design.* TRB, National Research Council, Washington, D.C., 1982.
2. Ohio Department of Transportation. *Ohio Certified Traffic Manual.* 2007. Accessed December 29, 2011. http://www.dot.state.oh.us/Divisions/TransSysDev/MultiModalPlanning/ModelForecastingUnit/Documents/OH_Cert_Traffic_Manual.pdf.
3. Florida Department of Transportation. *Project Traffic Forecasting Handbook.* 2012. Accessed December 29, 2011. http://www.dot.state.fl.us/planning/statistics/trafficdata/ptf.pdf.
4. U.S. Department of Transportation. *The Manual on Uniform Traffic Control Devices* (MUTCD). Accessed June 10, 2013. http://mutcd.fhwa.dot.gov/kno-2003r1.htm.
5. Levinson, D., B. Marion, and M. Iacono. Access to Destinations, Phase 3: Measuring Accessibility by Automobile, Report #11, Access to Destinations Study, Minnesota Department of Transportation, March, 2010.
6. Cambridge Systematics, Inc. *NCHRP Report 716: Travel Demand Forecasting: Parameters and Techniques.* Transportation Research Board of the National Academies, Washington, D.C., 2012. Accessed June 10, 2013.
7. Martin, W. A., and N. A. McGuckin. *NCHRP Report 365: Travel Estimation Techniques for Urban Planning.* TRB, National Research Council, Washington, D.C., 1998.
8. Sosslau, A. B., A. B. Hassam, M. M. Carter, and G. V. Wickstrom. *NCHRP Report 187: Quick-Response Urban Travel Estimation Techniques and Transferable Parameters: User's Guide.* TRB, National Research Council, Washington, D.C., 1978.
9. Federal Highway Administration. *Travel Model Validation and Reasonableness Checking Manual, Second Edition.* Travel Model Improvement Program, U.S. Department of Transportation, September 2010.
10. Cambridge Systematics, Inc. *Quick Response Freight Manual II.* Publication No. FHWA-HOP-08-010. Federal Highway Administration, U.S. Department of Transportation, September 2007.
11. *Trip Generation Handbook: An ITE Recommended Practice*, 2nd Edition, Institute of Transportation Engineers, Washington, D.C., June 2004.
12. Donnelly, R., G. Erhardt, R. Moeckel, and W. Davidson. *NCHRP Synthesis 406: Advanced Practices in Travel Forecasting.* Transportation Research Board of the National Academies, Washington, D.C., 2010.
13. Chiu, Y-C., J. Bottom, M. Mahut, A. Paz, R. Balakrishna, T. Waller, and J. Hicks. *Transportation Circular E-C153: Dynamic Traffic Assignment: A Primer.* Transportation Research Board of the National Academies, Washington, D.C., June 2011.
14. Cambridge Systematics, Inc. *Utilization of Dynamic Traffic Assignment in Modeling Guidebook*, Federal Highway Administration, U.S. Department of Transportation, September 2012.
15. Federal Highway Administration. Traffic Analysis Tools. Accessed December 29, 2011. http://ops.fhwa.dot.gov/trafficanalysistools/.
16. DeCorla-Souza, P., and N. J. Grubb. Network Focusing—A Tool for Quick Response Subarea Analysis. *ITE Journal*, Vol. 61, No. 9, Washington, D.C., September 1991, pp. 33–39.
17. Abrahamsson, T. Estimation of Origin-Destination Matrices Using Traffic Counts—A Literature Survey. International Institute for Applied Systems Analysis, Laxenburg, Austria, May 1998.
18. Bain, R. *Toll Road Traffic & Revenue Forecasts: An Interpreter's Guide*, 2009.
19. Travel Forecasting Resource. Accessed December 29, 2011. http://www.tfresource.org/.
20. Federal Highway Administration, *Interim Guidance on the Application of Travel and Land Use Forecasting in NEPA.* March 2010. Accessed December 29, 2011: http://environment.fhwa.dot.gov/projdev/travel_landUse.asp.
21. *Highway Capacity Manual 2010* (HCM2010). Transportation Research Board of the National Academies, Washington, D.C., 2010.
22. Committee for Determination of the State-of-the-Practice in Metropolitan Area Travel Forecasting, *Special Report 288: Metropolitan Travel Forecasting: Current Practice and Future Direction.* Transportation Research Board of the National Academies, Washington, D.C., 2007.
