NCHRP SYNTHESIS 358

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Statewide Travel Forecasting Models

A Synthesis of Highway Practice

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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Statewide Travel Forecasting Models

A Synthesis of Highway Practice

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SUBJECT AREAS
Planning and Administration

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Chapter three was written with the assistance of Xia Jin. Appendix C was principally written by David Farmer, with contributions from Alan Horowitz. The material has been excerpted from the *Guidebook on Statewide Travel Forecasting Models.* Appendix D presents material originally developed for NCHRP Project 8-43, "Methods for Forecasting Statewide Freight Movements and Related Performance Measures." It was written by Alan J. Horowitz, K. Ian Weisser, Cheng Gong, and Joe Blakeman.

FOREWORD

By Staff
Transportation Research Board

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

This synthesis describes statewide travel forecasting models designed to address planning needs and provide forecasts for statewide transportation, including passenger vehicle and freight movement. It discusses the types and purposes of models being used, integration of state and urban models, data requirements, computer needs, resources (including time, funding, training, and staff), limitations, and overall benefits. Five case studies are included, two that focus on passenger components, two on freight components, and one on both passenger and freight. In addition, definitions of common technical terms and an annotated bibliography of statewide and national forecasting techniques are provided. An excerpt from the *Guidebook on Statewide Travel Forecasting Models* concerning passenger and intercity travel forecasting is included as an appendix.

This synthesis effort was based on the results of surveys received from each state that has a statewide travel forecasting model. A literature review was also undertaken, with major information sources (studies, databases, surveys, and programs) cited and discussed.

Alan Horowitz, Center for Urban Transportation Studies, University of Wisconsin–Milwaukee, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

STATEWIDE TRAVEL FORECASTING MODELS

SUMMARY

Statewide travel forecasting models attempt to meet some of the same goals for statewide transportation planning that urban travel forecasting models have met for urban transportation planning. The earliest experiments in statewide travel forecasting in the 1970s adapted methods that had been developed specifically for urban travel forecasting; however, those early statewide modeling efforts were severely hampered because of difficulties in adequately covering large geographic areas in sufficient detail. In the past 10 years statewide transportation planners have seen dramatic improvements in socioeconomic and network databases, tools for accessing these databases, and computational power. Consequently, interest in fully capable statewide travel forecasting models has steadily increased. Each succeeding generation of models within a state has become more ambitious. Approximately one-half of the states now have functional models. This synthesis is particularly directed toward those states that want to develop a model from scratch and those states that are interested in upgrading their existing models.

The core of this synthesis is the results of surveys received from every state that has a statewide travel forecasting model. Information about modeling activities was provided by 49 states returning at least one questionnaire. The responses to the synthesis questionnaires, along with those from an earlier questionnaire distributed by the TRB Statewide Travel Demand Models Peer Exchange in 2004, allow for a general assessment of the state of the practice. The questionnaires focused on individual components of the models and the modeling process. To achieve a better understanding of how all the pieces fit together, five case studies are presented to provide a broader overview. Two of the case studies, Indiana and Kentucky, deal specifically with passenger components. Two other case studies, Virginia and Wisconsin, cover freight components. One additional case study from Ohio explores a newer approach to statewide models that integrates the traditional passenger and freight components with forecasts of economic activity and land use that had been pioneered in Oregon. In addition, several states were asked to expand on their questionnaire responses with regard to how statewide models have been successfully applied.

Preceding the survey results are reviews of the literature and key concepts. The reviews provide the basis for a full understanding of current practice without duplicating literature reviews contained in other readily available documents. These reviews focus on standard references on statewide models, recently published research on intercity travel in the United States, and key databases. Chapter one finishes with a glossary of terms that are often used by those individuals who build statewide travel forecasting models, but which might be less familiar to others. Additional reviews of literature in passenger and freight modeling are found in Appendixes C and D, respectively.

The state of the practice has matured over the last 10 years. Many statewide travel forecasting models now have network detail similar to urban models. Validation standards have increased, such that some models are now able to achieve the same level of accuracy as urban models. With the exceptions of Ohio and Oregon, statewide models still closely follow urban models in structure within their passenger travel components. However, there is a trend away from truck-only freight components toward commodity-based freight components,

which better exploit available freight databases. Ohio and Oregon are implementing a new modeling paradigm that integrates forecasts of economic activity and land use into the travel model.

Statewide models have proven to be versatile tools in assisting in the development of both statewide and metropolitan area plans. Such models are primarily used for intercity corridor planning, statewide system planning, and bypass studies; however, they are also frequently used for providing input to metropolitan planning organization (MPO) models, replacing MPO models, or serving as the main forecasting means for rural projects. Statewide models have been used in several states for air quality conformity analysis, freight planning, traffic impact studies, economic development studies, project prioritization, and many other planning needs.

Given that there are no best-practice standards for statewide models, different states have taken different approaches to building their models to meet their particular needs. Development times range from approximately 6 months to 8 years, and development costs have ranged from less than $100,000 to many millions of dollars. The level of detail in both networks and zone systems also varies greatly. Models fall into five general categories: (1) origin–destination (OD) table estimation and assignment, (2) freight only, (3) passenger only, (4) combined passenger and freight, and (5) integrated passenger/freight/economic activity.

Most states with models have avoided original data collection; tending to rely heavily on secondary data sources. Important data sources for passenger components include the Census Transportation Planning Package, the National Household Travel Survey, MPO databases, the American Travel Survey, and in-house traffic counts. Some states have purchased National Household Travel Survey add-ons. Freight data often came from the Vehicle Inventory and Use Survey, a particular freight data vendor, the Commodity Flow Survey, and the Rail Carload Waybill Sample.

Most passenger components are multimodal, and all passenger components include automobiles. Other commonly found modes are intercity railroad, intercity bus, local bus, and commuter railroad.

The geographic size of states means that many statewide models are still spatially and temporally coarser than urban models. The coarseness is exacerbated by the need to consider long distance trips that start or end in other states. Indiana, Ohio, and Texas have the largest zone systems, with more than 4,500 zones each. Most models have avoided the use of special generators. Networks with more than 200,000 links have been created. Although smaller states are capable of running peak-period traffic assignments, most states run 24-h traffic assignments.

Statewide models tend to have several trip purposes, covering both the traditional urban trip purposes and assorted long distance trip purposes. A few states have been able to use Fratar factoring for trip distribution, because of the availability of OD matrices for certain trip purposes. Otherwise, the various steps of passenger components tend to be similar in structure to those found in urban models.

There are two fundamentally different styles of freight forecasting: (1) direct forecasting of vehicle flows without reference to commodities and (2) forecasting of commodities, and then using the commodity flow forecast to estimate vehicle flows. Three-fourths of states reporting freight components base their forecasts on commodities. Some states have explored innovative methods, such as estimating OD tables from traffic counts to fill in gaps in secondary data sources.

Only three states reported using mode split expressions for freight. Most states rely on the historical share of tonnage carried by each freight mode. Commodities carried by truck are also assigned to vehicle types by fixed shares based on historical data. None of the models were directly concerned with truck–rail intermodal.

Statewide models are not yet fully integrated with urban models within the state. Approximately half of the statewide models are capable of providing independent estimates of traffic within urban areas; however, statewide models invariably yield to urban models if there is a disagreement. Also, about half of the statewide models are capable of developing external station forecasts for urban models. Many statewide models base their zone systems and network on urban models, although simplifications are often necessary.

Validation of statewide models exploits many of the same techniques and data sources as urban models. However, most states do not expect their models to validate as well as urban models. Prominent validation data sources are passenger vehicle counts, truck counts, national default trip generation values, OD flows from the Census Transportation Planning Package, and locally collected survey data.

The five case studies help to illustrate the wide range of reasonable approaches to statewide travel forecasting. The cases studies concentrate on the more promising approaches and indicate how even modest expenditures of resources can result in powerful tools for statewide transportation planning. The Ohio case study, in particular, shows what might be accomplished when budgets and time permit a full treatment of the interaction between transportation supply, transportation demand, land use, and economic activity.

There have been many successful applications of statewide models; however, modelers still struggle to overcome many obstacles to achieve good results within a reasonable budget. Ongoing problems include:

- Scales of statewide models;
- Zone systems that are coarser than urban models within a given state;
- Databases that are geocoded to county-sized geographical areas or larger; and
- Many models that are unable to do peak-hour forecasts, because intercity trip lengths are too long for the static traffic assignments currently in use.

CHAPTER ONE

INTRODUCTION

Statewide travel forecasting models address numerous planning needs by estimating, for a future date, the number of vehicles that use major transportation facilities within a state. Statewide models can encompass both passenger and freight issues, and provide forecasts for a variety of modes including highways, urban transit systems, intercity passenger services, airports, seaports, and railroads. Statewide models are particularly useful for forecasting in rural areas that are not covered by urban travel forecasting models. Statewide models provide a consistent way to forecast travel on transportation facilities across a state in a manner that reflects current understanding of travel behavior.

Only about half of the 50 states have created statewide models. Most of these models resemble urban transportation planning (UTP) models in structure. However, almost all states with models have faced unusual challenges resulting from the large sizes respective of their geographic areas and the large amounts of data required to adequately describe these areas. With few exceptions, several characteristics of statewide planning demonstrate the need for distinguishing between statewide and urban models.

- Statewide models cover far more land area than urban models within the same state.
- Statewide models cover far more facilities than urban models within the same state.
- Statewide models are often concerned with economic developments that extend well beyond the borders of a region, such as national and international trade issues and trends.
- There is less experience with statewide models than urban models.
- There is less research on intercity travel patterns than on urban travel patterns.
- Statewide models must incorporate long distance, multiday trips.
- Statewide freight components require recognition of many modes, whereas most urban freight components only focus on trucks.
- Software products do not address the special needs of statewide models.
- The legal impetus for statewide models is insufficient when compared with metropolitan planning organization (MPO) models.
- There are data opportunities for statewide models that are not available for urban models, such as freight flow databases and economic forecasts for subareas.

Statewide travel forecasting models seek to determine the amount and location of travel by looking at parts of the traveler decision processes. A model based on behavioral principles would differ substantially from one based entirely on empirical findings, such as growth factor methods. Nonetheless, some states feel that purely empirical models still meet their needs.

MAJOR SOURCES OF INFORMATION ON STATEWIDE TRAVEL FORECASTING MODELS

There are few general sources of information on statewide or intercity passenger components; however, there have been two significant NCHRP studies on statewide freight modeling. This section highlights important historical and recent documents that have been useful to individuals or groups building statewide travel forecasting models.

Appendix C is an excerpt from the literature review section of the *Guidebook on Statewide Travel Forecasting* (Horowitz 1999) that concerns passenger and intercity travel forecasting. Appendix D is an annotated bibliography of the statewide and national freight forecasting techniques. References to the literature found in this section are intended to update these earlier literature reviews.

Guidebook on Statewide Travel Forecasting 1999

The *Guidebook* (Horowitz 1999) was the last major reference that covered both passenger and freight components of statewide models. This resource contains extensive advice on individual steps within the models, network preparation, and data sources. A comprehensive literature review and several short case studies are included in an appendix. One chapter is devoted entirely to time series methods such as Box–Jenkins techniques.

The *Guidebook* emphasizes three- or four-step modeling approaches. Details are given on how urban transportation modeling software packages could be adapted for statewide models. It recommends that freight forecasting be commodity-based, although there was some treatment of truck-only models.

The *Guidebook* does not include discussions of two emerging topics: tour-based passenger components and combining freight and passenger components with a built-in economic activity component.

Transportation Research Circular E-C011: Statewide Travel Demand Forecasting (Conference Proceedings) 1999

This specialty conference, roughly coinciding time-wise with the publication of the *Guidebook*, heard reports from several states about their existing statewide models and plans for new statewide models. Breakout sessions also provided research recommendations. Presentations were made by representatives from California, Florida, Indiana, Kentucky, Michigan, New Hampshire, New Jersey, Oregon. Rhode Island, Washington, and Wisconsin.

NCHRP Report 260: Application of Statewide Freight Demand Forecasting Techniques 1983

This report (Memmott 1983) provided a methodology for building a freight component for a statewide model. The report recommended a commodity-based approach and suggested that commodity distribution be performed by a gravity expression. An all-or-nothing mode-split step was proposed. Modal costs were to be determined with the help of regulated tariffs then in effect. The location of commodity consumption was to be determined by an input–output (IO) model.

NCHRP Report 8-43, Methods for Forecasting Statewide Freight Movements and Related Performances 2005

This draft report (Cambridge Systematics, Inc., et al. 2005) is a comprehensive reference on the current state of the practice in statewide freight forecasting models. It describes several approaches to model building, depending on project needs and data availability, including the direct facility flow factoring method, origin–destination (OD) factoring method, truck model, four-step commodity model, and economic activity model. Ten case studies of freight components are presented: Minnesota Trunk Highway 10 truck trips, Florida ports, Ohio's interim freight component, FHWA's Freight Analysis Framework (FAF), New Jersey truck trip table, Southern California Association of Governments heavy-duty trucks, Indiana commodity transport, Florida statewide freight, Cross-Cascades Corridor Analysis Project, and Oregon combined passenger and freight.

Statewide Travel Demand Models Peer Exchange 2004

The attendees of the Peer Exchange (Longboat Key, Florida, September 23–24, 2004) included representatives from 14 states and consultants who reported on their statewide modeling efforts. The proceedings are distilled from a questionnaire completed by many of the representatives. States reporting on their models were Florida, Indiana, Kentucky, Louisiana, Massachusetts, Missouri, New Hampshire, New Jersey, Ohio, Oregon, Virginia, and Wisconsin. The proceedings of the Peer Exchange have been published by TRB as *Transportation Research Circular E-C075*.

Presentations at the 2004 Annual Meeting of the Transportation Research Board, Session on Statewide Travel Forecasting Models

This session involved presentations by six authors on new developments in statewide travel forecasting models.

- Ohio Statewide Travel Demand Forecasting Model
- An update on the Transportation and Land Use Model Information Project (TLUMIP) in Oregon
- Wisconsin Statewide Model
- Statewide Modeling: The New Frontier
- The Trouble with Intercity Travel Demand Models
- A Brief Synthesis of the State of the Practice in Statewide Travel Forecasting.

The PowerPoint slides can be found on the Statewide Travel Forecasting website: http://www.uwm.edu/~horowitz/statewide.html.

On-Line Documents About Statewide Travel Forecasting Models

Numerous states or their consultants have web pages that contain documents about their statewide travel forecasting models. These web pages are volatile, and a fresh web search is required to find the most current information. Here are a few web pages that were active at the time of this report.

- Florida Statewide Freight Model: webservices.camsys.com/freightmodel/freightmodel.htm.
- Vermont Statewide Model: http://www.aot.state.vt.us/planning/TDModel.htm.
- Virginia Statewide Model: http://www.wilbursmith.com/vdotmodel/howandwhen.html.
- Virginia Statewide Freight Model: http://www.wilbursmith.com/vdotmodel/attachments/082902/Freight%20Report%20(Draft%2008-20-02).pdf.
- Ohio Statewide Model: http://www.dot.state.oh.us/urban/AboutUs/Statewide.htm.
- Connecticut Statewide Model: http://www.ct.gov/dot/cwp/view.asp?a=1383&q=259806.
- Oregon Statewide Model: http://www.oregon.gov/ODOT/TD/TP/TMR.shtml.

Quick Response Freight Manual 1996

Although not specifically for statewide models, the *Quick Response Freight Manual* (*QRFM*) (Cambridge Systematics, Inc., et al. 1996) (Travel Model Improvement Program, FHWA) has been used by states to implement the truck mode within a freight component. The *QRFM* provides default coefficients for trip generation and trip distribution steps.

NCHRP Report 187: Quick-Response Urban Travel Estimation Techniques and Transferable Parameters: User's Guide **1978 and *NCHRP Report 365: Travel Estimation Techniques for Urban Planning*** **1998.**

NCHRP Report 365 (Martin and McGuckin 1998) is essentially an update of *NCHRP Report 187* (Sosslau et al. 1978). Although not specifically for statewide models, these two reports have allowed states to quickly implement passenger components when there were data deficiencies as to local travel patterns in urban areas. The reports provide transferable parameters for trip production estimation, trip attraction estimation, gravity expressions for trip distribution, time-of-day, automobile occupancy, and delay calculations.

RECENT RESEARCH ON UNITED STATES INTERCITY TRAVEL FORECASTING

"Critical Review of Statewide Travel Forecasting Practice" 1999

This article by Horowitz and Farmer (1999) is based primarily on the literature review section of the *Guidebook*. It offers suggestions for areas where statewide travel forecasting models can be improved.

"The Trouble with Intercity Travel Demand Models" 2004

Miller (2004) critically reviews the literature on intercity passenger demand modeling. The article particularly contrasts models of total demand with nested logit algorithms. Also described are the issues involved in applying intercity passenger demand models.

"Evaluating Role of Distance and Location in Statewide Travel Demand Forecasting by Using American Travel Survey" 1999

O'Neill et al. (1999) present average distances of person travel, cross-tabulated by purpose and mode for California, Colorado, Florida, Massachusetts, and Michigan. Modes investigated were personal vehicle, air, bus, train, and water. As expected, the study found that trips by air were much longer than the other modes; however, there was no clear break point of trip length that separated modes.

"The Land Development Module of the Oregon2 Modeling Framework" 2004

Hunt et al. (2004a) explains one of the seven modules of the Oregon2 statewide travel forecasting model. The model allocates activities to grid cells (30 m × 30 m) once each year until reaching the planning horizon.

"Driving to Distractions, Recreational Trips in Private Vehicles" 2000

Mallett and McGuckin (2004) present descriptive statistics of recreational trips by private automobile from the 1995 American Travel Survey (ATS) and the National Personal Transportation Survey (NPTS) from 1990. Comparisons were made of both urban and long distance recreational trips across racial and income groups.

"Modeling the Competition Among Air Travel Itinerary Shares: GEV Model Development" 2005

This article by a research group from Northwestern University (Coldren and Koppelman 2005) presents results from the creation of an itinerary share prediction model for air travel. Both multinomial logit expressions and nested logit algorithms were created to forecast choices of travelers when booking air travel based on service characteristics such as number of stops, connection quality, distance, competing carriers, aircraft type, and time of day.

MAJOR DATABASES OF PARTICULAR INTEREST FOR STATEWIDE TRAVEL FORECASTING

American Travel Survey 1995

The ATS was conducted in 1995 and early 1996 by the Bureau of Transportation Statistics (BTS). It is the only comprehensive national database on long distance (more than 100 mi) passenger travel. Approximately 54,000 households provided information, with each household reporting on one year of travel in four quarterly surveys. Data about each trip include the reason for making the trip, principle mode (including vehicle type), mode of access or egress, origin, destination, intermediate stops, travel dates, duration, nights away from home, type of lodging, and travel distance. Origins and destinations are geocoded to states and metropolitan areas. Most surveys were obtained by telephone, although some personal visits were made. Individual trip records and complete household data are available on CD-ROM. There are no immediate plans to do another long distance survey similar to the ATS, although some information on long distance travel can be obtained from the NHTS.

National Household Travel Survey

Formerly known as the National Personal Transportation Survey, this survey of passenger travel has been conducted at varying times since 1969, with the last survey completed in 2002. Approximately 66,000 households were surveyed, of which about 40,000 were from 9 specific geographic areas (who requested add-on samples) and the remainder was a general coverage of the entire United States. Households were sampled by means of random-digit dialing and were interviewed by telephone. Data on all trips in a household over a 24-h period were collected as were data on long distance trips, defined as greater than 50 mi, over a 28-day period. Individual household and trip records are available on CD-ROM from the BTS. Daily trip data include trip times, modes, purposes, vehicles used, durations, lengths, day of the week, and the presence of other travelers for the same trip. Long distance trip data include dates of travel, whether the trips are recurring, purposes, primary modes, destinations, types of lodging, overnight stops, and access and egress information for air, bus, and rail modes. It should be noted that the definition of "long distance" is different from that used by the ATS; therefore, the data sets are not directly comparable. The results of the survey may have been affected by the September 11, 2001, terrorist attacks.

Individual trip records from the NHTS are available and are easy to summarize or analyze. Much of the transferable parameters in *NCHRP Report 365* were developed from the 1990 National Personal Transportation Survey. Planning is currently underway for the next survey in 2008. More information may be obtained from http://nhts.ornl.gov/2001/html_files/introduction.shtml.

Commodity Flow Survey

The Commodity Flow Survey (CFS) is a survey of shippers in the United States. Shipments from most major industries are represented in the sample, last taken in 2002. It was composed of a stratified random sample of approximately 50,000 establishments with 2.6 million shipments. Establishments reported a sample of their shipments (or all shipments for smaller establishments) for one week in each of four calendar quarters. Information about each shipment included the origin, destination, value, weight, mode, distance estimated from a network, and commodity group. Modes covered by the survey included for-hire truck, private truck, rail, inland water, deep sea water, pipeline, air, and parcel delivery or U.S. Postal Service. Data are also available from the 1997 and 1993 surveys. The CFS does not contain data on imports, and its level of spatial detail is coarse. Industrial sectors included mining, manufacturing, wholesale trade, electronic shopping, and mail-order businesses. The survey excluded services, transportation, construction, other retail, farms, fisheries, gas and oil extraction, and most government-owned establishments. The U.S. portions of imports that are transshipped from within the United States are included. Shipments passing entirely through the United States are excluded. Detailed tables can be obtained on CD-ROM from the BTS. Planning is underway for the next CFS in 2007. More information on the survey may be found at http://www.bts.gov/programs/commodity_flow_survey/.

Vehicle Inventory and Use Survey

The Vehicle Inventory and Use Survey (VIUS), formerly known as the Truck Inventory and Use Survey, consists of data on the operation and physical characteristics of commercial vehicles. The survey was first done in 1963, and is currently conducted every 5 years. The latest survey was done in 2002, with the next on schedule for 2007. Operating characteristics include number of miles driven and commodities carried. Individual truck records are available for almost 100,000 trucks. Operational characteristics that are of general interest for travel models are base state, average weight with payload, type of business, miles driven outside state, miles driven by trip length, miles driven by commodity group (50 groups including empty and waste), miles driven by hazardous materials class and type of service. VIUS data may be obtained from the U.S. Census Bureau. More information about VIUS may be obtained from http://www.census.gov/svsd/www/tiusview.html.

Transborder Surface Freight Data

The Transborder Surface Freight Data set is a large sample of shipments between the United States and Canada and the United States and Mexico. Freight flow data in dollars and tons are provided by destination state or origin state, by point of entry or exit, by commodity and by mode (mail, highway, rail, vessel, and pipeline). Data are updated monthly. Individual shipment records may be obtained. More information on the Transborder Surface Freight Data may be obtained from http://www.bts.gov/transborder/.

Freight Analysis Framework

The FAF, developed by FHWA, is a modeling system that forecasts the amount of freight traveling on modal (truck, water, and rail) networks throughout the United States. It is primarily a policy tool for the federal government. Forecasts for 2010 and 2020 have been made. Results for commodities are reported at the two-digit Standard Transportation Commodity Code (STCC) level. The model itself and much of the input data are not available for state use. However, the FAF provides the following results for its base year (1998) and forecast years that can be of use to statewide travel forecasting models:

- Tons of freight shipped in the United States by state or international gateway, type of commodity, and mode of transportation;
- Flows of freight along major routes by range of tonnage and mode; and
- Number of trucks using road segments.

The FAF is currently undergoing major revisions to provide additional detail and to make its results more useful. Results are downloadable from the FHWA website. More information on the FAF may be obtained at http://ops.fhwa.dot.gov/freight/freight_analysis/faf/. This site explains planned revisions to the

FAF. The FAF has recently been reviewed by the TRB Committee on the Future of the FHWA's Freight Analysis Framework (Meyburg 2004).

Census Transportation Planning Package

The Census Transportation Planning Package (CTPP) is a special tabulation of the decennial census that reports data by traffic analysis zone (TAZ), both rural and urban. By analysis of the journey-to-work questions, the CTPP provides information on home-to-work flows, modes of travel to work, ridesharing to work, vehicle availability, commute times, and employment counts at the workplace. Demographic data are tabulated by both place of work and place of residence. The CTPP is a valuable source of information about employment in the workplace by industrial sector and is available on CD-ROM from the BTS. CTPP is usually available approximately 4 years into the decade. More information may be found at http://www.fhwa.dot.gov/ctpp/.

Public Use Microdata Sample

The Public Use Microdata Sample (PUMS) is an output of the decennial U.S. Census. The sample contains 5% of all household records from the long form that have been cleaned of any identification and geocoded coarsely to special zones called PUMAs (Public Use Microdata Areas), which are areas with at least 100,000 persons. PUMS allows special tabulations that are not normally available for a metropolitan area, county, or state. Many planning agencies use PUMS to understand household structure when building trip generation models.

ES-202

ES-202 is a cooperative program where states report information on employment that is derived from the states' unemployment insurance programs to the federal government. ES-202 data can provide employment at the workplace by industrial category; however, federal rules dictate that the confidentiality of the data must be respected. The quality of the data and the ways in which it is administered differ across states. As with all secondary sources of employment data, the geocoding of work locations requires considerable cleaning and verification. The most serious problem for travel forecasting is that the mailing addresses of employers do not necessarily agree with the addresses of the actual workplaces. ES-202 data may be available from a state's labor or employment agency. The data set is continuously updated.

National Networks

The National Highway Planning Network is available as geographic information system (GIS) layers and contains a topological description of 450,000 mi of arterial highways in the United States. A similarly comprehensive GIS database is available for the National Rail Network. Networks are available by state, and are obtainable from the BTS on the National Transportation Atlas Database CD-ROM. This CD-ROM also contains the U.S. Army Corps of Engineers Navigable Waterway Network, hydrographic features, fixed-guideway transit networks, runways, seaports, Amtrak stations, airports, intermodal terminals, and jurisdictional boundaries.

Railroad Carload Waybill Sample

Railroads doing business of more than 4,500 carloads per year are required to submit a sample of their waybills to the Surface Transportation Board. Waybills contain information on origin and destination points, type of commodity, number of cars, tons, revenue, length of haul, participating railroads, interchange locations, and cost. Publicly available data from the sample are geocoded to Bureau of Economic Analysis (BEA) regions; however, commodities are reported to five-digit STCC. The 2002 sample contains information on nearly 600,000 shipments from 66 railroads. The confidential data are available to a single point of contact with a state government, often an agency that regulates railroads; therefore, it is possible for a state department of transportation (DOT) to gain access to data with precise geocoding. Strict rules apply to disseminating data outside of state government. Data within the waybill about revenue from a shipment are considered to be inaccurate by the Surface Transportation Board.

COMMERCIAL DATABASES AND FORECASTS IN USE BY STATES

The following commercial databases and forecasting services were specifically mentioned by states when answering questions about their models. This section is included to amplify on state responses and is not intended to be a comprehensive listing or review of such databases.

Reebie TRANSEARCH

Reebie can supply data on multimodal commodity flows between locations in the United States at a greater level of spatial detail than the CFS. Reebie integrates data from both public and proprietary data sources.

Commercial Demographic Forecasts

Companies such as Global Insight (formerly WEFA and DRI) and Woods & Poole can provide economic and demographic forecasts by county. Similar forecasts may be available for certain states through universities or state agencies.

Commercial Employment Databases

D&B (formerly Dun and Bradstreet) maintains a comprehensive database of U.S. companies and their characteristics.

Info USA is a mailing list company that tries to maintain a complete list of businesses in the United States. Claritas provides demographic data. All three companies are possible sources of data on employment at the workplace.

Regional Economic Model, Inc.

Regional Economic Model, Inc. (REMI), essentially has two products, Policy Insight and TranSight. Policy Insight is designed to forecast the economic impacts of major governmental policy initiatives. TranSight specifically forecasts the economic impacts of transportation projects.

DEFINITIONS OF COMMON TECHNICAL TERMS USED TO DESCRIBE STATEWIDE TRAVEL MODELS

Technical Concepts

All-or-nothing traffic assignment—A model step where all traffic between an origin and destination is assigned to the shortest path between that origin and destination and no traffic is assigned to any other path. An all-or-nothing traffic assignment is unresponsive to delays caused by traffic. Historically, many statewide models have used the all-or-nothing traffic assignment because volume-to-capacity ratios were difficult to determine for 24-h forecasts and networks in urban areas were sketchy. Many freight components still use all-or-nothing assignment to preload trucks to a highway network.

BPR curve—A simple expression that computes travel time as a function of volume, originally developed at the Bureau of Public Roads (BPR). A BPR curve has two parameters, α and β, that can be varied by functional class:

$$t = t_0 \left[1 + \alpha \left(\frac{v}{c} \right)^{\beta} \right]$$

where t_0 is free flow travel time, v is the assigned volume, and c is the capacity. The BPR curve is used within a traffic assignment step to provide loaded travel times so that traffic can be placed on the shortest path.

Commodity group—A grouping of similar commodities that can be analyzed and forecasted together. The groupings are often based on the Standard Classification of Transported Goods or the older STCC. Standard Classification of Transported Goods codes are of up to five digits, organized such that adding a digit increases the precision of the commodity description.

Composite impedance (or composite disutility)—A measure of the separation between an origin and a destination (often as a function of travel time, travel cost, and convenience) that takes into consideration the accessibility of more than one mode between the origin and destination. Composite impedances are often used along with gravity expressions. The following equation shows a composite impedance expression, t_{ij}, for two modes (1 and 2) between origin zone i and destination zone j. The empirical constant, θ, is usually of similar size to the in-vehicle time coefficient from a logit mode-split expression, provided the impedance has units of minutes.

$$t_{ij} = \frac{1}{\theta} \ln \left[e^{\theta t g 1} + e^{\theta t g 2} \right]$$

Composite impedances are especially important for statewide and intercity models, where the travel times by various modes can differ radically, but trip distribution must be accomplished ahead of (before knowing) mode split.

Dynamic all-or-nothing assignment—See "all-or-nothing traffic assignment." Trips are assigned within small intervals of time so as to track the progress of packets of vehicles over time between their origins and destinations. The principle advantage of dynamic traffic assignment for statewide models is an ability to determine the amount of traffic that occurs during peak hours within urban areas.

Dynamic equilibrium traffic assignment—An application of equilibrium principles (see static equilibrium traffic assignment) where trips are also assigned within small intervals of time, so as to track the progress of packets of vehicles over time between their origins and destinations. A single dynamic equilibrium traffic assignment requires several dynamic all-or-nothing assignments (see "dynamic all-or-nothing assignment").

Four-step model—A modeling paradigm that has become standard practice in urban areas and involves the major steps of trip generation, trip distribution, mode-split, and traffic assignment. A common variation is a three-step model that eliminates the mode-split step. A four-step model may involve minor steps, including time-of-day and automobile-occupancy calculations.

Fratar factoring—A popular empirical technique for forecasting origin-to-destination trip patterns by applying row and column factors to an existing origin-destination (OD) table. Fratar factoring can also be applied to a production-to-attraction trip table.

GPS (Global Positioning System)-based survey—Use of the GPS to trace the location of a traveler or vehicle over time, which would be linked to a travel diary.

Gravity expression—Sometimes called a "gravity model," which determines the production-to-attraction trip pattern as a function of the number of productions and attractions in each zone and measures of proximity between zones. Gravity expressions can be either singly or doubly constrained. A singly constrained gravity expression holds productions by zone constant, allocating trips to other zones on the basis of a measure of their zonal attractiveness. A doubly constrained gravity expression, often used in statewide models, allocates trips between zones while also holding trip productions and trip attractions constant. A typical gravity expression finds the number of trips, T_{ij}, between production zone i and attraction zone j:

$$T_{ij} = P_i X_i A_j Y_j f(t_{ij})$$

where P_i is the number of productions in zone i, A_j is the number of attractions in zone j, and $f(t_{ij})$ is a measure of proximity between zones i and j, as a function of impedance, t_{ij}, between zones. The measure of proximity, $f(t_{ij})$, is often called a friction factor. X_i and Y_j are balancing factors that are set such that the numbers of productions and attractions, respectively, are conserved in each zone. Some implementations of the gravity expression have a term, k_{ij}, which are called "*k*-factors" or "socioeconomic adjustment factors." *k*-factors are empirical adjustments to the gravity expression based on household travel surveys or screenline counts to provide a better fit between the model and base-year data.

Household sectors—Groups of households within an economic or land use model, usually organized by economic or life-cycle status.

Industrial sectors—Groups of similar businesses, usually organized by type of product or service. Industrial sectors are often defined according to North American Industry Classification System or the older Standard Industrial Classification codes. North American Industry Classification System codes are of up to six digits, organized such that adding a digit increases the precision of the industry description.

Input-output (IO) model—A type of economic model that tracks flows of revenue (or sales) between industries and households in a national or regional economy. An IO model is organized by industrial sectors. A single cell in an IO table would list the amount of revenue gained by a producing sector from sales to a consuming sector.

Logit expression—Sometimes called a "logit model," this is a method for determining the number of people who will make a particular choice (such as mode or destination) given the "utilities" of each alternative. A logit expression determines the proportion of people, p_i, who choose an option, i:

$$p_i = \frac{e^{U1}}{\sum_k e^{U_k}}$$

where U_i is the utility of option i, and an option can be either a mode or a destination, or both. Utility is usually taken to be a linear combination of travel time, travel costs, and measures of convenience, such that U_i becomes more negative or less positive as trip lengths increase.

When used for destination choice, a logit expression is a form of a singly constrained gravity expression. Logit expressions are preferred for activity allocation within land use components of integrated models. Logit expressions can replace gravity expressions for trip distribution within a traditional four-step model. When doing so, the number of trip attractions in a zone is calculated by the expression rather than given as an input. Therefore, logit expressions are more sensitive to changes in policies and infrastructure. There is no consensus as to when logit expressions are preferred over gravity expressions for trip distribution.

Microscale traffic simulation—Sometimes called traffic microsimulation, this is traffic simulation that tracks the location and performance of individual vehicles. Microscale traffic simulations can be used as post-processors for output from a statewide travel forecasting model, so as to provide better estimates of delay from the assigned traffic.

Monte Carlo simulation—A technique that is used within microsimulation that can generate random events, such as households of given characteristics, trips, start times, modes, and vehicles. The probability of an event is taken from historical information or from theory, such as a logit expression.

Multiclass assignment—A method of traffic assignment that separately accounts for different vehicle classes. Different vehicle classes may be assigned to different routes if the link impedances vary across vehicle types. Multiclass assignments may take many different forms, static or dynamic and all-or-nothing or equilibrium. Multiclass assignments also account for the differential impact heavy vehicles have on the traffic stream. Multiclass assignment can be used to distinguish automobiles from trucks and buses, single-occupant automobiles from multiple-occupant automobiles or low-income drivers from high-income drivers.

Nested logit algorithm—The use of two or more logit expressions to determine the number of people who will make a particular choice when the decision process is assumed to consist of a sequence of preliminary choices. Nested logit algorithms are organized as a hierarchy, such that modes become more specialized in the lower parts of the hierarchy. Similar modes tend to be grouped together into "nests." Travelers are assumed to make decisions between nests before making decisions about the individual modes within nests. A utility for a nest is created as a composite of utilities of all modes within a nest (see composite impedance).

Origin–destination (OD) table estimation from ground counts—A method of determining the OD patterns of vehicles by primarily using observations of ground counts. OD table estimation usually requires a good guess as to the OD patterns, often referred to as a "seed" or "prior" table. The estimation algorithm tries to make limited improvements to the seed table, so that the assigned volumes will be closer to ground counts. There are many mathematical formulations to the OD estimation problem, and the various formulations will result in different OD tables using the same data. For example, a simple generalized least-squares approach attempts to minimize this expression:

$$min\ P = \sum_{a=1}^{A} w^a \left(V^a - s \sum_{i=1}^{N} \sum_{j=1}^{N} p_{ij}^a T_{ij} \right)^2 + z \sum_{i=1}^{N} \sum_{j=1}^{N} \left(T_{ij}^* - sT_{ij} \right)^2$$

where

V^a is a ground count for link direction a,

T_{ij} is the number of trips between origin i and destination j to be estimated,

T_{ij}^* is the seed trip table,

p_{ij}^a is the proportion of trips between zones i and j that use link direction a (as determined by an equilibrium traffic assignment),

N is the number of zones,

w^a are link weights,

z is the trip table weight, and

s is a single factor that is either set to 1 or selected by software to scale the trip table to produce the correct average traffic count.

Each direction of a two-way link, a, may have a separate ground count. T_{ij} is constrained to be no smaller than zero (i.e., cannot be negative), otherwise T_{ij} is unbounded.

It is readily apparent that there are as many variables in the constrained minimization problem as there are cells in the OD table. Thus, computation times can be long for large networks. Many formulations and algorithms have been proposed to accelerate computation times.

Special generator—A business or other activity site that is so large or so specialized that it should not be included in standard trip generation calculations for a traffic analysis zone. A special generator may have a separate zone in the model or its trips may be added to those coming from more general land uses in a zone.

Static equilibrium traffic assignment—A method by which traffic is assigned such that travel times on links are consistent with volumes and volumes are consistent with travel times. A "user-optimal" equilibrium traffic assignment method, which has been implemented in statewide models, also routes each vehicle on its shortest path between an origin and a destination. The most common algorithms for static equilibrium traffic assignment require that the assigned volumes from several all-or-nothing assignments be averaged.

Stochastic multipath assignment—Traffic between an origin and destination is divided across many paths between that origin and destination, with the shortest path usually getting the largest share.

Transshipment—Goods shipment with multiple legs of the journey, with short-term storage between the legs, either in warehouses or at terminals. Alternatively, transshipment can refer to importing goods from one country (e.g., China) that pass through another country (e.g., Canada) on its way to the destination (e.g., United States).

Notes About Terminology Used in This Synthesis

There is a tendency among those involved in building travel forecasting models to use the word "model" to describe various pieces of a model as well as the whole modeling framework. For example, planners often refer to a trip distribution technique as a "gravity model" or a mode-split technique as a "logit model." To help distinguish between various parts of a model, the following terms are used herein.

Algorithm—A series of expressions or computational processes that produces a specific result within a step. An example of an algorithm is path building.

Component—A collection of steps that leads to a particular result. Most statewide models have two components: passenger and freight.

Expression—A single equation that yields a single answer. For example, mode-split steps might be built around a logit expression, which itself contains a utility expression.

Model—The whole modeling framework, including software, databases, components, steps, algorithms, and expressions. A model excludes the personnel necessary to operate it or to interpret its results. These personnel would be included into the "modeling process."

Software—Models require software for their implementation. There are three major classes of software: statistical estimation software, travel forecasting modeling software, and GIS. Although different commercial software packages have distinguishing features, many are sufficiently general and flexible to meet the needs of statewide travel forecasting. Thus, this synthesis avoids mentioning or endorsing specific software products. Software can also be custom written for a model.

Step—A series of expressions or algorithms that represents a behavioral process within a component. An example of a step is mode split.

CHAPTER TWO

SURVEY OF STATEWIDE TRAVEL FORECASTING PRACTICE

SURVEY METHODOLOGY

The survey of states involved four stages; taking advantage of a Statewide Travel Demand Models Peer Exchange held in September 2004. First, the 14 states planning to attend the Peer Exchange were asked to answer several open-ended questions about their models, model creation, and model application. Second, an analysis of these responses was used to create the multiple-choice questions that would be answered by some or all states. Third, a very short screening questionnaire was prepared (see Appendix A) and e-mailed to all states to ascertain their general level of modeling capability and alternatives to modeling. Fourth, those states found to be reasonably far along in their model development process were mailed one of two follow-up questionnaires. The longer of the two follow-up questionnaires was sent to states not participating in the Peer Exchange and the shorter form was sent to those states represented at the Peer Exchange. The longer form is found in Appendix B. The shorter form omitted questions that appeared to be adequately covered by the Peer Exchange questionnaire.

All states except Hawaii responded to the screening questionnaire. Of all the states with models, only Louisiana and Oregon did not return the follow-up questionnaire; however, both states gave extensive responses to the Peer Exchange questionnaire and provided model documentation.

Montana's response to the survey indicated that it did not have a statewide model; however, its HEAT (Highway Economic Analysis Tool) (Cambridge Systematics, Inc.; Economic Development Research Group; ICF Consulting; and Short Elliott Hendrickson, Inc. 2004) has an embedded freight component that is similar in structure to those in other statewide models. Responses from Montana included here were based on a report about HEAT.

RURAL TRAFFIC FORECASTING NOT INVOLVING STATEWIDE MODELS

All states without models and some states with models handle project-level traffic forecasts through simpler techniques, such as growth factors and trend lines. Many states do not have a fixed methodology that applies to projects in general, whereas other states have implemented a standard technique for use everywhere. Of the 32 states reporting that they used simpler techniques, a majority reported using linear trend lines applied to historical count data. A few states use growth factors and one state (Wisconsin) uses Box–Cox regression, which produces a nonlinear trend line, heavily weighted toward higher traffic volumes. Box–Cox regression is described in the *Guidebook* (Horowitz 1999). South Dakota establishes growth rates by regression analysis of business data and historical vehicle-miles traveled (VMT) treads by county (Johnson 2000). A number of states find it necessary to modify their historical trend lines with local knowledge and other forecasts of business and population growth. It is not uncommon for a state to develop growth factors by highway functional class and by region within the state. Commercial vehicles are sometimes forecasted separately from passenger cars. Wyoming reported using a moving-average linear regression technique. None of the states reported using Box–Jenkins (sometimes called ARIMA or autoregressive integrated moving average) methods, which have become essential tools of business forecasting. (For a more complete discussion of Box–Jenkins methods see the *Guidebook*.)

Other approaches incorporate modeling concepts but stop short of a full-blown statewide model. Kansas reported using OD table estimation from ground counts as a stopgap before developing their own statewide model. New York encourages its MPOs to extend their models into rural areas to achieve a wider coverage and authorizes special models to be built when needed. Other states reported reliance on MPO models where possible.

South Dakota has pursued an interesting variation on trend–trend line forecasting that seems to embody principles of behavioral travel forecasting.

STATES WITH STATEWIDE MODELING CAPABILITY

Unlike MPO models, which are often permanent components of the UTP process and get incremental upgrades, statewide models go through a life cycle. Many of the statewide models are in transition; they are either being developed or redeveloped from scratch or are being extensively revised. Other models are dormant and one state is considering the possibility of building a model. Table 1 gives an overview of the status, at the time of data collection for this synthesis, of all states'

TABLE 1
STATUS OF STATEWIDE MODELING CAPABILITY, SPRING 2005

State	Model Condition	Cost	Development Time (years)	Comments
Alabama	None			
Alaska	None			
Arizona	None			
Arkansas	None			
California	Operational	$200,000	2.4	
Colorado	None	$400,000	1	
Connecticut	Operational			
Delaware	Operational			
District of Columbia	MPO model			
Florida	Operational	$1,500,000	4	
Georgia	Operational	$65,000	1	
Hawaii	None			Individual island models
Idaho	Dormant			
Illinois	Dormant			
Indiana	Operational	$1,500,000	3	7 more years for various upgrades
Iowa	Developing	$300,000	2	
Kansas	Developing			Has a dormant freight component
Kentucky	Operational	$370,000	2	New model under development
Louisiana	Operational	$500,000		Cost includes some applications
Maine	Operational	$500,000	5	Being revised
Maryland	None			
Massachusetts	Revising	$800,000		
Michigan	Operational	$1,000,000	2	
Minnesota	Partial			
Mississippi	Developing			
Missouri	Operational	$500,000		Revision completion soon
Montana	Operational			Freight only
Nebraska	Dormant			Base year model
Nevada	None			
New Hampshire	Revising	$2,000,000		
New Jersey	Operational	$500,000		Freight only
New Mexico	None			
New York	None			County-level OD assignment
North Carolina	None			
North Dakota	None			
Ohio	Operational	$6,000,000	8	Being revised; $3,500,000 for data
Oklahoma	None			
Oregon	Operational			Being revised
Pennsylvania	Developing			
Rhode Island	MPO model			
South Carolina	Operational	$25,000	0.5	
South Dakota	None			Feasibility study being conducted
Tennessee	Developing			Based on OD table estimation
Texas	Operational	$1,700,000	4	
Utah	None			
Vermont	Operational	$730,000	2.5	
Virginia	Operational	$1,500,000	3	
Washington	None			
West Virginia	None			
Wisconsin	Revising	$850,000	2.5	
Wyoming	None			

Notes: MPO = metropolitan planning organization; OD origin–destination.

modeling capabilities. The District of Columbia and Rhode Island do not have statewide models, because they are covered entirely by a single MPO model. This table does not reflect the common practice of states using MPO models for rural travel forecasting, when feasible. Those models shown as being revised are already functional, but are either being updated or being given greater capabilities. Figure 1 provides an additional overview of the status as of spring 2005, as well as a rough estimate of the cost of model development and, in a few cases, the amount of time allowed for model development.

RATIONALE FOR STATEWIDE MODELS

Dynamics of Modeling Process

Responses to the synthesis and Peer Exchange questionnaires revealed that the statewide modeling process is dynamic. A generalized process that has been followed by several states is illustrated in Figure 2, which shows that the design of the statewide model is influenced by past experiences with the use of the model and by the levels of knowledge by both staff and decision makers. A statewide model

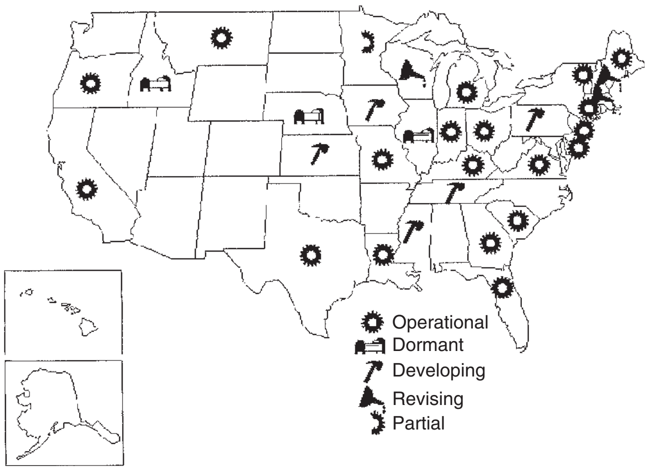

FIGURE 1 Status of statewide travel forecasting models, Spring 2005.

can flourish or become dormant depending on the amount of positive reinforcement that the process provides.