23. Willumsen, L. G. *Estimation of an O-D Matrix from Traffic Counts—A Review.* Institute of Transport Studies, University of Leeds, 1978.
24. Wardrop, J. G., Some Theoretical Aspects of Road Traffic Research. *Proc. of the Institute of Civil Engineers PART II*, Vol.1, 1952, pp. 325–378.
25. Horowitz, A., and D. Farmer. *Guidebook for Statewide Travel Forecasting.* Federal Highway Administration, U.S. Department of Transportation, July 1999.
26. *Special Report 209: Highway Capacity Manual.* Transportation Research Board, National Research Council, Washington, D.C., 1985.
27. Mannering, F. L., and C. Winston. A Dynamic Empirical Analysis of Household Vehicle Ownership and Utilization. *Rand Journal of Economics*, Vol. 16, No. 2, 1985, pp. 215–236.
28. De Jong, G., J. Fox, A. Daly, M. Pieters, and R. Smith. Comparison of Car Ownership Models. *Transport Reviews*, Vol. 24, No. 4, 2004, pp. 379–408.

29. Dissanayake, D., and T. Morikawa. Household Travel Behavior in Developing Countries: Nested Logit Model of Vehicle Ownership, Mode Choice, and Trip Chaining. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1805*, Transportation Research Board of the National Academies, Washington, D.C., 2002, pp. 45–52.
30. Train, K. E., and C. Winston. Vehicle Choice Behavior and the Declining Market Share of US Automakers. *International Economic Review*, Vol. 48, No. 4, 2007, pp. 1469–1496.
31. Bhat, C. R., and S. Sen. Household Vehicle Type Holdings and Usage: An Application of the Multiple Discrete-Continuous Extreme Value (MDCEV) Model. *Transportation Research Part B: Methodological*, Vol. 40, No. 1, 2006, pp. 35–53.
32. Shelton, J. A., G. A. Valdez Ceniceros, and E. Perales. Backcasting of Meso-Micro Model Simulation Results for User Class Restrictions on Freeway Corridors. Presented at 91st Annual Meeting of the Transportation Research Board, Washington DC, 2012.
33. Burghout, W., and J. Wahlstedt. Hybrid Traffic Simulation with Adaptive Signal Control. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1999*, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 191–197.
34. Villalobos, J. A., Y-C. Chiu, and P. Mirchandani. Domain Distributed Dynamic Traffic Assignment Model for Mega-Scale Problems. Online presentation, University of Arizona. Accessed December 29, 2011. http://urbanmodel.asu.edu/intmod/presentations/Malta_FHWA%20PeerReviewPanelPresentation_Nov2.pdf.
35. Litman, T. *Generated Traffic and Induced Travel: Implications for Transport Planning.* Victoria Transport Policy Institute, Victoria, British Columbia, 2011. Accessed December 29, 2011. http://www.vtpi.org/gentraf.pdf.
36. Lee, Jr., D. B.; L. Klein, and G. Camus. Induced Traffic and Induced Demand. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1659*, TRB, National Research Council, Washington, D.C., 1999, pp. 68–75.
37. Noland, R. B. Relationships between Highway Capacity and Induced Vehicle Travel. *Transportation Research A: Policy and Practice*, Vol. 35, No. 1, 2001, pp. 47–72.
38. Kuzmyak, J. R., R. H. Pratt, G. B. Douglas, and F. Spielberg. *TCRP Report 95: Traveler Response to System Changes, Chapter 15—Land Use and Site Design.* Transportation Research Board of the National Academies, Washington, D.C., 2003.
39. Committee for the Study of Impacts of Highway Capacity Improvements on Air Quality and Energy Consumption. *Special Report 245: Expanding Metropolitan Highways: Implications for Air Quality and Energy Use.* TRB, National Research Council, Washington, D.C., 1995.
40. Webster, F., and B. Cobbe. *Traffic Signals: Road Research Technical Paper 56.* Her Majesty's Stationery Office, London, 1966.
41. Public Transit Office. *The Florida Guidebook for Model Application in FTA New Starts and Small Starts.* Florida Department of Transportation, Tallahassee, Fla., October 2010. http://www.dot.state.fl.us/transit/Pages/ModelNewStarts2010.pdf.
42. *Guidebook on Methods to Estimate Non-Motorized Travel: Overview of Methods.* Publication No. FHWA-RD-98-165. Federal Highway Administration, U.S. Department of Transportation, July 1999. http://safety.fhwa.dot.gov/ped_bike/docs/guidebook1.pdf.
43. Putman, S. H., Preliminary Results from an Integrated Transportation and Land Use Model Package. *Transportation*, Vol. 3, 1974, pp. 193–223.
44. Mackett, R. L., Integrated Land Use Transport Models. *Transport Reviews*, Vol. 5, 1985, pp. 325–343.
45. Wegener, M. Overview of Land Use—Transport Models. In *Transport Geography and Spatial Systems*, Chapter 9 of Handbook 5 of the Handbooks in Transport Series, Pergamon/Elsevier Science, Kidlington, U.K., 2004, pp. 127–146.
46. Waddell, P. UrbanSim: Modeling Urban Development for Land Use, Transportation and Environmental Planning. *Journal of the American Planning Association*, Vol. 68, 2002, pp. 297–314.
47. Abraham, J. E., and J. D. Hunt. Random Utility Location, Production, and Exchange Choice; Additive Logit Model; and Spatial Choice Microsimulations. *Transportation Research Record: Journal of the Transportation Research Board, No. 2003*, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 1–6.
48. Salvini, P., and E. Miller. ILUTE: An Operational Prototype of a Comprehensive Microsimulation Model of Urban Systems. *Networks and Spatial Economics*, Vol. 5, No. 2, 2005, pp. 217–234.
49. Lee-Gosselin, M., and S. Doherty, eds. *Integrated Land-Use and Transportation Models: Behavioral Foundations.* Emerald Group Publishing, Bingley, U.K., 2005.
50. Loudon, W. R., E. R. Ruiter, and M. L. Schlappi. Predicting Peak Spreading Under Congested Conditions. *Transportation Research Record 1203*, TRB, National Research Council, Washington, D.C., 1988, pp. 1–9.
51. Allen, W. G., and G. W. Schultz. Congestion-Based Peak Spreading Model. *Transportation Research Record 1556*, TRB, National Research Council, Washington, D.C., 1996, pp. 8–15.
52. Barnes, J. Peak Spreading Analysis: Review of Relevant Issues and Synthesis of Current Practice, Phase I. Research Report No. WA-RD 459.1, Washington State Department of Transportation, Olympia, Wash., 1998. Accessed December 29, 2011. http://www.wsdot.wa.gov/research/reports/fullreports/459.1.pdf.
53. Clarke, P., and P. Davidson, Using Activity Based Modeling To Implement a Peak Spreading Model in a Practical Multi-Modal Context. *Proc. of the European Transport Conference*, 2007. Accessed December 29, 2011. http://www.etcproceedings.org/paper/download/2929.
54. *Economic Analysis Primer.* Office of Asset Management, Federal Highway Administration, U.S. Department of Transportation, August 2003. Accessed June 10, 2013. http://www.fhwa.dot.gov/infrastructure/asstmgmt/primer00.cfm.
55. Forkenbrock, D. J., and G. E. Weisbrod. *NCHRP Report 456: Guidebook for Assessing the Social and Economic Effects of Transportation Projects.* TRB, National Research Council, Washington, D.C., 2001.
56. Nadiri, M., and Mamuneas. T. The Effects of Public Infrastructure and R&D Capital on the Cost Structure and Performance of US Manufacturing Industries. 1994. Accessed June 10, 2013. http://www.econ.nyu.edu/user/nadiri/pub81.PDF.
57. ICF Consulting and HLB Decision-Economics. *FHWA Freight BCA Study: Summary of Phase II Results.* Federal Highway Administration, U.S. Department of Transportation, 2004. Accessed June 10, 2013. http://www.fhwa.dot.gov/policy/otps/summaries.htm#macro1.
58. Shatz, H. J., K. Kitchens, S. Rosenbloom, and M. Wachs. *Highway Infrastructure and the Economy, Implications for Federal Policy.* Rand Corporation, Santa Monica, Calif., 2011.
59. Weisbrod, G., D. Vary, and G. Treyz. *NCHRP Report 463: Economic Implications of Congestion.* TRB, National Research Council, Washington, D.C., 2001.

60. Rodrigue, J-P. The Lowry Model. *The Geography of Transportation Systems*, 3rd ed. Routledge, New York, 2013. Accessed June 12, 2013. http://people.hofstra.edu/geotrans/eng/methods/ch6m2en.html.
61. Putman, S. H., EMPAL and DRAM Location and Land Use Models: An Overview. *Proc., Travel Model Improvement Program Land Use Modeling Conference*, DOT-T-96-09. US Department of Transportation, 1996.