The modeling process is driven by needs in the form of general environmental and planning factors or by the requirements of a specific project, such as a major new highway corridor study. The process is also influenced by the needed level of spatial detail. These needs lead to the development of goals and objectives for the statewide model. The goals may be explicit or implicit, but are most often created in collaboration with decision makers and other stakeholders.

The actual design of the statewide model is dictated by the established goals; the level of funding available for model development; the state of the practice in statewide modeling; the state of the art in travel forecasting, in general; and the availability and quality of secondary data sources. The design of the model is also influenced by the level of expertise of the DOT staff and their consultants. Primary data sources can supplement secondary data sources, but at much greater cost. As staff expertise increases, the model can be upgraded for better accuracy and applications to a greater variety of policies and projects.

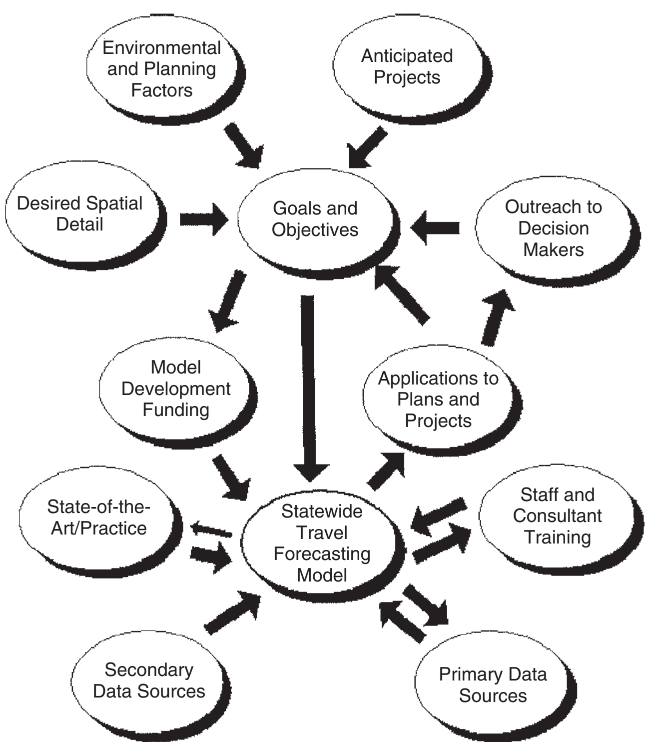

FIGURE 2 Typical statewide model development process.

The most important feedback loop in the modeling process involves five stages, shown counterclockwise in Figure 2:

- Goals and objectives,
- Model development funding,
- Statewide travel forecasting model,
- Applications to plans and projects, and
- Outreach to decision makers.

Successful applications of the model lead to increased awareness and confidence among decision makers, who in turn find additional uses for the model and provide the necessary financial support. Models that fail to continuously prove their utility will eventually be discarded.

Uses of Models

The *Guidebook* mentioned the need to address certain Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) planning factors as a major motivation for the development of statewide travel forecasting models. States with models reported an even broader rationale for model creation considering how the model is applied.

Corridor planning (19)
Statewide system planning or system environmental impact statement (EIS) (14)
Bypass studies (13)
Regional planning, assisting an MPO model (12)
Project-level traffic forecasts or project EIS (11)
Regional planning, substituting for a local model (9)
Air quality conformity analysis (6)
Freight and intermodal planning (6)
Traffic impact studies (6)
Economic development studies (6)
Long-term investment studies (6)
Detour analysis (5)
Project prioritization (5)
Toll, pricing, or tax studies (5)
Border crossing or port-of-entry studies (4)
Inputs to economic modeling (3)
Intercity bus planning (3)

- Land use planning (3) ■■■
- Passenger rail planning (3) ■■■
- Freight rail planning (2) ■■
- Homeland security (2) ■■
- Incident management planning (2) ■■
- Operational level studies (2) ■■
- Work zone planning (2) ■■
- Airport planning (1) ■
- Weigh station location (1) ■
- Revenue forecasting (1) ■
- Pavement life studies, equivalent single-axle loads (ESALs) (1) ■
- Highway alternatives analysis (1) ■
- Transit alternatives analysis (1) ■
- Park-n-ride location analysis (1) ■

The list of uses is in order of prevalence. The number following an item indicates the number of states reporting that item. States having a long history with models and great confidence in model validity tended to report a greater number of uses. The list illustrates the wide variety of applications for a statewide model. None of the states reported using their models for either truck weight studies or for safety analyses.

Although most states have found broad uses for their models once created, many models were initiated because of a very specific issue or project. For example Texas needed to analyze North America Free Trade Agreement (NAFTA) trade impacts, Louisiana and Wisconsin required input to their 2030 plans, Maine proposed to analyze a toll road, Rhode Island needed data for its air quality conformity analysis, and Indiana and Missouri were both writing an Interstate highway corridor plan. However, most models were started because of a realization by staff that there were general forecasting needs to be addressed. California and Ohio identified these needs through a formal set of workshops. In Ohio's case, the process resulted in a model specification (for both an interim model and a final model) and a program of data collection.

Many states found it useful to stage the development of the model, adding capabilities as the budget permitted. California, New Jersey, Ohio, Oregon, and Virginia are examples of states with a deliberate staging process—building a limited model to address immediate needs and expanding upon this model to address a greater range of issues.

Examples of Successful Applications of Statewide Models

In some locations the use of statewide models is multifaceted. Information about historical uses was solicited from states having recent, solid experience with applications. Similar information was also derived from the Peer Exchange questionnaire, where states had an opportunity to expound on the rationale for model investment. Although this section provides example success stories from Ohio, Indiana, Kentucky, Oregon, Florida, and Delaware, similar stories exist in other states.

Ohio

> Since coming on line in 2002, the Ohio Interim Statewide Travel Demand Model has been used for many statewide and project-level analyses. The three most important are described here. The model was used to analyze, verify, and update Ohio's Macro corridor listing as part of the statewide long-range plan update. Macro corridors are those that receive priority for capacity expansion. The model analysis was able to verify the existing corridors, but also added several important corridors, many with out-of-state connectivity that were missed in the original selection process. The model was also used to estimate truck diversion to the Ohio Turnpike, based on a truck speed limit increase and a decrease in truck tolls. This study was particularly sensitive because the bond rating of the Turnpike Commission was at stake if the toll decrease resulted in decreased revenues. The model predicted an approximately 20% increase in truck traffic on the Turnpike (enough to offset the toll reduction) and this amount was realized within a year of the changes. Finally, the model was used to estimate the road user benefits (in terms of travel time and vehicle operating cost but excluding crash costs) of the Governor's Jobs and Progress Plan. This plan envisions $5 billion in major new construction over 10 years. The analysis focused on those projects involving capacity expansion (about half of the program in dollars) and demonstrated an annual user benefit of $390 million per year over the 20-year life of the projects, which was enough to validate the proposal (G. Giaimo, personal communication, 2005).

A description of Ohio's next generation model is found later in this synthesis.

Indiana

> The Indiana DOT (INDOT) model was actually developed for the purpose of corridor-level economic development studies. The model has served as the basis for four corridor studies (I-69, SR-101, SR-37, and US-231). The model is used to produce VMT and vehicle-hours traveled (VHT) output of existing plus committed network and build networks for level-of-service (LOS) deficiency analysis, corridor-level and systemwide economic analysis (in conjunction with a benefit–cost add-on and an economic simulation model). The model was also used to produce future year growth factors to forecast future traffic volumes in a statewide interchange assessment study.
>
> The model output regarding link-level LOS for build and no-build conditions is a factor in project prioritization. INDOT uses the FHWA Highway Economics Requirements System with a 100% database to provide project-level benefit–cost analysis and implementation phasing input to supplement the travel demand model. The statewide travel model provides future year traffic for input into the FHWA Highway Economics Requirements System.
>
> The model is used at a systemwide level for safety analysis. The NETBC [Network Benefit Cost] cost–benefit calculator computes accident reduction costs from model output VMT by functional classification and facility type.
>
> The statewide travel demand model has been a valuable tool for INDOT in developing our 2030 INDOT Long-Range Plan. The model is used to display existing and future year congestion problems for discussion at a series of INDOT consultation meetings with our Metropolitan Planning Organizations and Regional

Planning Organization. The model provides information on proposed INDOT improvements and has been very valuable in the evaluation of improvements providing bypass alignments in smaller communities not covered by an MPO planning process (S. Smith, personal communication, 2005, and excerpts from the Indiana response to the Statewide Travel Demand Models Peer Exchange 2004).

The Indiana passenger component is described later in this synthesis.

Kentucky

The Kentucky model has been used primarily for corridor studies.

- I-66 Corridor Study. The study limits were between the Kentucky–Virginia state line and the Kentucky–Illinois/Missouri state line. The cost of the study was $1 million and recommendations from the study were to implement (build) portions of a new I-66 corridor. The Kentucky Statewide Model was instrumental in determining traffic volumes and the economic impact of the new corridor. A portion of I-66 is currently under design in Pulaski County. Other sections are being staged for later letting dates.
- I-69 Corridor Study. This study stretched between Texas and Michigan. The Kentucky Statewide Model was used to determine the traffic volumes in the state of Kentucky. I-69 will be built as a new facility in many locations (Indiana for instance), and in Kentucky existing four-lane highways will be improved and resigned.
- Other Corridors. The Kentucky Statewide Model has been used for many other important corridor studies such as I-64 (widening), I-875 (proposed new Interstate between Berea, Kentucky, and Chattanooga, Tennessee), and I-74 (extension of Indiana Interstate through Kentucky to Maysville). The model is able to give more accurate future growth rates and traffic diversions than other available tools.
- The Kentucky Statewide Model was used to optimize the location of potential commercial vehicle stations (weigh stations) by identifying the number of trucks that would use each location (N.R. Bostrom, personal communication, 2005).

The Kentucky passenger component is described later in this synthesis.

Oregon

Here is list of applications of the Oregon model for which case studies have been prepared.

- Willamette Valley Livability Forum. The Forum initiated a comprehensive regional visioning process for the future of land use and transportation in Oregon's populous Willamette Valley. The first generation of the Transportation and Land Use Model Integration Project (TLUMIP) model was used to model eight scenarios that varied by land use, road and public transit networks, and mileage tax. Results of modeling various combinations of land use, economic, and transportation policy options allowed decision makers to see the effects of each policy and how it will shape the future of the Willamette Valley.
- House Bill 3090: Eastern/Central Oregon Freeway. The 1999 Oregon Legislature directed the Oregon DOT (ODOT) to analyze whether a freeway in eastern and central Oregon would offload increasing traffic in the Willamette Valley. The TLUMIP model was used to evaluate the effectiveness of three alternative alignments to meet this objective.
- Newberg–Dundee Bypass Induced Demand. An EIS is being prepared for a proposed highway bypass of two small communities between Portland and McMinnville. The TLUMIP model was used to evaluate induced demand potential in rural Yamhill County as a result of the new bypass highway.
- Economic and Bridge Options Report. The TLUMIP model was used to examine the impacts of weight limits for vehicles using deteriorating bridges throughout Oregon. This analysis was the basis for a discussion with the 2003 legislature and resulted in a $2.5 billion investment in Oregon's transportation infrastructure.
- Oregon Transportation Plan Update. The ODOT strategic policy document for transportation is undergoing its first update since it was adopted in 1992. The statewide model is being used to help define a reference case and different transportation service and investment scenarios (W. Upton, derived from the Oregon response to the Statewide Travel Demand Models Peer Exchange Questionnaire, 2004, and personal communication, 2005).

Florida

The Florida model has a single focus.

The Florida Legislature established the Strategic Intermodal System (SIS) in 2003 to enhance Florida's economic competitiveness. The system encompasses transportation facilities of statewide and interregional significance and is focused on the efficient movement of passengers and freight. These facilities include Florida's major highways, rail facilities, airports, seaports, and waterways, as well as the intermodal connectors joining the SIS ports and terminals to its corridors.

The Florida Statewide Passenger and Freight Model has a highway network that includes all MPO model network links and major rural roadways. SIS highway links are identified in the model. Intermodal terminals, major seaports, and rail yards are included as special generators. The model will be used to analyze and evaluate conditions and performance of passenger and freight transportation under different scenarios, which will lead to the prioritization of proposed projects for SIS planning analysis (H. Shen, personal communication, 2005).

Delaware

Delaware's model was recently updated and the Delaware DOT (DelDOT) has not yet had extensive experience with it.

The updated model was immediately put to use as an integral tool within major studies of two long-standing, critical transportation issues.

The first effort was the US-113 North–South Study initiated in fall 2004. This involved analysis of projected traffic conditions and evaluation of more than 20 alternatives within a 50-mi-long corridor. The DelDOT Statewide Model was used to examine "average annual conditions." Because the corridor is significantly impacted by beach resort-oriented travel patterns at least 6 months of the year, the model was expanded to include equations and models focusing on "average summer conditions" and "peak weekend conditions." Development of the peak season models included postcard mailback surveys and other analyses to refine peak trip rates, OD patterns, develop a "day tripper" table, and review summer assignment patterns on "beach routes."

The second effort was the US-301 Environmental Impact Study initiated in spring 2005. This is a location and preliminary design study for a 15-mi-long study area projected to double its population and triple its employment by 2030. The DelDOT model was used to examine approximately 10 alignment options with various access scenarios and was used to assess travel impacts for a number of toll rate possibilities (M. DuRoss, personal communication, 2005).

GOALS AND OBJECTIVES

States have found it important to define goals and objectives for their models before embarking on initial model development or performing major updates. Two examples are provided here.

Oregon

Oregon set forth three goals and seven objectives for its second generation model development.

- Goal #1: Develop a set of integrated land use and transportation models that will enable ODOT and the MPOs to do [the] analysis needed to support land use and transportation decision making.
- Goal #2: Develop and maintain databases needed to make periodic long-term economic, demographic, passenger, and commodity flow forecasts for statewide and substate regions.
- Goal #3: Develop the expertise, guidelines, and institutional support necessary to sustain the models and databases needed for integrated land use and transportation facility analysis.
- Objective #1: Provide training on the integrated transportation and land use models.
- Objective #2: Connect the statewide and substate models with the metropolitan area models.
- Objective #3: Transfer the statewide and substate model to a platform that is extensible and can be modified by ODOT in the future.
- Objective #4: Integrate rail transportation into the statewide and substate model.
- Objective #5: Develop a working metropolitan model that integrates transportation and land use components.
- Objective #6: Establish data linkages between the statewide, substate, and metropolitan models and analytical software for assessing highway system performance.
- Objective #7: Establish university research linkages.

Wisconsin

Wisconsin listed six practical objectives for its model.

- Having the capability to analyze modal diversion impacts along major backbone and connecting corridors.
- Having the capability to analyze route diversion impacts once corridor-level improvements are made, such as adding lanes and changing design from expressway to freeway, thus increasing the operating speed and lowering the travel time.
- Analyzing the capacity (LOS) and safety impacts associated with increased truck travel on key Wisconsin interstates owing to the introduction of major new intermodal facilities such as Rochelle in north–central Illinois and with the ever-expanding regional commercial distribution centers like Wal-Mart, Lowe's, etc.
- Developing a planning and modeling process that integrates the on-going development of fourteen (14) MPO models and two (2) urban area models with our statewide model.
- The statewide model has two components: a passenger model and a freight model.
- To conduct AQ [air quality] regional emissions and conformity analysis for rural, isolated counties that do not have a MPO LRTP [Long-Range Transportation Plan] and TIP [Transportation Improvement Program].

INSTITUTIONAL ARRANGEMENTS

The development and maintenance of a statewide model is a major effort, involving costs for data, consultants, and in-house staff.

Overall Costs

There are no commonly accepted standards of statewide model design. Ideally, statewide models would be as detailed and accurate as the best of our urban models. This goal can be achieved in some smaller states (e.g., New Jersey or Rhode Island) either by expanding an urban model to encompass the whole state or by stitching together all of their urban models. For most states, however, compromises on quality must be made to stay within cost and time constraints. Some states find it difficult to estimate the full cost of their models because the development occurs over a long period of time or because the costs of certain related activities cannot be wholly attributable to the model development process. Given this caveat, there is an extremely wide range of costs. At the low end of the scale, South Carolina paid just $25,000; whereas at the upper end of the scale, Ohio paid $8 million, of which $5.5 million covered the cost of data collection. Approximately half of Ohio's data collection costs were for data that could be shared with MPOs. Both the Ohio and South Carolina models would be classified as being unconventional. (See chapter three for a more complete discussion of the Ohio model.) For more conventional modeling approaches, costs range between approximately $300,000 in less populated states (e.g., Delaware and Iowa) to approximately $1.5 million in populous states (e.g., Florida and Texas).

Most states were able to pay for their models exclusively with State Planning and Research funds, although a few states needed supplementary funds from either general purpose revenues or transportation-dedicated revenues. Other revenue sources were rare. Maine received funds from a toll road authority and New Hampshire used Congestion Mitigation and Air Quality funds.

Data Costs

Data collection can be a large component of the development of a statewide model. For example, Ohio's devoted almost 70% of its budget to data acquisition. Big ticket data items in Oregon included:

- Continuous Survey for Modeling in Oregon Pilot Project ($250,000).
- Freight commodity flow data collection ($390,000).
- Freight shipper and carrier survey ($300,000).

- Truck intercept survey ($175,000).
- Oregon Travel Behavior Survey ($125,000).
- Recreation/Tourism Activity Survey ($150,000).
- Household Activity and Travel Survey ($1,000,000).

Wisconsin paid $2.5 million for an NHTS add-on; however, the data are also usable by MPOs within the state. Kentucky paid just $176,000 for their NHTS add-on. Louisiana spent $100,000 on commodity flow data, which is typical. Indiana spent $60,000 on D&B employment data. Some other states reported negligible data acquisition costs.

Staffing and Maintenance

All states reported having the help of consultants when building their models. In some cases teams of consulting firms contributed to model development. The dependence on consultants for maintenance varied considerably across states; however, most states reported that routine maintenance was done in-house.

As with costs, staffing levels varied widely across states. Staffing levels ranged from a one-half full-time equivalent (FTE) in Florida, Indiana, and Kentucky to approximately three FTEs in Connecticut, Oregon, and Wisconsin. A little more than half of the states reported roughly one FTE. A few states noted that modeling responsibilities were spread across multiple staff members, each spending only a fraction amount of their time on the project. Some of the states with lower staffing levels reported having a larger amount of consultant help. Several states needed to add personnel as they increased their modeling activities.

Model maintenance is required to keep it up to date in terms of network structure, demographic data, link data, and calibration data. Models not maintained become obsolete and useless. However, maintenance should not be so burdensome that staff does not have sufficient time for applications. States with new models find that there is little need for maintenance, but states with mature models experience a more constant effort. A 50/50 split between maintenance and applications is typical among those states that were able to make an estimate.

Time Frame

Because situations vary significantly across states, there is no consensus as to how long it takes to build a model. Models in most states have evolved over many years; therefore, no time estimate is possible. A reasonable range for states that recently built their models from scratch is 1 year (Delaware) to 4 years (Florida and Texas). Ohio, with an unusually ambitious model, is taking 8 years (see chapter three).

Maintenance is largely a continuous process or on a very frequent cycle (1 to 2 years). Update cycles tend to coincide with statewide plan updates, with most states using a 5-year update cycle. Two states (Connecticut and Ohio) indicated using a 10-year cycle for major model revisions. Massachusetts noted that its next update would likely be driven by air quality conformity needs, whereas Indiana performs updates as needed for specific projects.

User Support

Training is considered an essential element of model deployment. A training session is often provided by the consultant on model delivery; thereafter, training happens sporadically. Only a few states have regular training cycles, with details differing from state to state. For example, Oregon has an arrangement with a local university to supply training, Connecticut sends employees to FHWA urban modeling courses, and Kentucky has an in-house annual training program lasting 2 days.

Users of the model tended to be confined to the state DOT and its consultants. States with organized urban model user groups (e.g., Florida and Iowa) can call on them for assistance with the statewide model, even though their members are not primary users of the model. Web pages tended to be located in those states with user groups.

A little more than half of the states with models have made provisions for distributing them to consultants and MPOs. Selected states will deliver their models to outside agencies or universities on request, although with conditions. For example, Texas asks borrowers to sign a confidentiality agreement, Kentucky requests that borrowers sign an agreement as to acceptable use of the model, Wisconsin has procedures by which it will allow the use of its model and the modeling software by outside parties, and Michigan only distributes trip tables and networks. The remaining states have had no experience with model distribution, and it is not clear whether these states have a policy against or simply no need for distribution.

All states with models will make results of model runs available on request. Requests are handled on a case-by-case basis. Some states will do custom model runs on request; however, those requests are fulfilled only for internal needs. Often the format of the requested data must be negotiated. For example, Vermont asks outside recipients of model results to sign a binding nondisclosure agreement to protect sensitive employment information.

INSTITUTIONAL BARRIERS TO MODELS

Given that only about half of the states have active models, there would appear to be reluctance on the part of some states to proceed with model development.

Agency Roadblocks

Only a few states reported having institutional barriers that needed to be overcome, and these barriers were not critical.

Massachusetts and Ohio each had trouble obtaining employment data from another state agency. A few states reported funding shortfalls until the need for the model could be convincingly demonstrated. Wisconsin found trouble getting good cooperation from the state's two largest MPOs and needed to deal with a change in governor, who required time to understand issues related to the statewide transportation plan.

Overcoming Resistance

Literature on innovation often makes reference to the need for a "champion" to effect change.

> I've learned that in every state where models are maintained and actively used in the planning process that there is an evangelist and visionary that drives the program. This person, by force of personality or position, is the key driver behind the success of the model. If this person retires or moves on to other things the modeling program often dies. Thus, maintenance of the model is often more a reflection of the priorities and capabilities of the evangelist more than a systematic or carefully considered process (R. Donnelly, Statewide Travel Demand Models Peer Exchange, 2004).

Cooperation is critical to an effective statewide travel modeling process.

> It is important to build and maintain relationships between technical staff and management. Well-established relationships between modeling staff and senior management make management more willing to take a chance on a process that does not support their initial preconceived ideas. Interest and support of modeling from 'outsiders' is helpful. Those who used the modeling tools in the past support and advocate for its use on new projects. It is helpful to have advocacy from others external to the process that are perceived as nonbiased and those that may better understand non-traditional model outputs (W. Upton, Statewide Travel Demand Models Peer Exchange, 2004).

Model Failure

A number of statewide models have gone dormant. One model developer writes:

> Models fail for one of several reasons:
>
> - Vague or poorly defined goals and objectives.
> - Developed with single purpose in mind.
> - Higher than expected maintenance and application costs. This includes the need for more highly skilled staff, the magnitude of data required (both in scale and scope), and inter-agency friction.
> - Lack of management support (read: the models do not provide information useful to decision makers in the metrics and time frames they need).
> - The models are cumbersome and inaccurate. The models are no better than the quality and quantity of the data used to develop them. Poor models are the only possible outcome from building them with poor or scarce data.
> - Failure to build linkages to economic models. Most state legislatures tend to look at transportation problems as economic problems. Models that simply address traffic flows do not provide the information on key linkages (and benefits) between the economy and transportation. In some instances I've seen state legislators discount modeled outcomes because they are at odds with, insensitive to, or seem uninformed by economic and market trends (R. Donnelly, Statewide Travel Demand Models Peer Exchange, 2004).

COMPUTER HARDWARE AND SOFTWARE

Questionnaire Results

All states reported using a high-speed personal computer to run their existing models; typically running a version of the Windows operating system. No other hardware requirements were noted.

A large majority of statewide models are built on software platforms originally designed for UTP. Oregon has constructed its own software specifically for statewide modeling. Most states use a GIS with their models; either a stand-alone GIS package or one built into their UTP software. Computation times vary considerably, ranging from only 30 s in South Carolina to 12 h in Maine. The median computation time is somewhere between 1 and 2 h; therefore, it is possible to conclude that the computational burden is not large.

Example of the Use of Geographic Information Systems

> In Louisiana, the statewide model network was developed based on several existing DOT legacy databases including:
>
> - Louisiana Road GIS file in Geomedia format;
> - Surface Type log file, a Microsoft Access database containing mile post and key roadway attributes; and
> - Highway Needs Inventory Summary log file, another Microsoft Access database, containing mile post and additional roadway attributes, roadway conditions, and future needs information.
>
> Substantial resources were devoted by the model development consultant Wilbur Smith Associates (WSA) to make sure these files were rendered suitable for modeling purposes and were linear referenced, facilitating future network update activities.
>
> - WSA first converted the original Geomedia Road GIS file to ArcInfo, created a Route System, and used the dynamic segmentation method to link the Surface Type log and Needs Inventory file to the GIS file. This process allowed WSA to access all the necessary network attributes from the two Microsoft Access databases. WSA decided to retain all of the links, including some local roads in the original GIS file for the Micro Model network.
> - The Road GIS file was designed for the Louisiana Department of Transportation and Development (LADOTD) for nonmodeling functions and therefore was not suitable for modeling. The original GIS file did not represent a modeling network of links and intersections. Network editing to split links was necessary to represent intersections properly. Because some of these intersections could be overpasses or underpasses, each required review so that network connections would replicate ground conditions.
> - Many stub links were found in the original GIS file. Network connectivity checks and editing were performed to make sure the network was suitable for modeling.
> - Additional roads were added, particularly within MPO areas. The sources for the additions were from the MPOs' modeling network file or Census Topologically Integrated Geographic Encoding and Referencing (TIGER) line files. Toll roads, bridges, and automobile ferry links were identified and added to the Micro network, because they were not present in the state database.
> - With substantial manual editing and link additions, the existing GIS file mile post information was either missing or distorted.

WSA developed automatic procedures (TransCAD) and Access database macros, allowing for the update of attribute information from LADOTD Summary log file or other files as long as these files contain beginning and ending mile posts for the updated attributes. With these macros, the updating network attributes become a simple task. For example, near the end of the model development work, LADOTD systematically reclassified their functional classification system, and WSA was able to incorporate this latest information easily for the final model revalidations.

In summary, given the scale and extent of the statewide model network coverage, the ability to link these DOT existing, well-established attribute databases to the modeling GIS network becomes increasingly important once the statewide model is developed. It eliminates duplicate efforts, reduces network coding errors, and increases job satisfaction by eliminating tedious manual work and increasing fast turnaround time in conducting alternative analysis, corridor studies, scenario planning, and other statewide planning activities (S. Yoder, personal communication, 2005, and Wilbur Smith Associates 2004).

OVERALL MODEL CONSIDERATIONS

All states with operational models have used them for long-range forecasting purposes. With the exception of Vermont, forecasts of 20 or more years have been done.

Measures of Effectiveness

A state selects measures of effectiveness (MOEs) that relate closely to the rationale of the model. MOEs are usually aggregations of results that would pertain to individual links (e.g., road segments) or nodes (e.g., intersections) and are aids to deciding between alternatives. MOEs are relied on during the decision-making process because people are able to readily grasp only a few indicators of system performance, and aggregate measures have a lower percentage of error than raw travel forecast outputs. The following is a complete list of MOEs used by states in order of prevalence.

- VMT (22)
- VHT (20)
- Volume and capacity ratios (18)
- Levels of congestion (15)
- Traffic growth rates (14)
- System delay (11)
- Passenger volumes by mode (9)
- Corridor delay (9)
- Employment by area (8)
- Time savings (8)
- Freight tonnages by mode (6)
- Air pollution emissions (3)
- Crash reduction (2)
- Greenhouse gas emissions (2)
- Benefit–cost ratio (2)
- Goods production by area (2)
- Interregional travel (1)
- Land prices (1)
- Shipping costs (1)
- Total trips by area (1)

MOEs are similar to those found in urban models. Among the seemingly obvious MOEs not mentioned were energy consumption and any user benefits other than time savings. States will often disaggregate MOEs by time of day or by location to better identify problems. For example, Massachusetts looks at congestion measures by time of day. Ohio breaks down its MOEs by Ohio DOT district and by county. Oregon computes various MOEs depending on the issue, such as VMT by travel market segment, VHT by travel market segment, shipping costs by area, total production by area, employment by area, land prices by market segment and area, and trips by travel market segment. Montana's HEAT included measures of accessibility, business activity within cities or markets, production costs, and personal income. Three states indicated that they had no MOEs.

Employment Data

Two particularly difficult aspects of travel forecasting are obtaining good TAZ level employment data and good long-range economic forecasts. Employment data from governmental sources are often restricted by confidentiality issues and incorrect street addresses. Many states have opted to obtain their employment data from commercial sources. Here are the primary sources of employment data reported by states, in order of prevalence. A state may have used more than one source.

- CTPP (10)
- MPO databases (10)
- Commercial data vendor (10)
- Department of Workforce/Employment/Labor Development (6)
- Workman's compensation tax records (5)
- Unemployment records (4)
- Employer or establishment survey (2)
- Regional economic model (2)
- Employer directory (1)
- Other unspecified (1)

Many states have taken advantage of MPO models for employment data. Although the same data problems also exist at an MPO, usually an individual(s) with good local knowledge has already confronted them. Ten states use the CTPP, which derives employee location from a large sample of households during the decennial census. The CTPP is especially attractive because of its low marginal cost. Although unemployment records (ES-202) seem to be an attractive source of data, some states have reported considerable problems in obtaining and using this database.

Economic forecasts are done regularly by the BEA; however, the BEA regions are usually too large for direct inclusion into a statewide model. Therefore, many states have opted for other sources of economic forecasts. The following is a list of the sources, in order of prevalence.

- State agency forecast (8)
- A regional economic model (5)
- An IO model (4)
- MPO databases (4)
- BEA (4)
- Commercial forecast vendor (3)
- State DOT (2)
- University (1)
- None or not mentioned (3)

The largest number of states obtain their economic forecasts from another state agency. Five states use a regional economic model, either a commercial model or one developed particularly for the statewide model, and three states use an IO model. As with employment data, a few states efficiently rely on their MPOs for economic forecasts.

Generic Model Structures

There is an intrinsic relationship between model structure and the policies and projects that can be addressed, as illustrated in Figure 3. This figure can be interpreted either backwards or forwards, depending on whether it is illustrating part of the model design process or model operation. The structure of the model dictates what it can reasonably produce as outputs, and the outputs limit what can be accomplished by the model when adding information to the decision process. However, the design of the model is largely derived from what the model is intended to accomplish. Conceptually this is a two-stage process, where the issues needing to be addressed dictate the required model outputs, which further dictate the model structure.

Figure 4 expands the relationship between the first two items in Figure 3, the generic structure and the range of model outputs. There are essentially six generic structures, ranging from statistical trend analysis to an integrated model of freight, passenger travel, and economic activity. The behavioral realism generally increases from left to right, except for the distinction between freight-only and passenger-only models. Although freight-only models may be as sophisticated as passenger-only models, their use for traffic operational analysis is limited. The arrow in Figure 4, deliberately drawn to be vague, shows how the behavioral realism of the model affects the uses to which the model can be put.

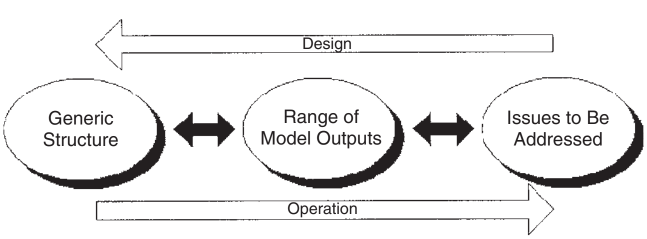

FIGURE 3 Relationship between model structure and policies and project decision making.

PASSENGER COMPONENTS

Statewide travel forecasting models are often thought of having two equally complex components: passenger and freight. In some models, vehicles in commercial service that do not carry freight are treated separately. With a few exceptions, passenger components look much like urban travel forecasting models in structure; containing the four major steps of trip generation, trip distribution, model spit, and trip assignment. Oregon's model and Ohio's new model (see chapter three) have more complex structures, but the four traditional steps are still present, conceptually. This section deals primarily with details of how the four steps are implemented.

Passenger Component Data

States use a wide variety of data sources to calibrate their statewide models, although only a few sources are used in each state. The following are the data sources identified by states in order of prevalence.

- CTTP (13)
- Census journey-to-work data (11)
- *NCHRP Report 365* (10)
- NHTS normal sample (10)
- MPO household survey(s) or panel(s) (9)
- ATS (9)
- Own household survey (8)
- Institute of Transportation Engineers (ITE) *Trip Generation* (7)
- PUMS (7)
- Roadside survey(s) (6)
- NHTS add-on (5)
- *NCHRP Report 187* (5)
- GPS-based survey (3)
- Amtrak (2)
- Intercity bus service (2)
- FAA sample ticket data (2)
- Ferry service (1)
- Tourism survey (1)
- Own on-board rail survey(s) (1)
- Bus on–off counts (1)
- Other agency survey (1)

The extensiveness of this list of calibration data sources indicates that modelers are being quite resourceful; using what is readily available and augmenting as necessary. With home interview surveys costing approximately $165 per sample (based on the cost of an NHTS add-on), there is a strong advantage to exploiting whatever data have already been collected. The most often cited data source was the CTPP. A total of 11 states either did their own household

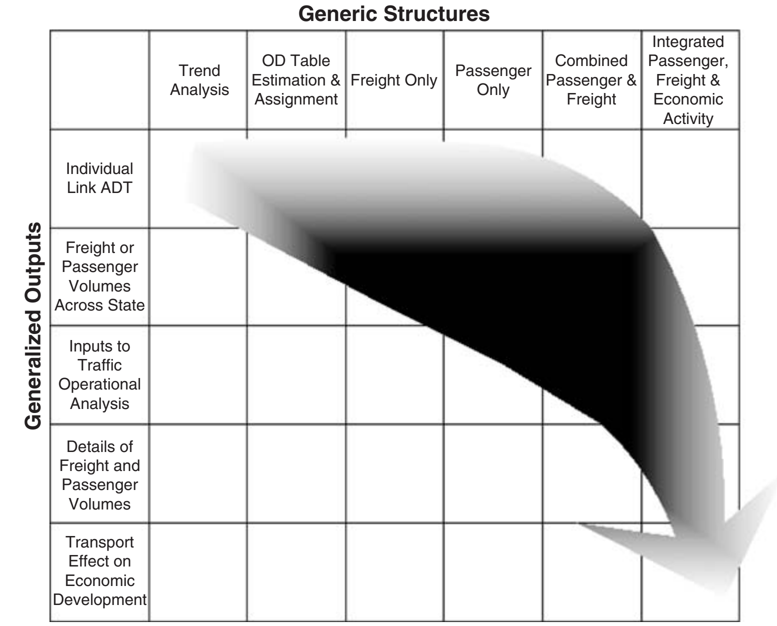

FIGURE 4 Generic model structures and their potential outputs.

survey or funded an NHTS add-on. Connecticut reported using both a household survey and an NHTS add-on, although the survey dated back to the 1970s. California did the most extensive home interview survey of their own with 17,000 samples. Seven states tapped into MPO household surveys. Ten states used either *NCHRP Report 187* (Sosslau et al. 1978) or *NCHRP Report 365* (Martin and McGuckin 1998) for transferable parameters. Maine transferred parameters from the Michigan model. Although the ATS is now 10 years old, many states believe that it is still essential. The ATS is the only comprehensive data source on long distance travel.

The NHTS add-ons varied greatly in size. Wisconsin bought the largest number of samples (17,610) and Massachusetts bought the fewest (500).

Interestingly, Oregon did not use the NHTS, but performed four different surveys in support of its statewide models, as well as MPO models: Household Activity and Travel Survey, Oregon Travel Behavior Survey, Recreation/Tourism Activity Survey, and Continuous Oregon Survey for Oregon Models.

Household socioeconomic data came from a few obvious sources as listed here. The U.S. Census dominated as a data source, followed by MPO databases, which most likely were derived largely from the U.S. Census. Five states obtained employment data from another state agency, although there were often considerable problems using such data.

Other U.S. Census than CTPP (15) ■■■■■■■■■■■■■■■
CTTP (12) ■■■■■■■■■■■■
MPO databases (10) ■■■■■■■■■■
Another state agency (5) ■■■■■
A regional economic model (4) ■■■■
Commercial data vendor (4) ■■■■
School enrollment data (3) ■■■
A state natural resources department (2) ■■
Local property tax records (1) ■
GIS maintained by another agency within your state (1) ■

There were only a few sources of highway traffic data, with most states relying on their own counts or their own Highway Performance Monitoring System (HPMS) database. Only six states used either their own speeds or travel times. Massachusetts was the only state reporting that it obtained counts from other states.

Own agency counts (18) ■■■■■■■■■■■■■■■■■■
HPMS (11) ■■■■■■■■■■■
Own agency speeds (6) ■■■■■■
Own agency travel times (5) ■■■■■
Toll or bridge authority counts (5) ■■■■■
Counts, speeds, or travel times from another agency (2) ■■
Other states (1) ■

Building passenger networks is an expensive and time-consuming task. Data that would allow the construction of statewide passenger networks (links and nodes) came mostly through MPO networks or through DOT road inventory systems. The National Highway Planning Network (NHPN) was used principally for out-of-state portions of the network. Delaware and Rhode Island asked neighboring states for network data. For out-of-state highway networks, Florida and

Texas and used a proprietary data source that came from their UTP model software vendor.

- Own agency road inventory/management system (17) ■■■■■■■■■■■■■■■■■
- NHPN (7) ■■■■■■■
- MPO networks (6) ■■■■■■
- TIGER (6) ■■■■■■
- Bus or rail published information (3) ■■■
- Neighboring state agency road inventory(ies) or management system(s) (2) ■■

More than half of the states reported the need to obtain locally collected data for their modeling efforts. Several states performed travel surveys, as noted previously. Texas performed a border survey. California, Delaware, and Ohio performed roadside surveys. The costs of the surveys varied considerably, from $2,000 in Virginia to more than $2 million in Michigan, Ohio, and Wisconsin.

Only Delaware, Indiana, and Oregon reported ongoing data collection efforts to support or update their models. Oregon is conducting its Continuous Survey for Modeling in Oregon (COSMO), which collects additional time–series information on household activities and travel.

The update cycles for passenger networks tend to be long, with most states reporting that they wait more than a year between updates. Networks are usually updated with DOT road inventory or MPO data.

There was no consensus about data deficiencies. Table 2 lists data items modelers wanted but could not get or data items needing improvements. Long distance and tourism data appeared to be a need in states that would prefer to avoid the dated ATS (from 1995).

Given the size of the databases necessary for statewide travel forecasting, a large majority of states with models are using GIS for storing passenger data or networks. Those states with a GIS integrated into their UTP software tended to use it instead of a stand-alone GIS product. Furthermore, a large majority of states obtained at least some of their network data from a GIS.

Passenger Level of Detail

Statewide models are distinguished from urban models primarily in their spatial extent and their level of detail. Historically, most statewide models were designed at a "sketch planning" level of detail so as to cover more area with fewer network elements. However, recent advances in computer hardware and GIS software have permitted much more detail in statewide models. The amount of detail relates to the numbers of zones, network elements (nodes and links), trip purposes, special generators, time of day, and modes.

MODAL CHOICE

All states with passenger components have at least the passenger automobile as a mode. A majority of the statewide models are multimodal. Listed here are the modes cited by states. The only passenger mode sometimes seen in urban models that has been universally omitted from statewide models is the taxi, although statewide models are likely to contain some treatment of intercity modes, particularly passenger rail and passenger aviation. With very few exceptions, each mode in a statewide model has its own network.

- Passenger automobile (21) ■■■■■■■■■■■■■■■■■■■■■
- Intercity passenger rail (conventional) (7) ■■■■■■■
- Intercity bus (6) ■■■■■■
- Local bus (6) ■■■■■■
- Commuter rail (5) ■■■■■
- Intercity passenger rail (high speed) (2) ■■
- Passenger aviation (2) ■■
- Metro rail or light rail (2) ■■
- Ferry (1) ■
- Intercity rail/bus (1) ■
- Commuter express bus (1) ■

Time of Day

Time of day is much coarser in statewide models than is typical of urban models. Only five states reported the ability to run peak-hour analyses. The other states run their models for a full 24 h, either during a weekday, a summer day, or an average

TABLE 2
REPORTED DATA DEFICIENCIES

State	Deficiency
Ohio	There was an underreporting of short and discretionary trips in survey data
Massachusetts	Lack of household trip data
Michigan	OD data are impossible to collect on major highways
Indiana	No external automobile trips from national sources
Maine	Nonwork origins and destinations; long distance travel patterns
California	Multimodal long distance or multiday trips
Kentucky	Up-to-date trip information; not enough samples from NHTS
Virginia	Long distance travel
Florida	Rural travel behavior characteristics and tourism trip OD data

Notes: OD = origin–destination; NHTS = National Household Travel Survey.

annual day. The coarseness of time-of-day representations has implications for being able to calculate accurate delays and for identifying congestion hot spots. The critical issue in time of day, as identified in the *Guidebook*, is that many trips statewide are longer in duration than a peak hour or a short peak period, but more than likely shorter than a day. The standard methods of overcoming this trip duration problem are dynamic traffic assignment or traffic microsimulation. Traffic microsimulation was being explored as a possibility in Ohio and Oregon, but consideration of dynamic traffic assignment has not been reported for any statewide model.

Zone Systems

All statewide models have zone systems for organizing spatial information on a network. Zone size varies greatly among states, with the largest zones being counties and the smallest zones corresponding to MPO TAZs. Many states that are revising their models do not have a good idea as to the number of TAZs, so data on this issue are incomplete. The relationship between the number of TAZs and the size of the state is shown in Figure 5 for those states reporting. A quick inspection of the graph indicates that the relationship between land area and zone size is, at best, not significant. However, if one were to separate out the five states with more than 3,000 zones but fewer than 70,000 square miles (Florida, Indiana, Kentucky, Massachusetts, and Ohio, in the upper left corner of the graph) two linear relationships emerge. The differences between the two sets of states appear to be related to modeling philosophy, rather than to any intrinsic characteristic of the state itself. Oregon, which did not provide an exact estimate of the number of zones, would fall into this upper group. Virginia, although appearing in the lower group, uses subzones for various model steps and is able to achieve considerable spatial detail in this manner. The lowest point on the graph is Georgia, which uses counties for zones.

Some states extend their zone systems beyond their borders, but others do not. Kentucky has the most aggressive statewide model in this regard, having 1,109 zones, almost one-third of its total in neighboring states. Other states with a large number of zones outside their borders include Virginia (522), Louisiana (465), Maine (463), Massachusetts (431), and Rhode Island (400). Other states have significantly fewer out-of-state zones and are dependent on external stations to account for trips with at least one end outside their borders.

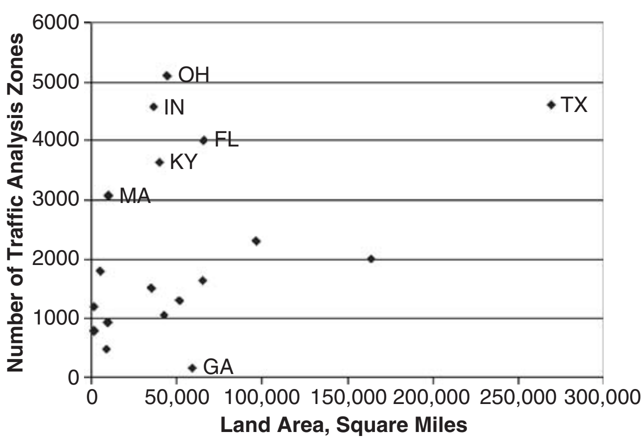

FIGURE 5 Relationship between land area and number of zones in statewide models.

The zone structures within the urbanized areas of the states were constructed using a variety of data sets. Most of the states borrowed MPO zones or aggregated MPO zones. The following are the methods used.

- Aggregations of MPO zones (11)
- Adopted MPO zone structures (6)
- Census tracts or aggregations of census tracts (6)
- Census block groups or aggregations of block groups (3)
- Census TAZ-UP (Update Program) (1)
- Counties (1)

Six states (Iowa, Kentucky, Louisiana, Michigan, Ohio, and Virginia) reported that their internal zones systems covered most or all of the United States. However, only two states (Maine and Michigan) mentioned having all or part of Canada or Mexico.

Subzones or grid cells are a means of greatly increasing spatial detail in certain model steps, particularly traffic assignment, and are used by Kentucky, Ohio, Oregon, and Virginia.

External stations are used in urban models to represent origins and destinations of trips that, at some point, leave the study area. Most statewide models do the same. States whose model zone systems fully or mostly encompass the United State do not have a need for external stations. In practice, external stations are placed just outside the study area along Interstate and major U.S. highways; therefore, their number is closely tied to the number of major roads entering or leaving the state. For example, Maine had just 20 external stations and Texas had 142.

Special Generators

A special generator is a network element, often similar to a zonal centroid that represents a single site. A special generator may be shown as its own node on the network or it may share a centroid with other land uses from the TAZs. Potentially, each special generator can have its own trip generation rates. Most states use special generators sparingly or not at all. However, two states, Michigan and Texas, use them extensively, with each having nearly 4,000 special generators. Only Virginia has a specified minimum size threshold for special generators. The following is a list of types of special generators cited by states (not the number of such special generators).

Tourist attractions (8)	■■■■■■■■
Major recreation sites (6)	■■■■■■
Universities (5)	■■■■■
Military bases (5)	■■■■■
Airports (5)	■■■■■
Shopping centers (4)	■■■■
Hotels (2)	■■
Hospitals (2)	■■
Public offices (1)	■
Bus terminals (1)	■

Michigan and Texas, as would be expected, cited the most types of special generators. The methods of determining trip generation rates for each special generator were split between dependence on ITE's *Trip Generation* (1997) and locally determined rates. Here are the methods used.

Counts, growth factors, or trends from actual trip making at sites (6)	■■■■■■
Trip rates from ITE's *Trip Generation* (6)	■■■■■■
Trip rates from local trip generation studies (3)	■■■
Rates from MPO models (1)	■

California had access to a park attendance database. New Hampshire differed from all other states by using a multinomial logit expression for tour formations that involved special generators.