62. Hunt, J. D., and J. A. Abraham. Design and Implementation of PECAS: A Generalized System for Allocating Economic Production, Exchange and Consumption Quantities. In *Integrated Land-Use and Transportation Models: Behavioral Foundations* (M. Lee-Gosselin and S. Doherty, eds.). Elsevier, Oxford, U.K., 2005, pp. 253–274.
63. de la Barra, T. *Integrated Land Use and Transport Modeling: Decision Chains and Hierarchies.* Cambridge University Press, Cambridge, U.K., 2005.
64. Anas, A., and Y. Liu, A Regional Economy, Land Use, and Transportation Model, *Journal of Regional Science*, Vol. 47, No. 3, Tucson, Ariz., August 2007, pp. 415–455.
65. Deal, B., J. H. Kim, G. J. D. Hewings, Y. W. Kim, Complex Urban Systems Integration: The LEAM Experiences in Coupling Economic, Land Use, and Transportation Models in Chicago, IL. In *Employment Location in Cities and Regions* (F. Pagliara, M. de Bok, D. Simmonds, and A. Wilson, eds.). Springer Berlin, Heidelberg, Germany, 2013, pp. 107–131.
66. Dowling, R. A. Skabardonis, and V. Alexiadis. *Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software*, Report No. FHWA-HRT-04-040. FHWA, U.S. Department of Transportation, Washington, D.C., July 2004.
67. Federal Highway Administration. *Traffic Analysis Toolbox Volume I: Traffic Analysis Tools Primer*, Report No. FHWA-HRT-04-038. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., July 2004.
68. Davis, S. C., S. W. Diegel, and R. G. Boundy. *The Transportation Energy Data Book*, 30th ed. U.S. Department of Energy And Oak Ridge National Laboratory, 2011. Accessed on December 29, 2011. http://cta.ornl.gov/data/tedb30/Edition30_Full_Doc.pdf.
69. Cambridge Systematics, Inc. *COMSIS Corporation, and University of Wisconsin—Milwaukee, Quick Response Freight Manual*, DOT-T-97-10. Travel Model Improvement Program, U.S. Department of Transportation and U.S. Environmental Protection Agency, Washington, D.C., September 1996. Accessed May 4, 2013. http://media.tmiponline.org/clearinghouse/quick/quick.pdf.
70. Zageer, J. D., M. Vandehey, M. Blogg, K. Nguyen, and M. Ereti. *NCHRP Report 599: Default Values for Highway Capacity and Level of Service Analyses.* Transportation Research Board of the National Academies, Washington, D.C., 2008.
71. Grant M., M. Day, R. Winick, A. Chavis, S. Trainor, and J. Bauer. *Showcasing Visualization Tools in Congestion Management.* Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2001. Accessed December 29, 2011. http://nhts.ornl.gov/. (As of December 29, 2011).
72. Jordan, Jones, & Goulding, Inc. *Traffic Forecast Special Report—Manual Gravity Diversion Methodology.* Kentucky Transportation Cabinet, Lexington, Ky., 2002. Accessed December 29, 2011. http://transportation.ky.gov/Planning/Documents/Manual%20Gravity%20Diversion%20Report.pdf.
73. Dowling, R., W. Kittelson, A. Skabardonis, and J. Zegeer. *NCHRP Report 387: Planning Techniques to Estimate Speeds and Service Volumes.* TRB, National Research Council, Washington, D.C., 1996.
74. *Permits Guidance Manual – Traffic Impact Study Requirements.* Kentucky Transportation Cabinet. Accessed December 29, 2011. http://transportation.ky.gov/organizational-resources/policy%20manuals%20library/permits.pdf.
75. Kentucky Transportation Cabinet, Design memorandum No. 03-11, Traffic Engineering Analysis. November 2011. Accessed December 29, 2011. http://transportation.ky.gov/Highway-Design/Memos/Design%2003-11.pdf.
76. *Transportation Impact Handbook.* Florida Department of Transportation, August 2010. Accessed December 29, 2011. http://teachamerica.com/tih/TIH_081210.pdf.
77. Transportation Planning Branch, North Carolina Department of Transportation. *Project-Level Traffic Forecasting: Administrative Procedures Handbook.* May 2011. Accessed December 29, 2011. http://www.ncdot.org/doh/preconstruct/tpb/PDF/TF_HANDBOOK_107.pdf.
78. Florida Department of Transportation. *Quality/Level of Service Handbook.* 2009. Accessed June 10, 2013. http://www.dot.state.fl.us/planning/systems/sm/intjus/pdfs/2009FDOTQLOS_Handbook.pdf.
79. Flyvbjerg, B., M. S. Holm, and S. Buhl. Inaccuracy in Traffic Forecasts. *Transport Reviews*, Vol. 26, No. 1, 2006, pp. 1–24.
80. Bain, R. Error and Optimism Bias in Toll Road Traffic Forecasts. *Transportation*, Vol. 36 No. 5, 2009, pp. 469–482.
81. Freeway System Operational Assessment. Paramics Calibration and Validation Guidelines (Draft), Technical Report I-33. Wisconsin Department of Transportation, District 2, June 2002.
82. Ismart, D. and Federal Highway Administration. *Calibration and Adjustment of System Planning Models.* U.S. Department of Transportation, Washington, D.C., December 1990.
83. Bain, R. On the Reasonableness of Traffic Forecasts: A Survey of Predictive Capability. *Traffic Engineering and Control*, Vol. 52, No. 5, May 2011, pp. 213–217.
84. Granato, S. Traffic Forecasting as if Intersection Control Matters: The Sequel, *Transportation Research Record: Journal of the Transportation Research Board, No. 1706*, TRB, National Research Council, Washington, D.C., 2000, pp. 9–16.
85. Cambridge Systematics, Inc. *FSUTMS-Cube Framework Phase II: Model Calibration and Validation Standards.* Prepared for Florida Department of Transportation Systems Planning Office, 2008.
86. Horowitz, A. J. The Evaluation of Transportation Model Random Error in Social and Environmental Indices. *Environment and Planning A*, Vol. 9, April 1977, pp. 385–394.
87. Wegmann, F., and J. Everett. *Minimum Travel Demand Model Calibration and Validation Guidelines for State of Tennessee*, The University of Tennessee, Center for Transportation Research, n.d.
88. *Traffic Volume Balancing.* Unofficial Wisconsin Traffic Analysis Guidelines website. Accessed June 10, 2013. http://www.wisdot.info/microsimulation/index.php?title=Traffic_Volume_Balancing.
89. Virginia Department of Transportation. VDOT Travel Demand Model Application Checklist. 2006. Accessed June 10, 2013. http://www.virginiadot.org/projects/resources/vtm/VDOT_Travel_Demand_Model_Application_Checklist.pdf.
90. Granato, S. The Impact of Factoring Traffic Counts for Daily and Monthly Variation in Reducing Sample Counting Error. *Transportation Conference Proceedings*, Center for Transportation Research and Education, Ames, Iowa, 1998, pp. 122–125.
91. Wright, T., P. S. Hu, J. Young, and A. Lu. Variability in Traffic Monitoring Data, Final Summary Report. Oak Ridge National Laboratory, August 1997.
92. Gadda, S., A. Magoon, and K. M. Kockelman. Estimates of AADT: Quantifying the Uncertainty. Presented at 86th Annual Meeting of the Transportation Research Board, Washington, D.C., 2007.

93. Sharma, S. C., B. M. Gulati, and S. N. Rizak, Statewide Traffic Volume Studies and Precision of AADT Estimates. *ASCE Journal of Transportation Engineering*, Vol. 122, No. 6, 1996, pp. 430–439.
94. Black, I., J. Fearon, and C. Gilliam. Forecasting and Appraising Travel Time Variability in Urban Areas: A Link Based-Approach. Paper presented at the European Transport Conference, Leiden, The Netherlands, 2009.
95. Gilliam, C., T. K. Chin, I. Black, and J. Fearon. Forecasting and Appraising Travel Time Variability in Urban Areas, Association for European Transport, Henley-in-Arden, U.K., 2008.
96. *Highway Capacity Manual 2010*, Transportation Research Board of the National Academies, Washington, D.C., 2010.
97. Federal Highway Administration. Computer Program for Urban Transportation Planning: PLANPAC/BACKPAC General Information, U.S. Department of Transportation, Washington, D.C., 1977.
98. Horowitz, A. J., and M. H. Patel. Through Trip Tables for Small Urban Areas: A Method for Quick Response Travel Forecasting. In *Transportation Research Record: Journal of the Transportation Research Board,. No. 1685*, 1999, pp. 57–64.
99. Horowitz, A. J. Tests of a Family of Trip Table Refinements for Quick Response Travel Forecasting. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1921*, 2005, pp. 19–26.