Trip Purposes

Statewide models tend to have a long list of trip purposes to capture both urban trips and long distance trips. To keep models reasonably simple, the urban trip purposes are often limited to those of *NCHRP Report 187*: home-based work, home-based nonwork, and nonhome-based. These urban trip purposes are then supplemented with a few purposes that describe long distance trips. Here are the trip purposes in statewide models, in order of prevalence.

Home-based work (19)	■■■■■■■■■■■■■■■■■■■
Home-based nonwork (home-based other) (16)	■■■■■■■■■■■■■■■■
Non-home based (16)	■■■■■■■■■■■■■■■■
Long distance recreation/vacation (10)	■■■■■■■■■■
Long distance commute (7)	■■■■■■■
Long distance business (7)	■■■■■■■
Long distance other (7)	■■■■■■■
Home—shop (5)	■■■■■
Long distance personal business (3)	■■■
Home—recreation (3)	■■■
Home—other (3)	■■■
Home—social/recreation (3)	■■■
Home—school (3)	■■■
Other—work (1)	■
Other—recreation (1)	■
Other—other (California) (1)	■
General (Georgia) (1)	■
Long distance, general (1)	■
Other (1)	■

Maine has separate trip purposes for both short and long distance trips for home-based social/recreation. Oregon segments its trip purposes by income.

Some of the newer statewide models contain very detailed networks, which are a consequence of incorporating most or all of the urban networks. Florida and Texas have approximately 100,000 links and Wisconsin and Virginia each have approximately 200,000 links. Some states have found it possible to work with smaller networks. For example, Delaware, New Hampshire, and Vermont have fewer than 7,000 links.

Passenger Component Methods

For the most part, statewide models have passenger components that are similar to those found in urban models. Models for large urban areas are traditionally four-step, encompassing trip generation, trip distribution, mode split, and traffic assignment. Many smaller urban models are three-step, replacing the mode split step with small downward adjustments to trip generation rates. Beyond these four steps, specific procedures must be introduced to handle the distribution of traffic across times of day and to calculate the average numbers of persons in a vehicle (termed automobile occupancy). The new models in Ohio and Oregon (see chapter three) deviate substantially from the norm, so it is difficult to classify their attributes in conjunction with traditional four-step models.

A solid majority of the statewide models are traditional four-step. The models in Kentucky, Maine, and Massachusetts are better classified as three-step, because they omit a formal treatment of mode split. Massachusetts handles the large transit ridership in Boston by removing riders at the trip generation step, based on information obtained from the Boston MPO model. Ohio and Oregon have integrated land use and economic activity components, which encompass the functionality of trip generation, trip distribution, and mode split.

Ohio implemented OD table estimation from traffic counts within its interim model. Montana uses OD table estimation from traffic counts to provide background traffic for its economic model, HEAT.

The calculation of trip productions during the trip generation step is for the most part performed by a cross-classification procedure. Exceptions include the new Ohio and Oregon models (as discussed earlier), New Hampshire, and Virginia.

New Hampshire relied on its tour-based multinomial logit expression for trip productions, and Virginia factored data obtained from the 1995 ATS, the U.S. Census, and the NHTS. Although Connecticut, Indiana, and Vermont used cross-classification for some trip purposes, they also used trip rates or linear equations.

Table 3 shows the variables within cross-classification models for trip productions for those states that provided the information. Most models combine household size (persons per household) with some measure of wealth (income, number of workers, or automobile availability).

Trip attraction calculations are dominated by the use of linear equations of demographic variables or trip rates. New Hampshire, Ohio, and Oregon are exceptions because they use destination choice models. California and Kentucky both reported referencing *NCHRP Report 365* for trip rates.

Automobile occupancy calculations convert passengers to automobiles and usually follow the standard urban practice of dividing numbers of passengers by an automobile occupancy rate that varies by trip purpose. Here are the methods adopted by states:

- Automobile occupancy values for each trip purpose (10) ■■■■■■■■■■
- Rates that vary with trip distances (2) ■■
- Multinomial logit mode split model that includes drive alone, high-occupancy vehicle 2, and high-occupancy vehicle 3 (1) ■
- Rates that vary by metropolitan statistical area (MSA) size and Claritas Code (1) ■
- None, generation is in vehicles already (1) ■
- Rates that vary by vehicle ownership by TAZ (1) ■
- Microscopic activity patterns; occupancy is based on the individual travel decision (1) ■

No state reported using a single automobile occupancy rate for all purposes or using automobile occupancy rates that vary by trip duration.

The gravity expression remains popular as a method for trip distribution. Three states (California, Florida, and Texas) create composite impedances for multimodal trip making as an input to their gravity expressions. Virginia's and Louisiana's models and Ohio's interim model rely heavily on Fratar factoring of existing OD tables. New Hampshire, Ohio, and Oregon use destination choice models. The following list cites the numbers of states reporting each technique.

- Gravity expression, without composite impedances across modes (12) ■■■■■■■■■■■■
- Fratar factoring (3) ■■■
- Gravity expression, with composite impedances across modes (3) ■■■
- Logit expression, joint between distribution and mode split (2) ■■
- Tour-based multinomial destination choice model (1) ■

Those statewide models that are considered multimodal require a mode split step. A variety of methods is used.

- Logit expression, mode split only (5) ■■■■■
- Fixed shares (3) ■■■
- Nested logit (3) ■■■
- Logit expression, joint between distribution and mode split (3) ■■■
- Diversion curves (1) ■

The preferred method of traffic assignment depends on the network detail in congested areas, typically in dense urban centers. Models with highly detailed networks can estimate volume-to-capacity ratios with some degree of certainty, so that equilibrium conditions can be estimated. Models with abbreviated urban network representations are better off with a traffic assignment method that does not require delay information. The method of traffic assignment selected by most states is static equilibrium. Virginia uses stochastic multipath traffic assignment, whereas Maine, Michigan, and Montana use all-or-nothing traffic assignment. Dynamic traffic assignment (either equilibrium or all-or-nothing) is not used, even

TABLE 3
VARIABLES USED IN CROSS-CLASSIFICATION MODELS FOR TRIP PRODUCTIONS

State	Variables
Kentucky	MSA Size and Claritas Code (urban, second city, suburban, town, and rural)
Louisiana	Claritas Code (urban, second city, suburban, town, and rural)
Wisconsin	Household size by automobiles or workers by automobiles
Delaware	Income, employees per household, and persons per household
Texas	Household size by income
Massachusetts	Household size by automobile ownership; also household income, number of household workers, workers per vehicle, and numbers of school age children
Connecticut	Automobile availability by income category
Maine	Household size with either income or automobile ownership
Michigan	Household size and income and area type
Indiana	Household size by automobile availability by area type
California	Household size by income
Vermont	Household size by automobiles per household

Note: MSA = metropolitan statistical area though trip lengths in statewide models exceed the duration of a peak period. Although some states intend to investigate traffic microsimulation for their statewide models, actual applications of microsimulation have not yet been reported.

Given the limitations of the available traffic assignment algorithms, most states have chosen to ignore the peak period or do simple factoring of 24-h traffic into a peak. Here are the adopted methods.

Factored by percent of traffic in peak from traffic counts (7)	■■■■■■■
Peak period assigned directly (6)	■■■■■■
No factoring into peak (5)	■■■■■
Post-processed in another manner (2)	■■

No state overtly includes peak spreading. Massachusetts and Ohio reported having time-of-day models. Ohio's model includes travel time as a variable in its utility expression; therefore, there is some sensitivity to traffic congestion.

Every model uses speed and volume curves, such as the BPR curve, for delay calculations.

Special Treatment of Long Distance Trips

Beyond computational and data problems associated with the detail of networks in statewide models, the greatest obstacle for forecasting is good representation of long distance trip making. Obtaining good information on long distance trips has become more difficult as the 1995 ATS has aged; therefore, states have discovered numerous ways to work around this limitation.

All states with models are cognizant of the need to include long trips, and a little less than two-thirds of the states reported taking special actions to model long distance travel. A solid majority of these states create special trip purposes for long distance travel. There are three approaches: (1) segmenting existing trip purposes into short and long distance categories; (2) creating separate trip purposes, such as recreation/tourism, to capture long trips; and (3) Fratar factoring an OD table of long distance trip purposes.

Some other fixes were necessary, depending on the state. Delaware, Maine, and New Hampshire, in particular, reported the need to account for tourism during the summer months. California found it necessary to introduce *k*-factors during trip distribution; to use composite impedances for input to the gravity expression and to modify friction factors to account for long distance travel.

A variety of data sources, cited here, were used specifically to model long distance travel. There is no consensus as to the preferred data sources. Notably, Ohio performed a 2-week household survey of trips in excess of 50 mi. Four states are still using the 1995 ATS.

NHTS or NPTS (5)	■■■■■
ATS (4)	■■■■
Special long distance travel survey(s) (3)	■■■
Employment data from private vendor(s) (2)	■■
Employment data from public source(s) (2)	■■
Roadside surveys (2)	■■
Tourism economic or attendance data (2)	■■
U.S. Census (1)	■
Economic data from a private vendor(s) (1)	■
FAA data (1)	■
National and state park attendance database (1)	■
MPO survey data (1)	■
Borrowed data from another model (1)	■
Borrowed parameters from another model (1)	■
Own long distance survey (1)	■
Own household survey (1)	■
Seasonal traffic counts (1)	■

FREIGHT COMPONENTS

Freight components of statewide models do more than simply complement passenger components, as is typical for urban models. Indeed, the driving forces behind statewide model development in many states are economic development issues that cannot be fully analyzed without a good freight component. In addition, freight is more easily analyzed statewide than for urban areas because the scale of the geography is more compatible with available freight data sources. Thus, freight components for statewide modeling have evolved to a level of sophistication well beyond what is seen within MPO models. Freight components sometimes include commercial vehicles that are not carrying a commodity.

The following discussion includes Montana's freight component that is part of HEAT. HEAT is primarily a tool for economic forecasting, but contains a commodity-based truck model.

Nature of Freight Components

There are two fundamentally different styles of freight forecasting: (1) direct forecast of vehicle flows without reference to commodities or (2) forecasting of commodities, then using the commodity flow forecast to estimate vehicle flows. Of the 16 states reporting freight components as a part of their statewide travel forecasting model, 12 base their forecasts on commodities. Although they are much more complex, commodity-based models have a greater sensitivity to economic conditions and to state policies toward industrial development.

Commodity flows are derived from data sources in either tons or dollars. Finding the effects of freight on the transportation system requires that commodity flows be converted to trucks, rail cars, shiploads, aircraft, barges, or containers.

The correct conversion requires knowledge of how much of a commodity is carried by a particular vehicle. These payload factors (tons per vehicle) can be obtained from several sources, as listed here.

- VIUS (Florida, Georgia, Michigan, Montana, Ohio, Wisconsin (6) ■■■■■■
- Commercial freight data vendor (Kentucky, Louisiana, Tennessee, Texas) (4) ■■■■
- Rail Carload Waybill Sample (Georgia, Indiana, Ohio) (3) ■■■
- Data from another state or from an MPO (Kentucky, Virginia) (2) ■■
- Truck intercept studies (Georgia) (1) ■

VIUS pertains only to trucks, and the Rail Carload Waybill Sample only to railroads. However, the Rail Carload Waybill Sample can provide estimates of the density of commodities, which can then be applied to other modes.

Some freight components are closely tied to models of economic activity (e.g., Ohio's new model and Oregon's model) that account for commodity flows in units of dollars. To forecast vehicular flows there is an additional need for a conversion between dollars and tons. Two states, Georgia and Indiana, reported that their principal source of data on dollars per ton is the CFS.

Many sources of freight data give commodity flows as yearly totals. For single-day forecasts (or peak periods with a single day) it is necessary to determine the fraction of yearly commodities transported in a day. This fraction can be obtained implicitly through OD table estimation techniques or explicitly by calculating the number of truck days in a year. The number of truck days ranges from 261 in Kentucky to 365 in Texas and Virginia.

The distribution of commodities from zone to zone is handled by three methods, alone or in combination: (1) Fratar factoring a vehicle or commodity OD table that was created from data, (2) a gravity expression, or (3) a logit expression. Most states use a gravity expression. The new models in Ohio and Oregon, because of their economic activity and land use underpinnings, use logit expressions.

Five states (Indiana, Louisiana, Ohio, Tennessee, and Virginia) reported using techniques of OD table estimation from ground counts for improving their truck forecasts; however, Indiana used OD table estimation only for non-freight truck traffic and Ohio will be abandoning these techniques when its new model is completed.

Four states (Florida, Indiana, Michigan, and Vermont) reported using "quick response" methods, such as the ones from the *Quick Response Freight Manual,* to supplement their freight forecasts. For example, Florida used these techniques only for non-freight truck trips.

If a model is commodity-based, it is likely that states would need data on commodity flows for calibrating their trip generation and distribution steps. Slightly more then half of the states with freight components purchased the TRANSEARCH database from Reebie to understand commodity flows. Three states were able to use the CFS instead. Oregon performed its own shipper and carrier survey.

None of the major sources of commodity flows are complete. Some states have adopted different methods of dealing with missing commodities or industrial sectors and empty trucks, but the main objective is to adjust for the error by comparing assignment results to truck counts. Indiana, Louisiana, and Virginia use OD table estimation from traffic counts to bridge the missing commodities and account for empties. Florida ignores the missing categories and Kentucky lumps all the missing categories into one catch-all commodity group. Ohio did its own establishment survey, which included all commercial vehicle movements, not just freight shipments.

Freight components that are commodity-based usually require that commodity production totals be estimated for each commodity category for each zone. Almost all states with this requirement derived commodity productions from employment estimates and commodity output per employee. Kentucky obtained its production totals directly from Reebie.

Similarly, freight components that are commodity-based usually require that commodity consumption totals be estimated for each commodity category for each zone. Estimating consumption is more difficult that estimating production, because (1) the commodities consumed by an industry are not obvious by looking at the nature of the industry and (2) households consume a large fraction of the commodities. One method of understanding commodity consumption is IO analysis (as suggested in *NCHRP Report 260*); however, only Michigan, Montana, Ohio, Oregon, and Vermont use IO. All states (except Kentucky) with a need to estimate commodity consumption by zone do it through employment estimates along with consumption per employee or through household estimates and commodity consumption per household.

Commodity flow databases are often reported for fairly large spatial units such as counties or states. There is a need in some states to expand the flow matrices to cover much smaller spatial units. Half of the states with freight components created procedures for disaggregating their commodity flows. The method most often cited by states was to factor county-to-county flows into zone-to-zone flows using employment categories and population totals.

Commodity flows must be divided among modes. Only Florida, Ohio, and Oregon reported using mode split expressions (such as logit) to allocate commodities to modes. The remaining states use fixed shares from data. Indiana varies these shares by the distance of the shipment, which is facilitated by the way data are reported from the CFS. A model with fixed shares does not necessarily mean that the proportion of tonnage carried by each mode remains constant. Total mode shares can shift as commodity production and consumption patterns change in the future. However, fixed-share models are insensitive to changes in shipping costs that may give an advantage to one mode over another.

A few commodity-based components further calculate the fraction of commodities carried by each truck type. All states reported using fixed shares, derived from the CFS, Reebie's TRANSEARCH database, expert judgment, or the VIUS.

Traffic assignments usually involve the mixing of passenger and freight traffic. States have adopted two methods of assigning a mix of traffic: (1) preloading trucks onto highway links, and then performing a passenger car assignment or (2) loading trucks and passenger cars together. Preloading is often done with an all-or-nothing traffic assignment. When trucks and passenger cars are assigned together, a static user-optimal equilibrium traffic assignment is preferred. The decision between the two methods (preloading or together) revolves around the question of whether truck routing is heavily influenced by traffic congestion, which is essentially ignored in an all-or-nothing assignment. When trucks are assigned together with passenger cars, a multiclass traffic assignment algorithm is required to account for the mix of vehicles on each link and to ensure that trucks are assigned only to legal routes. Because trucks have a greater impact on congestion than passenger cars, it is further necessary to weight truck volumes by a passenger-car-equivalent factor when calculating delays from a multiclass traffic assignment. For example, Louisiana derived a statewide average factor of 1.83 from the *Highway Capacity Manual*, a value that is appropriate for the terrain in that state.

Only two states (Ohio and Wisconsin) explicitly handled transshipment of commodities.

Four states used FHWA's FAF for network development. A majority of states obtained network information from a GIS and used GIS for freight network storage.

Freight Component Level of Detail

Freight components can be either multimodal or concentrate on a single mode. No state reported concentrating on a single mode other than trucks, even though numerous railroad-only models have been described in the literature. Cited here are the modes reported as forecasted by statewide models. None of the models dealt directly with truck–rail intermodal, or indeed, any other intermodal pairings. Models also ignored categories of trucks that would be related to the economic structure of the trucking industry, such as a for-hire truck or a private truck.

Truck, general (15)	■■■■■■■■■■■■■■■
Rail freight (5)	■■■■■
Air freight (5)	■■■■■
Deep water shipping (4)	■■■■
Inland water shipping (3)	■■■
Less than truckload and truckload (1)	■

Florida, Ohio, and Wisconsin reported having all five of these major modes. All states with freight components have at least a truck network or a passenger network that has been modified for trucks. Ohio and Texas have networks for other modes besides trucks. Almost all states worked with all trucks together or just worked with heavy trucks. Michigan and Ohio divided trucks into heavy, medium, and light categories, similar to the categories in the *Quick Response Freight Manual*. Montana's HEAT divided trucks between truckload and less-than-truckload.

All statewide models with a freight component do a 24-h truck forecast. Five states also reported the ability to do a peak-period truck forecast.

It is desirable, but not necessary, that the in-state zone system for a freight forecast correspond to the zone system for a passenger forecast. All states reported consistent zone systems except Texas, which has a coarser zone system for freight. Kentucky, Ohio, and Virginia use subzones or grid cells to increase the spatial detail where necessary. Because of the ready availability of freight OD data for the whole United States, a majority of statewide freight components cover most or all of the continental United States rather than relying on external stations at the state borders. Half of the statewide freight components cover parts of either Canada or Mexico.

The following is a list of the ways in which zones are defined for out-of-state portions of the freight component. None of the states chose to use national transportation analysis regions. Some models used multiple sources of zones, depending on how far the area is from the state border.

Counties or aggregations of counties (6)	■■■■■■
BEA regions or aggregations of BEA regions (6)	■■■■■■
States or aggregations of states (6)	■■■■■■
TAZs (2)	■■
External stations (1)	■
Multistate regions (1)	■

Freight components use special generators sparingly, and most models do not have any. New Jersey has the most with 200. Special generators include rail yards, airports, seaports, truck terminals, warehouses or distribution centers, pipeline terminals, and regional shopping malls.

All truck networks have links that are coded to the same highway functional classes as passenger car networks. A state's truck network has about the same number of links as its passenger car networks.

Those freight components that use commodities have many commodity categories. Vermont has the fewest categories at 6 and Ohio has the largest number of categories at 32. There is a cluster of four states (Kentucky, Michigan, Virginia and Wisconsin) using between 25 and 28 categories.

LAND USE AND ECONOMIC ACTIVITY

A number of states formally consider economic activity as either an input to their forecasts or as a post-processor of model outputs. Ohio's new model and Oregon's model have land use and economic activity calculations that are tightly interwoven with the rest of their components. Chapter three includes a discussion of Ohio's model. Indiana and Maine specifically mentioned using a commercial regional economic forecasting model. Montana's HEAT is an economic model with a freight component. A few other states indicated that they are considering using a regional economic forecasting model to post-process the results of their statewide travel forecasts.

STATEWIDE AND URBAN MODEL INTEGRATION

Good linkages between statewide and urban models are desirable, but not necessary. Rhode Island is a special case, because its statewide model is an MPO model; therefore, there is no need to integrate. Here are some integration activities and the number of states participating in each.

- Statewide model provides independent estimates of traffic in areas covered by urban models (13) ■■■■■■■■■■■■■
- Statewide model is used to develop external station forecasts for the urban models (13) ■■■■■■■■■■■■■
- Statewide and urban models share geographic systems such as zones or networks (10) ■■■■■■■■■■
- Statewide and MPO models use similar computational steps, trip purposes, base-year, or modes to promote compatibility (7) ■■■■■■■
- Statewide model shares GIS databases with MPO models (6) ■■■■■■
- Urban models incorporated as part of the statewide model (6) ■■■■■■
- Institutional issues regarding the statewide model provide forecasts that might conflict with MPO models (3) ■■■
- Statewide model provides impedances for use in the MPO models (1) ■

Most statewide models are coarser than MPO models within urban areas; therefore, the relative validity of the statewide versus urban models is obvious. Seven states commented that although their statewide model can produce forecasts for urban areas, they defer to MPO model results if a conflict arises. As a condition for Wisconsin gaining the MPOs' cooperation in building its model, the state needed to ensure their two largest MPOs that the statewide model would not be used for urban forecasts. Except for Rhode Island, where an MPO model is available, statewide models are not used directly for urban forecasts. Integration efforts thus far have been heavily influenced by the need to share data and to provide external station forecasts for MPO models.

VALIDATION

All statewide models have been validated or are undergoing validation. The following is a list of the types of data used during validation.

- Passenger vehicle counts (24) ■■■■■■■■■■■■■■■■■■■■■■■■
- Truck counts (15) ■■■■■■■■■■■■■■■
- Comparisons to national default trip generation values (11) ■■■■■■■■■■■
- Commuting OD flows from CTPP (11) ■■■■■■■■■■■
- Comparisons to average values (or other statistics) from own travel surveys (8) ■■■■■■■■
- Known trip length frequency distribution(s) (8) ■■■■■■■■
- Comparisons to average values from similar states or cities (7) ■■■■■■■
- MPO models (5) ■■■■■
- Counts of passengers on buses (3) ■■■
- Counts of passengers on trains (3) ■■■
- MPO OD studies (2) ■■
- Goods production by sector or zone (1) ■
- Data from cordon surveys (1) ■
- HPMS VMT estimates (1) ■

States tended to use a variety of data sources for validation. All states already involved in validating their models used passenger car volumes. Most states also used truck counts.

Criteria for validation of statewide models closely follow those found in urban models. Each state chose to use a variety of measures.

- VMT by functional class absolute deviation (18) ■■■■■■■■■■■■■■■■■■
- Link root mean-square error (RMSE) by volume strata (17) ■■■■■■■■■■■■■■■■■
- Screenline count absolute deviation (17) ■■■■■■■■■■■■■■■■■
- Link absolute deviation (12) ■■■■■■■■■■■■
- Cordon count absolute deviation (10) ■■■■■■■■■■
- Correlation coefficient between link volume forecasts and counts (8) ■■■■■■■■

Link-by-link comparisons (1) ■
Other (1) ■

Only nine states reported using the *Model Validation and Reasonableness Checking Manual* (Barton–Aschman Associates, Inc. and Cambridge Systematics, Inc. 1997).

Most states did not provide a qualitative assessment of how well their models validated. A few states gave vague responses, such as "well," "acceptable," and "fair." Texas reported good comparisons between its freight component and flows from Reebie's database. California stated that 44% of the links meet the "maximum desirable deviation" standard and an *R*-square of 0.83 between link counts and base case link volumes. Michigan reported that 80% of links in major corridors were within the "standard." Louisiana provided a "maximum desirable deviation" chart showing 95% of links meeting the standard. Only two states used OD table estimation from traffic counts, which would tend to arbitrarily improve the match between observed and forecasted volumes before validation.

Because of the larger scales of statewide models, there is an expectation that the accuracy of these models would be less than urban models. Approximately half of the states applied the same validation standards to statewide models as urban models. The other half used less stringent standards for their statewide models. Louisiana explained that because most of their links in the statewide model were low volume, it was possible to meet the looser criteria for urban roads of similar volumes.

Oregon's model, having an unusual structure, also had unusual validation criteria.

> Research of current practices surprisingly found no existing clearly defined model calibration or validation criteria for integrated land use–transportation modeling. The modeling team and Peer Review Panel together developed several criteria for assessing model performance for the Gen1 Model:
>
> - Match production by sector and zone.
> - Match number of trips and average trip distances by trip purpose.
> - Minimize zone-specific constants by sector.
> - Network flows to match counts by mode of transportation, with emphasis on interurban routes.
> - Match increments of land to changes in land price.
> - Match CTPP distribution for commuting flows.
>
> Each criterion has a specific numeric target. The network flows, for example, must fall within specified ranges based on total observed volume. Some targets are more liberal than for traditional urban travel models, owing to the complexity of the integrated models and their coarser geographic detail.
>
> Several subjective performance tests were also developed. Each required the model to produce sensible and reasonable results. Additional criteria for which specific numeric targets could not be defined include:
>
> - Destination and route choice response behavior.
> - Trip generation sensitivities.
> - Path and transportation cost testing.

POST-PROCESSING

Post-processing of model results is sometimes needed to obtain information that is compatible with decision processes on alternatives or policies. The need for post-processors depends on the already built-in capabilities of the state's travel forecasting software package. States reported some post-processing for air pollution emissions, benefits evaluation, level of service determination, and economic impacts.

Air pollution emissions (9) ■■■■■■■■■
Level of service determination (7) ■■■■■■■
Benefit–cost analysis (3) ■■■
Economic impact (2) ■■
Factoring volume-to-capacity ratios (1) ■
Validation and model performance statistics (1) ■

Indiana and Michigan use the same post-processor for economic impact, which is a commercial regional economic analysis package. Indiana assesses project benefits with Highway Economic Requirements System and in-house software, whereas Michigan uses a benefits module developed by a local university. Virginia reported the need to adjust volume-to-capacity ratios downward to account for the unusually sparse networks with urban areas.

CHAPTER THREE

CASE STUDIES

This chapter presents five case studies of statewide models. The case studies emphasize the differences between statewide and urban models. Two case studies, Kentucky and Indiana, focus on the passenger component and two other case studies, Virginia and Wisconsin, focus on the freight component. The fifth case study, Ohio, presents a comprehensive framework for dealing with both passenger travel and freight while accounting for changing locations of economic activity. These particular case study states were selected because their models integrate a number of features described in chapter two, and they do not duplicate material found in the report from NCHRP Project 8-43.

CASE STUDY 1: KENTUCKY PASSENGER COMPONENT

Kentucky has had one of the longest involvements with statewide travel forecasting, starting in 1971. The Kentucky statewide model (KYSTM) has just recently been updated (a previous version was summarized in the *Guidebook*). Kentucky's model has always had a goal of being efficient in its expenditure of resources, achieving a very useful model on a small budget by piggybacking on data obtained from existing sources. The only data collection specifically for the model was the purchase of additional NHTS samples. The model also has a truck component. Kentucky's model is presented here as an example for states with modest forecasting needs and states now considering models for the first time or that are in the process of reactivating a dormant model.

The model is well integrated with agency decision making. "The main purposes of this model are to support highway planning and investment decisions, to permit a consistent methodology in project evaluations, and to allow testing alternative land use strategies." Previous versions of the model have been used for corridor planning, project-level traffic forecasts, regional planning and weigh station location. A stakeholder meeting was held early in the process to ensure that the model development met agency needs. The revision took approximately 2 years and cost about $370,000.

The overall structure of the passenger component consists of three steps: trip generation, trip distribution, and traffic assignment. Only highway vehicles are assigned to a network; therefore, a mode split step is not necessary. The application of the KYSTM's steps is similar to traditional urban models, except that there are three additional trip purposes to account for long distance travel.

The KYSTM highway network is very large, spanning all of the contiguous 48 states. The network, as shown in Figure 6, is focused on the state, with considerable detail extending approximately halfway into its neighboring states. This network has more than 77,000 links, more than 3,600 zones within the state, and more than 1,100 zones outside the state. Figures 7 and 8 illustrate the Kentucky zone system. The expansive nature of the network has allowed analysis of diversion from out-of-state highways.

Kentucky Statewide Passenger Component Summary
State population: 4.1 million
State area: 40,411 square miles
Gross state product: $129 billion
No. of internal zones: 3,644
External zone structure: Halo + BEA regions
Internal zone structure: TAZs, aggregations of TAZs
No. of external zones: 1,109
No. of links: 77,272
Passenger modes: Automobile
Trip purposes:
- Home-based work
- Home-based nonwork
- Nonhome-based
- Long distance business
- Long distance—Recreation/vacation
- Long distance—Other

Special generators: Military bases
Trip productions: Rates per household based on MSA size, area type
Trip attractions: Rates per level of activity
Trip distribution: Gravity expression, Fratar
Mode split: None
Assignment: Static equilibrium with subzones
Delay estimation: BPR curves
Major data: NHTS, HPMS, ATS, vendors
Time frame: Two years of development time
Computation time: 1 h
In-house staff: 1 FTE

The zone structure was built for compatibility with other databases. It is readily seen that zones well outside of Kentucky are based on BEA Economic Areas. Zones within Kentucky were created as part of census TAZ-UP participation. A level

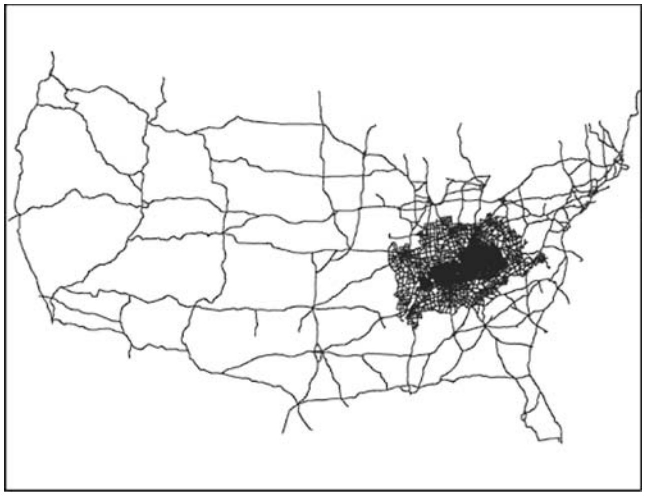

FIGURE 6 Kentucky's highway network. (*Source*: Wilbur Smith Associates 2005a.)

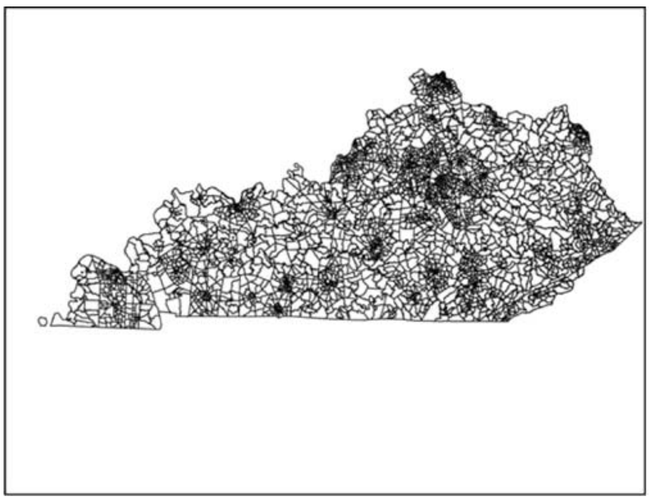

FIGURE 7 Kentucky's zone system, in state. (*Source*: Kentucky response to Peer Exchange questionnaire 2004.)

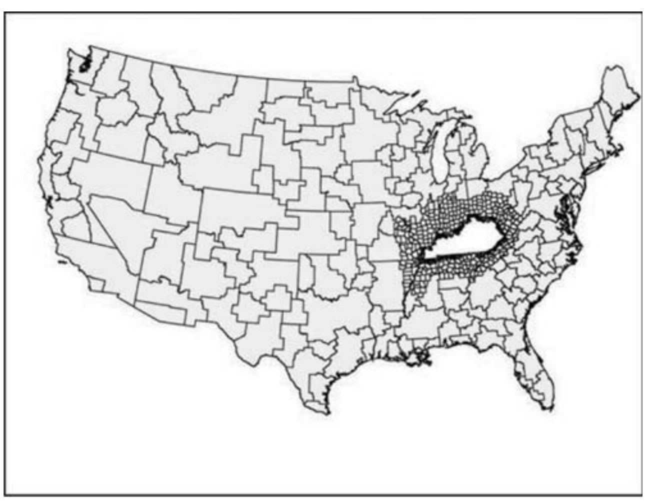

FIGURE 8 Kentucky's zone system, out-of-state. (*Source*: Kentucky response to synthesis questionnaire February 2005.)

of detail was selected so that the model could evaluate projects such as I-66 and I-69 and still be reasonably accurate within urban areas. Zones were custom aggregated from census TAZs in dense urban areas; however, census TAZs were adopted in fringe urban areas. TAZs in 72 rural counties were built from census block groups or census places. The halo of zones around Kentucky was represented by 660 census tracts and 296 counties.

The model was built from secondary data. Data sources included workplace employment data from Woods & Poole, D&B, and Claritas. Trip rate information was derived from the 2001 NHTS. Because there were only 390 samples in the standard NHTS, Kentucky contracted for an additional 1,154 samples to provide better geographic coverage. Household socioeconomic data were mostly derived from the 2000 Census. The census also provided journey-to-work data. Information on long distance travel came from the 1995 ATS. Network data within Kentucky were obtained from the Kentucky Transportation Cabinet Highway Information System. Network data outside Kentucky were developed from the NHPN for roadway geography and the HPMS for roadway characteristics.

A single trip production rate was applied for any zone for any trip purpose. Trip production rates per household were separately calculated for different MSA sizes and different Claritas area types (rural, town, suburban, second city, and urban), which were included in the NHTS. Trip attraction equations were taken directly from *NCHRP Report 187*, having demographic variables of households, retail employees, and nonretail employees. The NHTS also yielded automobile occupancy rates, one for each short distance purpose. The short distance occupancy rates were similar to those seen within urban areas. Long distance automobile occupancy rates were derived from the ATS, as found on Table 4.

Kentucky adopted a philosophy of using actual OD tables wherever possible. Thus, trip distribution was accomplished with a gravity expression only for home-based nonwork and nonhome-based purposes. Friction factors were chosen to match the trip length frequency distributions from the national and Kentucky NHTS. For home-based work, a zone-to-zone production-to-attraction table from the 2000 Census journey-to-work data was Fratar factored. Fratar factored trip tables from the ATS were used for long distance trip purposes. Table 5 shows how each long distance trip purpose

TABLE 4
LONG DISTANCE AUTOMOBILE OCCUPANCY RATES

Long Distance Trip Purpose	National Sample	Kentucky Sample
Business	1.82	1.80
Tourist	3.23	3.31
Other	2.48	2.43

Source: 1995 ATS.

TABLE 5
METHOD OF FRATAR FACTORING LONG DISTANCE OD TABLES

Long Distance Trip Purpose	Production	Attraction	Balance To
Business	Household	Total employment	Production
Tourist	Household	Retail/service employment	Production
Other	Household	Households and total employment	Production

was handled. OD data from the ATS were available only for county-to-county trips. The OD table was expanded to TAZs by apportioning the trips by zonal households, zonal employment, or both depending on the trip purpose and trip end.

Traffic assignment was accomplished with a static user-equilibrium technique, with trucks preloaded to the network and weighted by passenger car equivalent factors that depended on terrain. Delay came from BPR curves as a function of free flow speed and capacity. Free flow speeds were drawn from a table, and these speeds varied by functional classification, terrain type, number of lanes, and posted speed limit. Capacity per lane was determined from number of lanes, terrain, and functional class. Forecasts can be made for a full day or for shorter periods within a day.

It is well known that large zones can lead to lumpy traffic assignments. Kentucky's traffic assignment method divided TAZs into smaller subzones in order to improve the smoothness of the results. Subzones were built around highway routes within zones with the number of trips allocated to a subzone being in proportion to the mileage of each route. For some trip purposes the mileage was weighted such that routes of higher functional classes got more trips.

Validation results were not available at the time of this writing. Sources for this case study were: Kentucky response to Peer Exchange questionnaire (2004), Kentucky response to Synthesis questionnaire (Feb. 2005), and Wilbur Smith Associates (2005a).

CASE STUDY 2: INDIANA PASSENGER COMPONENT

The Indiana Statewide Travel Demand Model (ISTDM) (Bernardin, Lochmueller & Associates, Inc. and Cambridge Systematics, Inc. 2004) was developed principally to assist corridor-level economic development studies. ISTDM was recently expanded from a more localized model for the 26-county I-69 study area in southwestern Indiana. The local network was broadened to include the entire state, the TAZ structure was refined, traffic signals were integrated into the network, and new procedures for estimating free-flow speed and roadway capacities were developed. The model structure for the passenger component was similar to that of a four-step UTP model.

<u>Indiana Statewide Passenger Component Summary</u>
State population: 6.2 million
State area: 36,420 square miles
Gross state product: $214 billion
No. of zones: 4,720
External zone structure: Halo
Internal zone structure: TAZs
No. of links: 34,500
No. of signals: 3,900
Travel modes: Automobile, truck, intercity bus/rail
Trip purposes:
- Home-based work
- Home-based nonwork
- Nonhome-based
- Long trip

Trip productions: Rates per household based on household size, automobile ownership, and area type
Trip attractions: Rates per employment categories and households
Trip distribution: Gravity expression
Mode split: Fixed shares for short trip purposes Multinomial logit for long trip purpose
Assignment: Static equilibrium with feedback to distribution
Delay estimation: BPR travel time volume curves
Truck models: Commodity based for freight trucks; empirical for non-freight trucks
Major data: Census, NHTS, CTPP, own surveys
Time frame: Seven years of continuous improvement following 3 years of initial development
Computation time: 2 h
In-house staff: 0.5 FTE

The ISTDM covers all 92 counties in Indiana and parts of adjacent states. A detailed network was developed for areas within the state of Indiana, including all state jurisdictional highways (more than 19,500 links) and additional local streets (more than 11,500 links). A less detailed network was used for areas outside Indiana, as shown in Figure 9. Data from INDOT's updated Road Inventory Data (RID 2000) were incorporated into the network including number of lanes, shoulders, medians, access control types, traffic and truck count data, and functional classifications.

A total of 4,720 TAZs were created with external stations representing the areas in neighboring states (Figure 10). The TAZ structure was developed to generally conform to the roadway network and previously developed TAZs from the CTPP. New zones were created by subdividing CTPP zones. More than 10,000 centroid connectors (a maximum of three per zone) were added to the network using a fully automated process.

FIGURE 9 Indiana Statewide Travel Demand Model network.

Traffic signals in the entire state were located on the network. Signal information integrated to the network includes signal location, approach priority, and number of upstream signals. Almost 3,900 traffic signals were located on the network. INDOT's traffic signal data from 1997 was used to locate state jurisdictional highway signals (gray dots in Figure 11), and the INDOT's crash database for 1997 through 1999 was used to locate signals on local streets (black dots in Figure 11). Therefore, signals on local roads without a crash were missing from the ISTDM network.

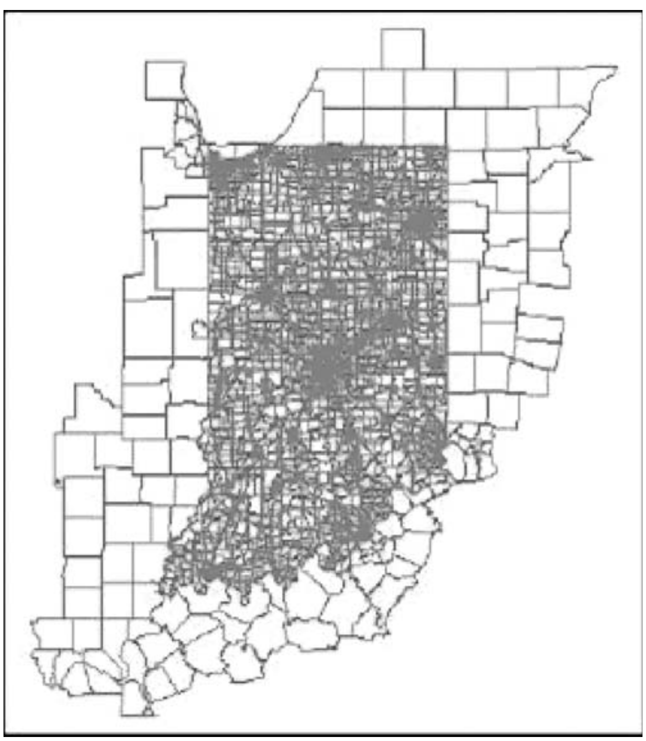

FIGURE 10 Indiana Statewide Travel Demand Model ISTDM TAZ structure.

A new procedure was developed to estimate free-flow speed based on detailed geometric features and functional types of the roadway. The data were obtained from the RID 2000 and the original I-69 speed survey database. Nonlinear regression analysis was conducted to define free-flow speed based on posted speed for each unique facility type (number of lanes, divided/undivided, area type, and access control type). Figure 12 gives the formulas developed for major facility types.

Highway Capacity Manual 2000 (*HCM 2000*) procedures were followed to calculate speed reduction factors based on the limiting factors from *HCM 2000*. The speed reduction factors were applied to estimate peak-hour roadway capacities. Daily capacities were then obtained by factoring the hourly capacities with the inverse of time-of-day factors (i.e., the percentages of daily traffic in the peak hour). Figure 13 gives an example of curve-fitted capacity adjustment factors for lateral clearance. A similar procedure was used for all capacity-reduction factors.

FIGURE 11 Traffic signals in Indiana Statewide Travel Demand Model network.

Area Type	Free-Flow Speed[1,2]	Condition	Note
2-lane 2-way undivided highways			
Rural	$0.009751 \cdot PSPD^2 + 30.03397$	$25 \le PSPD \le 55$	No or Partial Access Control
	25	$PSPD < 25$	
Suburban	$117.640917 \cdot PSPD^{0.0015+0.001279 \cdot PSPD} - 98.065483$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
Urban	$6.189 + 0.9437 \cdot PSPD$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
2-lane 2-way divided highways			
Rural	$(0.000017 \cdot (PSPD - 72.323105)^2 + 0.019702)^{-1} + 19.835323$	$25 \le PSPD \le 55$	No Access Control
	25	$PSPD < 25$	
Suburban	$3.180682 \cdot PSPD^{0.857638} - 84.105587 \cdot e^{-41.803252 / PSPD}$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
Urban	$(0.119687 - 0.023365 \cdot \ln(PSPD))^{-1} + 0.373821 \cdot PSPD$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
Multilane undivided highways			
Rural	$(0.000017 \cdot (PSPD - 72.323105)^2 + 0.019702)^{-1} + 19.835323$	$25 \le PSPD \le 65$	
	25	$PSPD < 25$	
Suburban	$3.180682 \cdot PSPD^{0.857638} - 84.105587 \cdot e^{-41.803252 / PSPD}$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
Urban	$(0.119687 - 0.023365 \cdot \ln(PSPD))^{-1} + 0.373821 \cdot PSPD$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
Multilane divided highways			
Rural	$2.836165 \cdot PSPD - 0.071256 \cdot PSPD^2 + 0.000744 \cdot PSPD^3$	$25 \le PSPD \le 50$	No or Partial Access Control
	$16.0359 + 0.8223 \cdot PSPD$	$50 \le PSPD \le 65$	
	25	$PSPD < 25$	
Suburban	$(0.000071 \cdot (PSPD - 64.166165)^2 + 0.035258)^{-1} + 9.061039 \cdot \ln(PSPD)$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
Urban	$(0.081714 - 0.016217 \cdot \ln(PSPD))^{-1}$	$25 \le PSPD \le 55$	
	25	$PSPD < 25$	
Full acess controlled highways			
	64.00	$PSPD = 55$	
	67.06	$PSPD = 60$	
	70.21	$PSPD = 65$	
	73.30	$PSPD = 70$	

Note: [1] Free-flow speeds in mph. [2] PSPD: Posted speeds in mph

FIGURE 12 Estimation formulas for free-flow speed.

Subsequently, the free-flow speed and roadway capacities were adjusted to account for signal delays by a process that first estimates control delays, d, at signals using a simplified version of the *HCM 2000* uniform delay term:

$$d = \frac{C}{2}\left(1 - \frac{g}{C}\right)^2 * PF$$

where C is the cycle length, g is the green time, and PF is the progression factor. The delay is then used in an empirical formula to create capacity-reduction factors for links with signals.

ISTDM trip generation models were developed for four trip purposes (home-based work, home-based other, non-home-based, and long purpose) and for three area types (urban, suburban, and rural). Cross classification of household size and automobile ownership was used for trip production estimation. Trip attractions were related to employment categories and number of households. Attraction trip rates as derived from linear regression are shown in Table 6. Year 2000 Census household data, the 1995 Indiana Travel Survey, and 2001 NHTS data were used for model development. The Corridor 18 Model dataset was adopted for external long purpose trips. Stratification curves were developed to breakout the households into categorical groupings to apply the cross-classification trip rates. The curves were calibrated using the CTPP TAZ level data. Figure 14 presents an example of the stratification curves.

Gravity expressions were used for ISTDM trip distribution. The friction factors were calibrated by trip purposes using the 1995 Indiana Household Survey and the 2001–2

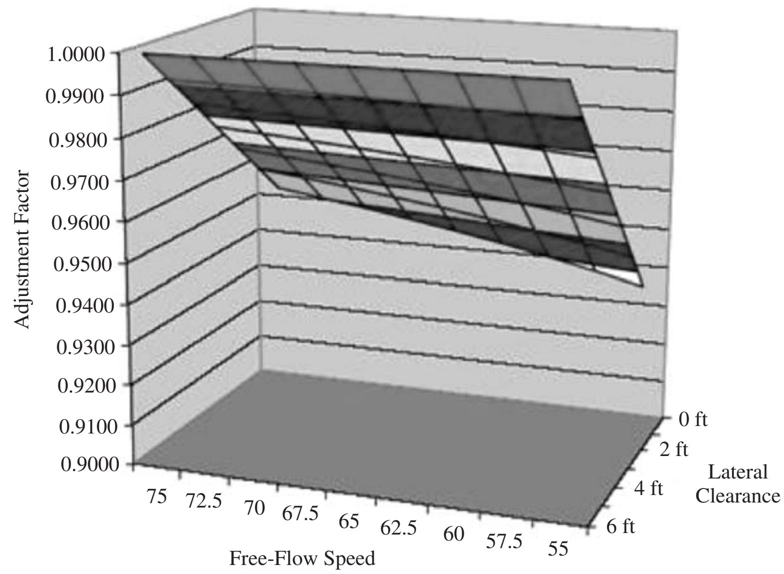

FIGURE 13 Capacity-reduction factors for lateral clearance for two-lane freeways.

NHTS dataset (see Figures 15 and 16). Socioeconomic adjustment factors (*k*-factors) were also validated to adjust trip distributions not explained by friction factors. ISTDM implemented a single feedback loop of congested times to the gravity expressions.

Fixed-mode shares for home-based work, home-based other, and nonhome-based trips by area types (urban, suburban, and rural) were calculated from the 1995 Indiana Household Survey and the 2001 NHTS data. Automobile occupancy rates were also obtained from the 1995 survey. For the long trip purpose, a multinomial logit expression was adapted from the California High Speed Rail Study Model and then recalibrated for the ISTDM for a division of trips between automobile and intercity bus/rail hybrid. Table 7 shows the calibrated model parameters.

"Freight and non-freight trucks were estimated separately. For freight trucks, base year 1993 truck trip tables from the Indiana University study were factored up to year 2000 levels by commodity group." Non-freight truck trip tables were estimated from truck ground counts after first removing freight trucks.

The ISTDM used a multiclass assignment approach for traffic assignment, with truck trips and automobile trips loaded to the network at the same time. Two trip tables were developed for truck trips: freight truck trips and non-freight truck trips. The traffic assignment procedure was run twice by including a feedback loop to trip distribution so that the gravity expression could use travel times based on the initially assigned roadway volumes. BPR travel time and volume curves were specified by functional classification.

TABLE 6
TRIP ATTRACTION RATES BY TRIP PURPOSE

Trip Purpose	Demographic Category	Rate
Home-Based Work	Employment in retail, FIRE, education, services, and government sectors	1.400
	Employment in non-retail; construction; manufacturing; agriculture, forestry, and fisheries; and transportation sectors	1.120
Home-Based Other	Employment in retail sector	4.850
	Employment in FIRE, education, services, and retail sectors	3.200
	Employment in education sector	1.750
	Households	1.650
Nonhome-Based	Employment in retail sector	4.490
	Employment in FIRE, education, services, and government sectors	1.130
	Employment in non-retail, construction, manufacturing, and transportation sectors	0.380
	Households	0.590
Long	Total employment	0.023
	Employment in FIRE, education, services, and government sectors	0.090
	Employment in agriculture, forestry, and fisheries; mining; construction; manufacturing; non-retail; and FIRE sectors	0.030
	Employment in retail and services sectors	0.020

Notes: FIRE = finance, insurance, and real estate

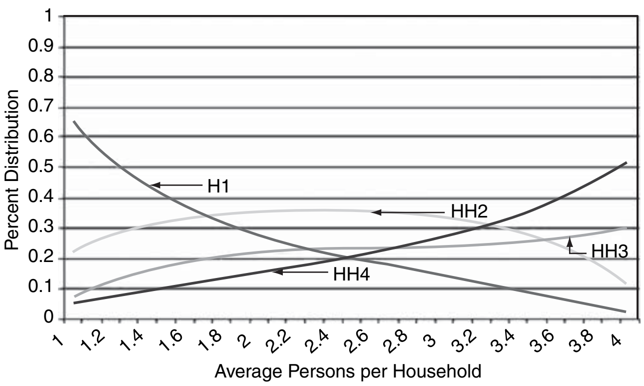

FIGURE 14 Household size stratification curves. (*Source*: Bernardin, Lochmueller & Associates, Inc. and Cambridge Systematics, Inc., 2004 and Indiana response to Peer Exchange questionnaire, Longboat Key, Florida, September 2004.) H1 = one-person household; HH2 = two-person household; HH3 = three-person household; HH4 = four-person household.

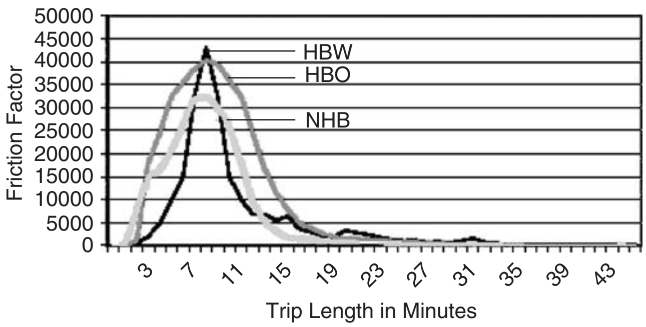

FIGURE 15 Short trip friction factors. (*Source*: Indiana response to synthesis questionnaire February 2005.) HBW = home-based work; HBO = home-based other; NHB = nonhome-based.

TABLE 7
REVALIDATED MULTINOMIAL LOGIT EXPRESSION PARAMETERS (long trip purpose)

Variable	Original Values	Adjusted Values
Cost ($)	–0.0276	–0.0276
IVTT—Line Haul Travel Time (min)	–0.0069	–0.0069
OVTT—Access/Egress Time (min)	–0.0083	–0.0083
Bias Constant	–0.87	–1.15

The ISTDM model was validated by comparing the base year observed daily traffic counts to the model estimates. Statistics used for validation included: percent RMSE, systemwide average error, mean loading errors, and total VMT errors. Once possible sources of model errors were identified, the components were revaluated and corrected. Adaptations included modifying trip production rates, adjusting friction factors or *k*-factors in the gravity expression, adjusting volume–delay functions, and modifying centroid connectors.

Overall, the ISTDM shows base–case forecasted volume as being close to actual volumes, as shown in Figure 17. The RMSEs in Figure 17 are similar to what might be seen in an urban model. The systemwide RMSE is 39.45%.

The ISTDM also includes a post-processor that uses the output of the travel model to estimate speeds, levels of service, crashes, and other measures of effectiveness.

The ISTDM paid particular attention to its socioeconomic forecasts, which underlie the traffic forecasts. Zonal population forecasts were developed by first establishing county control totals and then distributing the totals to TAZs using an accessibility-based regression model. Historical data from Woods & Poole economics forecasts (April 2004), Indiana State Data Center forecasts by county, and the Regional Economics Model, Inc. (REMI) forecast for the state of Indiana were examined to produce county-level population. Independent variables in the regression model included:

- Total population,
- Total households,
- Population density,
- Population under age 17,
- Percent of households with head of household over age 65,
- Household workers,
- Average household income,
- Accessibility to wealth (by place of residence),
- Accessibility to unoccupied housing units,
- Accessibility to schools,
- Accessibility to university enrollment,

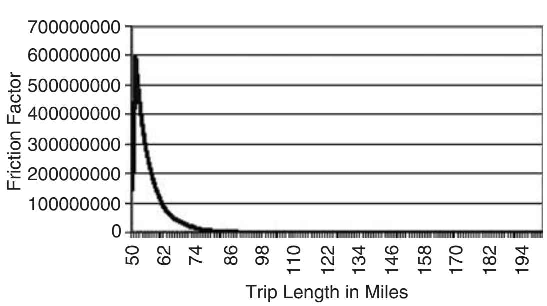

FIGURE 16 Long trip friction factors. (*Source*: HBA Specto Incorporated and Parsons Brinckerhoff Ohio 2005.).

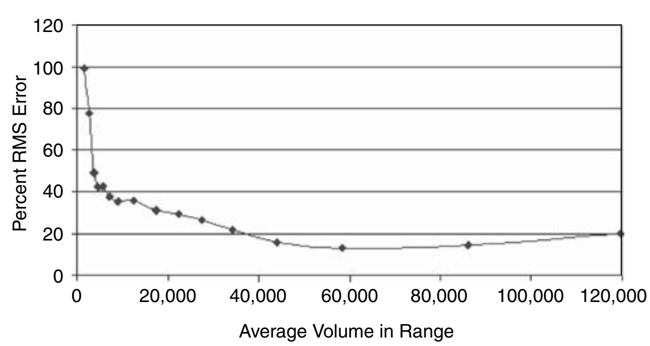

FIGURE 17 Validation accuracy for the Indiana model. (*Source*: Hunt and Abraham 2003.)

- Travel time to nearest city center,
- Travel time to nearest airport, and
- Travel time to nearest major arterial.

The regression model was calibrated by comparing the regression of year 2000 population against 1990 socioeconomic data with actual 2000 data. Then the model was used to produce population changes from year 2000 to 2030 in terms of changes in zonal shares of county totals. "Only half the modeled shift in zonal share of county population predicted by the regression model was applied to bias the final allocation towards the existing distribution of population given the inherent uncertainty in land use forecasting."

The same approach for forecasting population was used to forecast zonal employment. The independent variables included in the accessibility regression model were:

- Total population,
- Total households,
- Population density,
- Aggregate personal income,
- Presence of airport,
- Presence of hospital,
- University enrollment,
- Travel time to nearest city center,
- Travel time to nearest major arterial,
- Travel time to nearest freeway,
- Accessibility to intermodal freight facilities,
- Accessibility to households,
- Accessibility to population,
- Accessibility to university enrollment, and
- Accessibility to wealth (by place of residence).

"Only one-third of the modeled shift in zonal share of county employment predicted by the regression model was applied to bias the final allocation towards the existing distribution of employment given the inherent uncertainty in land use forecasting and the *r*-squared for the regression model."

ISTDM has been used for statewide system planning, corridor planning, bypass studies, economic development studies, air quality analysis, project prioritization, inputs to economic modeling, and long-term investment studies.

Sources for this case study were: Bernardin, Lochmueller & Associates, Inc., and Cambridge Systematics, Inc. (2004), Indiana response to Peer Exchange questionnaire, Longboat Key, Florida (Sep. 2004), and Indiana response to Synthesis questionnaire (Feb. 2005).

CASE STUDY 3: OHIO COMBINED PASSENGER AND FREIGHT COMPONENTS

Both Ohio and Oregon have statewide models that differ significantly from the typical four-step UTP model seen elsewhere. These two statewide models share many similarities, particularly their emphasis on forecasting the spatial distribution of economic activity and land use. The Oregon statewide model was recently described in the draft report for NCHRP Project 8-43. This section will emphasize the economic activity portions of Ohio's model, how the economic activity portions integrate with other components, and the microsimulation of activity-based trip patterns. Both the Ohio and Oregon models have the philosophy that travel is a consequence of human and economic activities; therefore, the spatial organization of the state's economy is first modeled comprehensively and aggregately. Activities result in trip making, which is then modeled in a disaggregated fashion, both in space and in time.

The scope of the Ohio model was decided on after a study of stakeholder needs. The model was designed to address three principal issues: economic development, congestion mitigation, and truck flows.

Ohio deliberately staged its model development by first creating an "interim model," which is currently operational. Of greater interest here is the "advanced" model, which is scheduled to be operational soon. The overall structure of Ohio's model may be seen in Figure 18 as being made up of several submodels. The submodels that seem most unusual in a statewide context are the Land Development submodel and the Activity Allocation submodel. These submodels are similar to aggregate land use models that have been implemented in some metropolitan areas. Because these submodels deal with both household and industry location simultaneously, there is an intrinsic linkage between the passenger and freight components. The other submodels, some nontraditional, replace similar functions of a four-step model or are post-processors.

<u>Ohio Statewide Model Summary</u>
State population: 11.4 million
State area: 44,828 square miles
Gross state product: $403 billion
No. of zones: 5,103
External zone structure: Halo, states
Internal zone structure: TAZs, grid cells
No. of highway links: 250,000
Freight modes: Truck
No. of commodities: 28 categories
No. of industries: 15 categories
Household composition: Microsimulation
Tour formation: Microsimulation
Passenger mode split: Microsimulation
Truck vehicle split: Microsimulation
Assignment: Static equilibrium, multiclass
Delay estimation: BPR curves
Major data: Household and business surveys, TRANSEARCH, CTPP, ES-202, County Business Patterns, assessor land values
Time frame: Eight years of development time
Computation time: Not determined
In-house staff: 1 FTE

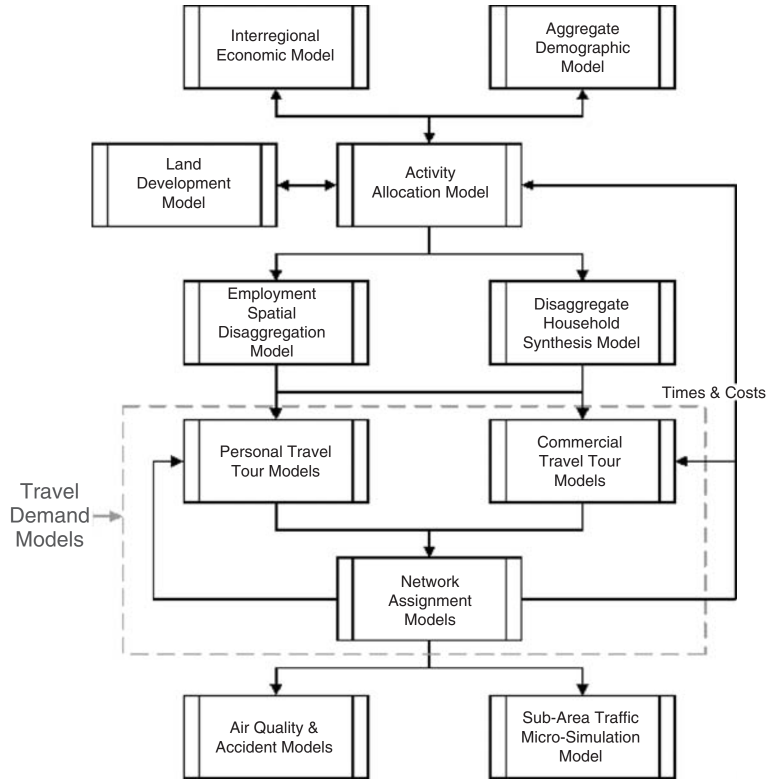

FIGURE 18 Overall structure of Ohio's statewide travel forecasting model. (*Source*: Hunt et al. 2004a.)

To keep computations reasonable, Ohio adopted three nested-zone structures. The economic activity portions of the model use approximately 700 "activity model zones," which are each made up of whole TAZs. The 5,103 TAZs are composed of many grid cells for (1) maintenance of land use and demographic data and (2) disaggregation of traffic assignment. Ohio's grid cells are also used for providing locations of origins and destinations for those steps that microsimulate freight and person travel. Small TAZs cover all of Ohio and a halo of approximately 50 mi into surrounding states. Larger zones extend to the rest of the 48 contiguous states. Ohio's TAZs are shown in Figure 19 and the network within Ohio is shown in Figure 20.

An extensive data collection effort was needed to support the goals of the model. The major data sources were:

- Household travel surveys,
- Household long distance travel survey,
- GPS-based travel survey,
- Business establishment survey,
- National Transport Networks,
- Ohio DOT Roadway Information Database,
- U.S. Census,
- ES-202,
- TRANSEARCH,

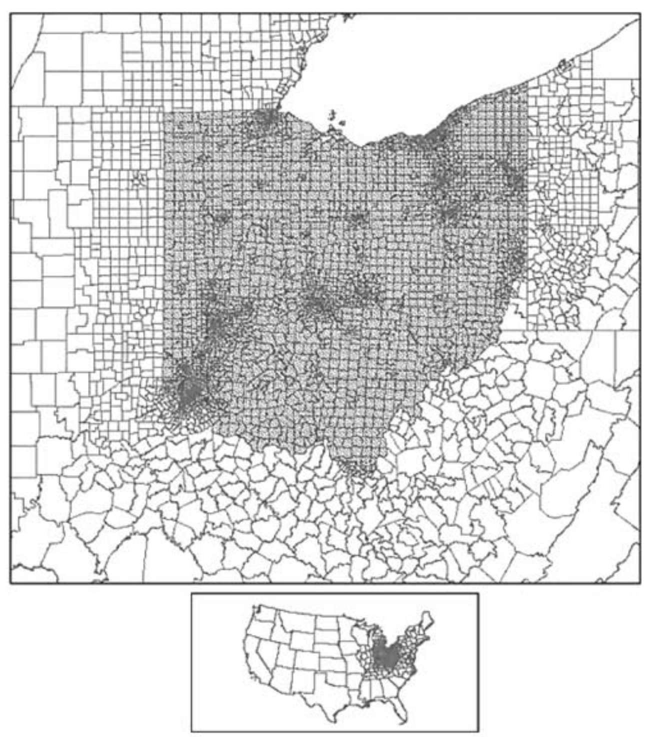

FIGURE 19 Ohio's traffic analysis zone structure. (*Source*: Ohio's response to the synthesis questionnaire 2005.)

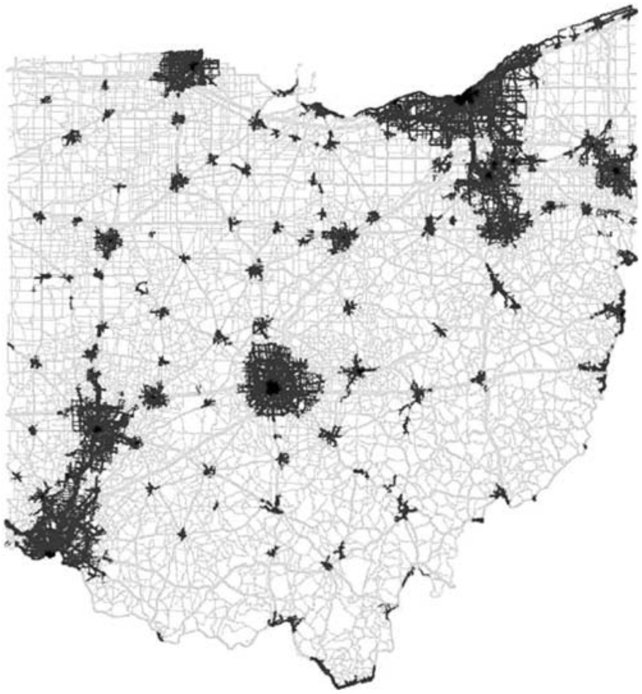

FIGURE 20 Ohio's network within state. (*Source*: Ohio's response to the Peer Exchange questionnaire 2004.)

- Department of Natural Resources land use data,
- County assessor land value data,
- Ohio DOT traffic counts,
- IMPLAN (IO model),
- Roadside surveys,
- Travel time studies,
- CTPP outside Ohio,
- County Business Patterns,
- BEA Regional Economic Information System program,
- College and university enrollments, and
- County auditor data.

The household travel surveys were composed of new surveys in small and medium MPOs, in addition to existing surveys in larger MPOs. These household surveys combined to yield approximately 25,000 responses. A GPS survey was simultaneously conducted to monitor underreporting of trips. The household long distance survey elicited information about trips of greater than 50 mi from 2,000 households. Roadside surveys were taken at approximately 700 locations. Approximately 800 business establishments were surveyed to provide information about services and commodities that are not included in the TRANSEARCH database. NHTS was not used.

The activity allocation and land use submodels were based on PECAS (*P*roduction *E*xchange and *C*onsumption *A*llocation *S*ystem) (Hunt and Abraham 2003), a land use model developed at the University of Calgary. In a manner similar to a compact IO table, PECAS tracks the flow of goods and services between industries and final demand (households), but does so spatially as well as monetarily. The model locates producers and consumers within zones in such a manner as to create a supply/demand equilibrium throughout the state. The supply/demand equilibrium is maintained by adjusting prices of commodities, services, labor, and land (or floor space). The allocations of goods, services, and labor are undertaken using logit and nested-logit expressions, where utility functions contain (1) the cost of travel or transport, (2) the size of zone, and (3) the price of the commodity. The allocations depend on what is already present or has been allocated in a previous time period. Industry is organized into the following categories:

- Agriculture, forestry, and fishing
- Primary metals
- Light industry
- Heavy industry
- Transportation equipment
- Wholesale
- Retail
- Hotel and accommodation
- Construction
- Health care
- Transportation handling
- Other services
- K-12 education
- Higher education
- Government and other.

Households are divided into six categories by income. The model is stepped through a sequence of 5-year time periods until the planning year has been reached. The Land Development submodel determines how categories of land are developed using a series of logit expressions. Land uses are:

- Residential,
- Commercial,
- Light industrial,
- Heavy industrial,
- Grade school,
- Post-secondary institutional,
- Health institutional,
- Agricultural,
- Forest and protected resource, and
- Vacant.

Ohio is also using the capability of PECAS to separate land uses in serviced and unserviced categories.

The traditional generation, distribution, and mode split steps for personal travel are replaced by microsimulation of household travel decisions. Separate submodels are provided for household synthesis; short-distance, home-based person tours; long distance, home-based person tours; commercial, work-based person tours; and visitor person tours.

- Household synthesis—This submodel uses a Monte Carlo process to create a list of households by TAZ. Each household has attributes that are required by other submodels. The Monte Carlo probabilities are based on the existing composition of the zone and the quantities of newly developed land.

- Person tours—The four tour submodels are conceptually similar. They use microsimulation to create a list of tours and then a list of trips within tours. Selection probabilities come from logit expressions. Trips have attributes of origin zone, destination zone, start time, and mode.

Transport of large commodities is handled somewhat traditionally, once the flows of goods have been established by the economic activity modules. Flows between activity model zones are converted to flows between TAZs by apportioning flows according to employment levels. OD flows of goods are converted to a whole number of vehicles grouped by vehicle types and departure times, using a Monte Carlo process. The list of vehicle trips, so obtained, can be post-processed in a traffic microsimulation or aggregated for a traditional traffic assignment. The 28 commodity categories are consistent with two-digit STCC.

Service and delivery commercial tours are created with microsimulation. As with person tours, logit expressions are used to obtain selection probabilities. The overall number of tours relates to the amount and types of employment in the activity model zone. The attributes of each trip are determined in the following order: stop purpose, stop TAZ, departure time (accounting for earlier stops on the tour), stop subzone, and vehicle type (light, medium, and heavy). This method is described in an article about Calgary's urban model (Hunt et al. 2004b). This method has these processes: tour generation, tour stop time, tour purpose and vehicle type, next stop purpose, next stop location, and stop duration. The last three processes are performed iteratively with earlier stops in the tour influencing the nature of later stops.

Traffic assignment is stochastic, multiclass, and user-optimal equilibrium. Capacities are coded for 24-h. Delay for the equilibrium assignment is calculated with BPR curves. Transit assignment is also done.

Post-processors have been provided for air pollution emissions and accident calculations and for traffic microsimulation of small portions of the network.

Sources for this case study were: Hunt and Abraham (2003), Hunt et al. (2004a), HBA Specto Incorporated and Parsons Brinckerhoff Ohio (2005), Ohio's response to the Peer Exchange questionnaire (2004), and Ohio's response to the Synthesis questionnaire (2005).

CASE STUDY 4: VIRGINIA FREIGHT COMPONENT

The Virginia freight component is designed to properly account for trucks on highways when loading passenger automobiles. The model combines trucks and automobiles within an equilibrium multiclass traffic assignment step that preloads trucks using all-or-nothing assignment. Truck OD tables are derived from Reebie's TRANSEARCH database and from systematic adjustments based on truck counts.

The TRANSEARCH data for Virginia gave commodity flows in tons from, to, and within Virginia. Data were organized geographically by state, BEA region, and Virginia county. Separate tables were given for each two-digit commodity group from STCC for truck, railroad, water, and air. Trucks were further divided into truck-load, less-than-truckload, and private. Eventually the model was organized into 28 commodity groups, as listed in Table 8. The TRANSEARCH database omits many agricultural products and local service and delivery trucks, which particularly affect estimates of truck movements within the state.

The freight component uses the same highway network as the passenger component. This network has nearly 247,000 links and almost 1,600 TAZs. The network is illustrated in Figures 21 and 22, although it is difficult to get a sense of the highly detailed network within Virginia from these figures. The zone system is illustrated in Figures 23 and 24. It can readily be seen that the network and zone system span the full contiguous 48 states, but is sharply focused on Virginia. A moderately detailed network and set of zones extend well into adjacent states and beyond. Virginia implements subzoning for traffic assignment that helps eliminate lumpy vehicle loadings to links.

<u>Virginia Statewide Freight Component Summary</u>
State population: 7.1 million
State area: 42,769 square miles
Gross state product: $304 billion
No. of zones: 1,584
External zone structure: Halo, aggregations of states
Internal zone structure: Micro/macro
No. of links: 246,935
Freight modes: Truck
No. of commodity categories: 28
Production: Employment by industry group
Consumption: IO, employment by industry group, population
Distribution: Fratar factoring freight flow database, OD table estimation to truck ground counts
Mode split: Fixed shares
Truck-type split: Fixed shares
Assignment: Static equilibrium, multiclass
Delay estimation: BPR curves
Major data: TRANSEARCH, IO tables
Time frame: Three years of development time
Computation time: 2.5 h
In-house staff: 1 FTE

Virginia's freight component concept is illustrated in Figure 25. OD tonnages by trucks from the TRANSEARCH database are converted to truck loads by the payload factors listed in Table 8, adopted from Texas. Daily tonnage was taken to be 1/365th of yearly tonnage. An initial traffic assignment was made. The truck OD table from the TRANSEARCH database

TABLE 8
VIRGINIA PAYLOAD FACTORS FOR COMMODITIES

STCC	Commodity Type	Movement Type		
		Intrastate	Interstate	Through
1	Farm products	16.1	16.1	16.1
9	Fresh fish or marine products	12.6	12.6	12.6
10	Metallic ores	11.5	11.5	11.5
11	Coals	16.1	16.1	16.1
14	Nonmetallic ores	16.1	16.1	16.1
19	Ordinance or accessories	3.1	3.1	3.1
20	Food products	17.9	17.9	17.9
21	Tobacco products	9.7	16.4	16.8
22	Textile mill products	15.2	16.1	16.5
23	Apparel or related products	12.4	12.4	12.5
24	Lumber or wood products	21.1	21.0	21.1
25	Furniture or fixtures	11.3	11.3	11.4
26	Pulp, paper, allied products	18.6	18.5	18.6
27	Printed matter	13.8	13.6	13.9
28	Chemicals or allied products	16.9	16.9	16.9
29	Petroleum or coal products	21.6	21.6	21.6
30	Rubber or miscellaneous plastics	9.1	9.2	9.3
31	Leather or leather products	10.8	11.0	11.3
32	Clay, concrete, glass, or stone	14.4	14.3	14.4
33	Primary metal products	19.9	19.9	20.0
34	Fabricated metal products	14.3	14.3	14.3
35	Machinery	10.8	10.8	10.9
36	Electrical equipment	12.7	12.8	12.9
37	Transportation equipment	11.3	11.3	11.3
38	Instruments, photo, optical equip.	9.4	9.4	9.7
39	Misc. manufacturing products	14.2	14.4	14.8
40	Waste or scrap metals	16.0	16.0	16.0
50	Secondary traffic	16.1	16.1	16.1

Note: STCC = Standard Transportation Commodity Code.

was found to substantially underestimate truck volumes because of the missing commodities. Instead of attempting to model these missing commodities directly, Virginia adopted a method of correcting the TRANSEARCH data by comparing the assigned volumes to ground counts.

Virginia used a maximum likelihood method of OD table estimation from ground counts that was contained within their travel forecasting software package. This method required a "seed" OD table, as well as numerous truck ground counts. The seed OD table was created by a gravity expression, where

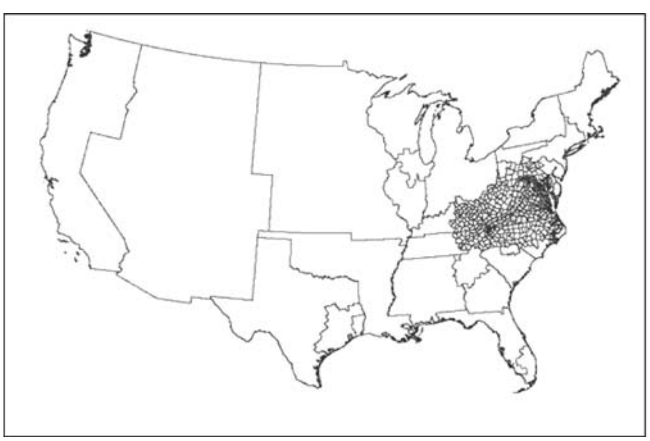

FIGURE 21 Virginia's zone system, full extent.

total employment by zone was taken to be the measures of both trip productions and trip attractions. The TRANSEARCH commodities were assigned to the network and the differences from ground counts were found. These differences were assumed to consist of trucks carrying the missing commodities in the TRANSEARCH database. The resulting OD table form of the gravity expression was scaled so that, on average, the total number of trucks was correct when assigned to the network. This scaled table was adjusted to the difference between the assignment and the counts.

Each commodity was forecasted individually by Fratar factoring its OD table. Each of the 28 commodity groups has been matched to a similar industry group for calculating changes in commodity production. Changes in production are directly proportional to changes in industrial employment. For commodity consumption, a weighted combination of industry employment and final demand is used. The weights are derived from analysis of sales from the National Input–Output Tables, Direct Requirements Table. Final demand was forecasted in proportion to a weighted combination of population and employment. Forecasts in employment were provided for counties by Woods & Poole and modified by national productivity coefficients. County-level data were apportioned to TAZs according to employment totals. There were no special generators.

(*text continues on page 47*)

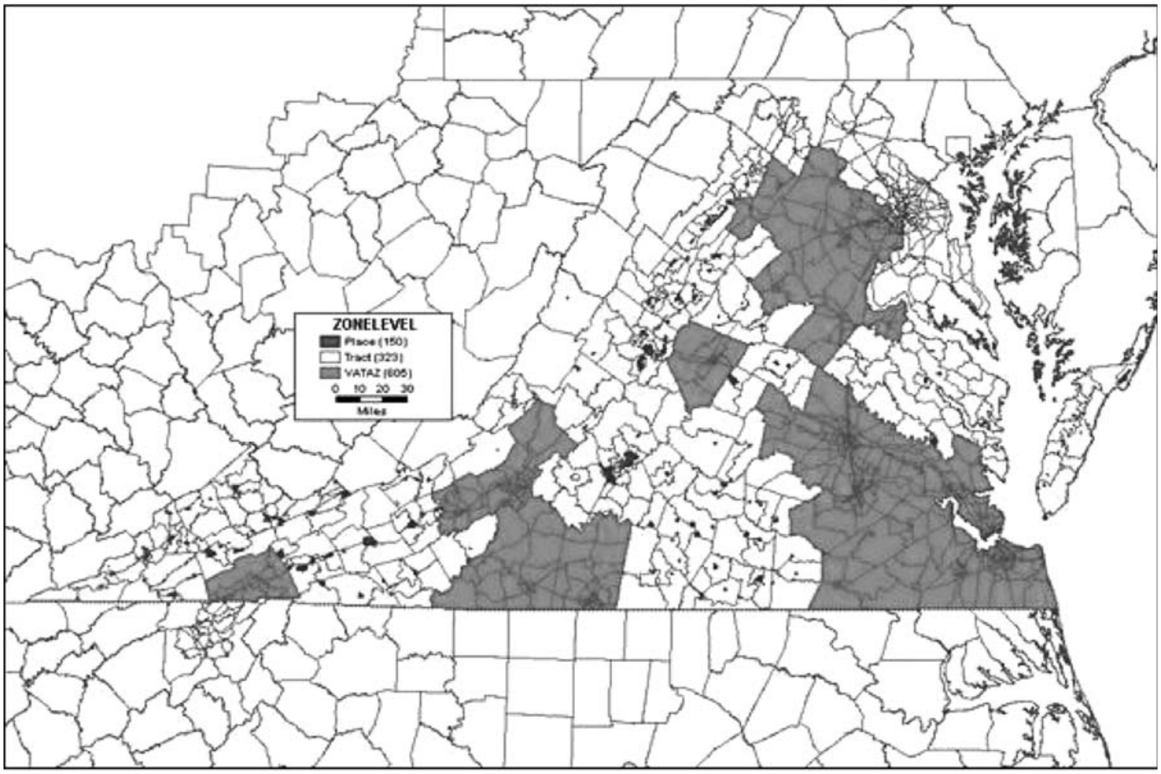

FIGURE 22 Virginia's zone system, in and near state.

FIGURE 23 Virginia's highway network, full extent.

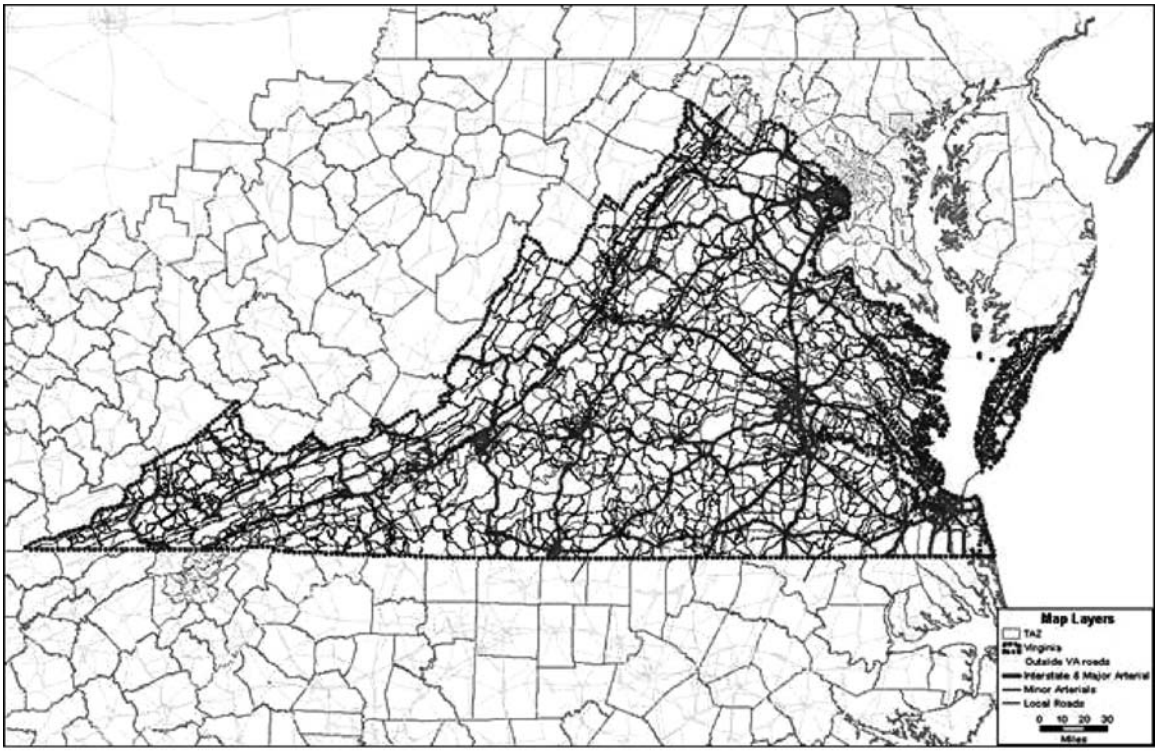

FIGURE 24 Virginia's highway network within state.

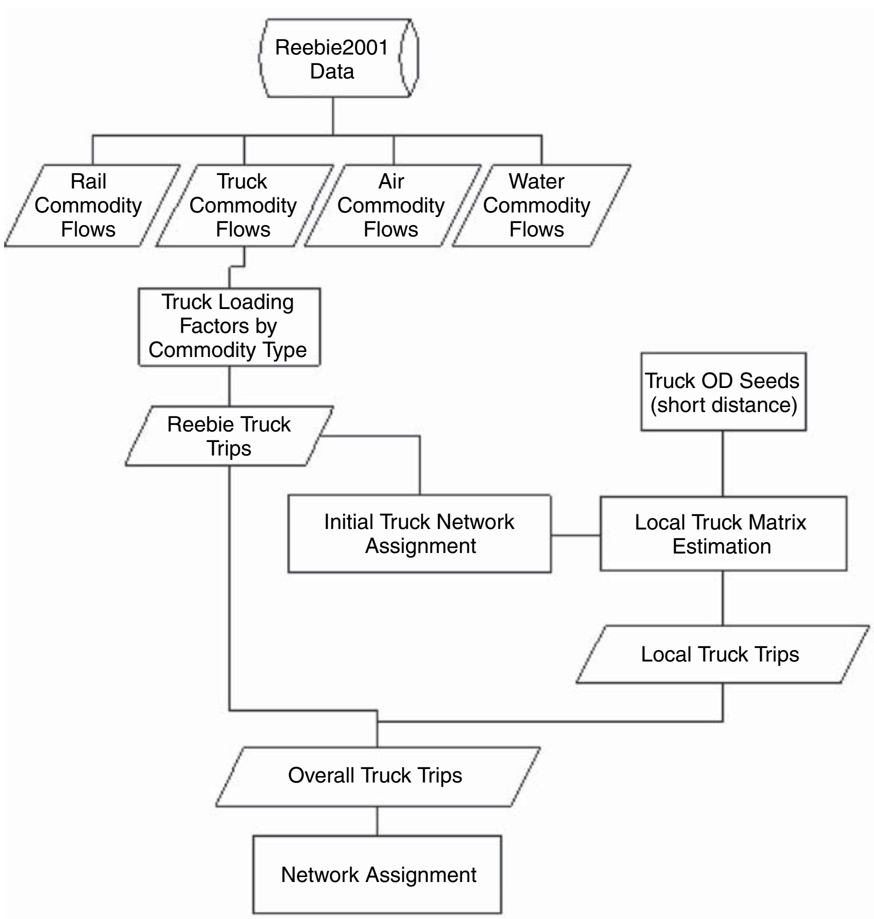

FIGURE 25 Major steps in Virginia's truck model.

The capacity restraint assignment involved estimating delays with the BPR curve, which requires free speed and capacity for a link. Free speeds and 24-h lane capacities were set separately by functional class. After an initial traffic assignment, capacities were adjusted upward within urban areas to account for the sparse network there. Because of the rural orientation for the model, the passenger car equivalent factor for trucks was one.

Both Virginia and Louisiana (Wilbur Smith Associates 2004) implemented essentially two distinct travel forecasting models, referred to as the "micro" model and the "macro" model. Together these two models create a way to consider long trips across states while still working at a sufficiently detailed scale for trips within the state.

The purpose of the macro model is to provide information on trips passing through Virginia or having one end within Virginia. The macro model spans the entire United States and works at the county level within the state. The macro model has just 204 TAZs, of which 135 are within Virginia. The macro network has almost 59,000 links.

The micro model operates within Virginia at the level of census tracts and places. The micro model provides the necessary forecasts of travel to satisfy statewide planning needs. (Sources: Wilbur Smith Associates 2003, Virginia's response to the Peer Exchange questionnaire 2004, Virginia's response to the Synthesis questionnaire 2005, Wilbur Smith Associates 2005b.)

CASE STUDY 5: WISCONSIN FREIGHT COMPONENT

At the time of this writing, Wisconsin had just finished the third generation of its travel forecasting model. However, documentation of model details had not been completed. This case study is based on a series of interim memoranda, the consultant's scope of work, questionnaire responses, and interviews with the modeling team.

Wisconsin's overall statewide modeling effort was designed to meet these needs:

- Long-range plan development (statewide and urban)
- Air quality conformity analysis
- Corridor planning for capacity investment, programming, and design
- Modal investments (e.g., introduction of new intercity bus service)
- Traffic forecasting for project design
- Traffic Impact Analysis
- Traffic diversion impacts
- Modal diversion impacts
- Congestion mitigation planning—Wisconsin DOT Intelligent Transportation System "blue route" corridor planning efforts
- Detour simulation analysis
- Bypass feasibility studies
- EIS traffic data input.

A major motivation for building the statewide model was the need to determine the impacts truck traffic has on major highways. The freight component addresses these needs by forecasting commodity-carrying truck volumes.

Wisconsin Statewide Freight Component Summary
State population: 5.5 million
State area: 65,503 square miles
Gross state product: $200 billion
No. of zones: 1,875
External zone structure: Halo, states, aggregations of states, BEA regions
Internal zone structure: Aggregations of TAZs
No. of links: 200,000
No. of commodities: 25 categories
Freight modes: Truck, rail, water (deep and inland), air cargo
Production: Employment by industry group
Consumption: IO table, employment by industry group, population
Distribution: Gravity expression
Mode split: Fixed shares
Truck type split: Fixed shares
Assignment: Static equilibrium, multiclass
Delay estimation: BPR curves
Major data: TRANSEARCH
Time frame: 2.5 years of development time
Computation time: 2 h
In-house staff: 3 FTEs

Wisconsin's freight component is multimodal and commodity-based. The key database for the model was Reebie's TRANSEARCH from 2001 aggregated to BEA regions. This database was factored into counties using commodity flow information for Wisconsin that was assembled by Reebie in 1996. The following is a list of the commodity groups, each of which consist of whole two-digit STCC groups or represent intermodal shipments.

- Farm and fish;
- Forest products;
- Metallic ores;
- Coal;
- Nonmetallic minerals;
- Food;
- Lumber;
- Pulp, paper, allied products;
- Chemicals;
- Petroleum or coal products;
- Clay, concrete, glass, and stone;
- Primary metal products;
- Fabricated metal products;
- Transportation equipment;
- Waste or scrap equipment;

- Secondary warehousing;
- Rail drayage;
- Other minerals;
- Furniture or fixtures;
- Printed matter;
- Other nondurable manufacturing products;
- Other durable manufacturing products;
- Miscellaneous freight;
- Hazardous materials; and
- Air drayage.

These commodity groups were selected to emphasize those commodities that were of the greatest economic importance to Wisconsin and to allow a direct match to industrial categories.

Wisconsin's freight component essentially contains the major UTP four-steps, as illustrated in Figure 26.

Wisconsin's zone system for freight differs somewhat from the passenger component. The zone system consists of (1) 1,642 small TAZs within Wisconsin, (2) counties within a thin halo around Wisconsin, (3) a few states or BEA regions near Wisconsin, (4) multistate regions for the rest of the contiguous United States, and (5) four huge zones for the rest of North America (see Figure 27). TAZs within Wisconsin and its halo match the passenger component exactly.

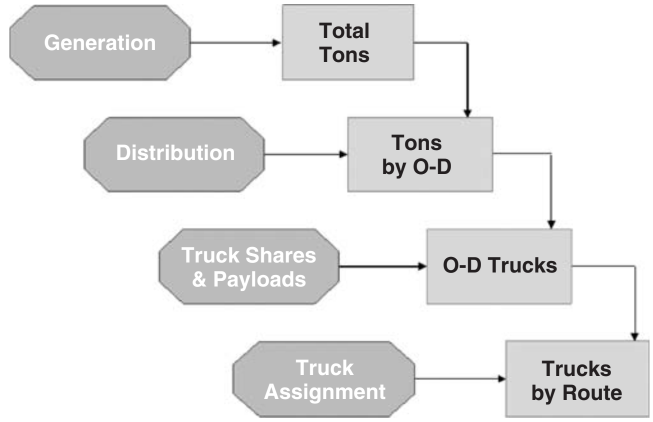

FIGURE 26 Structure of Wisconsin's freight component. O-D = origin–destination.

The truck network is nearly identical to the passenger car network within Wisconsin and its halo, as seen in Figure 28. This network is very detailed within and near Wisconsin and it spans most of the contiguous United States, except for the Southeast, at a coarser level of detail (owing to the aggregated southeast freight zone using Atlanta as a loading point). This contrasts with the passenger component whose network extends only into the halo. Wisconsin's truck network is nationwide to "account for global market impacts on

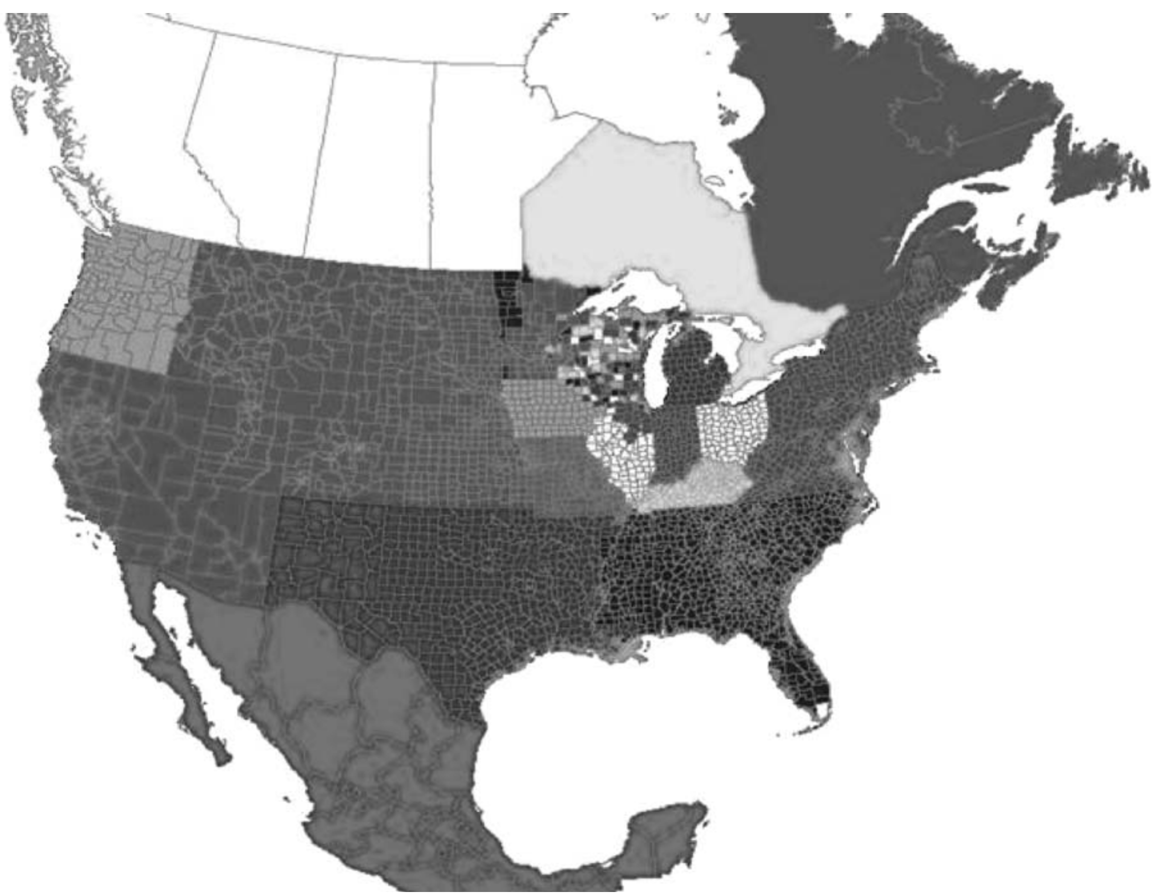

FIGURE 27 Wisconsin's freight component zone system.