100. Fratar, T. J. Vehicular Trip Distribution by Successive Approximations. *Traffic Quarterly*, Vol. 8, No. 1, 1954, pp. 53–65.
101. Horowitz, A. J., and L. Dajani. Tests of Dynamic Extensions to a Family of Trip Table Refinements Methods. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2003*, 2007, pp. 27–34.
102. Cambridge Systematics, Inc. Time-of-Day Modeling Procedures: State-of-the-Practice, State-of-the-Art, Final Report for FHWA. 1997. Accessed May 4, 2013. http://media.tmiponline.org/clearinghouse/time-day/.
103. *Transportation Planning Manual*, Chapter 9, Section 40—Data Elements of Roadway Traffic Forecasting. Wisconsin Department of Transportation, 2012. Accessed May 6, 2013. http://www.dot.wisconsin.gov/projects/planresources/docs/tpm-9.pdf.
104. Kentucky Transportation Cabinet. Traffic Forecasting Report—2008. Accessed May 2, 2013. http://transportation.ky.gov/Planning/Documents/Forecast%20Report%204-25-08_dah.pdf.
105. Traffic Forecasts and Analysis Section. Mn/DOT Procedure Manual for Forecasting Traffic on Minnesota's Highway Systems. Minnesota Department of Transportation. Accessed May 6, 2013. http://www.dot.state.mn.us/traffic/data/reports/forecast/Forecast_Manual_2012.pdf.
106. Barnes, J. Peak Spreading Analysis: Review of Relevant Issues and Synthesis of Current Practice, Phase I, Report WA-RD 459.1. Washington State Transportation Center, University of Washington, Seattle, Wash., 1998.
107. Giaimo, G., Congestion Management & Air Quality Analysis [CMAQ] Program Documentation. Ohio Department of Transportation, Division of Transportation Systems Development, Office of Multi-Modal Planning, 2005, pp. 11–12.
108. *Trip Generation Manual*, 9th ed., Institute of Transportation Engineers, Washington, D.C., 2012.
109. ITS Research Success Stories: Integrated Corridor Management. U.S. Department of Transportation, Research and Innovative Technology Administration, Intelligent Transportation Systems Joint Program Office. http://www.its.dot.gov/icms/success_icme.htm.
110. Chiu, Y-C., J. Bottom, M. Mahut, A. Paz, R. Balakrishna, T. Waller, and J. Hicks. *Transportation Circular E-C153: Dynamic Traffic Assignment: A Primer.* Transportation Research Board of the National Academies, Washington, D.C., June 2011. http://onlinepubs.trb.org/onlinepubs/circulars/ec153.pdf.
111. Pederson, N. J., and D. R. Samdahl. *NCHRP Report 255: Highway Traffic Data for Urbanized Area Project Planning and Design.* TRB, National Research Council, Washington, D.C., 1982.
112. Cambridge Systematics, Inc. Time-of-Day Modeling Procedures: State-of-the-Practice, State-of-the-Art, Final Report for FHWA. 1997. Accessed May 4, 2013. http://media.tmiponline.org/clearinghouse/time-day/
113. *2012 Project Traffic Forecasting Handbook.* Florida Department of Transportation Accessed May 3, 2013. http://www.dot.state.fl.us/planning/statistics/trafficdata/ptf.pdf, last access May 3, 2013.
114. *Transportation Planning Manual*, Chapter 9, Section 40—Data Elements of Roadway Traffic Forecasting. Wisconsin Department of Transportation, 2012. Accessed May 6, 2013. http://www.dot.wisconsin.gov/projects/planresources/docs/tpm-9.pdf.
115. Kentucky Transportation Cabinet. Traffic Forecasting Report – 2008. Accessed May 2, 2013. http://transportation.ky.gov/Planning/Documents/Forecast%20Report%204-25-08_dah.pdf.
116. Traffic Forecasts and Analysis Section. Mn/DOT Procedure Manual for Forecasting Traffic on Minnesota's Highway Systems. Minnesota Department of Transportation. Accessed May 6, 2013. http://www.dot.state.mn.us/traffic/data/reports/forecast/Forecast_Manual_2012.pdf.
117. Cambridge Systematics, Inc. *Quick Response Freight Manual.* Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 1996. Accessed May 4, 2013. http://media.tmiponline.org/clearinghouse/quick/quick.pdf.