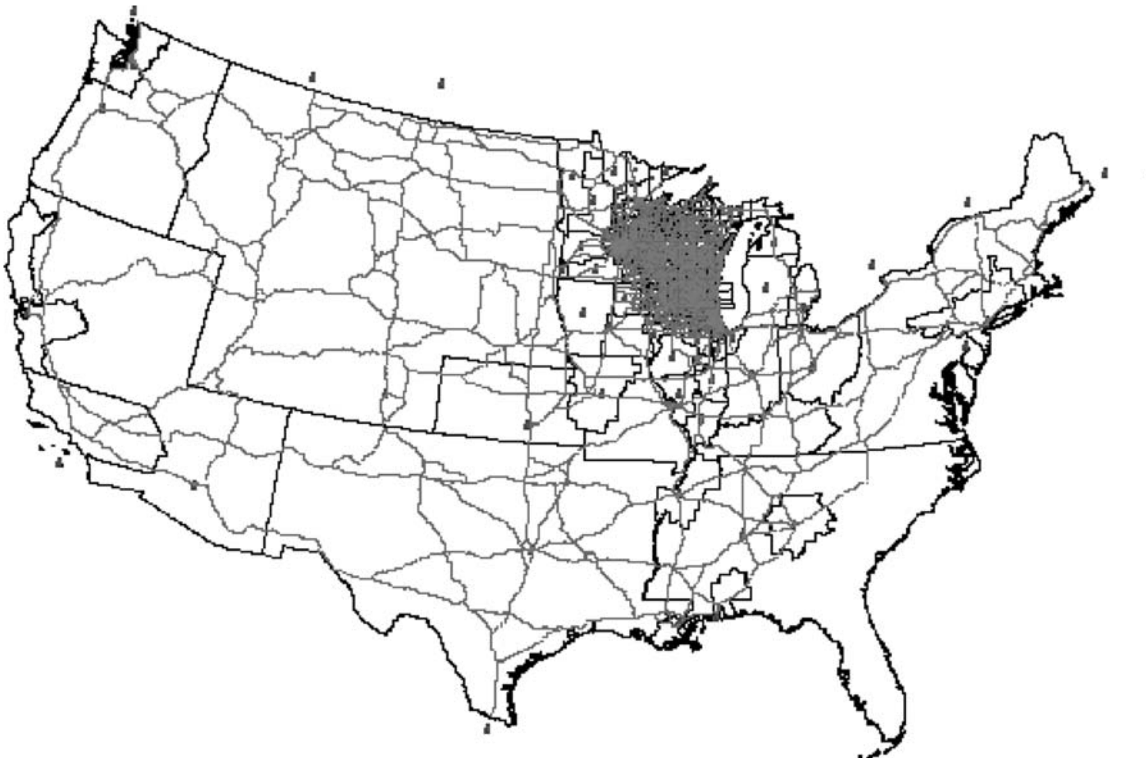

FIGURE 28 Wisconsin's freight component network.

freight movements." Rural portions of Wisconsin contain all functional classes that are major collector or higher. Urban portions of Wisconsin contain all functional classes that are collector or higher, except for the counties covered by the Southeastern Wisconsin Regional Planning Commission. Network attributes for links within Wisconsin come from either the Wisconsin Information System for Local Roads or the Wisconsin DOT's State Trunk Network inventory. The network outside of Wisconsin was obtained from FAF, NHPN, and TIGER line files.

Commodity generation equations were developed by linear regression between commodity production and industrial employment for each commodity group based on county-level data. In a manner similar to Virginia, Wisconsin identified consuming industries and final demand for a given commodity group by using a national IO table. Regression analysis was then performed to ascertain the relationships between consumption totals in the TRANSEARCH database and zonal employment and population. The independent variables used in the regression are shown in Table 9. Employment data were

TABLE 9
INDEPENDENT VARIABLES FOR TONNAGE GENERATION FOR SELECTED COMMODITY GROUPS

Commodity	Production	Consumption
Farm and Fish	SIC01 + SIC02 + SIC07 + SIC09	SIC20 + SIC54
Nonmetallic Minerals	SIC14 + SIC15 + SIC16 + SIC17	SIC14 + SIC15 + SIC16 + SIC17
Food	SIC20	Population
Lumber	SIC24	SIC24 + SIC25 + SIC50
Pulp, Paper, Allied Products	SIC26	SIC26 + SIC27
Chemicals	SIC28	Total employment
Clay, Concrete, Glass, and Stone	SIC32	Population
Primary Metal Products	SIC33	SIC33 + SIC34
Fabricated Metal Products	SIC34	Population
Transportation Equipment	SIC37	SIC42
Secondary Warehousing	SIC42	Population
Furniture or Fixtures	SIC25	Population
Printed Matter	SIC27	Total employment
Other Nondurable Manufacturing Products	SIC21 + SIC22 + SIC23	Population
Other Durable Manufacturing Products	SIC30 + SIC31 + SIC35 + SIC36 + SIC38 + SIC39	SIC50

obtained from Wisconsin's Department of Workforce Development. Employment and demographic forecasts came from Woods & Poole growth rates applied to the Department of Workforce Development base data.

Production or consumption of certain commodity groups did not correlate well with demographic variables. These commodity groups were handled by factoring base year production and consumption data from the TRANSEARCH database.

Wisconsin has 27 special generators for freight, which were county and commodity combinations. These special generators consist of retail distribution centers, truck–rail intermodal terminals, ports, airports, and obvious outliers from the trip generation calibration, such as a highly automated General Motors assembly plant. The only primary data collection specifically for the freight component was a pilot truck survey at the Union Pacific intermodal terminal in Rochelle, Illinois. Another survey at this location is planned.

When forecasting the relationship between employment and commodity production it is important to account for changes in worker productivity. Wisconsin obtained worker productivity factors for future years from a regional economic model.

Trip distribution is handled by a gravity expression, where the friction factor for each commodity has been calibrated such that the model replicates average trip lengths from the TRANSEARCH data applied to the FAF highway network. The metric for spatial separation was distance in miles, d_{ij}. Therefore, friction factors were determined by this formula

$$f(d_{ij}) = \exp(d_{ij}/\gamma)$$

where γ is a constant that varies by commodity group. Values of γ range from approximately 100 to 2,800, depending on the commodity.

Wisconsin's freight component has four principal modes: truck, air cargo, railroad, and water shipping (both deep and inland). The model also explicitly considers three intermodal combinations (truck–air, truck–rail, and truck–water) by including drayage links on the highway network between Wisconsin counties and major intermodal terminals, some of which are located in Illinois and Minnesota. Mode split was accomplished by fixed shares as derived from the TRANSEARCH database. Air, rail, and water modes are not assigned to a network.

Wisconsin's highway traffic assignment is 24-h, multiclass, and user-optimal equilibrium. Trucks are loaded to the network at the same time as passenger cars; therefore, the route choice of trucks is influenced by congestion. Trucks receive a constant passenger car equivalent factor of 1.9. Delay was estimated with BPR curves.

Annual tonnages of commodities were converted to daily trucks by using the payload factors from Table 10 and an assumed 306 trucking days per year. Table 10 was derived principally from Wisconsin records within VIUS.

TABLE 10
WISCONSIN PAYLOAD FACTORS BY TWO-DIGIT COMMODITY CODES

STCC	Description	Tons per Truck
1	Farm products	24
8	Forest products	13
9	Fresh fish or other marine products	6
10	Metallic ores	24
11	Coal	24
13	Crude petroleum, natural gas, or gasoline	14
14	Nonmetallic minerals, excluding fuels	19
19	Ordnance or accessories	24
20	Food or kindred products	18
21	Tobacco products	5
22	Textile mill products	5
23	Apparel or other finished textile products	3
24	Lumber or wood products	15
25	Furniture or fixtures	3
26	Pulp, paper, or allied products	16
27	Printed matter	9
28	Chemicals	22
29	Petroleum or coal products	19
30	Rubber or miscellaneous plastics products	4
31	Leather or leather products	3
32	Clay, concrete, glass, or stone products	23
33	Primary metal products	19
34	Fabricated metal products	24
35	Machinery—Other than electrical	9
36	Electrical machinery, equipment, or supplies	8
37	Transportation equipment	12
38	Instruments—Photographic or optical goods	5
39	Miscellaneous manufacturing products	2
40	Waste or scrap materials	16
41	Miscellaneous freight shipments	23
42	Shipping devices returned empty	4
43	Mail and express traffic	3
44	Freight forwarder traffic	4
45	Shipper association or similar traffic	3
46	Miscellaneous mixed shipments	7
47	Small packaged freight shipments	4
48	Hazardous waste	16
49	Hazardous materials	18
99	Unknown	12

Note: STCC = Standard Transportation Community Codes.

The only validation for the freight component that was distinct from passenger traffic was a comparison of commodity tonnages between the model and TRANSEARCH. Assigned trucks were also compared with truck counts at approximately 300 stations for reasonableness—a direct comparison is not possible because the model forecasts commodity carrying trucks only, not total trucks. Total truck VMT was checked against available data sources.

Outputs from the freight component aid other planning efforts. An important feature of Wisconsin's model is its interface with MPO models in the state. Internal truck travel in the MPO models is handled with procedures taken from the *QRFM*, but external traffic patterns come from the statewide model. In addition, forecasts from the statewide model are used to validate or supersede forecasts made from historical data using Box–Cox regression analysis. Outputs are also processed through STEAM (*S*urface *T*ransportation *E*fficiency *A*nalysis *M*odel) from FHWA to obtain systemwide benefits.

Major updates of Wisconsin's model are planned to occur on a 6-year cycle to coincide with Wisconsin DOT's Six-Year Highway Improvement Program.

DISCUSSION

The five case studies are representative of the newer generation of statewide travel forecasting models. Except for their philosophy in following a three- or four-step forecasting process, these case studies differ remarkably in both their details and execution. Each state has customized the model steps to match its own planning objectives. This chapter shows three distinct methods of modeling statewide passenger travel. However, there is more similarity in the freight models, particularly in basing the forecasts on commodity movements. Ohio's model emphasizes how non-freight commercial vehicles can be important to a forecast and might need special treatment apart from freight-carrying vehicles.

Furthermore, the five case studies show that statewide models are becoming large and complex. The models are increasing the demand for high-quality secondary data, faster hardware and algorithms, better data visualization methods, and greater expertise.

CHAPTER FOUR

FINDINGS AND SUGGESTIONS FOR RESEARCH

Statewide travel forecasting is becoming a more common activity in transportation planning. There is an increase in the number of states with models and many states are in the process of revising their models. The impetus for developing a statewide model varies greatly from state to state. In some states models were created to address the needs of a specific large project; in other states models were created for general planning needs. Statewide models have become essential in some states for intercity corridor and statewide system planning.

Most statewide models are similar in structure to four-step urban transportation planning models. Statewide models differ from urban models primarily in how the steps are configured. There exists no well-accepted definition of best practice in statewide models. Models range greatly in cost, staffing requirements, development time frame, and capabilities.

Special data collection efforts, apart from National Household Travel Survey (NHTS) add-ons, are sporadic. Most states are making efficient use of a wide variety of secondary data sources.

The following several distinct trends are apparent in recent statewide model development.

- Many newer models have network detail at about the same level of precision as urban models.
- There are more freight components that are commodity-based, rather than being truck-only.
- There is a greater and more effective use of geographic information systems to manage and acquire model data.
- There is more of a tendency to hold statewide models to the same standards of validation accuracy as urban models.
- There has been a doubling of states (from one to two) that are pursuing models with integrated economic activity components.
- Traffic assignments are less likely to be all-or-nothing and more likely to be equilibrium.
- There is a greater emphasis on multiclass traffic assignment for combining freight and passenger traffic forecasts.

There are planning needs that have not been fully realized because of deficiencies in either data or algorithms.

- The 1995 American Travel Survey (ATS), the last major source of information on long distance passenger travel, has not been updated.
- Models tend to still have a time period of 24 h; none of the states have implemented the dynamic methods necessary for good forecasts of peak-hour travel in larger states.
- There has been little progress in the creation and use of transferable parameters within any of the model steps.
- With the exception of a few geographically small states, there has not been a full integration of statewide and urban models. Integration is easier to achieve in small states where there are only a few metropolitan planning organizations in close proximity or one that spans the state. Statewide models defer to urban models within urban areas.
- There has been little progress in integrating statewide models with national models, particularly the Freight Analysis Framework (FAF).

This review identified two particular issues that are limiting progress in statewide model development.

- Many databases are organized by county or other spatial units that are too coarse.
- More experience is needed with modeling multiday, long distance trip making.

The following innovations in both statewide and national modeling may lead to better planning practice.

- Some states use nested zone structures to better tailor the level of spatial aggregation to the needs of a given model step. For example, several states have implemented subzones during traffic assignment to eliminate lumpy loadings. Other states have adopted dual sets of zones and networks to model both national and local travel effects.
- The full integration of freight, passenger, and economic activity offers a worthwhile direction for the next generation of statewide travel forecasting models.
- Some states have implemented tour-based passenger components within their statewide models.
- Proposed improvements to FHWA's FAF may enable more rapid development of statewide freight components that are more accurate and more policy sensitive.

At this time there is no pressing need for best practice standards for statewide models. In states with integrated models, the state of the practice exceeds the curricular content of transportation planning graduate programs.

The review of current practice supports the four principal research suggestions of the Statewide Travel Demand Models Peer Exchange. These research suggestions have been previously identified as being of high priority.

- Rural Area Trip-Making Characteristics. Many urban models have benefited greatly from the existence of transferable parameters for forecasting travel within urban areas. Notable sources of such parameters are *NCHRP Report 187*, *NCHRP Report 365*, and the *Quick Response Freight Manual* (*QRFM*). Similar data have not been compiled for intercity or rural travel. Some statewide models have used urban parameters for rural travel, perhaps introducing an unnecessary error to forecasts. Research is needed to define trip generation rates, trip distribution friction factors, vehicle occupancy rates, time-of-day factors, and mode-split model coefficients. This information is needed principally for passenger travel. A potential source of much of this information is the NHTS. The *QRFM* should be updated to include rural commercial trip characteristics.
- Development of a National Passenger Travel Model. The United States does not have a national model of passenger travel, although it does have a national freight model (FHWA's FAF). Currently, most statewide models have networks that extend well into neighboring states and beyond. A national passenger model would go a long way toward relieving statewide planners from the burden of modeling vast areas outside their borders to properly account for external travel. The main purpose of a national model would be to obtain reliable forecasts of passenger vehicle flows between states on major U.S. highways and passenger volumes through major airports and rail and bus terminals. Local detail in such a model would not be needed.
- Development of Validation Performance Standards for Statewide Models. There are well-recognized quality standards for urban travel forecasting models, but none for statewide travel forecasting models. Because statewide models tend to be coarser than urban models and because statewide models are used to study a narrower range of policies and project options, there is a sentiment within some states that statewide models do not need to meet strict urban standards for validation. Research is needed in these areas, as identified by the Peer Exchange.
  - Acceptable ranges of parameters and values used as inputs to statewide models.
  - Key market segments that should be addressed in statewide models.
  - Suitable and unsuitable applications of statewide models.
  - Potential sources of data to support and evaluate statewide models.
  - Multimodal performance standards for trip generation and activity, trip length and duration, mode choice, corridor assignment, low-volume roadway assignment, rural areas and facilities, multimodal demand, and multimodal assignment.
  - Comparison of urban and statewide planning model results and sensitivities.
  - Estimates of the time and costs for various options.
- Long-Distance Travel Data Collection. Many states found the ATS to be an invaluable source of information on long distance travel within and across their borders. However, the latest data from the ATS is now 10 years old, and although the 2001 NHTS also contains data on long distance, infrequent trips, the data set is limited in the number of samples and the number of trips reported. It is suggested that the ATS be repeated or the NHTS be upgraded to a comparable level of detail for long distance trip making.

In addition, the state of the practice suggests that additional research be undertaken in the following areas.

- Improvements in Traffic Assignment. As with urban models, traffic assignment is the step closest to the results that influence decision making. However, producing a traffic assignment is much more difficult in statewide models because of the larger sizes of the networks, the distance between origins and destinations, and the coarseness of zone systems. In particular, there are three issues that need further investigation.
  - Peak periods and traffic dynamics. In states where intercity trip durations greatly exceed 1 h, static traffic assignment is incapable of directly performing peak-hour forecasts. Dynamic traffic assignment can track groups of vehicles in both time and space; therefore, it potentially can estimate traffic volumes and delays for short periods of time. Because no state is currently using dynamic traffic assignment, its applicability should be tested on full-sized networks.
  - Spatial aggregation. To cover the full land area of a state, zone systems have been coarse. A few states have experimented with subzones during the assignment step to remove errors associated with large zones; however, more experience is necessary. Research is needed to determine the best methods for establishing subzones and to ascertain the potential benefits.
  - Speed of execution. Some newer models have very large networks, causing very slow path building and traffic assignment. There is a need for faster algorithms, either by writing better algorithms or by fully exploiting computer hardware. Speed of execution will be of increased concern as states adopt dynamic and multiclass traffic assignment methods.
- Intermodal Freight Networks. As with urban models, many statewide models have truck networks. Networks

for other freight modes are rare, and no state has reported networks capable of handling intermodal freight. Additional research and experience is necessary to determine the best way to build networks for handling freight that use more than one mode.

- Cost Models for Freight and Freight Modal Choice Parameters. Cost is the most important factor in freight mode choice. The knowledge of mode choice for long distance freight is inadequate, principally because the costs of transporting freight are not well understood. *NCHRP Report 260* contains detailed methods for estimating the costs of freight; however, those methods are now outdated. New research is needed to ascertain the costs of moving one ton of a particular commodity from origin to destination by a variety of competing models. Additional research is needed to determine the sensitivity of cost relative to other factors within the modal choice process. The effect of changing logistics practices on long distance freight movements needs to be quantified.
- Innovative Methods of Estimating Origin–Destination Tables from Ground Counts. Developing very large origin–destination tables for specific purposes, modes, and commodities is currently difficult because of the amount of required information and the amount of computation time. Better methods, suitable for highly detailed and multiclass models, are needed to find accurate tables that use more then simple ground counts as inputs. Such methods need to be validated for accuracy.
- Better Public Source Commodity Flow Information. The Commodity Flow Survey has been an invaluable source of information on freight shipments within the United States. However, the survey does not provide complete information. Innovative methods are needed for combining existing data sources and economic models for filling in the gaps in the Commodity Flow Study. These methods need to be expressed as simple procedures that can be executed by modeling staffs at state departments of transportation. The potential of FHWA's FAF for providing better commodity flow information could be explored.
- Better Information on Non-Freight Commercial Vehicle Movements. Both urban and statewide models could benefit from a better understanding of commercial vehicle movements that are not transporting freight. A means of acquiring such information might be a National Business Travel Survey, which would be analogous to the NHTS. Such a survey would also be an opportunity to learn more about business logistics practices and supplement the information from the Commodity Flow Survey. This information could also be helpful for developing default commercial trip making characteristics for an update of the *QRFM*.
- Improved Curricula for Transportation Planning Graduate Programs. The emergence of integrated transportation/land use/economic activity models suggests that related topics might be elevated in importance within graduate program curricula.

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APPENDIX A

Screening Questionnaire

National Cooperative Highway Research Program
Synthesis 36-09
Statewide Travel Forecasting Models

QUESTIONNAIRE
(All States, Initial Screening)

Attached is a short questionnaire seeking information about the current status of your statewide travel forecasting efforts. We need responses from all states, even those who are not currently involved statewide modeling. Feel free to supplement the answers to specific questions with any information you feel would give the best picture of your forecasting activities. Your input will be invaluable to the creation of a synthesis of best practice on this subject. The Synthesis will be especially helpful to those states that are thinking of developing a model from scratch or upgrading their current model. It will also help you benchmark your forecasting activities against methods that have been adopted elsewhere.

Please return this filled questionnaire and any supporting documents (by e-mail, fax, or regular mail) to:

Alan Horowitz
Professor of Civil Engineering
University of Wisconsin—Milwaukee
PO Box 784
Milwaukee, WI 53201

E-mail: horowitz@uwm.edu
Fax: 414-229-6958
Voice: 414-229-6685

It would be best to fill out the questionnaire within MS Word and then send the saved document by e-mail. Call or e-mail Alan Horowitz for clarifications of any question.

Your response is needed by February 1, 2005.

General Instructions

This questionnaire mostly consists of questions requiring short explanations. Please feel free to elaborate on any question.

I. Background and Overall Statewide Forecasting or Modeling Status

1. Name of state ______

2. Contact information about person who can best answer questions about your statewide travel or traffic forecasting activities:

Name ______
E-mail address ______
Title ______
Mailing address ______
Phone number(s) ______

3. What is the general status of statewide travel demand modeling in your state. A "statewide model" should be construed to be able to forecast traffic volumes on transportation facilities throughout the state from behavioral principles. One example (but not the only possibility) of a statewide model would be a "four-step" approach (consisting of trip generation, trip distribution, mode split, and traffic assignment). The model could be for passenger vehicle forecasting, freight forecasting, or both.

☐ No model
☐ Old model, not currently operational
☐ Model being revised, not yet operational
☐ Partially operational model
☐ Fully operational model
☐ Other (Explain) ______

4. Please give any other contact or source information here. ______

5. If you do not currently have an operational model, what techniques do you use to create traffic forecasts in rural areas or for intercity corridors that are needed for statewide planning requirements? ______

It would be helpful if you were to attach any documents that explain your methods of travel or traffic forecasting for rural areas that are not a model of the type described in Question 3.

Thank you!

Please return the questionnaire to Alan Horowitz by February 1, 2005

APPENDIX B

Full Questionnaire for States Not Participating in the Peer Exchange

National Cooperative Highway Research Program
Synthesis 36-09
Statewide Travel Forecasting Models

QUESTIONNAIRE
(For states that did not participate in the Peer Exchange)

Attached is a questionnaire seeking information about the current status of your statewide travel forecasting modeling efforts. Feel free to supplement the answers to specific questions with any information you feel would give the best picture of your modeling activities. Your input will be invaluable to the creation of a synthesis of best practice on this subject. The Synthesis will be especially helpful to those states that are thinking of developing a model from scratch or upgrading their current model. It will also help you benchmark your model against models that have been developed elsewhere.

Please return this filled questionnaire and any supporting documents (by e-mail, fax, or regular mail) to:

Alan Horowitz
Professor of Civil Engineering
University of Wisconsin—Milwaukee
PO Box 784
Milwaukee, WI 53201

E-mail: horowitz@uwm.edu
Fax: 414-229-6958
Voice: 414-229-6685

It would be best to fill out the questionnaire within MS Word and then send the saved document by e-mail.
Call or e-mail Alan Horowitz for clarifications of any question.

Your response is needed by February 15, 2005.

General Instructions

This questionnaire consists of multiple choice questions and questions requiring short explanations. For the multiple choice questions, check all items that apply. Feel free to elaborate on any choice within the multiple choice question or in the last, catch-all question at the end of each section. Phrases or terms with an asterisk (*) have explanations at the end of the questionnaire (Explanation of Less Common Terms).

I. Background and Overall Statewide Modeling Status

1. Name of state ______

2. Contact information about person who can best answer questions about your statewide model:

Name ______
E-mail address ______
Title ______
Mailing address ______
Phone number(s) ______

3. What is the general status of statewide travel demand modeling in your state? A "statewide model" should be construed to be able to forecast traffic volumes on transportation facilities throughout the state from behavioral principles*. One example (but not the only possibility) of a statewide model would be a "four-step" approach (consisting of trip generation, trip distribution, mode split, and traffic assignment). The model could be for passenger vehicle forecasting, freight forecasting, or both.

☐No model
☐Old model, not currently operational
☐Model being revised, not yet operational
☐Partially operational model
☐Fully operational model
☐Other (Explain) _____

4. Is your agency willing to supply detailed information about your statewide model(s) so it can serve as a case study within the Synthesis?

☐No ☐Yes

5. Are there documents on-line that explain your statewide model?

☐No ☐Yes (give location) _____

6. Please give any other contact or source information here. _____

II. Model Beginnings

1. How long did/will it take to develop the model? _____years

2. How much did/will it cost to develop the model? _____ dollars

3. How was the model funded?

☐State general purpose revenues
☐State dedicated transportation funds
☐Federal State Planning and Research (SPR) funds
☐Other federal funds
☐Other (Explain) _____

4. Were there serious institutional hurdles to cross?

☐No ☐Yes (Explain) _____

5. Where did the impetus for model development begin?

☐Needs identified through a technical oversight committee
☐Needs identified through workshops or questionnaires
☐General forecasting needs
☐Needs of a specific project
☐Other specific forecasting needs (Explain) _____

6. Was the model development designed to be staged in terms of forecasting capabilities (that is, were some capabilities operational well ahead of others)?

☐No ☐Yes (Explain staging) _____

7. Provide any other information that would help explain how your model was initiated. _____

III. Creation/Maintenance of Both Passenger and Freight Components

1. Who was primarily responsible for the creation of the model?

☐Primarily in-house ☐Primarily consultants or university
☐Both in-house and consultants or university
☐Other (Explain) ______

2. Who was primarily responsible for the maintenance of the model?

☐Primarily in-house ☐Primarily consultants or university
☐Both in-house and consultants ☐Little or no maintenance yet required
☐Other (Explain) ______

3. How many in-house staff are dedicated to maintaining/using the model (include estimates of partial time for multitasked staff)? ______ persons (Leave blank if cannot be estimated)

4. Was any staff added or reassigned from other duties because of the statewide model?

☐No ☐Yes

5. Of all the time spent in-house on the model, what percentage is spent maintaining the model (versus applying it)? ______ % (Leave blank if cannot be estimated)

6. Do you have a regular update cycle?

☐No ☐Yes

7. If you have a regular update cycle, what gets updated on what intervals? ______

8. What computer configuration is typically used for running the model? ______

9. With this computer configuration, about how much computation time is necessary for a forecast (both passenger and freight)? ______

10. Do you have a specific training program for DOT staff in the use of the model or its results?

☐No ☐Yes (Explain) ______

11. Do you have a statewide model users group?

☐No ☐Yes (Describe) ______

12. Is there a statewide model user's web page?

☐No ☐Yes (Give the web address) ______

13. Is the model used by people outside of your agency?

☐No ☐Yes (Describe how the software is distributed to outside users) ______

14. Do you use a commercial GIS package with your statewide model?

☐No ☐Yes (Name of product) ______

15. Do you use a commercial travel forecasting package(s) for your statewide model?

☐No ☐Yes (Name of product) ______

16. Provide any additional comments about creation and maintenance. ______

IV. Use of Both Freight and Passenger Components

1. What are the primary measures of effectiveness used from the model?

- ☐ Vehicle miles traveled
- ☐ Vehicle hours traveled
- ☐ Air pollution emissions
- ☐ Greenhouse gas emissions
- ☐ Energy consumption
- ☐ Levels of congestion
- ☐ Volume/capacity ratios
- ☐ System delay
- ☐ Corridor delay
- ☐ Traffic growth rates
- ☐ Freight tonnages by mode
- ☐ Passenger volumes by mode
- ☐ Time savings
- ☐ Benefit/cost ratio
- ☐ Crash reduction
- ☐ Employment by area
- ☐ Goods production by area
- ☐ Shipping costs
- ☐ Land prices
- ☐ User benefits other than time savings (Explain) ______
- ☐ Other (Explain) ______

2. What have been the major uses of the model?

- ☐ Statewide system planning or system EIS
- ☐ Land use planning
- ☐ Corridor planning
- ☐ Detour analysis
- ☐ Incident management planning
- ☐ Work zone planning
- ☐ Bypass studies
- ☐ Project prioritization
- ☐ Project level traffic forecasts or project EIS
- ☐ Operational level studies
- ☐ Economic development studies
- ☐ Inputs to economic modeling
- ☐ Freight/intermodal planning
- ☐ Truck weight studies
- ☐ Passenger rail planning
- ☐ Intercity bus planning
- ☐ Freight rail planning
- ☐ Airport planning
- ☐ Air quality conformity analysis
- ☐ Safety analysis, crash "hot spot" analysis
- ☐ Toll, pricing, or tax studies
- ☐ Traffic impact studies
- ☐ Border crossing or port-of-entry studies
- ☐ Weigh station location
- ☐ Revenue forecasting
- ☐ Long-term investment studies
- ☐ Regional planning, assisting an MPO model
- ☐ Homeland security
- ☐ Pavement life studies, ESALs (equivalent single-axle loads)
- ☐ Regional planning, substituting for a local model
- ☐ Other ______

3. Describe any unique features of your model that facilitate any of the analyses in the previous question.

______

4. What is the farthest-out forecast year you have modeled?

- ☐ Have not yet performed a forecast
- ☐ 5 or less years into the future
- ☐ 5 to less than 10 years into the future
- ☐ 10 to less than 20 years into the future
- ☐ 20 or more years into the future

5. What were the primary sources of workplace employment data for either passenger or freight models?

- ☐ MPO databases
- ☐ Employer/establishment survey
- ☐ Employer directory
- ☐ Unemployment tax records
- ☐ Workman's compensation tax records

☐Census Transportation Planning Package (CTPP)
☐Commercial data vendor (Explain) ______
☐Other (Explain) ______

6. What were the primary sources of economic forecast data for either passenger or freight models?

☐An input–output model* ☐Bureau of Economic Analysis
☐A regional economic model (Explain) ______
☐State agency forecast (Explain) ______
☐Commercial forecast vendor (Explain) ______
☐Other (Explain) ______

7. Are there air quality conformity issues in your state that would require a statewide forecasting model to address?

☐No ☐Yes

8. Are there other statutory requirements in your state that would require a statewide forecasting model to address?

☐No ☐Yes (Explain) ______

9. Briefly explain the process by which outside requests for model results are handled. ______

10. Provide any other information that would help explain how your model is used. ______

V. Data for Passenger Forecasting

1. Does your model have a passenger component?

☐No (If No, skip all remaining questions in Section V.) ☐Yes

2. What were the primary sources of travel behavior data for your passenger modeling effort?

☐American Travel Survey (ATS)
☐MPO household survey(s) or panel(s)
☐Census journey-to-work data
☐Public-Use Microdata Samples (PUMS)
☐AMTRAK
☐FAA sample ticket data
☐Intercity bus service
☐*NCHRP Report 365*
☐*ITE Trip Generation*
☐Census Transportation Planning Package
☐Roadside survey(s)
☐GPS-based survey*
☐Other passenger railroad
☐Ferry service
☐Tourism survey
☐*NCHRP Report 187*
☐National Household Travel Survey (NHTS) normal sample
☐National Household Travel Survey (NHTS) add-on; Size of add-on: ______ samples
☐Own household survey (Explain. Please attach survey form.) ______
☐Own on-board bus survey(s) (Explain. Please attach survey form.) ______
☐Own on-board rail survey(s) (Explain. Please attach survey form.) ______
☐Other (Explain) ______

3. What were the primary sources of household socioeconomic data for your passenger modeling effort?

☐Census Transportation Planning Package
☐Other US Census
☐MPO databases
☐GIS maintained by you
☐GIS maintained by another agency within your state
☐GIS maintained by a neighboring state
☐A regional economic model
☐A state natural resources department
☐Local property tax records
☐School enrollment data
☐Commercial data vendor (Explain) ______
☐Federal agency other than Census (Explain) ______
☐Other (Explain) ______

4. What were the primary sources of traffic data for your passenger modeling effort?

☐Your own agency counts ☐Your own agency speeds
☐Your own agency travel times ☐Toll or bridge authority counts
☐Highway Performance Monitoring System (HPMS)
☐Counts, speeds, or travel times from another agency (Explain) ______
☐Other (Explain) ______

5. What were the primary sources of network data for your statewide modeling effort?

☐MPO networks
☐TIGER
☐National Highway Planning Network (NHPN)
☐Your agency road inventory or management system
☐Neighboring state agency road inventory(s) or management system(s)
☐Bus or rail published information
☐Other (Explain) ______

6. Did you obtain locally collected passenger data specifically for the modeling effort?

☐No ☐Yes

7. If Question 6 is Yes, list data collection efforts. ______

8. If Question 6 is Yes, how much did (will) the passenger data collection effort cost to complete the model?

______

9. Is there an ongoing passenger data collection effort primarily for support/update of the model?

☐No ☐Yes

10. About how often are passenger networks updated?

☐More often than yearly ☐About yearly
☐Less often than yearly but more often than every 5 years ☐Less often than every 5 years

11. What sources of passenger information are used to update networks?

☐Road inventory in your agency ☐MPO networks
☐Other (Explain) ______

12. What passenger data couldn't you get that you wish you could? ______

13. Were there serious problems with completeness of any passenger data set?

☐No ☐Yes (Explain) ______

14. Was GIS used for storing passenger forecasting data or networks?

☐No ☐Yes (Explain) ______

15. Were passenger networks or network data obtained from a GIS database?

☐No ☐Yes (Explain) ______

16. Place additional comments about passenger data here. ______

VI. Scale/Level of Detail Passenger Model

(If you do not have a passenger model, skip Section VI.)

1. What passenger modes are in the model?

☐Passenger automobile
☐Local bus
☐Intercity passenger rail (conventional)
☐Commuter rail
☐Passenger aviation
☐Other (Explain) ______
☐Intercity bus
☐Taxi
☐Intercity passenger rail (high speed)
☐Metro rail or light rail
☐Ferry

2. Which passenger modes have networks within the model?

☐Passenger automobile
☐Local bus
☐Intercity passenger rail (conventional)
☐Commuter rail
☐Passenger aviation
☐Other (Explain) ______
☐Intercity bus
☐Taxi
☐Intercity passenger rail (high speed)
☐Metro rail or light rail
☐Ferry

3. For what time period is the analysis?

☐24 hours (Weekday)
☐Peak hour
☐Other (Explain)
☐24 hours (Average day)
☐Peak period (Explain)

4. How many traffic analysis zones are used to represent areas within your state? ______ zones

5. How may traffic analysis zones are used to represent areas outside your state? ______ zones

6. How would you describe the zone structure within the urbanized areas of your state?

☐Adopted MPO zone structures
☐Aggregations of MPO zones
☐Census tracts or aggregations of census tracts
☐Other (Explain) ______

7. Does the model encompass most or all of the states in the U.S.?

☐No ☐Yes

8. Does the model encompass all or parts of Canada or Mexico?

☐No ☐Yes

9. How many special generators* are in the model? _______ generators

10. Do you have a minimum size threshold for passenger special generators*?

☐No ☐Yes (Explain) _______

11. What types of special generators* are in the model?

☐Not applicable ☐Universities ☐Military bases
☐Tourist attractions ☐Airports
☐Other (Explain) _______

12. How are special generators* modeled?

☐Not applicable
☐Trip rates from ITE *Trip Generation*
☐Trip rates from local trip generation studies
☐Growth factors or trends from actual trip making at sites
☐Other (Explain) _______

13. How many external stations are in the model? _______ stations

14. What trip purposes for passengers are included in the model?

☐Long distance commute ☐Long distance business
☐Long distance personal business ☐Long distance recreation/vacation
☐Long distance other ☐Home-based work
☐Home-based nonwork (home-based other) ☐Non-home based
☐Another purpose (Explain) _______

15. Are subzones used for any step in the model (e.g., traffic assignment)?

☐No ☐Yes (Explain) _______

16. How many links are in the passenger highway network? _______ links

17. Are two-way arterial streets counted as one link or two links?

☐One link ☐Two links
☐Other (Explain) _____

18. Provide any other information that would help explain the level of detail in your passenger model. _____

VII. Steps for Passenger Travel

(If you do not have a passenger model, skip Section VII.)

1. What structure would best describe your passenger model?

☐Three-step (trip generation, trip distribution, traffic assignment)
☐Four-step (trip generation, trip distribution, mode split, traffic assignment)
☐Other (Explain) ______

2. Does the passenger model use OD table estimation techniques (from traffic counts)*?

☐No ☐Yes (Explain) ______

3. What is the general structure of your passenger trip generation step for productions?

☐None, no productions
☐Linear equations or rates per level of activity
☐Rates as a function of income
☐Rates as a function of automobile availability
☐Cross-classification (Explain categories) ______
☐Other (Explain) ______

4. What is the general structure of your passenger trip generation step for attractions?

☐None, no attractions
☐Linear equations or rates per level of activity
☐Other (Explain) ______

5. What is the general structure of your automobile occupancy step?

☐None, generation is in vehicles already
☐One automobile occupancy value for all purposes
☐Automobile occupancy values for each trip purpose
☐Rates that vary with trip distances
☐Rates that vary with trip lengths in minutes or hours
☐Other (Explain) ______

6. What is the general structure of your trip distribution step for passengers?

☐Fratar factoring*
☐Gravity expression*, without composite impedances* (or disutilities) across modes
☐Gravity expression*, with composite impedances* (or disutilities) across modes
☐Logit expression*, distribution only
☐Logit expression*, joint between distribution and mode split
☐Other (Explain) ______

7. What is the general structure of your mode split step for passengers?

☐None, only one mode ☐Fixed shares
☐Logit expression*, mode split only ☐Nested logit*
☐Logit expression*, joint between distribution and mode split
☐Other (Explain) ______

8. Which assignment techniques are used for loading automobiles to a highway network?

☐All-or-nothing* ☐Dynamic all-or-nothing*
☐Stochastic multipath* ☐Static equilibrium (with or without trucks)*
☐Dynamic equilibrium* (with or without trucks) ☐Microsimulation (with or without trucks)
☐Other (Explain) ______

9. If your forecast is for a week day or an average day, how are forecasts done for peak periods or hours?

☐Peak period assigned directly ☐No factoring into peak
☐Factored by percent of traffic in peak from traffic counts
☐Other (Explain) ______

10. Are there any peak spreading mechanisms in the model?

☐No ☐Yes (Explain) ______

11. How are delays determined for assigned traffic?

☐Speed/volume curve(s); e.g., BPR curves*
☐Explicit traffic controls (signs, signals) from mesoscale techniques*; e.g., HCM*
☐Explicit traffic controls (signs, signals) from microscale techniques*; e.g., microsimulation
☐Other (Explain) ______

12. Provide any other information here about the steps of your passenger model. ______

VIII. Long Distance/Recreational/Tourism Travel for Passengers

1. Does your model have special treatment for long distance or recreational/tourism trips?

☐No (If No, skip all remaining questions in Section VIII.) ☐Yes

2. Are special times of year modeled to account for recreational and tourism trips?

☐No ☐Yes (Explain) ______

3. How are models of long distance or recreation/tourism integrated with the normal passenger travel demand models?

☐Not integrated ☐Specific trip purposes
☐Other (Explain) ______

4. How are long distance origin–destination tables created?

☐Gravity expression* ☐From OD data, then Fratar factored*
☐Other (Explain) ______

5. Are any techniques not normally associated with metropolitan travel demand models used for handling long distance or recreational travel?

☐No ☐Yes (Explain) ______

6. What special data sources were required to handle long distance or recreational travel?

☐None ☐ATS (American Travel Survey)
☐NHPN (National Highway Planning Network) ☐US Census
☐Economic data from a private vendor(s) ☐Employment data from public source(s)
☐Employment data from private vendor(s) ☐Special long distance travel survey(s)
☐HPMS (National Highway Performance Monitoring System)
☐NHTS (National Household Travel Survey) or NPTS
☐Other (Explain) ______

7. Provide any other information here about long distance/recreation/tourism components of your model.

______

IX. Freight/Commercial Vehicle Modeling

(If you do not have a freight model, skip Section IX.)

1. What is the overall structure of the freight model?

☐Direct forecast of vehicle flows without reference to commodities
☐Forecast commodity flows first, then forecast vehicle flows
☐Other (Explain) ______

2. If load weights (payload factors) are used to convert tons of commodities to vehicles, what is the source of that information?

☐Not applicable ☐Vehicle Inventory and Use Survey (VIUS)
☐Rail Carload Waybill Sample ☐Truck intercept studies
☐Data from another state or from an MPO
☐Other (Explain) ______

3. If monetary values of commodities are used to convert dollar flows of commodities to weight of commodities, what is the source of that information?

☐Not applicable ☐Commodity Flow Survey (CFS)
☐Local surveys of establishments ☐Data from another state or from an MPO
☐Other (Explain) ______

4. If the model converts yearly flows (or vehicles) to weekday flows or vehicles, how many weekday equivalents are there in a year? ______ equivalent days

5. What technique is used for vehicle or commodity distribution?

☐None ☐Fratar factoring*
☐Gravity expression* ☐Logit expression*
☐Other (Explain) ______

6. Does the freight model use OD table estimation techniques (from traffic counts)*?

☐No ☐Yes (Explain) ______

7. For which model steps are quick response methods (e.g., the *Quick Response Freight Manual*) used?

☐None ☐Trip generation
☐Trip distribution (gravity expression*) ☐Time of day
☐Other (Explain) ______

8. Which commodity flow data sets are used?

☐None ☐Reebie* (Transearch)
☐Commodity Flow Survey (CFS)
☐Other (Explain) ______

9. How are the commodities or sectors not covered by these commodity flow data sets accounted for? ______

10. If commodity flows are estimated in the model, how are commodity *production* totals estimated in each zone?

☐Not applicable
☐Derived from employment estimates and commodity output per employee
☐Other (Explain) ______

11. If commodity flows are estimated in the model, how are commodity *consumption* totals estimated for each zone?

☐Not applicable
☐Derived from employment estimates and commodity consumption per employee
☐Derived from household (or population) estimates and commodity consumption per household (or population)
☐Other (Explain) ______

12. Was input–output analysis* used to derive commodity consumption rates?

☐No ☐Yes

13. Are commodity (or vehicle) flows converted from large spatial units (e.g., counties) to small spatial units (e.g., traffic analysis zones)?

☐No ☐Yes (Explain) ______

14. How are commodities split to freight modes?

☐No commodities within model
☐Shares from data that vary with distance
☐Expert judgment
☐Some other mode split method (Explain) ______
☐Fixed shares from data (e.g., CFS or Reebie*)
☐Shares from data that vary with shipment size
☐Logit*, nested logit*, or pivot point* expression

15. How are commodities that are carried by truck split to vehicle types?

☐No commodities within model
☐Fixed shares from data (e.g., CFS or Reebie*)
☐Some other method (Explain) ______
☐Only one truck type
☐Expert judgment

16. Is a multiclass assignment* procedure used to mix truck traffic with automobile traffic?

☐No ☐Yes (Explain) ______

17. Which assignment techniques are used for loading trucks to a highway network?

☐All-or-nothing*
☐Dynamic all-or-nothing*
☐Stochastic multipath*
☐Static equilibrium* (with or without passenger vehicles)
☐Dynamic equilibrium* (with or without passenger vehicles)
☐Microsimulation (with or without passenger vehicles)
☐Other (Explain) ______

18. Is transshipment* of commodities explicitly handled in the freight model?

☐No ☐Yes (Explain) ______

19. If commodity shipment costs are part of any model step, how were these costs estimated? ______

20. Was any use made of the Freight Analysis Framework (FAF) within the statewide freight model?

☐No ☐Yes (Explain) ______

21. Was GIS used for storing freight forecasting data or networks?

☐No ☐Yes (Explain) ______

22. Were freight networks or network data obtained from a GIS database?

☐No ☐Yes (Explain) ______

23. Provide any comments here about your freight model. ______

X. Scale/Level of Detail Freight Model

(If you do not have a freight model, skip Section X.)

1. What freight modes are in the model?

☐Truck, general ☐Truck, for hire ☐Truck, private
☐Rail freight ☐Truck–rail intermodal ☐Air freight
☐Deep water shipping ☐Inland water shipping
☐Other (Explain) ______

2. Which freight modes have networks within the model?

☐Truck, general ☐Truck, for hire ☐Truck, private
☐Rail freight ☐Truck–rail intermodal ☐Air freight
☐Deep water shipping ☐Inland water shipping
☐Other (Explain) ______

3. What truck vehicle types are in the model?

☐All trucks together
☐Four-tire vehicles (vans, pickup trucks, etc.) ☐Single-unit with six or more tires
☐Heavy or combination
☐Other (Explain) ______

4. For what time period is the analysis?

☐24 hours ☐Peak hour
☐Peak period (Explain) ______
☐Other (Explain) ______

5. For your truck component how many traffic analysis zones are used to represent areas within the state?
______ zones

6. For your truck component how many traffic analysis zones are used to represent areas outside the state?
______ zones

7. Are subzones used for any step in the truck component of the model (e.g., traffic assignment)?

☐No ☐Yes (Explain) ______

8. Does the truck component encompass most or all of the states in the US?

☐No ☐Yes

9. Does the truck component encompass all or parts of Canada or Mexico?

☐No ☐Yes

10. How would you describe the freight zones outside of your state?

☐Counties or aggregations of counties
☐National transportation analysis regions (NTARs)
☐Bureau of Economic Analysis (BEA) regions or aggregations of BEA regions
☐States or aggregations of states
☐Other (Explain) ______

11. How many special generators* are in the truck network? ______ generators

12. Do you have a minimum size threshold for special generators*?

☐No ☐Yes (Explain) ______

13. What type of special generators* are in the model?

☐Rail yards
☐Seaports
☐Warehouses or distribution centers
☐Other (Explain) ______
☐Airports
☐Truck terminals
☐Pipeline terminals

14. Does the truck network differ in functional classes from the passenger highway network?

☐No passenger model ☐Same as passenger model
☐Differs from passenger model (Explain) ______

15. How many links does your truck network have? ______ links

16. How many commodity categories are separately identified in your freight model? ______ categories

17. Provide any comments here about the level of detail of your freight model, especially if you have networks for modes other than truck. ______

XI. Economic or Land Use Component Level of Detail

1. Does your model have an economic or land use forecasting capability?

☐No (If No, skip all remaining questions in Section XI.) ☐Yes

2. How many zones are used for land use or economic forecasting? ______ zones

3. How many industrial sectors* are in your land use or economic forecast? ______ sectors

4. How many household sectors* are in your land use or economic forecast? ______ sectors

5. If the economic or land use forecast is time-stepped (dynamic), at what interval is the model stepped?

☐Not time-stepped ☐Less often than yearly
☐Yearly ☐More often than yearly
☐Other (Explain) ______

6. Provide any comments here about the level of detail of your economic or land use forecasting component.

______

XII. Statewide/Urban Model Integration

1. Do the statewide and urban models share geographic systems such as zones or networks?

☐No ☐Yes

2. Is the statewide model used to develop external station forecasts for the urban models?

☐No ☐Yes

3. Are the urban models incorporated as part of the statewide model?

☐No ☐Yes (Explain) ______

4. Do statewide and MPO models use similar computational steps, trip purposes, base-year, or modes to promote compatibility?

☐No ☐Yes (Explain) ______

5. Does the statewide model provide impedances for use in the MPO models?

☐No ☐Yes (Explain) ______

6. Can the statewide model provide independent estimates of traffic in areas covered by urban models?

☐No ☐Yes

7. Are there institutional issues regarding the statewide model providing forecasts that might conflict with MPO models?

☐No ☐Yes (Explain) ______

8. Does your statewide model share GIS databases with MPO models?

☐No ☐Yes (Explain) ______

9. Provide any comments here about the integration of statewide and MPO models. ______

XIII. Validation

1. Was the model validated?

☐No (If No, skip all remaining questions in Section XIII.) ☐Yes

2. What data were used to validate the model?

☐Passenger vehicle counts ☐Truck counts
☐Counts of passengers on buses ☐Counts of passengers on trains
☐MPO origin–destination studies ☐MPO models
☐Goods production by sector or zone
☐Commuting OD flows from Census Transportation Planning Package (CTPP)
☐Comparisons to national default trip generation values
☐Comparisons to average values from similar states or cities
☐Comparisons to average values from own travel surveys
☐Known trip length frequency distribution(s)
☐Other (Explain) ______

3. What were the validation criteria?

☐Link root mean square error (RSME) by volume strata
☐Correlation coefficient between link volume forecasts and counts
☐Link absolute deviation
☐Screenline count absolute deviation
☐Cordon count absolute deviation
☐VMT by functional class absolute deviation
☐Other (Explain) ______

4. Did you use the "Model Validation and Reasonableness Checking Manual"?

☐No ☐Yes

5. How well did it validate? ______

6. Was OD table estimation (from traffic counts)* used ahead of any validation?

☐No ☐Yes

7. Do the validation criteria for your statewide model differ from urban models in your state?

☐Same
☐Statewide model is less stringent than urban models
☐Statewide model is more stringent than urban models
☐Other (Explain) ______

8. Provide any other information that would help explain your validation process. ______

XIV. Postprocessing

1. Do you use a postprocessor for air pollution emissions?

☐No ☐Yes (Explain) ______

2. Do you use a postprocessor for benefit/cost analysis?

☐No ☐Yes (Explain) ______

3. Do you use a postprocessor for level of service determination?

☐No ☐Yes (Explain) ______

4. Do you use a postprocessor for economic impact?

☐No ☐Yes (Explain) __________

5. Do you use any other postprocessors?

☐No ☐Yes (Explain) __________

6. Please explain any other postprocessing of model outputs that is notable or innovative. __________

Thank you!

Please return the questionnaire to Alan Horowitz by February 15, 2005

Explanation of Less Common Terms

All-or-nothing traffic assignment: All traffic between an origin and destination is assigned to the short path between that origin and destination and no traffic is assigned to any other path.

Behavioral principles: Modeling philosophy that seeks to determine the amount and location of travel by looking at components of traveler decision processes. A model based on behavioral principles would differ substantially from one based entirely on empirical findings, such as growth factor methods.

BPR curve: A simple expression that computes speed as a function of volume, originally developed at the Bureau of Public Roads.

Composite impedance (*or composite disutility*)*:* A measure of the separation between an origin and a destination (often as a function of travel time, travel cost, and convenience) that takes into consideration the accessibility of more than one mode between the origin and destination.

Dynamic all-or-nothing assignment: See "all-or-nothing assignment." Trips are assigned within small intervals of time, so as to track the progress of trips over time between their origins and destinations.

Dynamic equilibrium traffic assignment: An application of equilibrium principles (see "static equilibrium traffic assignment") where trips are also assigned within small intervals of time, so as to track the progress of trips over time between their origins and destinations.

Fratar factoring: A technique for forecasting origin-to-destination trip patterns by applying row and column factors to an existing origin–destination table.

GPS-based survey: Use of the global positioning system to trace the location of a traveler or vehicle over time, which would be linked to a travel diary.

Gravity expression: Sometimes called a "gravity model," which determines the production-to-attraction trip pattern as a function of the number of productions and attractions in each zone and measures of proximity between zones.

HCM: Highway Capacity Manual.

Household sectors: Groups of households within an economic or land use model, usually organized by economic status or life-cycle status.

Industrial sectors: Groups of similar businesses, usually organized by type of product or service.

Input–output (*IO*) *model:* A type of economic model that tracks flows of revenue (or sales) between industries and households in a national or regional economy. An IO model is organized by sectors. A single cell in an IO table would list the amount of revenue gained by a producing sector that comes from a consuming sector.

Logit expression: Sometimes called a logit model, a method for determining the number of people who will make a particular choice (such as mode or destination) given the "utilities" of each alternative.

Mesoscale traffic simulation: A traffic simulation using delay estimation procedures that involve interactions between lanes of flow.

Microscale traffic simulation: A traffic simulation that tracks the location and performance of individual vehicles.

Multiclass assignment: A method of traffic assignment that separately accounts for different vehicle classes.

Nested logit: The use of two or more logit expressions to determine the number of people who will make a particular choice, when the decision process is assumed to contain a sequence of preliminary choices.

OD table estimation from ground counts: A method of determining the origin–destination patterns of vehicles by using observations of ground counts. OD table estimation usually requires a good guess as to the OD patterns, often referred to as a "seed" or "prior" table.

Pivot point expression: A simplified version of a logit expression that has just one variable in the measure of a trip's "utility."

Reebie: A company that sells commodity flow data and related services.

Special generator: A business or other activity site that is so large or so specialized that it should not be included in standard trip generation calculations. A special generator may have a separate zone in the model, or their trips may be added to those coming from more general land uses in a zone.

Static equilibrium traffic assignment: A method by which traffic is assigned such that travel times on links are consistent with volumes and such that volumes are consistent with travel times.

Stochastic multipath assignment: Traffic between an origin and destination is divided across many paths between that origin and destination, with the shortest path usually getting the largest share.

Transshipment: Goods shipment with multiple legs of the journey, with short-term storage between the legs.

APPENDIX C

Literature on Statewide and Intercity Passenger Travel Forecasting

This appendix was principally written by David Farmer, with contributions from Alan Horowitz. The material has been excerpted from the *Guidebook on Statewide Travel Forecasting Models*.

INTERCITY PASSENGER LITERATURE

Intercity travel is a broad heading that includes statewide travel. As used here, the term "intercity" forecasting involves the prediction and assignment of traffic volumes between cities or other points of interest that are separated by some significant distance. The term intercity is also used to distinguish these models from "urban" models, which typically involve travel between more closely spaced points of interest within a localized area. Intercity models include corridor, statewide, regional, and national models. Statewide models are therefore a subset of intercity models. The main point, first expressed as early as 1960 (*C1,C2*), is that the characteristics of intercity travel are inherently different from those of travel within an urban area. It is assumed that people travel according to a somewhat different set of rules over longer distances and between metropolitan areas. The intercity models encountered in the literature are often associated with an academic exercise, and therefore make use of fewer, more carefully chosen origin–destination (OD) pairs than would normally be included in a meaningful statewide model. Consequently, they generally present situations that are a little more abstract in nature. The similarities to statewide models are many.

Types of Intercity Passenger Models

A number of reviews have been made of the early history of intercity modeling (*C3–C7*) and most include some discussion of the taxonomy of intercity models. Intercity models can essentially be divided into four types on the basis of two categories: data and structure. The models can make use of either aggregate or disaggregate data, and can be of a direct-demand or sequential structure. The four resulting combinations are: (1) aggregate direct-demand models, (2) aggregate sequential models, (3) disaggregate direct-demand models, and (4) disaggregate sequential models. Intercity travel demand models can be further classified by whether they encompass only a single mode (mode-specific) or multiple modes (total demand), and by which trip purposes they include.

Aggregate data make use of the socioeconomic data for the OD pairs in the model and can also include the service characteristics of the modes of travel between them. Disaggregate data go further to examine the motives and characteristics of the trip makers at an individual or household level and are typically used to generate the probability that a particular trip is taken or mode is used. In terms of model structure, a direct-demand model is one that calculates all of the desired travel information in one, singly calibrated step. (Direct-demand models are sometimes called econometric models because of their resemblance to statistical models of economic demand.) A sequential model, on the other hand, divides the modeling process into several individually calibrated steps. The urban "four-step" modeling process, which many departments of transportation (DOTs) have adopted for the statewide modeling purposes, presents the quintessential example of a sequential model.

Aggregate Direct-Demand Models

The earliest intercity models were of the direct-demand type and were developed in the 1960s as part of an examination of the Northeast Corridor (*C6*). The most famous of these was Quandt and Baumol's abstract mode model (*C8*). The reader is referred to the reviews referenced in the previous section [especially Koppelman et al. (*C6*)] for a more complete historical perspective of significant intercity modeling efforts. The following direct-demand models—some of which are not mentioned in those references—are noted here because they possess features that might prove useful to modeling at the statewide level.

A notable early innovation was attempted by Yu (*C9*). Yu took the standard direct-demand formulation—regressed from cross-sectional data—and recognized that the elasticities present in the cross-sectional data would not necessarily remain constant over time. His paper presents two single-purpose (one for business travel and one for personal travel) direct-demand models in which the regression coefficients each include a time–series component. It is a novel idea that does not appear to have been picked up by succeeding authors. Another innovative idea is found in Cohen et al. (*C10*). Here, as part of two single-purpose (business and nonbusiness) direct-demand models, the authors propose to use a pivot-point procedure. The procedure is intended to eliminate the effects (on the traffic volumes to be forecasted) that result from variables that have been excluded from the models. Description of the pivot-point procedure is brief, however, and use of this procedure does not seem to have been adopted by other researchers.

By the late 1970s, direct-demand models were being constructed to include an increasingly wider range of variables to account for the enormous variety of factors that influence travel behavior. Models presented by Peers and Bevilacqua

(*C11*) and Kaplan et al. (*C12*) give some sense of this trend. Peers and Bevilacqua describe a model that includes a long list of policy-sensitive variables, arranged into three groups: (1) extensive variables, including population and employment; (2) intensive variables, including persons per household, income per household, and employment per acre; and (3) system variables, including travel speeds and costs. Meanwhile, Kaplan et al. describe their Passenger Oriented Intercity Network Travel Simulation (POINTS) model, a multimodal model that explicitly includes consideration of accessibility to the transportation system. Both of these models provide a bridge from an earlier emphasis on aggregate modeling to the growth in disaggregate modeling research by the early 1980s.

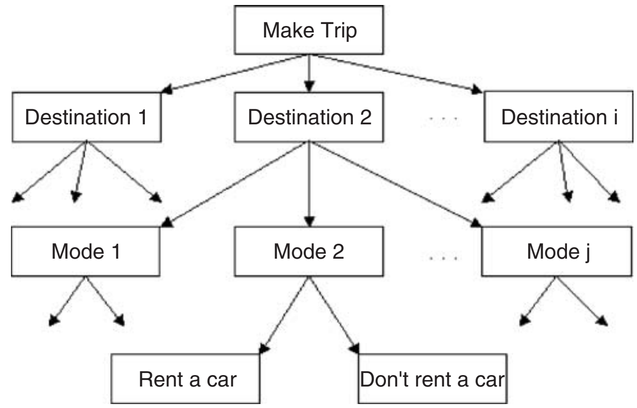

FIGURE C1 Structure of Morrison and Winston's model.

Disaggregate Sequential Models

One of the first applications of disaggregate (or behavioral) modeling was for the mode-choice step of sequential models. It is possible to develop a mode-choice model without disaggregate data, as DiRenzo and Rossi did, using a "reasoned diversion model" (*C13*). Disaggregate models, however, typically use a logit formulation to provide a convenient way of including a number of mode-abstract, transportation accessibility, policy-related, and behaviorally based variables in the modeling process. Owing to parallel research in urban area forecasting in the early 1980s, these models became more attractive. They were thought to be especially useful in the effort to estimate the shifts in mode share that were expected from deregulation in the air and intercity bus industries, and from the anticipated implementation of high-speed rail transportation (*C14,C15*). Again, Koppelman et al. (*C6*) provides a review of many of the earlier disaggregate mode choice models. In addition, Miller (*C16*), Forinash (*C17*), and Forinash and Koppelman (*C18*) provide studies of the various structures (binomial, multinomial, and nested-multinomial) available to more realistically represent the cross-elasticities between modes and to eliminate irrelevant alternatives in the logit mode-split formulation.

Armed with an increasing understanding about the implementation of disaggregate modeling techniques and fueled by the increasing availability of disaggregate data, several researchers have developed complete travel-demand models based on the analysis of disaggregate data in a number of discrete, nested steps. Morrison and Winston, for example, present multimodal models (one for vacation travel and one for business) with the hierarchical structure shown in Figure C1 (*C19*). Similarly, Koppelman (*C20*) and Koppelman and Hirsh (*C21,C22*) present a multimodal model with a structure shown in Figure C2. Morrison and Winston make use of the 1977 National Travel Survey data, whereas Koppelman and Hirsh use both the National Travel Survey and the 1977 National Personal Transportation Survey (NPTS) data. Both pairs of researchers sought to use this disaggregate data in a model structure that mimics the behavioral logic of trip making.

One Disaggregate Direct-Demand Model

Another model of interest is the disaggregate direct-demand model developed in the 1980s by the Egypt National Transportation Study (*C23–C25*). The Egyptian Intercity Transportation Planning Model estimates travel on seven modes for travelers in three income levels. It is unusual in its use of disaggregate data in a single equation (direct-demand) format. Also, unlike many intercity passenger models, it includes capacity restraints on the network, most notably for the shortage of passenger rail cars. Because it deals with a very practical situation, the Egyptian model could reasonably be noted in the section of this appendix describing statewide forecasting techniques; however, because the transportation situation in Egypt is sufficiently an abstraction of the situation in the United States, it seems fitting to include it with the intercity models. It might also be noted that, in its treatment of rail car capacity restraints, it resembles some freight models, as well.

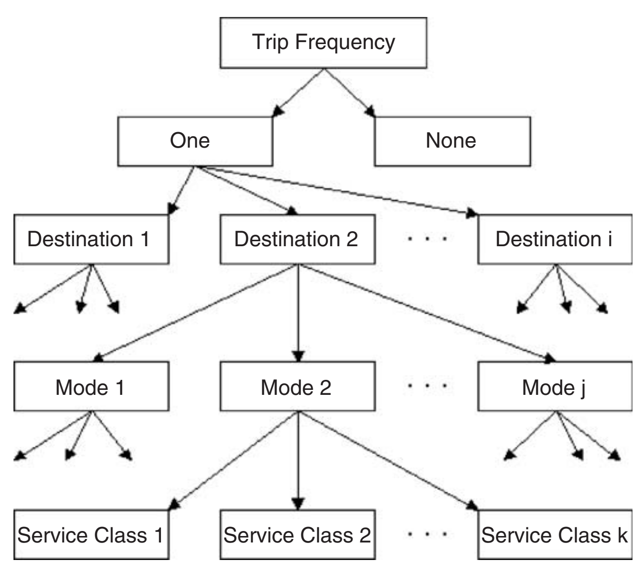

FIGURE C2 Structure of Koppelman and Hirsh's model.

Single-Mode and Single-Purpose Models

Besides the ubiquitous single-mode automobile models, there are two other types of single-mode models of interest: bus and air. (Most passenger rail models are a part of a multimodal model.) Modeling of intercity bus travel has proven to be difficult (*C26*) and examples of intercity bus models are rare. One interesting bus model is presented by Neumann and Byrne (*C27*). His model describes a probabilistic (disaggregate) model based on a Poisson distribution of ridership, as opposed to a regression model. He concludes that this formulation provides a simpler and more reasonable estimate of ridership on rural bus routes.

Several air travel models are also of interest. As early as the 1960s it was recognized that the year-to-year growth in air travel makes the use of time–series techniques valuable, and a 1968 paper by Brown and Watkins (*C28*) addresses this issue with simple linear regression techniques. A later paper by Oberhausen and Koppelman (*C29*) also looks at time–series analysis of air traffic patterns using a Box–Jenkins procedure to account for cyclical (seasonal and yearly) variations in travel behavior. In another study, Pickrell (*C30*) uses a combination of techniques to assess future trends in intercity air travel. Pickrell uses a single-mode direct-demand model to estimate the total demand for air travel. At the same time, he uses an aggregate mode-choice model to predict the percentage of market share that the air mode could generate under several alternative futures. Other air travel models of interest include a regression analysis of travel between small cities in Iowa by Thorson and Brewer (*C31*), and an elaborate direct-demand model of intercity air travel based on quality-of-service measures by Ghobrial and Kanafani (*C32*).

Finally, the one other single-purpose intercity model worth noting is the disaggregate model of recreational travel presented by Gilbert (*C33*). Gilbert's model is sufficiently abstract to be included here with the other intercity models, but more will be said about recreational travel models in Section 2. It should be sufficient to state here that Gilbert's paper, published in 1974, is one of the latest papers found to specifically address the recreational trip purpose.

Discussion

As will be seen in the following sections, the intercity forecasting techniques employed in most existing statewide models are principally those of the aggregate sequential type. This is partly owing to the strong traditions of and training in the four-step modeling process, but it is also the result of the general failure of disaggregate techniques at a statewide scale. Although disaggregate models are attractive because of their ability to include the behavioral aspects of travel, their principal drawback is the lack of sufficient disaggregate data for calibration of statistically meaningful statewide models. Until further data are available, their use will remain limited.

It should also be noted that there is a place for aggregate direct-demand models at a statewide scale. This econometric type of model can be especially useful in tying the forecast of single quantity (e.g., annual vehicle-miles traveled or emissions) to forecasts of socioeconomic data.

STATEWIDE PASSENGER FORECASTING LITERATURE

Despite the amount of research involving the characteristics of intercity travel and its concentrations on econometric models and probability-based models, passenger travel forecasting, as practiced by the various state DOTs, has remained much more basic. In most of the states contacted as part of the research for this appendix no travel modeling is done on a statewide level. At the majority of state DOTs, forecasting is done for specific projects only, and forecasts are made based on historic trends, rather than on some formal model.

For the states that are engaged in some type of modeling process, the models used are all "four-step" models, with a modeling procedure borrowed almost entirely from the urban transportation planning (UTP) process. This is likely a function of the ready availability of urban modeling software and personnel trained to use it. As early as 1967, Arizona and Illinois had developed UTP-style models (*C34*), and by 1972 at least 19 different states were using or preparing statewide models (*C35*). Modeling activities were evidently so popular that in 1973 FHWA perceived the need to standardize the thinking about statewide modeling, and issued a guidebook on the subject (*C36*)—effectively institutionalizing the UTP-style model for statewide use. The enthusiasm for developing statewide models that was present in the late 1960s and early 1970s soon waned, however, whether owing to funding cuts or to frustration with the model results, and little activity seems to have taken place [studies in Florida and Kansas (*C37–C39*) were an exception until very recently]. Apparently, only Connecticut, Kentucky, and Michigan have been continuously developing models from the earlier period.

By the early 1990s, prompted by new federal legislation (Clean Air Act Amendment of 1990 and Intermodal Surface Transportation Efficiency Act of 1991), several states were rethinking their strategies. New Mexico (*C40*) and Texas (*C41*) produced interesting reports that outline this renewed focus on statewide modeling. The New Mexico report addresses both passenger and goods movement models within the broader context of statewide transportation planning. The Texas report, which includes reviews of circa-1990 models from Florida, Kentucky, and Michigan, concentrates more on the details of statewide modeling, especially the difficulties in isolating interzonal trips and the proliferation of "K-factors" in recent models. Despite this promising trend, neither New Mexico nor Texas is currently involved in statewide modeling. (Texas is, however, scheduled to issue a request for proposal for a model development contract in the fall of 1997.] A list of states contacted that sent information about their current passenger modeling efforts is presented in Table C1, and these are discussed below.

TABLE C1
CURRENT STATEWIDE PASSENGER MODELS

State	TAZs	Modes	Purposes	Comments
Connecticut	1,300 total	1. SOV 2. HOV 3. Bus 4. Rail	1. HBW 2. HBNW 3. NHB	• Mode split based on LOS information • Iterative-equilibrium assignment for highways
Florida	440 internal 32 external	Highway vehicles only	1. HBW 2. HB shop 3. HB soc./rec. 4. HB misc. 5. NHB 6. Truck/taxi	• All trips are modeled to maximize use of MPO models • Gravity friction factors based on MPO urban models • Mode split is auto occupancy only based on production zone • Extensive use of K-factors
Indiana	500 internal 50–60 external	1. Auto 2. Truck 3. Transit	1. HBW 2. Other business 3. HBO 4. NHB 5. Recreational 6. Truck	• Under development • Internal TAZs at the township level • Aggregate mode choice
Kentucky	756 internal 706 external	Auto only	1. HBW 2. HBO 3. NHB	• Model includes a large portion of surrounding states • NPTS national average data used for trip generation
Michigan	2,392 total	Auto only	1. HB work/biz. 2. HB soc./rec./vac. 3. HBO 4. NHB work/biz. 5. NHB other	• All trips modeled—previous models did not consider local trips • Two possible mode split models: (1) simple cross-classification and (2) LOS-based • LOS-based mode split model still under development • NTPS data used for calibration; CTPP data used for validation • Extensive use of K-factors
New Hampshire	1 per 5,000 pop.	1. SOV 2. HOV2 3. HOV3+ 4. Bus 5. Rail	1. HBW 2. Business related 3. Personal 4. Shopping 5. Recreational 6. Other	• Under development • Logit trip generation and distribution • Time of day and seasonal factors
New Jersey	2,762 internal 51 external	—	—	• Model created by merging five MPO models
Vermont	622 internal 70 external	Highway vehicles only	1. HBW 2. HB shop 3. HB school 4. HBO 5. NHB 7.Truck	• Based on extensive statewide survey
Wisconsin	112 internal 45 external	1. Auto 2. Air 3. Rail 4. Bus	1. Business 2. Other	• Under development • No external trips considered • Network used only to develop impedances for mode share calculations
Wyoming	5 internal 5 external	1. Auto 2. Truck	—	• Model created mostly to demonstrate techniques • Summer weekend travel is modeled • Full trip tables estimated using entropy maximization technique

Notes: TAZ = transportation analysis zone; SOV = single-occupancy vehicle; HOV = high-occupancy vehicle; HBW = home-based work; HBNW = home-based nonwork; NHB = nonhome-based; MPO = metropolitan planning organization; LOS = level of service; CTPP = Census Transportation Planning Package; HBO = home-based other; NPTS = National Personal Transportation Survey.

Data Collection for Passenger Travel

Ideally, travel forecasts are based on some sort of travel data. One obvious source of travel data is the survey. Surveys have been conducted at the statewide level since the earliest days of highway modeling (*C42*), and continue to be conducted at the statewide level (*C43,C44*). However, they are relatively expensive to conduct and must be supplemented by other data. Two other options make use of data that are already available: federal survey data and statewide traffic counts. U.S. Census data have always been valuable as inputs to travel modeling. The 1990 Census improved on this by including a journey-to-work survey, and by introducing the Census Transportation Planning Package (*C45*). The journey-to-work has proven especially useful in estimating home-based work trips on a statewide level, but has been criticized for its lack of information about other purposes (*C46*). The Census Transportation Planning Package provides transportation-related information at a transportation analysis zone level, which can be readily aggregated into township- or county-level data for statewide modeling. Another federal data source is provided by the U.S.DOT, which conducted its most recent NPTS in 1995. The NPTS data, which measure some intercity travel, have been used in the development of a number of statewide models. In addition to the aforementioned federal government sources, it should also be noted that estimated and forecasted data are also available from a wide variety of state, academic, and commercial sources.

Of course, for many years state DOTs have had in place systems of traffic counting equipment operating at a statewide scale. Research in the early 1980s (*C47–C49*) developed statistical methods of clustering together traffic counts on different roads based on their similar functional and geographical characteristics. In association with the introduction of FHWA's *Traffic Monitoring Guide* in 1985 (*C50*), Pennsylvania (*C51*), Washington State (*C52–C54*), and New Mexico (*C55,C56*) began to reevaluate their traffic monitoring systems to take advantage of clustering. The result is a larger and more statistically valid collection of traffic count data available for use in travel forecasting.

Data Synthesis for Passenger Travel

Even with advanced systems for traffic data collection, it is difficult for a state DOT to collect enough data to account for all of the likely paths between OD pairs being examined. To get around this difficulty, optimization methods have been developed to synthesize trip tables from available traffic count information (*C57–C59*). These methods have subsequently been applied to statewide analyses in Wyoming (*C60,C61*). Attempts have also been made to synthesize trip tables from census data at a sub-state level in New Jersey (*C62*).

Trend Analyses of Passenger Travel

As noted earlier, many of the DOT officials contacted for this appendix indicated that the only forecasts they make are not based on models, but are instead based on the extrapolation of trends observed in historical data. The Minnesota DOT has formalized this process as it applies to forecasting traffic for their state trunk highways (*C63*); however, such documentation seems to be the exception. Some indication of the possibilities of trendline analysis is given in a paper by Harmatuck (*C64*) for the Wisconsin DOT. In it he provides further insight into the particular ways of dealing with traffic data as a time–series. In addition, at least one state contacted for this appendix indicated that a growth factor method, similar to the method outlined for updating coverage counts in FHWA's 1992 *Traffic Monitoring Guide* (*C65*), is used for forecasting purposes. Otherwise little information is available on travel forecasting techniques in the absence of a statewide model.

Statewide Models of Passenger Travel

Of the states contacted as part of the research for this appendix, those having ongoing modeling efforts sent documentation of their progress. A summary of the passenger models in existence or under development is presented in Table C1. This includes work done in Connecticut (*C66,C67*), Florida (*C68,C69*), Indiana (*C70*), Kentucky (*C71*), Michigan (*C72*), New Hampshire (*C73*), New Jersey (*C74,C75*), Vermont (*C76*), Wisconsin (*C77*), and Wyoming (*C60,C61*). In addition to the states cited in Table C1, California has a statewide model, but it is being redesigned; therefore, documentation is currently unavailable. Oregon is also in the early stages of developing a comprehensive forecasting model that will include a land use element (*C78*). Several other states are currently in the initial stages of modeling projects—issuing requests for proposals to interested consultants.

As can be seen from Table C1, most of the models consider a large number of trip types (as many as five or six), but only a few modes. All of the models are of the four-step style. All use fairly standard UTP procedures, except for the model under development for New Hampshire. New Hampshire proposes to use logit formulations for trip generation and distribution. The Wisconsin model is unique in that it is essentially an intercounty model, with comparatively few transportation analysis zones. The Florida and New Jersey models are also interesting in the degree to which they have attempted to incorporate existing metropolitan planning organization models into the statewide modeling effort. The Kentucky and Michigan models are two of the more recent useable models from states with long histories of model development and are representative of the current state of the practice.

Recreational Travel Models

As early as 1963, recreational trips were considered an important enough purpose to warrant separate study (*C79*). Indeed, in the late 1960s and early 1970s NCHRP (*C80*), Indiana (*C81,C82*), Kentucky (*C83,C84*), and other states (*C85,C86*) conducted studies of the special characteristics of recreational travel. However, although Americans seem to have dedicated an increasing amount of time to pursuing recreational activities, the last of these studies was published more than 20 years ago. Because many state economies depend heavily on recreational activities, it would seem that this trip type might be important enough to require a closer examination than it has received in the past two decades.

Discussion

Using trendline procedures in statewide forecasting is probably better than not forecasting at all, especially for short-term planning horizons where large variations from recent trends are less likely. The use of travel forecasting models, however, grounds the forecast in the underlying statewide and national socioeconomic trends. Although these socioeconomic trends are themselves forecasts, it is hoped that they broaden the basis of the transportation model sufficiently to provide a more reasonable forecast of future travel.

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APPENDIX D

Annotated Bibliography of Statewide Freight Forecasting

This appendix presents material originally developed for NCHRP Project 8-43, "Methods for Forecasting Statewide Freight Movements and Related Performance Measures." The appendix was written by Alan J. Horowitz, K. Ian Weisser, Cheng Gong, and Joe Blakeman.

INTRODUCTION

A review of current planning practice indicates that the field of statewide travel forecasting is still in flux; a consensus does not exist as to the best way to construct a model for any given set of policy needs or planning requirements. States modeling efforts fall into one of these four categories:

1. No model—Specialized studies work from existing proprietary or public databases or from locally collected data.
2. Truck model—Truck models are used to account for the congestion effects of freight on highways or to help determine equivalent single-axle loads (ESALs) for pavement design purposes.
3. Commodity-based four-step model—Commodity-based models follow the same steps as passenger models, except that trip generation is performed for weight of commodities by groups of commodities.
4. Economic activity model—Economic activity models trace the flows of commodities between economic sectors and between zones. Economic activity models are often implemented within a framework that also forecasts the locations of employers and residences.

There is considerable variation in how statewide freight models have been implemented.

In addition to those models currently being used by states there is a large variety of models that have been implemented for such purposes as international trade, national trade, energy policy, and corridor studies. Furthermore, there are older statewide freight models that have been inactivated, models currently under development, international freight models, general guidelines as to how statewide freight models may be built, numerous academic studies that attempt to improve freight forecasting methodology, time–series methods of directly forecasting vehicular traffic on facilities, and research and development intended for passenger forecasting that carries over to freight.

OVERVIEWS OF STATEWIDE TRAVEL FORECASTING

There have been two notable attempts to define the scope and content of a statewide freight model. The first attempt was *NCHRP Report 260: Application of Statewide Freight Demand Forecasting Techniques*, and the second attempt was the *Guidebook on Statewide Travel Forecasting*. Before discussing these two reports, it is necessary to define "OD table factoring and assignment" as a widely used methodology of statewide freight forecasting.

Origin–Destination Table Factoring and Assignment

A frequently used method of freight forecasting can be described as origin–destination (OD) table factoring and assignment. This method (with some variation) has been used by many states, the I-10 corridor study, and FHWA's Freight Analysis Framework (FAF). The most prevalent application of this method follows these general steps.

1. Obtain base year OD tables (in tons per year) by commodity and by mode that matches the desired traffic zone system. Typically, flows between external zones that do not pass though the internal portions of the network are excluded.
2. Obtain base year and future year levels of economic activity (by industrial sector) for all zones.
3. Establish a mapping between industrial sectors and commodity categories, such that a percent increase in an industrial sector can be associated with a percent increase in a commodity.
4. Determine the percent increase in each commodity's origins and destinations by applying growth factors obtained in steps 2 and 3.
5. Apply Fratar factoring to each OD table to achieve the percent increases determined in step 4.
6. Determine the number of vehicles necessary to carry each OD flow for one equivalent weekday.
7. Assign each factored vehicle trip table to its respective modal network.

This method assumes that the mode split for any given commodity and for any given OD pair is a constant. Any modal shifts that occur in this method are the result of growth (or decline) or spatial shifts in economic activity and the consequential effects on commodity production and consumption patterns. Shifts owing to changes in costs, supply chain practices, shipping and transfer times, or vehicle technology are not included.

The method further assumes that the production, consumption, and shipping characteristics of commodities remain unchanged. Such assumptions can be eliminated by careful consideration of changes in (a) shipping density of commodities, particularly the result of packaging materials; (b) worker productivity when economic activity forecasts are given in number of workers in an industry; (c) value per ton when economic activity forecasts are given in monetary units; (d) the routing patterns of the supply chain; and (e) competitiveness of modes or intermodal combinations to carry specific commodities.

Those who have tried this method have had to account for important commodity flows that were not included in the original OD tables. In addition, it is necessary to adjust for the number of empty vehicles.

NCHRP Report 260: Application of Statewide Freight Demand Forecasting Techniques

Memmott, F., *NCHRP Report 260: Application of Statewide Freight Demand Forecasting Techniques*, Transportation Research Board, National Research Council, Washington, D.C., Sep. 1983, 210 pp.

This report was the first major effort to devise a standard method for statewide freight forecasting. The proposed method was based on the generalized procedure of OD table factoring and assignment. A considerable amount of space in the report was devoted to effectively exploiting existing data sources, to forecasting of future consumption of commodities, and to determining the costs of commodity shipment for the purposes of mode split.

The report assumes that commodity production is directly related to employment in industries that produce the commodity. For estimating consumption, the use of an input/output (I-O) table is recommended. Commodity consumption calculations follow a three-step process: (1) obtain an I-O table, (2) convert dollar amounts to tons and sum the columns of the table to find consumption by industry, and (3) allocate tons to counties [the assumed transportation analysis zone (TAZ) size] according to the employment by consuming industries and population (for final demand) in each county. These steps embody several assumptions, which are explained. The production and consumption estimates can be applied to an existing commodity-flow matrix or (in the absence of a matrix) incorporated into a gravity model of shipment distribution. Methods of forecasting industrial activity are described.

For mode split, the assumption is made that all shipments between a pair of counties of a given commodity are allocated to lowest cost mode among those available between the pair. The report goes on to develop a procedure for estimating the cost of shipment by truck, railroad, and barge. No mention was made of air freight or intermodal. All of the cost data are now obsolete, but the terms included in the cost equations are still relevant.

Truck cost is composed of insurance, driver wages and benefits, driver expenses, fuel, overhead, licenses and permits, ton-mile taxes, federal highway user taxes, tractor capital cost, tractor maintenance, tractor tire cost, trailer capital cost, trailer maintenance, trailer tire cost, stop and delay costs, and terminal cost.

The recommended method of rail costing was the Uniform Rail Costing System developed for the Interstate Commerce Commission, which needed a fair method for setting tariffs. Few details are provided on the operation of the computer program, which performs its cost estimates by referencing an extensive database of actual rail costs. The program reports line-haul costs, terminal costs, freight car costs, cost of specialized services, and costs of loss and damage.

Barge cost is composed of many components including terminal costs, ownership costs, towing costs, and switching costs. The barge cost module assumes an empty backhaul. Highly detailed information is required about the conditions of the shipment, including the specific origin and destination, tons per barge, towboat horsepower, barge investment, interest rates, and user fees.

Statistical rate equations to estimate tariffs for both truck (private, truck-load, and less-than-truck-load) and rail (trailer-on-flatcar and carload) are provided. These equations use such independent variables as distance, shipment size, value of the commodity, density, region of the country, rail car ownership, state of matter (liquid, gas, and particulate), and type of terminal at beginning and end of the haul. Shipper costs are added to the modal costs and represent the additional logistics cost borne by the shipper when choosing a specific carrier or mode. These costs include loss and damage, pick up and delivery, ordering, warehousing, inventory, and the possibility of running out of stock.

Guidebook on Statewide Travel Forecasting

Horowitz, A.J., "Freight Forecasting," Chap. 4, In *Guidebook on Statewide Travel Forecasting*, Report FHWA-HEP-99-007, Federal Highway Administration, Washington, D.C., July 1999.

Most of this guidebook relates to passenger travel forecasting, but one chapter deals exclusively with freight forecasting. This chapter outlines a general method for statewide freight forecasting and draws a distinction between statewide and urban freight models. The chapter is organized according to the four steps of a standard urban transportation planning model (trip generation, trip distribution, model split, and traffic assignment) plus network development. At each step, the report emphasizes the need to use existing secondary data sources. The general method has 10 steps.

1. Obtain modal networks,
2. Develop commodity groups,
3. Relate commodity groups to industrial sectors or economic indicators,
4. Find base year commodity flows,
5. Forecast growth in industrial sectors,
6. Factor commodity flows,
7. Develop modal costs for commodities,
8. Split commodities to modes,
9. Find daily vehicles from load weights and days of operation, and
10. Assign vehicles to modal networks.

A range of options is suggested for many of these steps. Some specific recommendations are as follows:

- Spatial unit of analysis—counties are the most convenient spatial unit within states.
- Networks—network should cover all 48 contiguous states, but focus on the state of interest. Modal networks outside of the state of interest can be adapted from secondary sources.
- Selection of modes—modes should be defined consistent with the Commodity Flow Survey.
- Selection of commodity groups—commodity groups should be developed from Standard Transportation Commodity Codes (STCCs) or Standard Classification of Transported Goods, disaggregated to the two-digit level.
- Trip generation—good production generation relationships for commodities can be established by relating industry output to an economic indicator for that industry, such as employment. Good consumption generation relationships can be developed by applying the data in an I-O table.
- Trip distribution—a gravity model is a good way of representing commodity flows between the production and consumption zones. Such a model can be calibrated to existing data, such as the Commodity Flow Survey.
- Mode split—mode split can be handled by a number of techniques, but the complex cost calculations of *NCHRP Report 260* should be avoided. Mode split techniques include application of historical fixed shares, aggregate demand formulations, the logit relation, the pivot-point relation, and elasticity methods.
- Traffic assignment—all-or-nothing traffic assignment is recommended; however, impedances should be adjusted to account for biases caused by shippers defining an optimal route differently from the shortest path as indicated by traffic speeds.

EXTENDED EXAMPLES OF STATEWIDE FREIGHT FORECASTING MODELS: OTHER NOTABLE STATEWIDE FREIGHT MODELS

Oklahoma Model

TranSystems Corporation, *Oklahoma Statewide Intermodal Transportation Plan Freight Report*, Oct. 2000. This document is included as Appendix B in the Oklahoma Department of Transportation's *Oklahoma Statewide Intermodal Transportation Plan*, Feb. 2001.

This model and forecast system were developed in 2000 by TranSystems Corporation. It is a conventional model based on Reebie TRANSEARCH data, but with a major difference in usability. The consultant built a calibrated truck trip model onto 31 corridor segments. The Oklahoma Department of Transportation (ODOT) uses a spreadsheet with the 31 corridors, upon which it can change growth factors or update truck volume. Although the spreadsheet cannot handle major changes in the network or economy, it is a very useful tool for day-to-day forecasting.

For clarity, "model" refers to the TranSystems Corporation model and work, whereas "spreadsheet" refers to the corridor truck forecasting system based on the model. TranSystems owns the model. ODOT uses only the spreadsheet.

The TranSystems model was built to identify the major freight corridors in the state. The model uses three zones within Oklahoma and eight zones outside the state to allocate Reebie data for external–external and external–internal trip tables. The same data identified the internal–internal trips between the three zones within Oklahoma. The study did not attempt to capture county-to-county trips or any scale finer than the three zones.

Each commodity is identified by modal split in the data.

The network includes only major corridors.

The model was calibrated using 1996–1998 ODOT truck volume counts. Additional local detail was introduced by segmenting the network corridors near cities.

For example, Reebie data on I-35 show long distance truck movements, which can be calibrated. Then, the heavier urban and suburban truck movements were picked out as part of the calibration process. These urban and suburban areas were placed in different corridor segments, so that an urban-rural-urban corridor would be three segments; high-low-high volume. In this way, some short trips in the corridor can be indirectly modeled using the intercity data.

Rail, air, and water trips are included in collected data, but are filtered out in the modeling process. ODOT keeps statistics on all modes, but models only truck movement.

I-66 Southern Kentucky Corridor

Wilbur Smith Associates, "Kentucky Statewide Traffic Model Final Calibration Report," Apr. 1997.

Wilbur Smith Associates, "Kentucky Statewide Traffic Model Update," Jan. 2001.

Model Structure

This model was developed in 1997 by Wilbur Smith Associates. The network and base data were updated in 2001 by Wilbur Smith, without changing the model methodology.

The model has 1,530 traffic analysis zones; about half in Kentucky and half in surrounding states. TAZs are based on groups of census tracts. The model includes TAZs up to 3-h drive time outside Kentucky, including St. Louis, Indianapolis, Cincinnati, Columbus (Ohio), Nashville, and Memphis. The Kentucky statewide model is truck only, and does not include rail, marine, or air freight.

It uses Reebie Associates data and cordon count data to determine truck trip generation. Future forecasts also use Fratar factors.

All truck trips ends in each county are assigned to a single TAZ. This is different from automobiles, which can have more than one TAZ per county.

Internal Trips

Reebie Associates data are disaggregated from 56 zones across North America, plus 28 zones in Kentucky, to 469 Kentucky model TAZs (maximum of one TAZ per county). Disaggregation is based on population and employment. Assumptions: equal truck trips daily (including weekends and holidays), and uniform weights of 16.8 tons per truck, regardless of commodity. Reebie data assumes that inbound and outbound trips and tonnage for each zone are not equal, but that total inbound and outbound sums of trips and tonnage for the entire Kentucky Model area are equal.

The resulting inbound and outbound trips for each county are not used directly, but become the baseline for the internal trip gravity model. This gravity model determines the internal truck trip table.

External Trips

External trips are based on cordon counts and surveys conducted in Ohio (1996) and on traffic counts. The cordon counts and surveys include autos and trucks. The cordon surveys show the external–external trips and provide the basis of distribution for the external–internal trips. The distribution of all external–internal trips is assumed to match the survey results. All external trips are assumed to be symmetrical, with one outbound trip matched by one inbound trip. Finally, the volume of external trips comes from existing traffic count data at each "entry station," where the trip enters and leaves the model. This volume and distribution becomes the basis for the external–external and external–internal truck trip tables.

Trip Table Calibration

This model does not have a method to calibrate truck trip tables.

Trip Assignment

Trip assignment is based on user assumptions and desired reports. Wilbur Smith Associates describes trip assignment as ". . . the least complex part of the [model]."

Growth Factors

Local truck trip growth is based on projected population and employment growth in that county. A Fratar model is used to apply the factors.

The Network

The network within Kentucky was developed on MINUTP. The network outside Kentucky was developed from National Highway Planning Network Version 2.0. The entire model network was migrated to TransCAD in 2001.

Updating the Model

The model can be updated with new Reebie data, new external distribution survey or truck volume data, and new Woods & Poole population and employment data.

Vermont

Cambridge Systematics, Inc., "Vermont Statewide Freight Study," Final Report, prepared for the Vermont Department of Transportation, Montpelier, Mar. 2001.

Cambridge Systematics developed a complete freight forecasting model as part of the Statewide Freight Study. This model follows a variation of the classic four-step model.

OD data included Reebie TRANSEARCH data, roadside surveys, motor carrier surveys, and interviews with key shippers. Link data included traffic recorder and weigh-in-motion detector, plus data from previous local and corridor studies. Future commodity-flow patterns were developed by Standard and Poor's DRI for years 2005, 2010, and 2020.

The network was created from 14 in-state zones and 16 out-of-state zones. The network links and nodes are not presented in the document.

Annual commodity flows were converted into truck movements using data from the 1997 Vehicle Inventory and Use Survey from the U.S. Census Bureau. The county-to-county truck trip tables were built from DRI forecasts, Reebie data and survey data. The truck trip tables were then converted to passenger car equivalents for assignment to the highway network.

After the highway assignment and a complete run of the model, mode split between truck and rail is determined using a sensitivity analysis based on the roadside surveys. Mode split is tailored for each region (method not explained). The resulting changes to OD tables can be compared with the truck-only model.

Appendixes detail Reebie data, surveys and interview formats.

Kansas

Russel, E., L. Sorenson, and R. Miller, "Microcomputer Transportation Planning Models Used to Develop Key Highway Commodity Flows and to Estimate ESAL Values," unpublished, prepared for the Midwest Transportation Center at Iowa State University and the Kansas DOT.

This network uses General Network Editor and Quick Response System II (QRS II) to model the flow of five agricultural commodities in Kansas. The network uses 202 zones and 2,200 links. The purpose of the model is to determine truck volume and axle weights (ESALs) for improved pavement design.

Data include existing K-Trans surveys and commodity data provided by Kansas State University. The model has not been validated and is not being updated. The study team offered recommendations on improved commodity weights, link speeds, and other network and model changes.

Nebraska

Jones, E. and A. Sharma, "Development of Statewide Freight Forecasting Model for Nebraska" (CD-ROM), Transportation Research Board, National Research Council, Washington, D.C., 2003.

The authors use standard four-step modeling techniques for a statewide model based on the Wisconsin model, but introduce a separate method for agricultural commodities based loosely on the Kansas model. Trip productions used normal data sources, such as the 1993 Commodity Flow Survey. IMPLAN software provided the I-O coefficients used to derive trip attractions. Agricultural shipments were modeled separately from other commodities to enable analysis of intermodal grain transportation. Agricultural surveys and data sources were used to accurately determine commodity productions for each zone. Production, elevator locations, and capacity and rail service determined mode split and trips for each agricultural commodity. Model details and algorithms are not provided.

Virginia

Brogan, J., S. Brich, and M. Demetsky, "Identification and Forecasting of Key Commodities for Virginia," *Transportation Research Record 1790*, Transportation Research Board, National Research Council, Washington, D.C., 2002, pp. 73–79.

The paper shows a model-building method based on only major commodity flows. It also includes lessons learned from the first step of Virginia's freight planning methodology. The freight planning methodology includes several model elements, not a complete forecasting model.

Virginia's six-step method of freight planning is:

1. Inventory the system—the lessons learned are from this step.
2. Identify the problem.
3. Establish performance measures.
4. Collect data for specific problems.
5. Develop and evaluate improvement alternatives.
6. Select and implement improvements

Rather than construct a model of all freight flows, the Virginia DOT purchased Reebie TRANSEARCH data and evaluated only the 15 top commodities based on weight or value. Once these commodities were identified, each was assigned to a set of OD matrices. The matrices are input to IMPLAN software with an integral employment database, creating relationships between commodity flow, employment, and dollar value. Comparing employment, population, and other factors with commodity production and consumption, the authors used a set of regression techniques to determine production factors and consumption factors for each key commodity. This way, changes in employment or related industries can be converted into changes in tons of commodity flow. The commodity flows are assigned to a statewide network, beyond the scope of the paper.

No single regression technique worked well for identifying generation of consumption factors of all types of generators or consumers on the network. Port facilities behaved very differently from other types of facilities. Variables including total employment and transportation employment were important factors for some commodities. Freight consumption models were more accurate than freight production models. Factors behind freight mode choice were not clear.

Louisiana

Apffel, C., J. Jayawardana, A. Ashar, K. Horn, R. McLaughlin, and A. Hochstein, "Freight Components in Louisiana's Statewide Intermodal Transportation Plan," *Transportation Research Record 1552*, Transportation Research Board, National Research Council, Washington, D.C., 1996, pp. 32–41.

The planning procedures for the freight components of Louisiana's Statewide Intermodal Transportation Plan for water, rail, and intermodal components are presented. The planning included U.S.DOT's four Cs (connection, choice, coordination, and cooperation), as well as reflecting actual freight movements.

The Louisiana Department of Transportation and Development set a 25-year planning horizon for the study, which included input from both freight users and providers. Low-cost and high-capital-cost improvements were considered for addressing capacity issues. These improvements were then evaluated by a sample of potential users and compared with goals.

A roster of statewide freight users was assembled to submit a draft of challenges to the staff for defining statewide intermodal needs. This statement was revised as input from concurrent technical analysis was presented. In addition, industry executives were interviewed to provide diverse perspectives.

For flow analysis, four types of trips were included, internal–internal, internal–external, external–internal, and external–external. Historic data were gathered from the U.S. Army Corps of Engineers (waterborne commerce statistics), Interstate Commerce Commission (rail waybill information), and Reebie Associates (TRANSEARCH database). The raw data were aggregated into business economic areas (BEAs) within the state and super BEAs for states outside Louisiana and international markets.

Commodities were broken into 11 categories based on their nature, transport, handling requirements, etc. All commodity movements were analyzed in terms of modal share, origins and destinations, and domestic or foreign trade flows so that factors affecting future growth could be identified and assessed. Relational database systems were built to extract and aggregate flow measures by commodity groupings, by mode, and by BEA or super BEA origins and destinations.

Demand projections focused on three growth scenarios, high, medium, and low. High and low were generated from forecasts for 1990–2000 made by federal agencies and industry groups. The growth rates were adjusted downward for all commodities beyond 2000 to incorporate long-term uncertainty. The study included three 10-year periods: 1990–2000, 2001–2010, and 2011–2020.

Evaluations were made for existing and future production to determine future market developments and augment earlier information provided by static quantitative growth forecasts. The analysis included specific industrial sectors, productivity trends, and the competitive position of transportation providers in the state.

Freight network analysis focused on transshipment facilities and intermodal connections. The methodology used included detailed capacity measures of the different transfer and storage aspects of intermodal terminals for rail–highway and marine facilities, augmented by analysis of the performance of terminal access routes that provide intermediate linkages to corridor and line haul routes.

Terminals used for capacity assessment included five generic types for water and rail-based freight. The capacity was determined using stock and flow analysis of terminal operations. The study determined that capacity was the product of two factors—effective transfer rate (tons/day) and effective working time (days/year).

Terminal access was also studied by use of a detailed inventory and assessment of intermodal terminal accessibility. An inventory of the characteristics of local access roads and rail spurs was made for public marine and rail–highway terminals in the state. Questionnaires were distributed to every operator of these terminals in the state and were supplemented by field surveys as necessary to document the physical, institutional, and operating aspects of terminal access.

Iowa

Iowa State University, "Developer's Guide for the Statewide Freight Transportation Model," Iowa State University Center for Transportation Research and Education, undated [Online]. Available: http://www.ctre.iastate.edu/Research/statmod/dev_guid.pdf.

This TRANPLAN-based model is not a forecasting tool, but is instead used for policy analysis. As with other similar models, it uses Reebie TRANSEARCH commodity data, organized by BEA zones, connected by TRANPLAN networks for multiple modes, and organized by standard industrial commodity codes. BEA zone data are disaggregated to county level using *NCHRP Report 260* techniques.

The model uses a simple gravity model, with different friction factors for food and machinery. Only internal–internal and internal–external trips are modeled. External–external trips are assumed to be beyond the policy applications of the model.

The model uses separate network layers for road and rail modes. The road network is typical of other plans. The rail network is subdivided by carrier, and interchanges between carriers are limited to actual interchange points defined by input from the rail carriers. Because most software is designed for roads, the rail network noninterchange nodes were assigned turn penalties. Impedance for road, rail, and intermodal movements are based on cost only, not time.

The model can be used for evaluation of changes in transport cost, production or consumption, and infrastructure (network).

SIMPLER METHODS

Simpler methods are intended for rapid application of existing data to determine one or a few forecasted items. Usually intended for short-term forecasts, many assumptions are needed to make them work and their range of applicability is limited.

Simpler Methods from the *Guidebook on Statewide Travel Forecasting*

Horowitz, A.J., *Guidebook on Statewide Travel Forecasting*, Report FHWA-HEP-99-007, Federal Highway Administration, Washington, D.C., July 1999.

Time–Series Methods—The *Guidebook on Statewide Travel Forecasting* discusses time–series methods for direct forecasts of vehicular volumes on highways and for forecasting the inputs to four-step models. Major emphasis is on ARIMA (autoregressive integrated moving average) models and on growth factor methods. Examples are primarily for passenger car forecasting; however, the methods are equally applicable to truck forecasting.

I-40 Truck Model—The *Guidebook* describes a linear regression model to forecast truck volumes on I-40 in New Mexico. Commercial truck traffic was found to be a linear function of the year, the U.S. disposable income, U.S. gasoline costs, and the New Mexico cost of residential construction.

Simpler Methods from the *Quick Response Freight Manual*

Cambridge Systematics, et al., *Quick Response Freight Manual*, Report DOT-T-97-10, Travel Model Improvement Program, Federal Highway Administration, Washington, D.C., Sep. 1996.

The *Quick Response Freight Manual* (*QRFM*) describes two methods of applying growth factors to traffic volumes that are applicable to rural highways as well as urban highways. The first method involves estimating a growth factor from current and past truck count data and applying the resulting factor to future years using a conventional compound interest formula. The second method determines several growth factors, one each for many economic indicator variables, usually employment in local industrial sectors. The future growth in economic indicator variables, as calculated by a compound interest formula, is used to forecast growth in commodity groups, which is then used to forecast the growth in trucks carrying each group of commodities. Necessary assumptions about the economy and freight characteristics are discussed. A similar concept is described in *NCHRP Report 388*.

Truck Model from the *Quick Response Freight Manual*

Although the *QRFM* was intended for urban forecasts, it outlines a process that might also be used to create a statewide truck model. The *QRFM* follows a three-step process of trip generation combined with vehicle split, trip distribution, and traffic assignment. The most interesting aspect of the *QRFM* is the generation of truck origins and destinations (not productions and attractions) for each zone by three categories of commercial vehicles: four-tire trucks, other single-unit trucks, and combination trucks. Origins and destinations are linear functions of employment in industrial sectors and numbers of households.

Elasticity Methods from *NCHRP Report 388*

Elasticity and cross-elasticity methods are suggested in *NCHRP Report 388* in the appendix, "Rail/Truck Modal Diversion." Tables of cross-elasticities are given between rail and truck by commodity group as derived from a proprietary model, the Intermodal Competition Model developed by the Association of American Railroads. A cross-elasticity can be interpreted as the percentage change in one mode's share given a one percent change in an attribute of another mode. For example, it might be possible to estimate a change in the rail share of carrying primary metals from the change in cost of carrying primary metals by truck.

Pivot Mode Share Method from the *Guidebook on Statewide Travel Forecasting*

The pivot formulation of a mode split model as found in the *Guidebook on Statewide Travel Forecasting* was applied in the Florida model discussed earlier. This method can be used as a stand-alone technique to estimate mode shares for localized generators. A pivot formulation is able to forecast new mode shares from knowledge of existing mode shares and the change in a single variable in the "utility" of transporting a unit amount of a commodity by a particular mode. The *Guidebook* recommended using cost as the single variable.

Forecasting Based on Cost Data

Memmott, F.W. and R.H. Boekenkroeger, "Practical Methodology for Freight Forecasting," *Transportation Research Record 889,* Transportation Research Board, National Research Council, Washington, D.C., 1982, pp. 1–7.

The freight-demand forecasting technique discussed in this paper is a very simple and straightforward methodology. Compared to a formal mathematics model, the technique described in this paper is really a process for systematically making a large number of revenue and/or cost calculations. The structure of the model follows these steps: (1) prepare model inputs; (2) compute base case transport costs and revenues; (3) develop alternative futures, scenarios, and conditions; (4) compute alternative transport costs and revenues; (5) summarize computed information and print reports; and (6) conduct highway impact analysis. Computations for different states involve either hand or computer calculations. By adding some other components, the structure can be modified for use in different transport models. The most important inputs are origins and destinations of the movements or flows and the unit costs and revenues. The paper gives some formats for unit costs and revenues. Two examples are described: one is for a Montana study and the other is for a U.S. Army Corps of Engineers study. Control information, commodity flows, revenues or charges, costs, unit distances, and vehicle equivalents are needed for study. Highway impact analysis is also discussed in this paper.

Application of Regression and Elasticity Techniques

Morton, A.L., "A Statistical Sketch of Intercity Freight Demand," *Highway Research Record 296*, Highway Research Board, National Research Council, Washington, D.C., 1969, pp. 47–65.

Time–series regression analysis is used to estimate demand for truck and rail. The first part of the paper describes data, which were organized into five commodity groups: agriculture, animals and products, products of forests, products of mines, and manufactures and miscellaneous. The rail and truck price index and truck rate series were needed to estimate the price and the cross-price elasticity of demand. The gross national product (GNP) was used to estimate the income elasticity of demand. A logarithmic form of a regression equation was selected after three demand equations were estimated, both logarithmically and untransformed. It was assumed that one year is long enough to estimate the traffic volumes by using the previous year's prices. In total, 12 markets were studied; two sets of equations and 324 coefficients were estimated. For rail the growth in GNP generated new traffic at the level of three-fifths of the rate of economy expansion. Economic growth generated new traffic for truck at double the rate of economy expansion, and truck traffic was more influenced by price.

OTHER RELEVANT NCHRP STUDIES

NCHRP Report 177

Roger Creighton Associates and R.L. Banks and Associates, *NCHRP Report 177: Freight Data Requirements for Statewide Transportation Systems Planning: Research Report*, Transportation Research Board, National Research Council, Washington, D.C., 1977.

This report reviewed data needs and data availability for statewide freight planning during a period of time when freight planning was in its infancy. Because many of the data sets no longer exist or have changed in character, the specific recommendations about them are no longer relevant. In addition, methods for freight planning have also changed substantially.

Still of current relevance is a matrix for each mode (rail, truck, ports, inland waterways, pipelines, and air cargo) that relates planning issues to data needs. The report identifies and describes 64 planning issues that could be better addressed by analysis of freight data.

NCHRP Report 178

Roger Creighton Associates and R.L. Banks and Associates, *NCHRP Report 178: Freight Data Requirements for Statewide Transportation Systems Planning: User's Manual*, Transportation Research Board, National Research Council, Washington, D.C., 1977.

This report describes ways to implement the findings of *NCHRP Report 177*, a companion report to this one. Most of the database descriptions in this report are now obsolete; however, the authors have provided general guidance on how to use freight data in transportation planning that is still quite useful. The report outlines a procedure for identifying freight data requirements consisting of these steps:

1. Identify Freight Issues and Problems,
2. Arrange Issues and Problems in Priority Order,
3. Establish Planning Program for Freight Transportation,
4. Determine Planning Methods, and
5. Determine Data Needs and Available Resources.

The report further discusses the advantages of assembling data from secondary sources and ways of obtaining primary source data. Primary source data includes traffic flow data, carrier data, shipper and consignee attributes, physical and operational data, and direct and indirect impacts. A lengthy appendix provides guidance on how to organize and conduct a shipper survey, one of the possible primary data sources.

NCHRP Report 388

Cambridge Systematics, Inc., et al., *NCHRP Report 388: A Guidebook for Forecasting Freight Transportation Demand*, Transportation Research Board, National Research Council, Washington, D.C., 1997.

NCHRP Report 388 is intended as a guidebook to help planners perform freight planning and forecasting. It gathers reference information about freight transportation planning processes, techniques, tools, data, and applications. The first chapter of the report describes its purpose, the characteristics of the freight demand, the current study, and some related research. The second chapter describes factors that influence freight demand. The third and fourth chapters discuss demand forecasting for both existing and new facilities. New facility options include new highways for serving rail yards, new rail facilities for current railroads, new rail facilities for competing railroads, and new U.S. or foreign port terminals. The last chapter describes policy analysis.

The report's appendixes contain a wealth of useful information; factors influencing freight demand, reviews of freight-demand forecasting studies, freight activity data sources, freight transportation survey procedures and methods, statistical forecasting techniques, estimating transport costs, rail and truck modal diversion, three modal-diversion models, case studies, and the information needs perceived by public agencies.

Appendix B is an annotated bibliography of several of the more important freight-demand studies.

- Cambridge Systematics, Inc., *Alternative Planning Approaches: Structural and Direct*, NCHRP Project 20-17, Statewide Freight Demand Forecasting, May 1980.
- Memmott, F. and Roger Creighton Associates, *NCHRP Report 260: Application of Freight Demand Forecasting Techniques*, Transportation Research Board, National Research Council, Washington, D.C., 1983.
- Memmott, F.W. and R.H. Boekroeger, "Practical Methodology for Freight Forecasting," *Transportation Research Record 889*, Transportation Research Board, National Research Council, Washington, D.C., 1982, pp. 1–7.
- Kim, T.J. and J.J. Hinkle, "Model for Statewide Freight Transportation Planning," *Transportation Research Record 889*, Transportation Research Board, National Research Council, Washington, D.C., 1982, pp. 15–19.
- Middendorf, D.P., M. Jelavich, and R.H. Ellis, "Development and Application of Statewide, Multimodal Freight Forecasting Procedures for Florida," *Transportation Research Record 889*, Transportation Research Board, National Research Council, Washington, D.C., 1982, pp. 7–14.
- Hu, P., T. Wright, S. Miaou, D. Beal, and S. Davis, *Estimating Commercial Truck VMT of Interstate Motor Carriers: Data Evaluation*, Oak Ridge National Laboratory Report, Oak Ridge, Tenn., Nov. 1989, 176 pp.
- Friedlaender, A.F. and R.H. Spady, "A Derived Demand Function for Freight Transportation," *Review of Economics and Statistics*, Vol. 62, No. 3, 1980, pp. 432–441.
- Lawrence, M.B. and R.G. Sharp, "Freight Transportation Productivity in the 1980s: A Retrospective," *Journal of the Transportation Research Forum*, Vol. 32, No. 1, 1991, pp. 158–171.
- Winston, C., "The Demand for Freight Transportation: Models and Applications," *Transportation Research*, Vol. 17 (A), 1983, pp. 419–427.
- Crainic, T., M. Florian, and J.-E. Leal, "A Model for the Strategic Planning of National Freight Transportation by Rail," *Transportation Science*, Vol. 24, No. 1, 1990, pp. 1–24.
- Stevens, B., *Basic Regional Input-Output for Transportation Impact Analysis*, NCHRP Project 8-15A, Regional Science Research Institute, Philadelphia, Pa., July 1982.
- Eusebio, V. and S. Rindom, *Grain Transportation Service Demand Projections for Kansas: 1995 and Beyond*, Kansas Department of Transportation, Topeka, July 1990.

Some of these reports and articles are also reviewed here.

Appendix C contains detailed descriptions of three dozen data sources related to freight transport activity and demand. These include:

- 1993 Commodity Flow Survey;
- TRANSEARCH;
- Freight Transportation and Logistics Service;
- U.S. Exports by State of Origin of Movement;
- Directory of U.S. Importers and Exporters;
- National Transportation Statistics, Annual Report;
- Freight Commodity Statistics;
- North American Trucking Survey;
- LTL Commodity and Market Flow Database;
- Nationwide Truck Activity and Commodity Survey;
- Ship Movement Database;
- Truck Inventory and Use Survey;
- State Estimate of Truck Traffic;
- Quarterly Coal Report;
- Natural Gas Annual;
- Surface Transborder Trade-Flow Data; and
- Port Import and Export Reporting Service.

NCHRP Synthesis 298

Fischer, M.J. and M. Han, *NCHRP Synthesis of Highway Practice 298: Truck Trip Generation Data*, Transportation Research Board, National Research Council, Washington, D.C., 2001, 81 pp.

This report is essential. It describes vital data sources, key considerations for forecasting, many best-practices techniques, and many common mistakes made in planning and modeling.

Chapter two discusses how truck productions and attractions differ from automobile trips and activities. It also includes a discussion of data collection techniques.

Chapter three is an annotated bibliography of data sources, organized by topic. Topics include compendia of trip generation data, engineering studies, special generator studies, ports and intermodal data sources, vehicle-based travel demand models, commodity-based travel demand models, and other critical data resources.

Chapter four describes the current (2000) state of the art. A key lack of uniformity in statewide vehicle-based forecasting is the discrepancy between linked (truck with multiple stops) and garage-based (truck with single destination) truck trips. Metropolitan and statewide models treat each differently, making comparisons or pattern identification difficult. Vehicle-based models as a function of employment are popular within metropolitan models. Commodity-based models are more popular at the statewide level and have different problems. Errors in commodity payload factors and other assumptions are the most common.

The report does not recommend methods to standardize or share data among different models (and different organizations), and calls for additional research mostly on improved data collection. There is no significant discussion of alternative or lower cost data, new mathematical or computer tools to improve the process or changes, or alternatives to the basic process of trip generation–trip distribution–traffic assignment. The report does not address intermodal activities beyond bibliographic references to special generator models.

ACTIVE NATIONAL OR INTERNATIONAL MODELS AND TOOLS

Freight Analysis Framework

"The Development of the Freight Analysis Framework Database and Forecast," no date (around 2003), Booz, Allen and Hamilton [Online]. Available: http://www.ops.fhwa.dot.gov/freight/lambert_files/CombinedFinalMethodologyPiece-2.doc.

Fekpe, E., M. Alam, T. Foody, and D. Gopalakrishna, "Freight Analysis Framework Highway Capacity Analysis, Draft Methodology Report," Battelle, Apr. 18, 2002 [Online]. Available: http://www.ops.fhwa.dot.gov/freight/lambert_files/Capacity-Method-report-revised.doc.

The FAF is a freight forecasting model, developed by FHWA, which covers the contiguous 48 states and the District of Columbia. FAF employs the general methodology of OD table factoring and assignment to perform forecasts to 2010 and 2020 from base year OD tables of 1998.

GBFM

"Great Britain Freight Model" [Online]. Available: http://www.mdst.co.uk/MDSTBody-gbfm.htm.

GBFM is an offshoot of STEMM (Strategic European Multimodal Modelling) and contains specific improvements for applications in Great Britain.

NEAC

The NEAC-Model, "The Solution to Western and Central European Transport Information Problems! Base Year 1997—Forecast 2020" [Online]. Available: http://www.nea.nl/dutch/publicaties/Brochures/NEAC-folder.pdf.

NEAC is a decision support system covering all of Europe that provides the link between traffic and economic development in and between regions. The advantage of NEAC's database is that it can determine the exact origin and destination of commodities in region-to-region transport as well as the organization of transport (direct or with transshipment). Information on the route of shipment can be provided. The NEAC transport chain database can help analysis of transport flows and forecasting based on economical relations. The concept of the transportation chain is described as follows: It is a sequence of transport modes used to carry a certain good from its first origin to its final destination. Along the chain, one or more transshipments take place. NEAC has been applied in some European regions on a range of topics including transport flow analysis, corridor analysis, infrastructure analysis, market potential analysis, and policy impact analysis.

EUFRAT

PRODEC Resources, "The European Freight Assessment Model" [Online]. Available: http://www.prodec.dk/resources/eufrat/eufrat.htm.

EUFRAT is a multimodal freight assessment model. The network includes all major road, rail, inland waterway, and sea connections, which covers all of the European Union, the European Free Trade Association countries, and all of Eastern Europe, including Russia and Ukraine. It has been applied with reported good results. It uses the common European standard for regional statistics (NUTS2, sometimes NUTS3) and the freight volumes are based on the OECD SITC Rev. 2 commodity classes.

SAMGODS

"National Freight Model System for Sweden" [Online]. Available: http://www.rand.org/publications/MR/MR1663/MR1663.pdf.

SAMGODS is a freight model for Sweden that is currently under development.

GTAP

"Global Trade Analysis Project (GTAP)," Purdue University, West Lafayette, Ind. [Online]. Available: http://www.gtap.agecon.purdue.edu.

Hertel, T. and T. Marinos, "Structure of GTAP," Draft of Chapter 2, In *Global Trade Analysis: Modeling and Applications*, Cambridge University Press, 1997 [Online]. Available: http://www.gtap.agecon.purdue.edu/resources/download/86.pdf.

The Global Trade Analysis Project (GTAP) is a complex set of databases and sophisticated economic modeling tools developed by an international consortium of universities, institutions, and government departments in the developed world. The consortium began work in 1993, and research and development work is ongoing.

The international consortium approach to developing the model and framework has led to wide use of GTAP economic models for policymaking in the World Trade Organization (WTO), World Bank, and several international conferences.

The model uses 57 commodity sectors, some of which do not need freight transport (banking, electricity), but are still considered commodities for purposes of the economic model. Charts show the mapping of these sectors to U.S. STCC groups. Only three types of industrial sectors are identified: agriculture and food, energy, and goods and services. The Earth is divided into 66 regions for determining trade between them.

The main uses are to model the effects of economic growth, trade policy changes, and impacts of changes in resources, technology, and the environment.

The model structure uses generally accepted market-based economic principles, in most cases, to determine number value (as opposed to real quantity or dollar) relationships between producers, consumers, and governments. The set of interlocking relationships causes value to flow and the economy to change or grow, as it would in a real economy. The dynamic flow of value is monitored and held in equilibrium by a layer of accounting within the model. For example, the change in price of commodity X is determined not just by supply and demand, but also by weighted averages of the costs of related commodities and possible substitutable commodities. Tax structures and import and export taxes are included.

Because the model uses market-based economic behavior predictions, government fiscal and revenue policy is highly discretionary. Government is also immune to many of the accounting checks. Balanced budgets are neither assumed nor required in the GTAP universe. Similarly, the value flows and accounting levels are assumed to be transparent to macroeconomic policies, monetary policy changes, and other non-market-driven events. The feedback from market to policy is political, not economic, and no adequate modeling mechanism exists.

Firms purchase land, labor, capital, intermediate inputs, and knowledge (technology) to produce their outputs. Each input varies based on the firm's location in the global (or regional) economy, the skills base, and the readiness of substitutes. For example, firms in developed nations tend to use capital-intensive, technologically sophisticated production that minimizes land, labor, and intermediate input costs. Determining rates of substitution of resources is a major part of modeling firm behavior; for example, purchasing more efficient equipment when fuel prices rise. Another example is that intermediate inputs may be locally produced or purchased internationally. Finally, each sector of the economy (agriculture, machine manufacture, and banking) has its own special resource needs.

Households input government services, income, and goods, and output taxes, purchasing, and savings. Purchase rates by industrial sector are based on birth rates and other criteria. Changes in purchasing are based on elasticities of demand (goods prices), taxes, population change, and other factors.

The GTAP world also includes mechanisms for inflation and the distribution of multiregional (or transnational) investments.

Regions exchange value using the model's Global Bank and Global Trade mechanisms. Both are monitored only in terms of value. Global Trade does include commodities, but by value instead of tonnage.

For use in statewide freight forecasting, GTAP has limited usefulness. The model can provide predicted rates of economic growth within the given regulatory and tariff framework, but converting such models into economic forecasts is already done by the U.S. Department of Commerce and other organizations. Specifically for states with major international port or border activities, GTAP can provide useful commodity value forecasts that can be converted into tonnages.

GTAP use as a long-term predictive model is unknown. Its methodology is complicated, but not controversial. It has not seen major use as a predictive model, and has been in use for only 10 years.

STEMM

"STEMM Final Summary Report" [Online]. Available: http://www.cordis.lu/transport/src/stemmrep.htm, last updated April 1999.

STEMM (Strategic European Multimodal Modelling) has a multimodal freight model that has flow attributes, including disaggregation levels and mode and route choice algorithms. For each mode and route a generalized cost is calculated by adding financial cost and various qualities of service penalties. Only alternatives within a certain percentage of the lowest generalized costs are considered and if they are the same, then traffic will be split between them.

The MDST model was designed according to requirements of the corridor studies (Cross-Channel and Trans-Alpine). In both cases, traffic is predicted on a limited set of international links where modal change is either essential or at least viable.

The STAN (Strategic Transport Analysis) model was used for Nordic case studies. Attribute structure comes from the STEMM Ideal Model Shell and mode and route choices are made using the STAN algorithm. For the Scan Link Corridor case study, the network included subnetworks for nine modes: road, rail, fast rail, truck ferry, car and truck ferry, rail ferry, sea bulk, general sea, and inland waterways. During the analysis, new features were added to STAN, including path analysis.

Both MDST and STAN produced plausible results for their respective studies.

SOFTWARE PRODUCTS SPECIFICALLY FOR FREIGHT FORECASTING

STAN

Crainic, T.G., M. Florian, J. Guelat, and H. Spiess, "Strategic Planning of Freight Transportation: STAN, An Interactive-Graphic System," *Transportation Research Record 1283*, Transportation Research Board, National Research Council, Washington, D.C., 1990, pp. 97–124.

This study details the process used to develop a freight modeling program. The program was coded in ANSI FORTRAN 77 and was developed to be user friendly by standards at the time. It includes modules for input, modification, display, and output for multicommodity networks. It also includes a network editor, matrix editor, and function editor.

The networks are described by modes, products, vehicles, base network, and transfers. The matrices are used to display OD information similar to EMME/2. The functions are used on links and transfers as unit cost functions, and there are a maximum of three for each product in the scenario.

STAN uses a general assignment procedure that is a multimode multiproduct method that minimizes the total cost of shipping for products considered, from origins to destinations, and by means of permitted nodes. Penalties must be added as functions because capacity is not included in the software.

This model does not identify shippers and carriers explicitly, but is used for scenario comparisons when major investments are considered. The shippers' behavior is therefore only defined in the OD matrix. STAN also does not include an algorithm for simultaneous determination of flows and demand matrices.

Crainic, T., M. Florian, and J. Leal, "A Model for the Strategic Planning of National Freight Transportation by Rail," *Transportation Science*, Vol. 24, No. 1, pp. 1–24.

The authors use a STAN-based network to model the effects of different infrastructure investment scenarios among several modes. The model is trip-based and most detailed in rail operations. The rail model algorithms are included. The entire model is not presented. There is no discussion of forecasting beyond the effect of differing traffic assignments and mode splits.

Guelat, J., M. Florian, and T. Crainic, "A Multimode Multiproduct Network Assignment Model for Strategic Planning of Freight Flows," *Transportation Science*, Vol. 24, No. 1, pp. 25–39.

This paper describes an economic model, based on cost minimization, for mode split and network assignment. The model is built into the STAN network assignment application. The network assignment algorithm is presented. There is no discussion of forecasting beyond the effect of differing traffic assignments and mode splits.

Guelat, J., M. Florian, and T.G. Crainic, "A Multimodal Network Assignment Model for Strategic Planning of Freight Flows," *Transportation Science*, Vol. 24, No. 1, pp. 25–39.

The class of models described is network models that predict multicommodity flows over a multimodal network with detail appropriate for large geographical regions or nations. The model described does not consider shippers and carriers as distinct actors, but aggregates all data to origins and destinations that are large areas.

The model uses a network of links, nodes, and modes, and links are defined as triplets. Each link contains an origin node, destination node, and mode. Transfers are represented by arcs connecting nodes on different modes.

The model bases freight flows on least total cost. The model considers a set of nodes, arcs, modes, and transfers. Each arc and transfer is associated with a cost function that relates to the volume of goods on the arc or other arcs in the network.

The cost functions that are used to model delays and costs on the links and transfers of a freight network are link separable except for transportation services that share the same facilities. The code that implements the solution algorithm for the model includes partial derivatives for the computation of marginal costs that is carried out by a precise numerical approximation procedure.

The solution algorithm includes the Frank and Wolfe linear approximation method. The shortest path algorithm allows transfers that are similar to turn penalties in urban networks and is an adaptation of Dijkstra's label setting algorithm.

The model is imbedded in the STAN interactive graphic system and has been used successfully in practice in southeastern Brazil.

Crainic, T.G., M. Florian, and J. Leal, "A Model for the Strategic Planning of National Freight Transportation by Rail," *Transportation Science*, Vol. 24, No. 1, pp. 25–39.

The goal of the article is to achieve an aggregate, strategic modeling framework of freight transportation by rail that may adequately reflect the economic and spatial–temporal relations typical to the rail mode.

A brief overview of STAN is presented. The network optimization model that is used to simulate network flows in STAN is a nonlinear multimode–multiproduct assignment formulation that minimizes the total generalized system cost while satisfying the usual flow conservation constraints. The modeling framework provides both an adequate representation of large multimodal–multiproduct transportation systems for strategic planning purposes and a mathematical structure well suited for efficient solution methods.

The article also provides a framework for dealing with empty flow estimation in the rail mode. The author uses a procedure based on a gravity (or entropy maximizing) model for forecasting empty rail car traffic similar to that used for Canadian National Railways. The model uses an approach where empty cars are defined as a separate product and an OD empty movement demand matrix is estimated by the gravity model.

OD demand of empty movements could be estimated by a variety of heuristic and exact methods, but a gravity model is used in this application.

Cube Cargo

Cube Cargo Software Package, Citilabs Inc., Oakland, Calif., 2003 [Online]. Available: http://www.citilabs.com/cargo/index.html.

Citilabs' Cube system is a local transportation planning package. Three interrelated products comprise the system: Voyager for passenger transport, Cargo for freight transport, and ME for freight and passenger matrix estimation.

Cube Cargo uses commodity-based four-step modeling to estimate freight flows and assignments. It uses OD matrices and input commodity data and multivariate linear regression models to determine tons of each commodity group produced and consumed in each zone. Each production and consumption commodity is further divided into internal (local) and external (import and export) segments. Productions and consumptions are distributed by a combination of short-haul and long-haul movements, each using a gravity model with different cost functions. Short trips travel by road; long-haul trips can be split between different modes or mode combinations based on time, distance, and cost in a multinomial logit equation. Trip assignments are calculated from mode and commodity group trip tables. In addition, two submodels cover the effects of major transportation and intermodal facilities and the traffic assignment effects of local delivery and non-goods-related truck traffic. Product documentation claims uses for local and regional but not statewide planning. The software was not available for evaluation. Cargo appears to be compatible with the procedures of the *Guidebook on Statewide Travel Forecasting*.

Cube ME finds optimal trips matrices from a variety of data sources, including ground counts, using maximum likelihood estimation. Product literature suggests that the methodology is appropriate for estimating truck trip matrices.

GENERAL TOOLS RELATED TO FREIGHT FORECASTING

Trip Table Estimation from Ground Counts

Value of Data Sources

Rios, A., L.K. Nozik, and M.A. Turnquist, "The Value of Different Categories of Information in Estimating Freight Origin-Destination Tables" (CD-ROM), Presented at the 81st Annual Meeting of the Transportation Research Board, Jan. 13–17, 2002.

Trip table estimation from ground counts or other partial data sources has application to freight forecasting because the entire OD table for a given mode or a given commodity is rarely known. The authors report on their ability to estimate multimodal freight OD tables from a variety of information sources, including ground counts, origin totals, destination totals, and flows between specific OD pairs. Tests were performed on two supernetworks containing rail, truck, and rail–truck intermodal. The authors varied the quantity and quality of inputs to the OD estimation process and compared the results with a known trip table. They found that link count data were most useful for correctly ascertaining OD tables, followed by origin and destination totals. Of all links counts, the ones on higher volume facilities had the greatest positive impact on the quality of the OD matrix. The formulation used to estimate OD tables involved minimizing an entropy term while simultaneously minimizing the squares of errors to input data. Weights were applied to each item of data in the minimization based on its quality.

State of the Art in OD Matrix Estimation

Abrahamsson, T., "Estimation of Origin-Destination Matrices Using Traffic Counts—A Literature Survey," IR-98-0212, International Institute for Applied Systems Analysis, Laxenburg, Austria, May 1998.

OD trip table estimation from ground counts has been an active field of research for almost three decades; however, most applications of the concept are still considered experimental. A recent comprehensive literature review is provided in this document, which looks at 24 different research efforts on static trip table estimation. A number of mathematical approaches to the problem have been proposed (e.g., entropy maximization, generalized least squares, linear programming, Bayesian inference, and heuristic algorithms), but there does not yet appear to be a consensus as to the best method for any given problem. All of the most researched methods require that a solution to an optimization problem be found, and all methods are highly computational. Particular attention in this review article is given to generalized least squares formulations of the optimization problem and gradient search methods for solving the required optimization problem. The formulations often require a considerable amount of information from a traffic assignment, typically the probability that a trip measured on a given link had its origin and destination in a particular OD pair. When there is congestion on the network, these probabilities are dependent on the OD table used in the assignment and, by logical extension, the estimated OD table. Thus, many of the reviewed articles deal with the problem of obtaining stable OD tables in conjunction with equilibrium traffic assignment. Because the solution of the OD estimation problem is not unique (there are usually many OD tables that can be equally good at fitting a set of ground counts), a persistent line of research has incorporated a "target" OD table into the formulation, with the idea of preserving as much information as possible from the target.

Genetic Algorithm

Kim, H., S. Baek, and Y. Lim, "Origin-Destination Matrices Estimated with a Genetic Algorithm from Link Traffic Counts," *Transportation Research Record 1771*, Transportation Research Board, National Research Council, Washington, D.C., 2001, pp. 156–163.

Genetic algorithms (GAs) use many iterations and randomized factors to "evolve" an optimized solution. Unlike gravity model or Fratar model iterative adjustments, GAs do not necessarily converge toward the optimal solution with each iteration and require much more computing power and many more iterations. GAs for developing OD tables may have the potential to be robust, requiring less input data than currently needed.

The paper explains GAs thoroughly, including a step-by-step method, and offers an example of building an OD table from link flow volumes. The goal is a tool to make data collection cheaper. The sample 8-node network required approximately 500 iterations to construct a trip table from link volumes and had an average error of 2.5% for each estimated OD pair volume.

The sensitivity of the algorithm to erroneous data was measured by running the sample network with various (5%, 10%, 15%, 20%) error rates in link volumes. In each case the algorithm, once converged to a solution, had individual OD pairs of up to twice the error rate (for example, 5% underreporting of link volume led to maximum 10% underreporting of the same link in the finished table). However, the errors averaged out throughout the network to below the original link volume error rate (e.g., 15% error on each link led to an average of 8.6% error for the entire network).

This paper is a very good introduction to the concept of genetic algorithms and their applications. The methods and theory are described clearly, and the sample network is explained well.

A Wyoming Application

Wang, J. and E.M. Wilson, "Interactive Statewide Transportation Planning Modeling Process," *Transportation Research Record 1499*, Transportation Research Board, National Research Council, Washington, D.C., 1995, pp. 1–6.

In Wyoming the primary concerns for transportation planning are goods movements and tourism travel, especially during summer months. Consequently, the goal of the travel model is to obtain weekend truck and passenger vehicle traffic flows. Automatic traffic record reports, the port of entry truck counts, and the vehicle miles book data are used to build an OD trip table. An entropy maximization scheme is used to estimate a vector of X_a's, which are used to find the number of trips between zones i and j:

$$T_{ij} = t_{ij} \prod_a X_a^{p_{ij}^a} \quad \text{(D1)}$$

where

T_{ij} = number of trips from i to j,
$p^a{}_{ij}$ = proportion of trips from i to j that use link a,
t_{ij} = trips from i to j from a preliminary OD table, and
X_a = trip estimation factor for link a with a traffic count.

A program was written in Visual Basic, with the $p^a{}_{ij}$'s coming from a Quick Response System II output file. In Wyoming, 50% of goods movements are external–external, so having a well-estimated truck trip table from ground counts is important to the planning process.

Practical Issues

Van Aerde, M., H. Rakha, and H. Paramahamsan, "Estimation of O-D Matrices: The Relationship Between Practical and Theoretical Considerations" (CD-ROM), Presented at the 82nd Annual Meeting of the Transportation Research Board, Jan. 12–16, 2003.

The paper is a good overview of many different OD table estimation techniques. It includes a brief discussion of synthetic OD estimation based on entropy, minimum information, and link counts. The authors discuss two approximation techniques. No specific model or application is presented.

Surveys

State-of-the-Art Review

Lau, S., "Truck Travel Surveys: A Review of the Literature and State-of-the-Art," NCHRP Web Doc 3, MTC, Oakland, Calif., Jan. 1995, In *Multimodal Transportation Planning Data: Final Report*, 1997 [Online]. Available: http://books.nap.edu/books/nch003/html/166.html.

The paper describes different survey methods used by various metropolitan planning organizations (including Chicago; Ontario; Vancouver; Phoenix; Alameda County, California; New York–New Jersey; El Paso; and Houston–Galveston) to estimate truck trips. The paper also gives information about types of data, use of truck survey data, and method used. Most of the surveys divide trucks by weight, number of axles, and truck type. The major survey method is a telephone–mailout–mailback, and the main uses of the truck data are for regional truck travel model development and corridor and route analysis. The paper discusses the cost of surveys, gives recommendations for new truck data and analysis tools, and lists numerous truck facts. Survey forms are not provided.

Radwan, A.E., M. Rahman, and S.A. Kalevela, "Freight Flow and Attitudinal Survey for Arizona," *Transportation Research Record 1179*, Transportation Research Board, National Research Council, Washington, D.C., 1988, pp. 16–22.

A mail survey about highway freight movements and carrier attitudes was designed by the Arizona Freight Network Analysis to evaluate the performance of Arizona's highway system for freight movement. The survey had two parts, a freight movement survey and a carrier attitudinal survey. After analysis the existing data (including Reebie data and Associates of Greenwich, Connecticut), the Arizona Freight Network Analysis researchers found that existing data could be used, so the group decided to use a random mail survey to gather data. The survey was only sent to the freight carriers. Carriers were selected according to their rank by total annual miles: 100% of the top 1,200 carriers, 50% of carriers from 1,201 to 1,900, and 5% of carriers from 1,901 to 12,900. The survey mailing package asked carriers to provide information for a "recent representative week" of 7 days. The freight movement survey obtained the carrier code, contact person, date, carrier type, shipping date, commodity shipped, gross weight, shipment's destination city and state, Arizona routes taken in travel, and comments. Conclusions about Arizona's freight traffic were made.

Methodology

Casavant, K.L., W.R. Gillis, D. Blankenship, and C. Howard, Jr., "Survey Methodology for Collecting Freight Truck and Destination Data," *Transportation Research Record 1477*, Transportation Research Board, National Research Council, Washington, D.C., 1995, pp. 7–14.

The paper describes the methodology and procedures used to collect statewide freight truck data in Washington State, and the authors say that it was the first study of collecting statewide freight truck OD data directed through personal interviews with the truck drivers. Roadside interviews of truck drivers were judged by the authors to be the most efficient technique. The survey was designed to be statistically reliable for all major Washington State highways and was implemented over a 24-h period in each of the four seasons. Permanent weigh stations and ports of entry were used as the primary data collection sites. The questionnaire included information on time-of-day movements, truck and trailer configuration, cargo type, payload, use of intermodal facilities, routes used between major origins and destinations and the specific route. Approximately 30,000 drivers were interviewed. Because the survey was designed to obtain statewide information for each season, it needed to be conducted for 5 weeks at 25 sites at each season, and the survey needed to maintain consistency as to day-of-week at each site. Interview team recruitment and training were important components of the survey method. The importance of the officer, equipment needs, and the quality control procedures are also described in the paper.

There are three particular lessons from the Washington State freight truck survey. First, community service clubs can be a viable labor force for conducting personal interviews. Second, the officer is a critical factor in obtaining information from truck drivers. Last, site set up and the use of systematic sampling techniques are the important factors to get traffic flows and promote cooperation at the interview sites.

MODAL STUDIES

Rail

Demand Study

Nazem, S.M., "Forecasting Rail Freight Transportation Demand," *Business Economics*, Vol. 11, No. 4, 1976, pp. 65–69.

The article looks at forecasting rail freight in two ways, by aggregate derived demand and by commodity derived demand, and then compares the two. The aggregate derived demand approach uses a simple econometric model based on GNP. The commodity derived demand approach forecast is based on certain major commodities handled by railroads. Both models showed the same degree of performance. From the users' point of view the commodity model is easy to visualize; however, the aggregate model can provide a good monitoring system under normal economic conditions.

Analysis of Carload Waybill Data

Lee, H. and K. Viele, "Loglinear Models and Goodness-of-Fit Statistics for Train Waybill Data," *Journal of Transportation and Statistics*, Vol. 4, No. 1, 2001 [Online]. Available: http://www.bts.gov/publications/jts/v4n1/paper5/lee.html.

The paper is concerned with estimating counts of carloads by commodity type and by origin and destination as found from rail waybills. Log-linear models can be used to compare flows of freight between different areas, search through data for unusual flows, and make predictions of future flows. The authors used waybills from states that have more than 4,500 carloads per year of traffic or 5% or more of a state's traffic from 1988 to 1992. Analysis focuses on the origins of shipments, the destinations, and the types of commodity. STCC codes are used to divide commodities into groups.

The full log-linear model in this context is

$$\log m_{ijk} = \log a_i + \log b_j + \log c_k + \log d_{ij} + \log e_{ik} + \log f_{jk} + \log g_{ijk} \quad \text{(D2)}$$

or

$$m_{ijk} = a_i b_j c_k d_{ij} e_{ik} f_{jk}\, g_{ijk} \quad \text{(D3)}$$

where a_i is a main effect for origin i (and b_j and c_k are analogous); d_{ij} is an interaction effect for when origin i and destination j have cargo flows not proportional to the product of the main effects a_i and b_j (e and f are analogous); and g_{ijk} is a three-way interaction between origin i, destination j, and commodity k. The actual counts n_{ijk} of commodity k from i to j follow a Poisson distribution with mean m_{ijk}:

$$P(n|m) = \prod_{i=0}^{181}\prod_{j=0}^{181}\prod_{k=1}^{37} \frac{(m_{ijk})^{n_{ijk}}\, e^{-m_{ijk}}}{n_{ijk}\,!} \quad \text{(D4)}$$

It was found that train cargo flow is not related to distance; therefore, the paper focuses on the complex interaction effects of the variables.

Rail Costs

Morlok, E.K. and J.A. Warner, "Approximation Equations for Costs of Rail, Trailer-on-Flatcar, and Truck Intercity Freight Systems," *Transportation Research Record 637*, Transportation Research Board, National Research Council, Washington, D.C., 1997, pp. 71–77.

This paper describes and compares equations for estimating the costs of rail, trailer-on-flatcar, and truck intercity freight systems. Data sources are old, but the general procedures are still applicable.

Rail carload. For analysis purposes a typical car was assumed to have a 59-Mg (65-ton) weight capacity and a volume capacity of approximately 139 m^3 (4,900 ft^3). The procedure determines shipment characteristics (shipment weight, shipment distance, commodity density, type of rail car used, and highway-access coefficient), computes the number of rail cars that are needed for shipment, selects an applicable cost formula, and calculates cost. Other considerations are the costs of interchange movement between two railroads, intertrain switching within the same company, and intratrain switching of cars of the same train. The study region was east of Wisconsin and Illinois and north of Kentucky and North Carolina.

Trailer-on-flatcar. Trailer-on-flatcar costs are calculated from an assumed cost per ton-mile carried. Operation costs are based on a regional average, which is taken from information in the Rail Carload Cost Scales 1973. The procedure for estimating costs is the same as for the rail carload, using dimensions for trailer-on-flatcar trailers of $V = 2{,}550$ ft^3 and $W = 490$ cwt.

Highway common carrier. The ICC Statement and the Cost of Transporting Freight by Class 1 and 2 Motor Common Carriers of General Commodities 1973 were used for estimating the costs on the highway intercity freight system. The main difference between the highway system cost-estimating procedure and the rail-carload procedure was explicitly taking into account the density of the shipment.

Air Freight

Carey, E., H.S. Mahmassani, and G.S. Toft, "Air Freight Usage Patterns of Technology-Based Industries," *Transportation Research Record 1179*, Transportation Research Board, National Research Council, Washington, D.C., 1998, pp. 33–39.

This is a survey of technology-based firms in the Austin, Texas, area. The survey was conducted concerning actual use of air transportation and other modes by these firms. Surveyors wanted to determine for both inbound and outbound freight such information as origin and destination, description of items shipped, weight, size, other characteristics, approximate value, frequency of shipments, and mode of shipment. Firms were identified using a directory of manufacturers.

Eight-six firms were contacted in person, and then by mail. Only 13 firms responded to the original detailed form. A shorter less detailed form was then developed. Only 20 more firms responded to the shortened form. In total, only

33 of 86 (38.4%) were returned and only 18 of that 33 gave information about freight.

Owing to the small number of firms surveyed, only trends can be shown in various aspects of freight. This includes regions of shipments and mode (parcel, air, truck), as well as regions where air freight is sent to and from and where air passengers travel. Results show a high dependency of technology-based firms on the parcel and air services.

Truck

Truck Routing

Wang, X. and A. Regan, "Assignment Models for Local Truckload Trucking Problems with Stochastic Service Times and Time Window Constraints," *Transportation Research Record 1771*, Transportation Research Board, National Research Council, Washington, D.C., 2001, pp. 61–68.

The paper describes a framework for a local truck routing algorithm. Routing is by load (load A, load B, load C, etc.), not geographically. Focus is on the probabilities involved with sending a truck to pick up and deliver loads within its prescribed time windows and the incurred costs. The model is logistical, and it lacks a geographic component beyond time and cost. It may be useful for determining the effect of new technologies on truck operating costs, and may also have use in modeling industrial interactions within a metropolitan area beyond I-O analysis.

Truck Weight

Hewitt, J., J. Stephens, K. Smith, and N. Menuez, "Infrastructure and Economic Impacts of Changes in Truck Weight Regulations in Montana," *Transportation Research Record 1653*, Transportation Research Board, National Research Council, Washington, D.C., 1999, pp. 42–51.

This study, although not concerned with statewide freight forecasting directly, uses similar tools to explore two important directions. First, from commodity flows, the authors use a Regional Economic Modeling, Inc. (REMI) model to determine the public infrastructure costs of projected freight flows at several potential future weight limits. Second, the authors use the REMI model to develop comparative economic feedback forecasts (productivity, employment, personal income, and Gross State Product) based on projected freight flows at several potential future weight limits. The model and methods are not discussed in detail.

Data required are I-O tables from the U.S. Department of Commerce, Bureau of Economic Analysis and commodity-flow surveys from the U.S. Department of Commerce, Bureau of Census. The data are free.

The methodology is proprietary and is not discussed in the paper. The study discussed trucks only, and did not explore the effect of mode split owing to different truck weights. It also did not explore changes in industrial efficiency (productivity, consumption, substitution, etc.) beyond changing truck weight; nor did it consider economic growth unrelated to transportation. Therefore, the results are predictable. Lower axle weights result in lower public infrastructure costs, higher private infrastructure costs, higher cost of transportation per unit of commodity, lower productivity, lower employment, lower personal income, and lower Gross State Product. Higher axle weights show the reverse effects.

The main point of this paper is to show the additional uses of a statewide freight model to predict infrastructure costs and to feedback economic input data.

Trucks Between the United States and Mexico

Mendoza, A., C. Gil, and J. Trejo, "Multiproduct Network Analysis of Freight Land Transport Between Mexico and the United States," *Transportation Research Record 1653*, Transportation Research Board, National Research Council, Washington, D.C., 1999, pp. 69–78.

The authors use border-crossing data and all-or-nothing traffic assignment to identify rail and truck differences in cross-border trade, looking for inequalities, issues, or underserved markets. This is a large-scale model analogous to the FAF or the later Latin American Trade and Transportation Study (LATTS).

The data are from the Mexican Secretariat of Commerce and Industrial Development. OD tables comprise 104 zones, including Mexican and U.S. states and zones near the border crossings. Mode split is already known, determined by the data source. Traffic assignment uses the STAN program. The output indicates that all-or-nothing assignment was used.

There was no attempt to forecast future growth or systematic evaluation of mode split. Like FAF or LATTS, this analysis uses data and traffic assignment to provide a snapshot of the existing (1996) freight network.

Trucks and NAFTA

McCrary, J. and R. Harrison, "North American Free Trade Agreement Trucks on U.S. Highway Corridors," *Transportation Research Record 1653*, Transportation Research Board, National Research Council, Washington, D.C., 1999, pp. 79–85.

The authors use border-crossing data and all-or-nothing traffic assignment to identify truck cross-border truck corridors within the United States. The study looks at truck traffic crossing the Canadian and Mexican borders. This is a large-scale model analogous to the FAF or the later LATTS.

The data are from the U.S. Department of Commerce and the U.S. Department of Transportation, Bureau of Transportation Statistics. Traffic assignment and network model are done on TransCAD. The output indicates that all-or-nothing assignment was used.

There was no attempt to forecast future growth. As with FAF or LATTS, this analysis uses data and traffic assignment to provide a snapshot of the existing (1996) freight network.

Truck Forecasting

Russel, E., R. Miller, and E. Landman, "Monitoring Travel Patterns of Heavy Trucks—Summary Report," unpublished, prepared for the Kansas Department of Transportation, K-Trans Study No. 92–93, 1997.

The Kansas DOT, surprised by truck traffic growth in western Kansas, collected survey data and modeled the traffic assignment on their in-house network. Unlike many other modeling efforts that are driven by congestion concerns, K-Trans' primary interest was truck axle weight (ESALs) for better pavement design.

They experienced data processing problems owing to personnel issues, and their results were limited to modeling the resulting OD tables. There was no attempt to forecast future truck growth. The vehicle-based survey data told planners where external trips terminated, but the state's network lacked external zones and links to distribute the trips.

After several years' delay, the project was terminated.

Special Uses

Middleton, D.R., J.M. Mason, Jr., and T. Chira-Chavala, "Trip Generation for Special-Use Truck Traffic," *Transportation Research Record 1090*, Transportation Research Board, National Research Council, Washington, D.C., 1986, pp. 8–13.

Special-use truck traffic is usually very short (fewer than 100 mi), tends to be cyclic in nature (trips made several times in a typical day), and both the origin and destination are the same from month to month, but will change eventually. The Texas State Department of Highways and Public Transportation supported a study to obtain trip generation characteristics for this kind of truck traffic. This study was divided into two parts, with each looking at different kinds of commodities. One group was called "agriculture" and included timber, grain, beef cattle, cotton, and produce; the other group was called "surface mining" and included sand, gravel, and crushed stone. The first step in the study process was selecting special-use industries, which have specific commodities unique to the Texas highway system. The second step was determining industry characteristics. On-site, telephone, and field interviews were used at sites that represent primary operations, have a significant number of trips, or exhibit a widespread problem in Texas. The next step was to determine vehicle characteristics associated with selected industries. This task was accomplished by telephone requests to related state departments. The last step was determining trip-making characteristics. Data for both the radius of influence, representing maximum distance from a center, and trip generation rates were collected from on-site interviews. The center was selected randomly and a total of 83 were chosen. The vehicle classification count was made using 15-min intervals for all traffic entering and leaving the facility during a total time period of one day.

Marine

Inland Navigation Systems Analysis

Veith, M.T. and M.S. Bronzini, "Commodity Flow and Multimodal Transportation Analysis for Inland Waterway Planning," *Transportation Research Record 636*, Transportation Research Board, National Research Council, Washington, D.C., 1997, pp. 8–14.

The purpose of the paper is to describe a model and to explain how it is used to estimate demand for inland waterway transportation. Forecasts of demand for commodity transportation are provided by commodity flow analysis and allocated to modes by means of multimodal analysis based on cost and performance criteria.

The INSA model allows cost and level of service to influence the spatial patterns, mixes, and quantities of commodity flows. Dependent variables were developed for quantities shipped from region i to region j, by mode; by mode and route; and by mode, route, and network element (node or link). Simultaneous equation models and direct-demand models can be used; however, a chain of sequential models is used for the INSA.

The INSA commodity-flow model uses economic activity by region and analyzes flow patterns by use of multiregional general equilibrium logic, which is similar to an I-O model. The commodity flow iterates through a series of calculations to arrive at predicted annual commodity flows for the current year and demand estimates for the following year. The model uses successive approximations to forecast commodity flows and tests for convergence between the last two iterations. The main features of the model are calculating minimum cost and location, allocating demand, estimating transportation cost, forecasting economic activity, allocating commodity flow, and computing consumption.

The principle output of the model is a set of region-to-region commodity flows that can be used in the planning process, and additional outputs include regional economic activity, national income, and value-added.

The INSA model does not use a separate mode split model, but combines a modal share and network routing analysis. It also uses a circuity constraint of an ellipse of given eccentricity being constructed about the origin and destination regions for a particular commodity movement. In addition, an optional inertia effect may be used to constrain a specified portion of any commodity shipment to observe modal-share percentages input by the user for that shipment.

Hawnn, A.F. and F.M. Sharp, "Inland Navigation Systems Analysis," *Transportation Research Record 636*, Transportation Research Board, National Research Council, Washington, D.C., 1977, pp. 14–22.

The purpose of the INSA commodity-flow model is to forecast the demand for interregional bulk commodity transportation. The model is an I-O model in which market dynamics determine the location, composition, and pricing of output, and the behavior of economic aggregates determines the level of output.

The model uses economic inputs such as economic activities, regional attributes for 173 BEA areas, demand, and transportation costs. Operations in the model are determination of minimum cost and location, computation of consumption, determination of demand, organization of transportation costs, forecast of economic activity, and allocation of commodity flow. Outputs include a commodity-flow report, a domestic-demand report, and an origin-flow report.

The operations of the path-selection algorithm yield identification, number of tons assigned, shipping costs for each commodity shipment, and shipping costs and transit time of assigned traffic. An ellipse about the origin and destination is used to reduce the number of paths, and commodities may also be restricted as to which modes of transportation they may use. INSA also includes an optional inertia effect, and an iterative procedure is used to assign shipments to the network.

Time–Series Analysis

Branyan, C.O. and G.D. Mickle, "Projecting Commodity Movements for Inland Waterways Port Development," *Transportation Research Record 669*, Transportation Research Board, National Research Council, Washington, D.C., 1978, pp. 5–7.

This study contains a preliminary analysis including gathering information from the BEA and local agencies to identify various commodity groups and historical data. The study also contains a detailed analysis to compute a series of time–series equations for straight line, second-degree curve, exponential curve, and second-degree exponential curve. Owing to multicollinearity problems with the original 15 variables, 5 runs were made with different combinations of variables that limited the problems. After running mathematical methods to obtain forecasts, non-mathematical procedures based on judgment and the knowledge of analysts was used. The study was very basic in nature.

Intermodal

Intermodal Demand in Arkansas

Ozment, J., "Demand for Intermodal Transportation in Arkansas," Walton College of Business, University of Arkansas, Fayetteville, unpublished paper (undated, around 2001).

In this white paper, the author asserts that the demand for truck and rail intermodal services in Arkansas is the result of ineffective public policy relating to intermodal and misperceptions of traffic managers as to the cost advantages of intermodal. The author states that application of conventional logistics theory would suggest many additional opportunities for intermodal shipping, especially in commodities of low value per weight. The analysis applied a series of cost assumptions to a variety of specific commodities (not commodity categories). The computed total logistics cost was composed of

$$\text{Total Cost} = OC + CC + Tr + PC + It + SS + \text{Other} \quad \text{(D5)}$$

where
OC = order placement cost,
CC = inventory carrying cost,
Tr = transportation cost,
PC = product cost,
It = inventory in transit cost, and
SS = safety stock cost.

and where

$OC = A(R/Q)$,
$CC = 1/2(QVW)$,
$Tr = rRwt/100$,
$PC = VR$,
$It = iVRt/365$, and
$SS = BVW$.

and where

Q = optimal order quantity (EOQ), $Q = (2AR/VW)^{1/2}$,
A = cost of placing an order,

R = annual rate of use,
V = value per unit,
W = carrying cost as a percentage of average value of inventory,
r = transportation rate per 100 pounds (CWT),
wt = weight per unit,
i = interest rate or cost of capital,
t = lead time in days, and
B = buffer of inventory to prevent stockouts.

Thus,

$$TC = A(R/Q) + 1/2(QVW) + rRwt/100 + VR + iVRt/365 + BVW \quad \text{(D6)}$$

Original Source: Coyle, J.J., E.J. Bardi, and C.J. Langley, Jr., *The Management of Business Logistics*, 6th ed., West Publishing, St. Paul, Minn., 1996 and Ballou, R.H., *Business Logistics Management*, 4th ed., Prentice Hall, Upper Saddle River, N.J., 2004.

COMMODITY STUDIES

Agricultural

Effect of Unit Trains

Linsenmeyer, D., "Effect of Unit-Train Grain Shipments on Rural Nebraska Roads," *Transportation Research Record 875*, Transportation Research Board, National Research Council, Washington, D.C., 1982, pp. 60–64.

This paper explores the effect of a change in market area and effect on truck ton-miles by a change in rail operating practice. Truck ton-miles increased 71%, profitable length-of-haul increased by 8–15 mi, and heavier trucks became more profitable as a result of switching from single-rail carloads to unit-trains, with an accompanying concentration of grain elevators.

The paper provides a clear methodology for relationships between agricultural production and different modes, but the relationships are not applicable outside of this case. Not directly useful for modelers, the paper does provide a good example of unintended effects.

Shipper Expectations of Rail

Vachel, K. and J. Bitzen, "Long-Term Availability of Railroad Services for U.S. Agriculture," *Transportation Research Record 1790*, Transportation Research Board, National Research Council, Washington, D.C., 2002, pp. 66–72.

This study is a survey of the expectations of Midwest grain shippers and railways on the effect of technology and market changes. It has limited use for models in agricultural areas, because it reflects opinion only and no specific data or analysis are presented. Consensus is that light-duty track mileage and car fleet size will decrease owing to low growth and increasing efficiency. Mileage losses will occur as heavier-duty mainline track, which can carry heavier cars, will cause elevator expansion along main routes and eliminate market areas of smaller elevators on other routes.

Empties

Comparison of Methods

Holguin-Veras, J. and E. Thorson, "Practical Implications of Modeling Commercial Vehicle Empty Trips" (CD-ROM), Presented at the 82nd Annual Meeting of the Transportation Research Board, Jan. 12–16, 2003.

The paper compares four methods of modeling empty truck trips for feedback into OD tables. Empty trips represent 30% to 50% of freight trips. Each method is used in a two-zone simulation and in a 26-zone simulation based on data from New York City. All methods produced undercounts of the total number of truck trips, but the Holguin–Veras and Thorson (HVT5) and Noortman and van Es (NVE) methods produced the smallest errors, approximately 5% to 6% of total observed trips.

Hazardous Materials

Erkut, E. and T. Glickman, "Minimax Population Exposure in Routing Highway Shipments of Hazardous Materials," *Transportation Research Record 1602*, Transportation Research Board, National Research Council, Washington, D.C., 1997, pp. 93–100.

This paper uses a two-step routing method for hazardous truck shipments. First it sets a constraint criterion, such as population along a network link. Any links exceeding the criterion are excluded from the second step. The second step is a typical shortest path or minimum impedance routing algorithm. The larger implications or applications to modeling or forecasting are not explored. Applications to oversize, overweight, or other constrained trucks are not explored.

Coutinho-Rodrigues, J., J. Current, J. Climaco, and S. Ratick, "Interactive Spacial Decision-Support Systems for Multiobjective Hazardous Materials Location-Routing Problems," *Transportation Research Record 1602*, Transportation Research Board, National Research Council, Washington, D.C., 1997, pp. 101–109.

The authors created a computer application, ISDSS, to model hazardous material flows, including production or generation, transport, use, and disposal or processing. The model is oriented toward risk management, not transport.

The application optimizes flows and locations based on user-defined networks and weighted criteria. The model algorithms are not discussed. This is not routing or forecasting software, but solution software for hazardous material risk management.

Chang, T., L. Nozick, and M. Turnquist, "Routing Hazardous Materials with Stochastic, Dynamic Link Attributes: A Case Study" (CD-ROM), Transportation Research Board, National Research Council, Washington, D.C., 2002.

The authors describe a multi-objective routing algorithm with case study. The label-correcting network algorithm uses a convolution-propagation approach, based on the algorithm's ability to "test" different paths and rule out some early. The multiple objectives are incorporated using probabilities, including hazardous material release probabilities and driver and population exposure probabilities. The algorithm includes variables for congestion and time of day to determine different routes. The algorithm is clearly presented. The example network is summarized, and only a single route is determined.

Patel, M.H. and A.J. Horowitz, "Optimal Routing of Hazardous Materials Considering Risk of Spill," *Transportation Research A*, Vol. 28A, No. 2, Mar. 1994, pp. 119–132.

The authors propose an algorithm for routing hazmat that minimizes the risk of population exposure to airborne toxic substances that might be released in a crash.

ADVANCED METHODS STUDIES

Mode Split

Log-Linear and Logit Models

Murthy, A.S.N. and B. Ashtakala, "Modal Split Analysis Using Logit Models," *Journal of Transportation Engineering*, Vol. 113, No. 5, 1987, pp. 502–519.

The study includes the analysis of survey and questionnaire data collected in Alberta, Canada, from shippers and consignees. Log-linear and logit models were then used to create a more statistically credible and comprehensive method to identify the dominant modes of commodity movement.

Communities were classified as shippers (sources), consignees (sinks), or both. Major commodity-flow data such as type, mode, loads (full or less than full), control, hire (private or for-hire), and market share were gathered, as well as demographic data such as population, retail sales volumes, etc., and other data from transportation and government agencies. Of the surveys gathered, 1,318 of the responses were shippers and 6,175 were consignees.

The data from both shippers and consignees were combined, and the five explanatory variables for modal choice considered in the study were average shipment size, loads (full or less than full), hire (private or for hire), and control. The study only uses the truck and rail modes, because all other modes carry very little freight.

For the log-linear model different combinations of load (L, $i = 1,2$), hire (H, $j = 1,2$), and mode (M, $k = 1,2$) were considered. For example, a log-linear model [LH][MH] is a model that includes the association of "loads" and "hire" individually with "modes." Two cases yielded a likelihood ratio less than one. After testing the two for statistical significance and finding the chi-squared value, the model with fewest variables was chosen because there was no substantial difference. The saturated model chosen was [LM][HM] and is expressed as

$$\ln m_{ijk} = \mu + \mu_{L(i)} + \mu_{H(j)} + \mu_{M(k)} + \mu_{LM(ik)} + \mu_{HM(jk)} \quad \text{(D7)}$$

The second part of the study was to construct a logit model to develop a table of log odds to understand how changes in the combined levels of explanatory variables affect the response variable. The logit equation that was used is defined as

$$\text{logit}_{ij} = 2[\mu_{M(1)} + \mu_{LM(i1)} + \mu_{HM(j1)}] \quad \text{(D8)}$$

Odds ratios then were calculated and proportions were found using the transformation proposed by Berkson in 1944 by mode, load, and hire for different commodities.

Mode Choice Factors

Wilson, F.R., B.G. Bisson, and K.B. Kobia, "Factors That Determine Mode Choice in the Transportation of General Freight," *Transportation Research Record 1061*, Transportation Research Board, National Research Council, Washington, D.C., 1986, pp. 26–31.

This study examines the factors that shippers in eastern Canada use to determine modes of freight shipments by hired truck, private truck, and rail. A survey was used instead of gathering waybill data, because waybill data do not include level of service attributes and differences in record keeping, and many shippers consider waybill data to be proprietary.

This study classifies four factors for mode choice, including characteristics of the transportation system, characteristics of the shipment, characteristics of the local carriers, and characteristics of the shipper.

Analysis was performed using three linear logit models. The difference between the first two is that one considers in-transit damage and one considers commodity value because both cannot be used in the same model owing to multicollinearity problems. The third model uses derived variables instead of specified variables.

The data showed increasing use of rail as length of transit increases. Shipping cost, in-transit damage, and commodity value were not significant in influencing mode choice. Significant influences for both rail and private truck modes were not covered in this survey. Data suggest that model data should be gathered using personal interview data, which provide a higher level of accuracy and could be used to explore other factors not covered in a survey.

Flows

Accuracy Study

Metaxatos, P., "Accuracy of Origin-Destination Highway Freight Weight and Value Flows" (CD-ROM), Presented at the 82nd Annual Meeting of the Transportation Research Board, Jan. 12–16, 2003.

This paper presents a method of estimating interstate or international (external–internal) freight flows using matrices and commodity data similar to common internal–internal OD tables. The external side of the commodity flow is represented by a single data source, a seaport or border crossing. The internal side of the commodity flow is represented at the county level using existing disaggregation. A set of OD matrices uses a gravity model to simulate long-distance freight flows and determine value or weight. Results are determined by the number of iterations of the gravity model, which is governed by the desired confidence level. The paper does not explore possible expansion of the technique to external–external or internal–internal freight flows or to distributed external sources. No example problem or comparison to an existing gravity model is provided.

Disaggregation

Sivakumar, A. and C. Bhat, "Fractional Split-Distribution Model for Statewide Commodity-Flow Analysis," *Transportation Research Record 1790,* Transportation Research Board, National Research Council, Washington, D.C., 2002, pp. 80–88.

A variation of the four-step modeling process, the authors create a Texas model using fractional–split distribution. This distribution uses fractions to determine origins and destinations. For example, zone A produces 1 good, and zone B consumes 1/10th of the good. Zone B also consumes 1/20 of the same good produced at Zone C.

The data were from the Reebie TRANSEARCH database. Only three commodity groups were used. Beyond the structure of fractional–split methodology, the model is not shown. The model results are compared to a normal four-step gravity model process. The fractional–split and gravity models were in close agreement. The advantages and disadvantages of each method are not clearly discussed.

Gravity Model

Black, W.R., "The Utility of the Gravity Model and Estimates of Its Parameters in Commodity Flow Studies," *Proceedings of the Association of American Geographers*, Vol. 3, 1971, pp. 28–32.

The paper reports and evaluates the results obtained from applying the gravity model to 24 sets of interregional commodity flows for the United States in 1967. The study uses a variation of the gravity model, substituting shipments and demands for productions and attractions.

The total shipments and demands are assumed known for each region and represent the row and column sums for a commodity-flow matrix. The only unknown term used in the study was the friction factor coefficient and it was increased by 0.025 in a stepwise procedure until the correlation between the actual and estimated flows failed to increase.

The study used high regional generalization in the flows reported between the nine census regions and 81 possible inter- and intraregional flows. The interregional distance was defined as half the square root of the region's area.

The estimates obtained from the gravity-type trade model for the 24 shipper groups were quite accurate and the model accounted for 93% of the variance in the flows examined. Overall, the study suggests that it is clearly possible to estimate reliable friction factors.

Ashtakala, B. and A.S.N. Murthy, "Optimized Gravity Models for Commodity Transportation," *Journal of Transportation Engineering*, Vol. 114, No. 4, 1988, pp. 393–409.

The objective of the study was to reexamine survey data (Murthy and Ashtakala 1987) and develop models for commodity transportation. A gravity model with a new technique for calibration is proposed.

The commodity data were classified and survey data about shippers and consignees were gathered. The data collected were origin and destination of commodity movement, type of commodity, type of firm, annual tonnage, average shipment size, type of load (full or less than full), type of hire (private or for-hire), control (yes or no), and market share. Demographic data were also gathered.

OD tables were developed showing origins (sources) and destinations (sinks). A series of production-constrained gravity models were then applied to the data from source to sink and compared differences in interchanges using regression analysis. The gravity model with the highest R^2 value was used as the best representation of real data. The spatial separation factor is specific to each commodity category, so there is one gravity model for each category. The models are shown by statistical measures and commodity haul frequency diagrams to be acceptable.

Trip Length

Holguin-Veras, J. and E. Thorson, "Trip Length Distributions in Commodity-Based and Trip-Based Freight Demand Modeling Investigation of Relationships," *Transportation Research Record 1707*, Transportation Research Board, National Research Council, Washington, D.C., 2002, pp. 37–48.

The trip length distribution (TLD) in freight-demand modeling can be defined as either a tonnage TLD or vehicle TLD for different models. The main aim of this paper is to exam the characteristics of the tonnage TLDs and vehicle TLDs to find the relationship between the two and to identify problems when using TLDs. The shape of a TLD will be different within different environments in which freight movements take place. Major generators have a significant impact on the shape of a TLD. If a mathematical relationship between the two types of TLDs can be found, it will help exploit the best features of commodity-based and truck-based models.

Input–Output

Application of I-O for Commodity Flows

Sorratini, J.A., "Estimating Statewide Truck Trips Using Commodity Flows and Input-Output Coefficients," *Journal of Transportation and Statistics*, Vol. 3, No. 1, Apr. 2000, pp. 53–67.

Sorratini, J.A. and R.L. Smith, Jr., "Development of a Statewide Truck Trip Forecasting Model Based on Commodity Flows and Input-Output Coefficients," *Transportation Research Record 1707*, Transportation Research Board, National Research Council, Washington, D.C., 2002, pp. 37–48.

This study used inexpensive data, the 1993 Commodity Flow Survey and I-O coefficients to create freight trip generation tables. The resulting tables were used in a standard four-step modeling process. Results were generally within 25% of traffic counts. These papers deal only with freight highway flows.

The network was made of 72 internal zones within Wisconsin, plus 70 external zones. Zones matched the Reebie Associates TRANSEARCH data used for freight productions. Network characteristics were not discussed.

Freight internal productions consisted of the 1993 Commodity Flow Survey, employment for each zone and economic sector (U.S. Census *County Business Patterns*), population for each zone (U.S. Census), and tons of commodity per truck for each STCC (Reebie Associates). Each commodity is disaggregated into STCC, zone, and internal-to-internal or internal-to-external trip type. Truckloads were assumed to be uniform across 6 days each week (312 days per year). The final freight productions were a series of 624 tables showing tons produced by each of 28 STCC sectors at each of the 624 network TAZs in Wisconsin. Productions for external zones were not considered.

Freight internal attractions were determined using I-O coefficients. From the IMPLAN software package and 1994 Wisconsin data (source not cited) and IO coefficients (source not cited), the monetary amount of one product needed by each industry to produce its output were summed for each of the 28 sectors used, resulting in a statewide estimate of total internal freight attraction volume. The total was disaggregated by employment (U.S. Census *County Business Patterns*) to the TAZ level. If no reliable employment numbers were available, population was used for disaggregation.

Freight external attractions (imports) were based on the IMPLAN final-demand report. Demand was disaggregated to the TAZ level using employment and/or population. IMPLAN regional purchase coefficients (source not cited) determined the amount of final demand allocated to internal and external supply.

Trip distribution was done by the gravity model function of TRANPLAN. Traffic assignment was mentioned, but not discussed.

The model was calibrated to 40 selected links. Root mean square error (RMSE) of predicted flows against actual counts (Wisconsin DOT) ranged from 32% to 61% under different conditions of complexity. Several iterations of the gravity model changed the RMSE range from 27% to 57%. The highest errors were in the lower volumes. Volumes of more than 2,000 vehicles and three or more gravity model iterations had an RMSE of 27%.

Vilain, P., L. Liu, and D. Aimen, "Estimation of Commodity Inflows to a Substate Region," *Transportation Research Record 1653*, Transportation Research Board, National Research Council, Washington, D.C., 1999, pp. 17–26.

This is a method of developing external-internal trip tables using existing I-O data and commodity-flow data instead of cordon counts and surveys. The article includes a calibrated example. The sum of estimated commodity flows calculated from I-O tables in the example was within 6.6% of the observed value shown in the 1993 Commodity Flow Survey. Weighted average error for individual commodities was up to 28%.

Data required are I-O tables from the U.S. Department of Commerce, Bureau of Economic Analysis, and commodity-flow surveys from the U.S. Department of Commerce, Bureau of Census. The advantages of this method are that the data collection is easy, including data for calibration, and that the method can be set up on existing spreadsheet applications. Disadvantages include methodological assumptions and limitations that can lead to significant errors in some commodity groups.

The method, using matrix algebra, is to convert the I-O table into a supply-side commodity-flow matrix. Then the method determines the location quotient (percent of regional employment divided by percent of total U.S. employment) for each industry. Commodities and industries are 38 standard types used by the U.S. Department of Commerce for I-O tables. The final result is external-to-regional commodity flows for each industry and commodity type. The possibility of using areas smaller than regional (such as county or TAZ level) was not explored.

Two important assumptions are that commodities used by each industry are identical nationally, and cannot vary from region to region, and that the fraction of each commodity purchased locally is identical across all industries. For example, industry A uses four tons of commodity *N* input for each ton of output, regardless of the local price or availability or possibility of substitution. Furthermore, if 10% of all of the state's use of commodity *N* is produced internally, then industry A will purchase 10% of its *N* locally, regardless of production, transportation, regulatory, or other impacts.

In the example problem, the sum of commodity flows was measured against the 1993 Commodity Flow Survey benchmarks. The sum of all commodities was overreported by 6.6% of actual flow, with a weighted mean average of 28% error for individual commodities. Mineral products and petroleum and coal products predictions were particularly poor, and removing them changed the sum of commodities underreported by 9% with a weighted mean average of 17% for individual commodities.

Final matrix and table results from this method are yearly flows. Breakdowns by day or time-of-day were outside the scope of study.

Networks and Traffic Assignment

Sequential Shipper-Carrier Networks

Friesz, T.L., J.A. Gottfried, and E.K. Morlok, "A Sequential Shipper-Carrier Network Model for Predicting Freight Flows," *Transportation Science*, Vol. 20, No. 2, 1986, pp. 80–91.

The authors report on the development of three similar intercity freight models that have their greatest emphasis on obtaining accurate traffic assignments. Each of the models contains these major elements: trip distribution with a doubly constrained gravity model; a shipper mode choice and route choice process; a way of allocating shipments to carrier networks; and a carrier route choice process. Separate, but compatible, networks are used to model the shipper and carrier routing decisions. The shipper routing decision process is based on an elastic-demand user-optimal equilibrium assignment, where as the carrier routing decision is a fixed-demand system optimal over the carrier's subnetwork. These shipper and carrier decision steps are sequential (without feedback). The carrier choice networks provide for movements across carriers, backhauling, and delays along mainlines and in yards. Both link cost and link traversal time are used in the route choice process. Tests were conducted on networks with up to 15 commodity groups and up to 15,000 single-direction links (arcs). The unit of spatial aggregations was a BEA region.

Hypernetworks

Friesz, T.L. and E.K. Morlok, "Recent Advances in Network Modeling and Their Implications for Freight Systems Planning," *Transportation Research Forum Proceedings*, 1980, pp. 513–520.

This paper reports on initial efforts at building freight forecasting models that are superceded by later work by the same authors. The intent of the paper is to draw a distinction between passenger models and freight models. The authors concentrate on traffic assignment and show how transshipment can be accommodated with a hypernetwork. The paper makes two contributions: (1) it shows how user-optimal equilibrium assignments may be accomplished with multiple classes; and (2) it demonstrates that carriers can choose their own criteria for optimizing their paths.

State of the Art, Early 1980s

Friesz, T.L., R.L. Tobin, and P.T. Harker, "Predictive Intercity Freight Network Models: The State of the Art," *Transportation Research A*, Vol. 17A, No. 6, 1983, pp. 409–417.

The authors review several similar approaches to intercity freight forecasting, with an emphasis on their own work. They concentrate on routing decisions within macroscopic equilibrium network frameworks. Although the authors mention heuristic attempts to solve complex problems of shipper and carrier behavior, they are much more interested in algorithms based on optimization theory or variational inequality theory and how these models have developed incrementally as additional theory is added to what has already been done. They critique six full-scale models in terms of 16 attributes:

- Treatment of multiple modes,
- Treatment of multiple commodities,
- Sequential loading of commodities,
- Simultaneous loading of commodities,

- Treatment of congestion phenomenon via nonlinear cost and delay functions,
- Inclusion of elastic transportation demand,
- Explicit treatment of shippers,
- Explicit treatment of carriers,
- Sequential solution of shipper and carrier submodels,
- Simultaneous solution of shipper and carrier submodels,
- Sequential solution of macroeconomic model and transportation network model,
- Simultaneous solution of macroeconomic model and transportation network model,
- Solution employing nonmonotonic functions,
- Explicit treatment of backhauling,
- Explicit treatment of blocking strategies, and
- Inclusion of fleet constraints.

"Blocking strategies" refers to means of collecting carloads into trains for more efficient shipping by rail. The authors report at length on recent (at that time) attempts to impart further realism to the models in the areas of simultaneous shipper-carrier decision making, including competitive and cooperative behaviors, simultaneous macroeconomic and network models, and fleet constraints. Issues that have not been handled well according to the authors are backhauling and blocking.

Whole Models

National Energy Model

U.S. Department of Energy, Energy Information Administration, Office of Integrated Analysis and Forecasting, *The National Energy Modeling System: An Overview 2000*, Mar. 2000 [Online]. Available: http://www.eia.doe.gov/oiaf/archive/aeo00/overview/index.html.

The National Energy Modeling System is used to forecast U.S. energy production, demand, and prices over 20 years. The model is composed of a series of modules. Each module includes a single type of supply, conversion, demand, or other input or output of the system. Modules include macroeconomic activity, carbon emissions, transportation demand for energy, electricity markets, oil and gas supplies, coal markets, and more. The results of the model are one input to the annual U.S. Department of Energy *Annual Energy Outlook* report.

Each annual iteration of the forecasting model includes multiple baseline cases and changes in assumptions. For example, the model for 2000 included 5 baseline cases plus 32 nonbaseline cases to explore the impacts of varying key assumptions. This method of varying key assumptions is not significantly used in freight transportation forecasting.

The "integrating" module expedites changing assumptions by ensuring data uniformity among modules and by testing module output for iterative convergence. The integrating module automatically relaxes some impedance parameters (prices) to encourage convergence, if needed. Each module of the model can also be executed independently.

The macroeconomic module includes four submodules to predict economic activity. Rather than build a model of the economy, the Department of Energy rents four models from Standard and Poor's/DRI: U.S. Quarterly Model of the Economy, Personal Computer Model of Industrial Output, Employment Model by Industry, and Regional Model. These four models each provide some of the variables for input to the National Energy Modeling System, and provide valuable cross check on results and assumptions. The macroeconomic module integrates the results of the four models and provides limited ability to question assumptions within them to provide baseline cases.

State of the Art, Early 1970s

Smith, P.L., "Forecasting Freight Transport Demand—The State of the Art," *The Logistics and Transportation Review*, Vol. 10, No. 4, 1974.

This is an excellent review essay about the evolution of six major approaches to freight-demand forecasting through the early 1970s. The author reviews 44 articles relating to: (1) market share models, (2) I-O models, (3) inventory theoretic models, (4) gravity models, (5) abstract mode models, and (6) linear programming models. The paper focuses on the assumptions behind and limitations of each approach. The author emphasizes the tradeoff between analytical or theoretical sophistication and the amount of data necessary for calibration. The simplest and most prevalent technique is mode-share models, but gravity models and linear-programming models offer better policy sensitivity and should extrapolate better to future situations. The author cautioned against I-O models with advice that is still relevant: "The fundamental problem of using input-output models in multiregional or multi-country analysis is the massive data requirements. This problem would be even more severe for a modally disaggregated, transport oriented inter-regional input-output model."

State of the Art, Late 1970s and Early 1980s

Winston, C., "The Demand for Freight Transportation: Model and Applications," *Transportation Research*, Vol. 17A, No. 6, 1983.

In what could be described as a follow-up review essay to the one by Smith (1974), Winston reviews several demand formulations developed by researchers through about 1981. This article was written during a period of deregulation in the U.S. freight industry; therefore, the review was slanted toward those models that would help readers understand deregulation issues. The article offers opinions as to the most worthwhile directions in freight-demand models, promoting disaggregate models, particularly those with behavioral underpinnings, over aggregate models. The paper emphasizes the need to look at a full range of options that relate to the mode selection decision by shippers, including shipment size, service quality, and location. The author briefly discusses "inventory" models that reflect decisions made by the receiving firm.

Combined Model

Chang, E., A. Ziliaskopoulos, D. Boyce, and S. Waller, "Solution Algorithm for Combined Interregional Commodity Flow and Transportation Network Model with Link Capacity Constraints," *Transportation Research Record 1771*, Transportation Research Board, National Research Council, Washington, D.C., 2001, pp. 114–121.

This paper describes a classic regional, statewide, or interstate model framework. The initial data are I-O tables and transportation network, and the final output is OD demand for each node in the network, link volumes, and system cost. The model has an entropy coefficient to find cross-hauling and dispersion effects.

I-O flows are converted to commodity flows and to truckloads using different conversion factors for each commodity. The model goal is a combination of OD demands and link volumes that result in optimum system cost. Once the OD demands are set, the algorithm uses Danzig–Wolfe decomposition to distribute the flows to the network.

The test network included 36 zones and 13 commodities. The algorithm functioned as expected, but was not validated or calibrated.

The model recognizes congestion and capacity constraints, but not truck weight constraints or time-of-day issues.

Use of Secondary Data Sources

Chin, S., J. Hopson, and H. Hwang, "Estimating State-Level Truck Activities in America," *Journal of Transportation and Statistics*, Jan. 1998, pp. 63–74.

This study estimates the amount of freight shipped by truck within, to, from, and through each state. The data come from the 1993 Commodity Flow Survey, the 1992 Census of Agriculture, the 1992 Truck Inventory and Use Survey, the 1993 and 1994 Transborder Surface Freight data, the 1993 U.S. Waterway Data, and the 1993 county business patterns.

Truck flows were assigned to the Oak Ridge National Highway Network. Assignment was based on shortest path, with a travel time impedance factor.

Agricultural trips were estimated and added. Import and export freight was estimated and added. Assignment of originating, destination, and through flow was adjusted for international imports and exports, with the port shown as "through" rather than origin or destination.

The ton-mile estimate error may be up to 7% off, owing to the disparate data sources.

This study used a simple model and simplifying assumptions for the network. It did not go through the four-step model, instead loading tons, origins, and destinations into ton-miles on the network. The goal was a set of ton-mile estimates, not assigned trips.

Feedback to Generation

Park, M. and R. Smith, "Development of a Statewide Truck-Travel Demand Model with Limited Origin-Destination Survey Data," *Transportation Research Record 1602,* Transportation Research Board, National Research Council, Washington, D.C., 1997, pp. 14–21.

The authors explore a method of creating statewide OD tables using very limited initial data and a selected-link-based (SELINK) analysis. This method, applied to a statewide model using OD data from only 14 of 624 zones, underreported trips by only 18%. The goal is to provide a tool to lower the cost of data.

SELINK analysis is a feedback process from traffic assignment back to trip generation. The entire trip generation-to-gravity model-to-traffic assignment and then feedback to trip generation process requires three iterations to provide best results. Each selected link is compared with known volumes after traffic assignment, and an adjustment is computed. For the statewide model example, there are 32 selected links.

Details of the methods, algorithms, and data requirements are clearly shown in the paper. The study covered internal–internal trips only. Error is measured by RMSE. In the statewide model example, RMSE for Interstate highways is 24%, for U.S. highways 46%, and for state highways 104%.

State-of-the-Art Review

Pendyala, R., V. Shankar, and R. McCullough, "Freight Travel Demand Modeling: Synthesis of Approaches and Development of a Framework," *Transportation Research Record 1725*, Transportation Research Board, National Research Council, Washington, D.C., 2000, pp. 9–16.

The article offers a very good review of recent and historical trends up to 1999, and then develops a conceptual framework for freight transportation planning. The authors briefly review freight forecasting and data requirements, adding nothing new.

This is a good introduction to the field or a primer on the subject. It is a good brief summary of work in the field.

Sequential Models

Ashtakala, B. and A.S.N. Murthy, "Sequential Models to Determine Intercity Commodity Transportation Demand," *Transportation Research A*, Vol. 27A, No. 5, 1993, pp. 373–382.

The objective of the study is to determine the demand for commodity transportation using the conventional sequential modeling approach. The first three stages are commodity production and consumption, distribution, and modal split. The route assignment stage is not included because the conventional all-or-nothing assignment is not found to be adequate for predicting commodity transport volumes on the highway network.

Survey data were gathered and log-linear and logit models were developed for modal split and an optimized gravity model was developed for distribution. Commodity demands were represented graphically in the form of commodity-flow diagrams between origins and destinations. The diagrams are similar to desire line diagrams and show demands for rail and truck.

From the study it is evident from commodity-flow diagrams that the nearest source supplies the necessary commodities to the communities around it and as the distance increases, the amount of interchange between the sources and sinks diminishes.

The study shows that sequential modeling can be applied effectively for estimating commodity flows. The gravity model is also found to be applicable for various commodity categories. The modal split model used in the study is useful and innovative. Lastly, the source nearest a sink supplies the necessary commodities to it.

State-of-the-Practice Review, Early 1980s

Bronzini, M.S., "Evolution of a Multimodal Freight Transportation Network Model," *Proceedings Transportation Research Forum*, Vol. 21, 1980, pp. 475–485.

The paper describes the development of different national multimodal freight transportation network models that occurred at different times and with different visions. All are associated with the national network project, which encompassed rail, highway, waterways, and pipeline networks developed in late 1960s.

The INSA project developed a model that could determine the lowest cost path by considering both the shipment cost and the cost of delay as perceived by shippers. Node and link characteristics, which are related to the time and cost in the network, are described. The model was applied to a system that contains waterways and railroads. The model used the commodity flows between BEA regions, consisting of both local and interregional traffic. The model's estimates of major trends and patterns in transportation cost and traffic levels are reasonable, although local traffic estimates were not accurate.

The next vision was the Transportation Systems Center Freight Energy Model, which allowed modal choice and routing decisions to be based on the energy consumption. The Transportation Systems Center model extensively revised the network and operation database. The links and nodes in the network were modified, and the transit time, energy use, and cost data were reestimated.

The National Energy Transportation Study transportation network model expanded the study area and modified the network database. Equilibrium-seeking traffic assignment routines were developed for the study and were used to predict flows on the model network. The effect of the equilibrium assignment is described in the paper.

The Electric Power Research Institute (EPRI) model focused on the network effects of energy supply. The railroad routing algorithm developed by EPRI was much more detailed than before. Results from the EPRI model are not reported in the paper.

Across the different visions, the greatest need for a transportation network model is a comprehensive interregional commodity-flow database. Cost is the most important potential source of error in the modal choice and routing algorithms.

Underdeveloped Regions

Jones, P.S. and G.P. Sharp, "Multi-Mode Intercity Freight Transportation Planning for Underdeveloped Regions," TTR, P523 (incomplete reference).

This paper describes a freight model for parts of eight states between Brunswick on the Georgia coast to Kansas City—a corridor that is approximately 1,200 mi long and 100 mi wide. The transportation system there includes several Interstate, secondary rail lines, and waterways. The Standard Industrial Classification codes are used to describe commodity groups and there are separated arcs in the network for highway, rail, and water modes. This is a conventional model consisting of 111 zones and 53 commodity and industry groups. For mode split, transport time and cost are independently derived from the network.

Modifying a Four-Step Model

Kim, T.J. and J.J. Hinkle, "Model for Statewide Freight Transportation Planning," *Transportation Research Record 889*, Transportation Research Board, National Research Council, Washington, D.C., 1982, pp. 15–19.

The authors developed a multicommodity, multimodal statewide freight transportation planning model by modifying the existing Urban Transportation Planning System (UTPS) package developed by FHWA and the Urban Mass Transportation Administration. There are five classes of submodels: network analysis, freight transport demand analysis, vehicle requirements, assignment, and evaluation. Freight transport demand analysis was done in four steps: freight volume generation, interzonal commodity distribution, modal split, and freight volume assignment. UTPS.ULOGIT and UTPS.AGM were used in the calibration of modal split and commodity distribution from freight volume OD data. Truck backhaul was estimated from the volume to be carried, the distance, truck size, cost, and OD table. A separate program dealt with empty rail car movements. UTPS.UROAD was used to assign trucks and cars to different networks.

An Early Application in Florida

Middendorf, D.P., M. Jelavich, and R.H. Ellis, "Development and Application of Statewide, Multimodal Freight Forecasting Procedures for Florida," *Transportation Research Record 889*, Transportation Research Board, National Research Council, Washington, D.C., 1982, pp. 7–14.

This paper documents an early effort to create a statewide freight forecasting model for Florida. The general method was OD table factoring and assignment.

Belgium

Van Herbruggen, B., *In-Depth Description of the Tremove Model*, Transport & Mobility Leuven; Leuven, Belgium, Mar. 2002 [Online]. Available: http://www.tmleuven.be/Expertise/Download/Tremove_Description.pdf.

The TREMOVE model is a Belgian model to forecast emissions. It is used to model changes in policy and technology on air pollution, and is not suited for forecasting freight.

Freight demand is based on mode, price, and time of day. Freight supply is based on price of vehicle and price of fuel. There is no network, no distinction between freight types, and no infrastructure. Interestingly, there is time-of-day sensitivity and multiple modes.

Sweden

Swedish Institute for Transport and Communication Analysis (SIKA), "A Conceptual Framework for Analysis and Model Support for Swedish Studies of Freight Transport and Transport Policy—An Idea Study," Nov. 2001 [Online]. Available: http://www.sika-institute.se/utgivning/sam01_1.pdf.

SIKA is the Swedish transportation statistics bureau. This study for a model framework draws mostly from the *QRFM*. The paper is an exploration of how to make the *QRFM* framework work with existing Swedish statistical reports and software.

The model begins with economic assumptions from the Ministry of Finance, analogous to the U.S. Department of Commerce, data on employment, and manufacturing value. Matrix estimation uses employment disaggregated to zonal level. Similarly, through the four-step process, the authors explore local parallel data sources and software to stay close to the *QRFM* method.

Other

Morlok, E. and S. Riddle, "Estimating the Capacity of Freight Transportation Systems," *Transportation Research Record 1653*, Transportation Research Board, National Research Council, Washington, D.C., 1999, pp. 1–8.

The authors present a method of measuring the capacity of an entire system, rather than individual links or components. Given a network with known capacities of individual components, plus known traffic patterns (OD pattern), plus fleet size, the 13 equations of the algorithm will estimate the system capacity. The system capacity can be compared with the existing flows. Additionally, a modified method can be used to estimate capacity change resulting from change in the network or fleet size.

The authors used a very small rail network for their example. Applications or potential to forecasting or modeling are not discussed. The 13 equations are shown.

Don Breazeale and Associates, Inc., "Task II—Data Collection Strategic Analysis Report for Strategic Planning Advice for Freight/Truck Model Development Project, Prepared for Los Angeles County Metropolitan Transportation Authority, Oct. 2002.

At 234 pages plus Executive Summary, the report covers only Task II (data collection strategies) of Los Angeles County MTA's regional Freight Forecasting project. It does not include the model. The report has a useful summary of data sources, methods, and technologies, some of which are useful for statewide forecasting. No new methods are developed. The consultant recommends long-term relationships with major shippers as a source of reliable OD data. Also includes an annotated bibliography of data sources for regional and statewide modeling. Very complete and usable as a reference guide.

A Typology

Souleyrette, R., T.H. Maze, T. Strauss, D. Preissig, and A.G. Smadi, "Freight Planning Typology," *Transportation Research Record 1613*, Transportation Research Board, National Research Council, Washington, D.C., 1998, pp. 12–19.

Most models built for freight transportation are based on two concepts: spatial price equilibrium and network equilibrium. Most of these models have had implementation difficulties that have limited their use. The authors contend that it is more important to focus on the economic sectors for the freight traffic demand because most state and regional economics are dominated by a few sectors. The freight planning "typology" focuses on addressing the needs of state and regional transportation planning. The first step is to identify key issues. Freight is divided into groups with the same transportation requirements. Each commodity or sector becomes a layer. Sectors are overlayed to form an aggregate forecast of all freight traffic volumes. The paper used a case study of "meat product and farm machinery industries in Iowa" to demonstrate the method.

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
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
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
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