118. Beagan, D., M. Fischer, and A. Kuppam. *Quick Response Freight Manual II.* Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2007, Accessed May 6, 2013. http://www.ops.fhwa.dot.gov/freight/publications/qrfm2/qrfm.pdf.
119. Chiu, Y-C., J. Bottom, M. Mahut, A. Paz, R. Balakrishna, T. Waller, and J. Hicks. *Transportation Circular E-C153: Dynamic Traffic Assignment: A Primer.* Transportation Research Board of the National Academies, Washington, D.C., June 2011.
120. Cambridge Systematics, Inc. Utilization of DTA in Modeling: Guidebook, Draft Report. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2012.
121. *A Policy on Geometric Design of Highways and Streets*, 6th ed. (commonly referred to as the "Green Book.") American Association of State Highway and Transportation Officials, 2011.
122. Liu, Y., A. Horowitz, and J. Effinger. Development of a Traffic Diversion Estimation Model for Freeway Construction, Smart Work Zone Deployment Initiative, Report # TPF-5(081), December 2011.
123. Box, G., and G. Jenkins. *Time Series Analysis: Forecasting and Control*, Holden-Day, San Francisco, Calif., 1970.
124. Savage, J. P. Simplified Approaches to Ferry Travel Demand Forecasting. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1608*, TRB, National Research Council, Washington, D.C., 1997, pp. 17–29.
125. Cain, A., M. W. Burris, and R. M. Pendyala. Impact of Variable Pricing On Temporal Distribution of Travel Demand. *Transportation Research Record: Journal of the Transportation Research Board, No. 1747*, TRB, National Research Council, Washington, D.C., 2001.
126. *Highway Capacity Manual 2010.* Transportation Research Board of the National Academies, Washington, D.C., 2010.
127. Comsis Corp. *Urban Transportation Planning System (UTPS) Highway Network Development Guide.* Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., January 1983.

128. Schoen, J., A. May, W. Reilly, and T. Urbanik. Speed-Flow Relationships for Basic Freeway Sections. Final Report, NCHRP Project 3-45, JHK & Associates, 1995.
129. PB Americas, Inc. ARC Activity Based Modeling System: Future Year Sensitivity Testing. Prepared for the Atlanta Regional Commission in cooperation with PBS&J, Atlanta, Ga., 2010.
130. Bautista E., and H. Titi. Mechanistic-Empirical Pavement Analysis and Design Educational Module. 2004.
131. Perone, S., J. Ma, and S. Menneni. Regional VISSIM Operational Corridor Development—Task 2.3—Model O-D Demand Development, Memo to Jennifer Rosales, PVT, June 30, 2009.
132. *Transportation Research Circular 212: Interim Materials on Highway Capacity.* TRB, National Research Council, Washington, D.C., 1975.
133. *Simplified Highway Forecasting Tool*, Ohio Department of Transportation, Columbus, Ohio, 2012.
134. Boyle, D. *TCRP Synthesis 66: Fixed-Route Transit Ridership Forecasting and Service Planning Methods.* Transportation Research Board of the National Academies, Washington D.C., 2006.
135. URS, Corp., and Wilbur Smith Associates. *I-10 Phoenix-Tucson Bypass Study.* Arizona DOT, Transportation Planning Division, 2008.
136. Horowitz, A. *NCHRP Synthesis 358: Statewide Travel Forecasting Models.* Transportation Research Board of the National Academies, Washington, D.C., 2006.
137. Evans, S. P. Derivation and Analysis of Some Models for Combining Trip Distribution and Assignment. In *Transportation Research*, Vol. 10(1), 1976, pp. 37–57.
138. Horowitz, A. J., and S. Granato. Practical Considerations in Implementing Travel Time Reliability in Regionwide Travel Forecasting. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2302*, Transportation Research Board of the National Academies, 2012, pp. 184–191.
139. Weiner, E. *Urban Transportation Planning in the United States.* Praeger Publications, 1999.
140. Horowitz, A. J. Origin-Destination Table Disaggregation Using Biproportional Least Squares Estimation. In *Transportation*, Vol. 37, 2010, pp. 689–703.

ABBREVIATIONS, ACRONYMS, AND INITIALISMS

AADT	Annual average daily traffic
ABM	Activity-based model
ACS	American Community Survey
ADT	Average daily traffic
AR	Autoregressive
ARC	Atlanta Regional Commission
ARIMA	Autoregressive, integrated, moving average
ARX	Autoregressive model with explanatory variables
A/T	Axles per truck
ATC	Automatic traffic counter
ATDM	Active traffic demand management
ATR	Automatic traffic recorder
ATRI	American Transportation Research Institute
AWSC	All-way-STOP-controlled
BCDCOG	Berkeley-Charleston-Dorchester County Council of Governments
BPR	Bureau of Public Roads
BTS	U.S. Bureau of Transportation Statistics
BUS	Belle Urban System
CBD	Central business district
CHATS	Charleston Area Transportation Study
COM	Commercial vehicles
CT	Combination truck
CV	Coefficient of variation
DDHV	Directional design hourly volume
DHT	Design hour truck
DHV	Design hourly volume
DOT	Department of transportation
DRAM	Disaggregate residential allocation model
DTA	Dynamic traffic assignment
DTV	Daily truck volume
DUE	Dynamic user equilibrium
E+C	Existing plus committed
E-E	External to external
E-I	External to internal
EJ	Environmental justice
EMPAL	Employment allocation model
ESAL	Equivalent single axle load
FAF	Freight Analysis Framework
FC	Functional class
FDOT	Florida Department of Transportation

GDP	Gross domestic product
GEH	Geoffrey E. Havers
GFA	Gross Floor Area
GIS	Geographic information system
GPS	Global positioning system
GR	Growth rate
GRP	Gross regional product
HBNW	Home-based, non-work
HBO	Home-based other
HBW	Home-based, work
HCM	*Highway Capacity Manual*
HCM2010	*Highway Capacity Manual 2010* (5th ed.)
HOT	High-occupancy toll
HOV	High-occupancy vehicle
HPMS	Highway Performance Monitoring System
HTK	Heavy trucks
I-E	Internal to external
I-I	Internal to internal
IPF	Iterative proportional fitting
ITE	Institute of Transportation Engineers
ITS	Intelligent transportation systems
Lat-long	Latitude and longitude
LED	Local employment dynamics
LOS	Level of service
LRS	Linear referencing system
LRTP	Long-range transportation plan
MAE	Mean absolute error
MDCEV	Multiple discrete continuous extreme value
ME	Mean error
MEPDG	Mechanistic-Empirical Pavement Design Guide
MOE	Measure of effectiveness
MPO	Metropolitan planning organization
MSA	Method of successive averages
MSA	Metropolitan statistical area
MSE	Mean square error
MTK	Medium trucks
NAFTA	North American Free Trade Agreement
NAICS	North American Industrial Classification System
NEPA	National Environmental Policy Act
NHB	Non-home-based
NHTS	National Household Travel Survey
OD	Origin-destination
ORNL	Oak Ridge National Laboratory
PCE	Passenger car equivalent
pc/mi/h	Passenger car equivalents per mile per lane
pcph	Passenger car equivalents per hour

pcphl	Passenger car per hour per lane
PFFS	Percent free flow speed
PSWADT	Peak season weekday average daily traffic
PTR	Permanent traffic recorder
PTSF	Percent time spent following
PUMA	Public use microdata areas
PUMS	Public use microdata sample
QC/QA	Quality control/quality assurance
QRFM II	*Quick Response Freight Manual II*
RMS	Root-mean-square
RMSE	Root-mean-square-error
SAR	Spatial/seasonal component autoregression
SARX	Spatial/seasonal component autoregression
SIC	Standard industrial classification
SMITE	Spreadsheet Model for Induced Travel Estimation
SMITE-ML	SMITE-Managed Lanes
SNR	Signal-to-noise ratio
SOV	Single-occupancy vehicle
SPASM	Sketch-Planning Analysis Spreadsheet Model
SQRT	Square root
STEAM	Surface Transportation Efficiency Analysis Model
TAZ	Traffic analysis zone
TDSP	Time-dependent shortest paths
TMIP	Travel model improvement program
TMP	Transportation management plan
TOD	Time of day
TSA	Transportation Satellite Accounts
TSM	Transportation systems management
TWLTL	Two-way left-turn lane
TWSC	Two-way STOP controlled
URL	Uniform resource locator
V/C	Volume/Capacity
VC_1	Volume-to-capacity ratio
VDF	Volume-delay function
VHT	Vehicle hours of travel
VIUS	Vehicle Inventory and Use Survey
VMT	Vehicle miles traveled
VPD	Vehicles per day
VPH	Vehicles per hour
vphpl	Vehicles per hour per lane
WIM	Weigh-in-motion
WisDOT	Wisconsin Department of Transportation
X-X	External to external

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation