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Guidebook on

STATEWIDE TRAVEL FORECASTING

U.S. Department of Transportation
Federal Highway Administration

Guidebook on Statewide Travel Forecasting

Prepared for
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Chapter 1. Introduction

This guidebook reviews the state-of-the-practice of statewide travel forecasting. It focuses on those techniques that have been considered essential to good statewide travel forecasting. In addition, this guidebook presents specialized and advanced techniques of potential interest to persons involved in statewide travel forecasting.

Emphasis is placed on practical methods. In some places in the guidebook, methods are presented that have not been tried in statewide travel forecasting but show strong potential to improve the process. This guidebook does not describe methods that have been presented in the academic literature and are considered to be still under development. Persons interested in recent research on this topic might want to consult the appendix, “The State of the Art in Statewide Travel Demand Forecasting”.

There are many facets of statewide travel forecasting and it is not possible to create a one-size-fits-all model to deal with every possible situation. This guidebook advocates the need to select the technique that is most applicable to the problem. In some cases, a simple growth factor model may be preferable to a full-blown network analysis of the whole state.

This guidebook also makes a distinction between urban travel forecasting and statewide travel forecasting. Although there are similarities in theory, the differences in implementation are quite important.

This guidebook will make reference to travel forecasting software, but it does not provide guidelines for any particular software package, nor are the recommended techniques dependent upon the capabilities of any specific software package.

Structure of the Guidebook

After this introduction the guidebook consists of four chapters.

Time Series. Chapter 2 deals with methods for extrapolating upon existing trends in traffic volumes. Topics range from simple growth factor methods to ARIMA (autoregressive, integrated, moving-average) models.

Passenger Forecasts. Chapter 3 deals primarily with means for adapting the traditional urban “four step” model to statewide travel forecasting.

Freight Forecasts. Chapter 4 deals with the need to integrate freight forecasts with passenger forecasts. It discusses all freight modes, but emphasizes heavy trucks. Major portions of the chapter concern freight data sources.

Specialized Methods for Passenger Forecasting. There are many forecasting situations that are not addressed well by a traditional “four step” model. Chapter 5 lists several methods that have occasional value for statewide, corridor or intercity travel forecasts.

Reasons for Statewide Travel Forecasting

There are a number of reasons why a state might be interested in forecasting statewide or rural travel.

Forecasts of Rural/Intercity Travel. Overall assessments of the adequacy of the statewide transportation networks require forecasts of rural and intercity travel by all freight and passenger modes. Such forecasts can be helpful in programming the sequence of projects and their associated costs.

Supplement Urban Forecasts. Planners in most sizable urban areas have the ability to forecast traffic levels in their communities. A large portion of travel in most states is rural. Thus, investigations of statewide or national transportation policies would be incomplete without forecasts on rural highways and other intercity transportation modes. Indicators (such as VMT, air pollution emissions and consumer surplus) require forecasts from both urban and rural areas. In addition, statewide forecasts can be helpful to urban area forecasts by providing information on through trips.

Satisfy Mandated Planning Requirements. TEA 21 mandates that several issues must be considered in statewide transportation plans. The study of many of these issues can be facilitated by a good, multimodal or intermodal travel forecasting model.

Develop Project-Level Forecasts in Rural Areas. The sizing of facilities in the design process requires accurate estimates of future travel. Time series and hybrid techniques (time series combined with conventional four-step models) can be particularly useful for project-level forecasting.

Original ISTEA Planning Factors

ISTEA was more specific than TEA 21 in its required planning factors, and the relationship between the ISTEA factors and travel forecasting is somewhat clearer. Those factors that closely relate to travel forecasting are:

- Energy use;
- Border crossings, major transportation facilities and military;
- Connectivity between metropolitan areas;
- Efficient use of existing facilities;
- Traffic congestion reduction; and
- Efficient movement of commercial vehicles.

These factors are consistent with TEA 21.

Overview of Approaches

There are three different approaches to travel forecasting that are of interest to planners in state DOTs: statewide, corridor and project. All three approaches are covered by this guidebook.

Statewide. Statewide forecasts most often require a full “four-step” simulation that considers each of the following elements:

- All passenger modes, such as auto, intercity bus, conventional rail, highspeed rail and air;
- All freight modes, such as truck, rail, water and air;
- All passenger travel purposes, such as commuter, business and recreation;
- All freight commodities, such as lumber, machinery and agricultural products;
- All or many times of day;
- All classes of facilities;
- Intermodal transfers; and
- Future growth or changes in industry and population.

Corridor/Intercity. Often the total demand in the corridor by time of day is considered constant or estimated externally. Thus, the forecast becomes an exercise in mode split and traffic assignment. Mode split models of some sophistication are often chosen to give precise estimates of modal shares.

Project. Project level forecasting is often of shorter term with few unforeseen intervening factors. In many cases, project level forecasts can be made by extrapolating upon current trends. Thus, time series methods are of greatest interest for project level forecasts.

Time Series Methods

A time series may consist of traffic levels, population levels, employment levels or any other socioeconomic or demographic characteristic of interest to forecasting. A time series may be of interest by itself or important as an input to a four-step model.

Growth Factor Methods. Growth factor methods are simple time series techniques that assume that the rate of growth is constant over time. Growth factor methods are recommended in FHWA's Traffic Monitoring Guide for interpolating traffic counts on road segments that are missing data elements for one or two years.

Linear Regression and Extensions. There are many time series methods based on statistical theory -- most often linear regression theory. Linear regression is a well-developed technique for fitting lines to X-Y data. The choice of formulation depends upon the nature of the data and the eventual use of the forecasts.

- Simple trend models assume that the year-to-year change is constant, differing from growth factor models that assume that the percentage of change from year to year is constant.
- Moving average models attempt to eliminate bumpiness within a data series by averaging a few items that are close together in time. Moving average methods can be used to eliminate seasonal, weekly and diurnal fluctuations in data. Other moving average methods can assure that only the most recent data is used in a forecast.
- ARIMA techniques form a class of models for fitting complex time series, particularly those with seasonal fluctuations. ARIMA models are sometimes referred to as Box-Jenkins models. Many transportation-related time series can be best forecasted with a Box-Jenkins model. A full understanding of Box-Jenkins models require a good knowledge of statistics, but the underlying principles can be easily explained.

Overview of Three/Four Step Models

Many states trying to build statewide travel forecasting models are doing so using the same theory and software used for urban models. This strategy may be appropriate or inappropriate, depending upon the policies or projects that are being evaluated.

The four traditional steps of an urban model are trip generation, trip distribution, mode split and trip assignment. The purposes of these steps will be explained later. There are other required steps of less importance. A three-step model would not include mode split. Such a model is typically used for forecasting automobile traffic on highways.

There are enough differences between statewide and urban forecasting to require changes to most of the steps. The ability of a given software package to model statewide travel is an issue to be considered, but the process should not be arbitrarily limited to the capabilities of any particular commercial software product.

The four-step models discussed in this guidebook are macroscopic in nature. They deal with groups of trips, travelers and vehicles rather than individual travelers and vehicles. “Microsimulation” methods have not been tried at the statewide level and are still considered experimental at the urban level.

Commodity Based Freight Models. This guidebook recommends that freight traffic be predicted from commodity flows. The recommended forecasting method makes effective use of available data sources and knowledge of freight flow processes. This method of modeling freight flow parallels the process for modeling passenger movements.

Calibration and Validation

A major emphasis of this guidebook is on effective calibration and validation of models, once they are created. Calibration and validation involve several distinct processes.

Adjustment of Parameters. A travel forecasting model has literally dozens of parameters that must be individually set for any given forecast. The process of setting all these parameters is called “calibration”. Most importance to statewide forecasting are the parameters related to trip generation (attractions and productions), mode split and trip distribution -- particularly gravity model friction factors.

Refining the Trip Table. Techniques have been developed to estimate trip tables from traffic counts. These techniques cannot estimate a trip table from scratch, but can be useful for modifying an existing trip table (perhaps from the gravity model) to better match traffic counts. Employing such a technique may be better than applying a set of ad hoc adjustments (known as k-factors in the parlance of the gravity model).

Adjustment to Traffic Assignment Inputs. Urban models often go through an extensive network “calibration” procedure where various link attributes, such as speed and capacity, are adjusted to achieve better agreement with ground counts. For statewide models there is less opportunity for adjustment, because there are fewer attributes; however, some states have found it useful to adjust speeds by a formula to account for driver preference for certain routes, for aggregation problems in the definition of the network and for lack of continuity of routes at state borders on the network.

Base Case Comparisons. An important step in any model development is to compare a base case (or year) forecast against known traffic counts. This comparison will not, by itself, assure that future year forecasts are valid. However, the comparison will demonstrate that major relationships have been simulated with some degree of accuracy and consistency.

Specialized Methods

There are several specialized methods to help solve particular problems related to corridor or intercity forecasting. They can constitute a complete forecasting procedure by themselves or enhance an existing model.

Hybrid Technique. The “pivot” method uses outputs from a travel forecasting model and from a time-series model to provide precise forecasts on one or a few highway segments. The forecast is made relative to existing traffic volumes.

Nested Logit. The nested logit model is a means of simultaneously forecasting traffic and patronage on a variety of intercity modes. The nested logit model has the ability to perform correct forecasts when there are many modes, some of them being close substitutes for each other.

Total Corridor Demand. Demand within a corridor is often modeled as a function of socioeconomic factors. Methods exist for forecasting total demand without needing to run a full-blown four-step model.

Stated Preference. Stated preference techniques ask travelers about hypothetical modal choices to determine the ridership potential of a new mode.

Introduction to Data Sources

This chapter will introduce a few data sources, but most discussion of the use of the data will be handled in later chapters.

Alternatives to Calibration. Calibrated model steps provide the greatest policy sensitivity. However, if the policy being evaluated does not use a calibrated model step in a meaningful way, then the effort to calibrate is wasted and more efficient ways of forecasting may be more appropriate. For example, a good commodity mode split model is very difficult to calibrate. If one were available, it would be quite useful in determining how commodity mode shares are affected by changes in shipping costs or improvements in service quality. However, it is entirely possible that the state is uninterested in policies that might affect costs or quality. In that case, the calibrated mode split model is not helping the forecasting process.

Alternatively, commodity mode split may be represented by a series of lookup tables developed from historical data. Such look up tables can be tabulated from the Commodity Flow Survey without a great deal of difficulty.

Spatial Aggregation Issues. Data is reported at different levels of spatial aggregation, depending upon the source. Generally speaking, lower levels of spatial aggregation result in better forecasts but cause an increase in costs and time for analysis. Possible levels of spatial aggregations include: traffic analysis zones (TAZs), counties, municipalities, states (outside your state), NTARs and BEA (Bureau of Economic Analysis) regions.

Moving data from one level of spatial aggregation to another is often a difficult process, so the primary spatial unit must be chosen carefully at the beginning of model development.

Key Data Sources

Appropriate use of existing data can speed the development of statewide models. Some of the better sources of data are public agencies, but private organizations can also provide data for statewide travel forecasting.

Census Bureau. The Census Bureau provides complete person and household data every ten years and data on a wide variety of socioeconomic conditions at other intervals.

Bureau of Transportation Statistics (BTS). The BTS is a source of many of the public databases useful for statewide travel forecasting. All products are available from its web page: www.bts.gov.

Proprietary Data Sources. Several companies provide proprietary data, demographic forecasts and economic forecasts. Many of the proprietary databases deal with lower levels of aggregation than public sources.

Original Data Collection. A high quality forecast will require some original data collection beyond traffic counts. These might include:

- Travel surveys of households
- Surveys of drivers of passenger and freight vehicles at cordon stations;

- Surveys of travelers within a corridor to ascertain their preference for new modes (behavioral intention); and
- Origin-destination information collected at a single, high demand point within the state (single station origin-destination survey).

Key Census Databases

Decennial Census. Specialized products from the decennial census have included questions related to journey to work (JTW) and the Census Transportation Planning Package (CTPP). The CTPP provides data aggregated to the TAZ (traffic analysis zone) level as defined by MPOs. The CTPP also provides information on the number of employees by zone of employment.

Economic Census. This data set includes: number of establishments (or companies); number of employees; payroll; and measures of output (sales, receipts, revenue, value of shipments or value of construction work done).

Census of Agriculture. All operators provide crop acreage and quantities harvested, inventories of livestock and poultry, value of products sold, land use and ownership, irrigation activities, amount of commodity credit loans, number of hired laborers, Federal program payments and operator characteristics. Selected operators provide additional information on production expenses (including interest), fertilizer and chemical use, machinery and equipment, market value of land and buildings and income from farm-related sources.

Commodity Flow Survey. This data set is derived from a sample of shipments from the US covering most commodities and modes. Data are reported at the national, state and NTAR levels.

Census of Manufacturers and Manufacturers Survey. Basic data from this data set include kind of business, location, ownership, value of shipments, payroll and employment. Additional data collected include cost of materials, inventories, new capital expenditures, fuel and energy costs, hours worked and payroll supplements. Mining is included in a separate but similar database.

National Personal Transportation Survey (NPTS) Overview

The NPTS is a household travel survey last updated in 1995. The survey collects data from a random, stratified sample of over 40 thousand households about all personal trips, by all modes, for all purposes. Trips were included for all persons age 5 and older.

Household data in the NPTS include: household size, number of household vehicles, income and location. Person data include: age, gender, education, relationship within the household, driver status, annual miles driven if a worker, worker status, if drive as an essential part of work if employed and seat belt use. Vehicle data include: annual miles driven, make, model and model year. Trip data include: trip purpose, mode, length (in miles and minutes), time of day, vehicle characteristics (if a household vehicle was used), number of occupants and driver characteristics.

American Travel Survey (ATS) Overview

The ATS is a survey of long (greater than 100 miles) trips. Approximately 80,000 households participated. Interviews were conducted approximately every three months by phone and in-person. Trip data included: the origin and destination of the trip, stops along the way and side trips from the destination, the principal means of transportation, the access and egress modes to airports, train and bus stations, information about the travel party, reason for the trip, number of nights spent away from home and the type of lodging. Route distances of all trips were calculated from a network.

Important Freight Data Sources

Commodity Flow Survey (CFS). The CFS is the most complete single public source of information on freight flows in the US. National data provides summaries by three-digit STCC, state and NTAR data by two-digit STCC. Raw data are not available. National data will give distance by mode by three-digit STCC. The CFS will be discussed extensively in Chapter 4.

Commercial Freight Flow Products. Reebie, for many years, has provided the TRANSEARCH database and custom data products from TRANSEARCH. TRANSEARCH provides traffic statistics between BEA regions by mode (water, rail, air and truck) and by commodity. It incorporates data from a “significant number” of truckload and LTL carriers, as well as a wide variety of publicly available databases. Reebie is currently developing a product, called the Intermodal Freight Visual Data Base, that disaggregates the TRANSEARCH data to counties for state-level forecasting purposes.

Commercial Economic Forecasts

Many firms provide economic forecasts that can be useful for statewide travel forecasts.

REMI. REMI does regional forecasts with a model called Policy Insight. Simulations with the model are used to estimate the economic and demographic effects of economic development programs and transportation policy changes.[1]

Woods & Poole. Woods & Poole’s database contains more than 550 economic and demographic variables for every county in the United States for every year from 1970 to 2020. This database includes population by age, sex and race; employment and earnings by major industry; personal income by source of income; retail sales by kind of business; and data on the number of households, their size and their income.[2]

NPA. NPA’s database is also aggregated at the county level. The database contains 212 economic or demographic items for the years 1967 to 2025. Also contained in the database are twelve categories of residential and nonresidential buildings and fifteen factors determining demand for new construction from 1980 to 2005.

Tools

Role of GIS

A geographic information system (GIS) is a mechanism for storing, retrieving, visually representing and analyzing spatial data. Many states (and the federal government) are creating GIS databases containing information useful for statewide travel forecasting.

Of particular interest here are those data from a GIS that allow for rapid development of a travel forecasting network. These data items include the location of intersections, the width of road segments, other information related to determining capacity and the types of traffic control at intersections and along uncontrolled road segments. Also available in GIS form are jurisdiction

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[1] REMI’s web site

[2] Woods & Poole’s web site

boundaries, boundaries of spatial data units, locations of bodies of water, land use inventories and socioeconomic and demographics information. GISs can also store data useful for validation purposes, such as traffic counts.

Even though the existence of a GIS can speed data preparation, it cannot totally automate the process of network creation. There are substantial incompatibilities between GIS data structures and those necessary for travel forecasting. Often the GIS provides too much detail, fails to properly show highway connectivity or continuity, or is not digitized with sufficient accuracy. Coding errors that can be minor for typical GIS applications (maps, statistical summaries, etc.) can be catastrophic to a travel forecast.

By and large, travel forecasting cannot be performed on a GIS (there is one notable exception), but many travel forecasting packages have mechanisms for transferring data to and from GISs.

Software Issues

Many organizations involved in travel forecasting have found it necessary to establish a library of programs for simulation and calibration.

Four-Step Model Packages. Several software products are available to forecast urban travel using the standard four steps. These software products are essentially similar internally (i.e., they share the same algorithms for computation), but differ considerably in their user interfaces. Models typically come with a graphics network editor to facilitate the input of nodes, links and their attribute values. Some packages come with interfaces to GISs. The needs of statewide travel forecasting have not been a priority in the design of these packages.

Mode Split Model Calibration. Mode split models are calibrated by applying statistical principles to observed travel patterns and mode choices. These statistical methods are somewhat unusual (especially when dealing with the “logit” model and its derivatives), so specialized products (separate from the four-step model) are often necessary to accomplish the calibration.

Statistical Packages. Calibration of other parts of the four-step model is often best accomplished with a stand-alone statistical package that contains linear regression, analysis of variance (ANOVA), tests of significance and single-variable descriptive statistics. A stand-alone statistical package will also have good time series analysis capabilities. A subset of the capabilities of a stand-alone statistical package may be found in a spreadsheet package, which is often the most convenient and transferable method of performing a calibration.

User Knowledge. All of these packages require training on the part of the user. Training periods can be considerable, depending upon what must be accomplished. Training consists of learning the underlying theory and learning the user interface for the particular software package.

Composing a Complete Forecast

Ultimately, a complete travel forecast should be able to produce estimates of link volumes for all intercity modes. This forecast would include both passenger and freight vehicles, any relevant urban forecasts and several measures of effectiveness (MOEs), including delay, energy consumption and emissions. However, a complete travel forecast is not always necessary, especially for project and corridor studies. This guidebook will not describe measures of effectiveness (MOEs).

Chapter 2. Time Series Methods

Introduction

This chapter presents several methods of time series analysis that have proven useful in short-term statewide, rural or intercity forecasts. The chapter is principally concerned with:

- Growth factors;
- Trend analysis with linear regression; and
- Box-Jenkins (ARIMA) methods.

Several enhancements to these techniques are described, including:

- Moving averages;
- Data transformations;
- Forecasting differences;
- Including economic and demographic factors;
- Including factors relating to the state of the system; and
- Handling seasonality.

Time series analysis is a branch of statistics. A good understanding of elementary statistical concepts and the use of statistical software packages would be required for successful application of the techniques.

What is Time Series Analysis?

Time series analysis is a means of understanding data variability over time. Because a time series model exclusively represents past events and relationships, it can be used to forecast the future as long as the future is expected to behave like the past.

Some of the more elementary time series methods require only readily available historical data, so they provide quick answers. Time series analysis is particularly appropriate when the forecast is short term and there is insufficient time and resources to build and calibrate a behavioral model.

Given more time and a broader set of data, rather sophisticated time series models can be built. The models can handle more than simple trends (growth and decline). They can also consider cycles in the data (annual, weekly, daily), discrete changes to some important influential factors and trends in important factors.

Applicability of Time Series Analysis

Modal Considerations. All modes can be analyzed with time series, but approaches may differ. Time series analysis can be especially helpful for short term forecasts where behavioral models have not been calibrated or input data are unavailable.

Policy Considerations. Time series can be used to forecast data needed for policy analysis, including:

- Attributes of traffic, such as vehicle occupancy, vehicle weight and vehicle classes;
- Enforcement needs;
- Economic trends;
- Environmental conditions; and
- Growth in competing modes.

Data Considerations. When doing a multimodal forecast on a network, time series are useful for:

- Forecasting inputs to trip generation;
- Forecasting comparatively minor modes (e.g., air freight, barges) when data limitations or time constraints prohibit application of a behavioral model;
- Forecasting external travel;
- Placing bounds on the reasonableness of forecasts; and
- Determining seasonal, monthly or day of week adjustment factors for postprocessing results from a behavioral model.

Cautions. Great care must be exercised when forecasting traffic volumes. Time series analysis has a limited ability to anticipate changes in future conditions. Events that have never before occurred cannot be modeled. Nor is it possible to model the effects of an existing causal factor that has not changed appreciably in the past. Like any other model, time series cannot anticipate rare future conditions or events.

Important Statistical Concepts

This guidebook cannot provide a complete background in statistical theory. However, some knowledge of elementary statistical concepts is required to understand most of the methods presented in this chapter. Of particular importance is the concept of a correlation.

Correlation. A correlation coefficient ranges from -1 to +1. The sign of a correlation coefficient is the same as the sign of the slope of the line drawn through the points on a (X-Y) scatter diagram. The magnitude relates to the quality of fit to a line. A typical correlation would describe: Traffic Volume versus Total Personal Income (either over time or over space).

The degree of agreement can be computed for unlike variables (correlation) or for data within the same series spaced at a fixed time span apart (autocorrelation).

The correlation coefficient between two variables has only limited use in time series analysis of traffic. Seasonal effects and other periodicity effects tend to cause lower values of correlation coefficients. The concept of autocorrelation is often better for understanding periodicity.

It is always necessary to understand the reasons behind a large correlation coefficient. A strong but spurious correlation can exist between two entirely unrelated variables.

Autocorrelation. An example autocorrelation might be:

Traffic in Year t versus Traffic in Year t-n

For example, if n is 5, the correlation would find the agreement between:

Traffic in 1997 versus Traffic in 1992
Traffic in 1996 versus Traffic in 1991
Traffic in 1995 versus Traffic in 1990
etc.

Autocorrelations tend to diminish as n increases, unless cyclic events are present in the data. For example, a strong autocorrelation may exist between Traffic in July of Year n and Traffic in July of Year n-1 as well as between Traffic in July of Year n and Traffic in June of Year n.

Additional elementary statistical concepts are discussed in the Appendix to this chapter.

Growth Factors

The growth factor method is a popular way of forecasting trends in variables that have been (by and large) increasing in time. Growth factors work best on time series where the change from period to period is proportional to the size of the series. A good example of a series that behaves this way is population. With a constant fertility rate and death rate and with zero net migration, the number of new people each year is proportional to the number of people already alive.

Transportation data series can sometimes be accurately modeled by growth factors. Growth factors work best when the variable to be forecasted is heavily influenced by other variables that inherently grow proportionally. For example, recent increases in the number of licensed drivers are heavily influenced by increases in population. Many transportation variables are heavily influenced by the overall size of the economy, which has grown steadily over time.

A growth factor is easily computed for any data series. With only a little more work (and spreadsheet software or a statistical package), it is possible to create a growth factor model that incorporates external influences.

Growth Factor Relationships

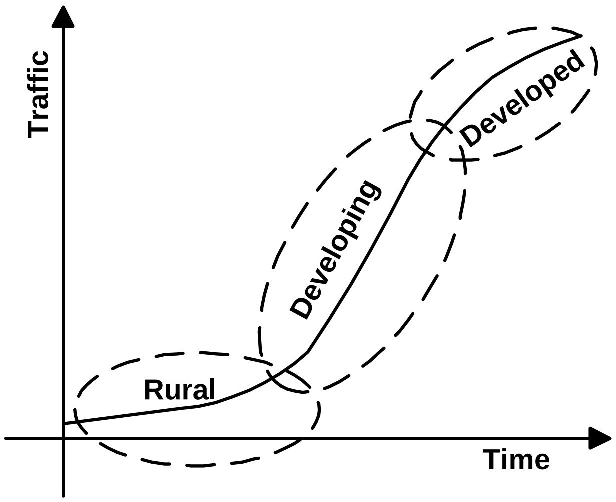
For a data series Y, the next period t+1 can be forecast from current period t times a growth factor (1 + i):

$$Y_{t+1} = Y_t(1 + i)$$

In this case, i is the growth rate, expressed as a fraction of current traffic levels. Y_t is the traffic in the current year, and Y_{t+n} is the traffic in the nth year beyond the current year. N periods can be forecast by repetition:

$$Y_{t+n} = Y_t(1 + i)^n$$

The above equations behave similarly to compound interest. Because of the compounding, a growth factor model (with a positive i) will be upward bending over time. The curve on the right illustrates a typical pattern of growth of traffic on highways in developing parts of a state. Take particular note of the "S" shape of the curve. It is important to select a method of replicating the time series that bends appropriately. For example, a simple growth factor model will not properly replicate the portion of the curve denoted as "developed", as it is downward bending. In some cases it might be necessary to gather additional information to understand the position of the data series on the "S" curve.



Clusters. Clusters can help span gaps in existing data. Clusters can be created to group traffic counting stations that have behaved similarly in the past. The Traffic Monitoring Guide gives some recommendations along these lines. The guide suggests, at a minimum, highway clusters consisting of:

- Interstate rural;
- Other rural;
- Interstate urban;
- Other urban; and
- Recreational highways.

These clusters are aggregations of functional classes. Clusters created for traffic monitoring can be used for forecasting, too. Such clusters will allow seasonal (or daily) forecasts where seasonal data are unavailable.

Similar concepts can be applied to other modes that may have strong seasonal or daily variations in traffic levels.

Limitations and Site Specific Uses. States are encouraged to perform their own cluster analysis to identify reasonable clusters for their traffic data. The previously cited clusters should be considered a rough guideline and a starting point. The Traffic Monitoring Guide provides information on how custom clusters may be developed. When looking at data from specific sites it is reasonable to assemble an ad hoc set of similar sites, rather than to rely on statewide clusters. The ad hoc set, if well chosen, should give a better indication of daily and seasonal variations in traffic.

Causality. Traffic volumes are often highly correlated with socioeconomic and demographic variables. For example, most places have a *causal* relationship between traffic volume and total personal income. Personal income forecasts are often readily available, so including personal income into the model makes sense (both theoretically and practically).

It is important to avoid variables that are not causal, even when the correlation is high. For example, a high correlation could exist between traffic on a state highway and the number of admissions at a local hospital. However, a surge in hospital admissions would not imply a big increase in traffic volume.

Additionally, it is import to understand the direction of causality. The number of speeding tickets could also be highly correlated with traffic volume. If we were to reduce the speed limit, tickets for speeding might increase but the traffic would probably hold steady (or maybe drop).

Linear Trend Model

Linear regression is a technique for fitting straight lines to data. Linear regression finds the best coefficients by minimizing the sum of the squares of all residuals (misfits of the line to data points). Linear regression can be used to extrapolate a time series into to the future.

If traffic (Y) in year t increases linearly with time, then the following equation should hold:

$$Y_t = b_0 + b_1 t + \varepsilon_t$$

For the linear trend model shown above, the two coefficients, b_0 (the y-intercept) and b_1, (the slope) are estimated from data using linear regression. Spreadsheet software packages come with versatile linear regression modules.

The independent variable t can be the exact date or a sequence index from the beginning of the series. Note that the error term ε_t makes this equation exact for any time within the series.

Linear regression can be used to model curvilinear trends by including higher order terms. For example:

$$Y_t = b_0 + b_1 t + b_2 t^2 + \varepsilon_t$$

could be used to model a time series that bends down or up.

The output from a linear regression includes measures of goodness of fit. Standard errors and t-statistics are provided for each coefficient, and R-square values are provided for the whole equation (see the Appendix of this chapter for descriptions of these statistics).

Including Causality. A more robust form of linear regression would estimate a model consisting of a single trend term and several terms for causal variables. Again, Y_t is the traffic in year t. The causal variables (x's) may consist of economic or demographic indicators or may represent the state of the system in any given time period.

$$Y_t = b_0 + b_1 t + b_2 x_2 + \cdots + b_n x_n + \varepsilon_t$$

The variable to be explained, Y_t in this case, is called the dependent variable. The explanatory variables, t and x's, are called independent variables.

Choosing Variables. There is no single method for determining whether an independent variable should be included in the equation. Often people will try every possible variable that might be relevant, then let the software select the set that best explains the dependent variable, as measured by R-square. This method ignores causality and the possibility of spurious correlations, leading to a model with dubious forecasting validity.

Furthermore, including two independent variables that previously behaved similarly can distort the contributions of one of them. For example, we might be able to predict the amount of traffic on a state highway by using both population and employment in a neighboring city. However, this city may have had an almost constant relationship between population and employment over the years. If this relationship were to change (a recession, for instance), then the model may lose its predictive ability. When two independent variables are strongly correlated they are said to be collinear. When a model has more than two independent variables that are strongly correlated, then the model is said to possess multicollinearity.

Each independent variable must make a unique, causal contribution to the model. It is important to rely on theories of travel behavior to indicate what those variables might be. Sometimes, the regression analysis might reject a variable that seemed at first reasonable, but fishing expeditions are never recommended.

Dummy Variables. Dummy (0,1) independent variables are quite useful for showing effects that occur only part of the time. For example, dummy variables can show holidays, special events and step changes to the economy, facilities or the environment. A dummy variable is set to 0 for some of the time and 1 for the rest of the time. The coefficient of a dummy variable can be interpreted as an additive effect. When the dummy variable is 1, the coefficient is added to the estimate of the dependent variable. When the dummy variable is 0, the coefficient is ignored.

Use of Error Terms. Error terms are explicitly considered when fitting a model to data, but error can never be predicted. Consequently, all error terms are replaced by the “expected value” of the error, which is zero.

Difference Model. A difference model forecasts the change in the data series between two successive periods. A simple difference model takes the following form:

$$Y_{t+1} = Y_t + \delta + \varepsilon_{t+1}$$

In words, a difference model forecasts the next period knowing the value of the data series in the current period. The δ is the year-to-year difference. Of course, causal variables may be added to a difference model.

Box-Cox Transformations

A mathematical assumption of linear regression is that the standard deviation of the errors in estimates is constant throughout the series. This assumption is not always valid for traffic data. A Box-Cox transformation is sometimes needed improve the uniformity of the standard deviation.

Possible Box-Cox transformations are given by this equation.

$$Y_\beta = \begin{cases} \dfrac{Y^\beta - 1}{\beta} & \beta \neq 0 \\ \log Y & \beta = 0 \end{cases}$$

In Box-Jenkins (ARIMA) models (to be discussed later) Box-Cox transformations are often employed to reduce the effect of the error term in larger values of the data series. Thus, β’s of 0 (giving a logarithmic transformation) or 0.5 are frequently used. The log transformation is most logical when a constant rate of growth can be assumed and errors increase in proportion to the size of the data item. This type of error might be found in traffic data that is affected by single large influencing factor, such as the overall economy of the state.

When errors may be due to many random influences, then a square root ($\beta = 0.5$) transformation is often useful. Traffic data often behaves this way, too.

When the standard deviation is constant, the errors are said to be homoscedastic. Thus, the quality of the model can improve when the original data is transformed to make the errors homoscedastic.

A Box-Cox transformation can also be used to model curvilinear trends. The recommend procedure for Box-Cox transformations in this case is to transform the data series for several values of β, fit the data series with linear regression, then choose the β corresponding to the best model as indicated by its R-square.

Once the coefficients of the model are found for the transformed series, the relationship must be untransformed to get estimates of the original series.

Moving Averages and Seasonality

There are two forms of moving averages commonly used for simple time series forecasting: exponential smoothing and unweighted moving averages over a cyclic time period. Both forms of moving averages may be applied to either trend or difference models.

Exponential Smoothing

Exponential smoothing uses a declining series of weights, starting with α ($0 < \alpha < 1$) and declining with the age of data,

$$\alpha \quad \alpha(1-\alpha) \quad \alpha(1-\alpha)^2 \cdots$$

so that the newest values in the time series get the largest weights. The average age of an exponentially smoothed series is $(1 - \alpha)/\alpha$. Observe that the rate of decline of weights for the moving average relates to the value of α. Values of α near 1 result in a fast decline. Values of α near 0 result in a slow decline.

Exponential smoothing is best applied to situations where cyclic patterns are not present in the data series.

Central Moving Average

Good time series models require many data points (50 or more), so it is often necessary to adopt a period of less than a year. When a period length of one month has been selected, strong seasonal fluctuations in traffic data often become apparent.

When cyclic patterns are present in the data, they are often removed by taking a central moving average. A central moving average uses data to each side of the current time period. A moving average based on the current period and n-1 previous periods can also be used, where n is the number of periods in a cycle.

When there is an odd number of periods in a cycle, then a central moving average is found by averaging the current period with the (n-1)/2 periods before and after. Thus, a moving average for Friday in a weekly cycle would average all data from the Tuesday before to the Monday after. When there is an even number of periods in a cycle (months in a year or seasons in a year), then the central moving average for period t is found by averaging together these periods:

t, t + 1, t – 1, … t + (n – 1)/2, t – (n – 1)/2 and one-half of t + n and t – n

This method produces a seasonally adjusted trend, where there is a seasonal adjustment factor (a multiplicative constant) for each time period in a cycle. A monthly index (MI) can be computed to convert the moving average (MA) back to a seasonal forecast:

MI = Average of (Data/MA) for month

In a similar fashion, seasonal adjustment factors can also be computed to convert raw monthly data to a yearly average.

Introduction to Box-Jenkins (ARIMA) Methods

Box-Jenkins is a large family of time series models that are able to track very complex historical patterns. There are many variations of Box-Jenkins models. The choice depends on the data series to be analyzed. It is possible to include causal variables in a Box-Jenkins model, so this class of models can be quite robust.

Statisticians want 50 or more data points for Box-Jenkins (ARIMA) methods, so they are probably not applicable to analysis of yearly traffic data. Monthly, daily, or (even) hourly data should produce satisfactory results.

Major commercial statistical packages contain Box-Jenkins routines. It is not possible to perform an interesting Box-Jenkins analysis on a spreadsheet. Box-Jenkins models are fit to data so as to minimize the sum of squares of the residuals, just as in linear regression. Therefore, many of the statistical concepts of linear regression also apply to Box-Jenkins models.

ARIMA

Box-Jenkins models consist of one or more of the following elements:

- Autoregressive (AR);
- Integrated (I);
- Moving Average (MA); and
- Combinations: AR, ARMA, ARIMA, MA or IMA.

Autoregressive. In an AR model, the value of the data series is estimated with one or more earlier values of the data series.

Integrated. An I model estimates the difference in data values in the series or the difference of differences.

Moving Average. In an MA model, the data series is estimated using knowledge of the error in a recent estimate.

Some of the most interesting Box-Jenkins models combine the three types. The examples in the next subsections illustrate the most elementary forms of these models.

Autoregressive (AR) Models

AR (Auto Regressive) models forecast period t knowing the conditions in period t-1 and, perhaps, prior periods. The premise of an AR model is that time series data rarely takes wild jumps or dips. The best predictor of a period is the immediate past period. For example, an AR(1) model looks like:

$$Y_t = \delta + \varphi Y_{t-1} + \varepsilon_t$$

when δ (delta) and φ (phi) are statistically estimated parameters. In this model δ is a constant period increment over a φ portion of the previous value. Again, ε_t is an error term (which is not used in a forecast). The theory underlying Box-Jenkins models tells us that the absolute value of φ is always less than 1.

An AR(2) model would take portions of two previous periods and look like:

$$Y_t = \delta + \varphi_1 Y_{t-1} + \varphi_2 Y_{t-2} + \varepsilon_t$$

There is no theoretical limit as to the number of terms in an AR model, but the contribution of each successive term tends to weaken with age.

Once the coefficients have been estimated, an AR model is easier to compute and understand than a growth factor model.

Integrated (I) Models

I (Integrated) models forecast the change from one period to the next. For example, a pure I model looks like:

$$Y_t - Y_{t-1} = \delta + \varepsilon_t$$

The δ term is the estimated average change between periods. Pure integrated models tend not to be very interesting. The power of an integrated model is best seen when combining it with AR and MA models and when including causal variables.

Integrated models work best when the long-term trend is stable but the variation from period to period contains strong random influences.

Logarithmic Transformations of Integrated Models. Economists sometimes apply a logarithmic transformation to their independent and dependent variables within integrated models. Thus, they forecast the change in the logarithm of the data series. The coefficients thus obtained can be interpreted as elasticities. For example, an integrated model that predicts traffic (Y) as a function of employment (E) might look like this.

$$\log(Y_t) - \log(Y_{t-1}) = \delta + b(\log(E_t) - \log(E_{t-1})) + \varepsilon_t$$

The b coefficient is interpreted as an elasticity, that is, the percent change in traffic given a one percent change in employment.

Moving Average (MA) Models

MA (Moving Average) models forecast period t knowing the error in the t-1 period forecast and, perhaps, prior periods. For example, an MA(1) model looks like:

$$Y_t = \mu + \varepsilon_t - \theta\varepsilon_{t-1}$$

where μ (mu) and θ (theta) are statistically estimated coefficients. Moving average models include past errors to get the estimate of values in the data series. In the above formulation, the additional error term is used to get a good estimate of μ; it cannot be known when forecasting more than one period beyond the present. For an MA(1) model the absolute value of θ must be less than 1. The negative sign preceding the moving average term is traditional, suggesting a correction effect. The coefficient μ is the estimated average value of the series.

An MA(2) model would look like:

$$Y_t = \mu + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2}$$

Steps in Building an ARIMA Model

The following five steps should be followed when building an ARIMA model:

- Plot and study data;
- Apply knowledge and intuition;
- Get indicator statistics, such as “autocorrelations”;
- Specify model, transform data and fit; and
- Analyze strength of model and individual components.

Intuition and common sense are necessary for creating a good Box-Jenkins model. Usually, a quick glance at the data series is enough to judge the best combination of elements. The major choices are:

> Should the model be integrated (i.e., deal with differences)?
>
> How many moving average terms must be included?
>
> How many autoregressive terms must be included and what are the lags?
>
> Do the period-to-period variations in the data suggest that the data series should be transformed?

An autocorrelation is the correlation between Y(t) and Y(t-n) where n is a selected number between 1 and the size of the time series. Any series has many autocorrelations. A partial autocorrelation is a measurement of the improvement to the model by the next term representing the (n-1) period when period n and all later periods have already been included.

Statisticians use autocorrelations and partial autocorrelations to help determine the structure of a Box-Jenkins model. For example, an AR(1) model is characterized by slowly dying autocorrelations and an abrupt cut-off of the partial autocorrelations after the first lag. An MA(1) model is characterized by slowly dying partial autocorrelations and an abrupt cut-off of the autocorrelations after the first lag. Statisticians have developed many rules of thumb to help make their choices, but these rules are complex and beyond the scope of this guidebook.

Special software is needed to estimate an ARIMA model, because one or more of the MA independent variables requires an estimate. Traditional linear regression methods cannot handle this situation.

Extensions to ARIMA (Examples from WisDOT)

In a study of the use of time series models for project level forecasting, the Wisconsin Department of Transportation (WisDOT) tried many variations on ARIMA. It added socioeconomics, such as total personal income, added step functions, such as capacity changes, and added impulses, such as Labor Day and deer hunting.

Here is one of many models tried.

Dependent Variable:

> Log of daily traffic I-94 near Johnson Creek

Independent Variables Included:

- Log daily traffic previous day
- Log daily traffic previous week
- Log daily traffic previous year
- Impulse dummy variables for deer hunting season, July, Labor Day weekend, Memorial Day weekend and Thanksgiving weekend
- Count of days from 1/1/1983
- Impulse dummy variables for 12/15/87, 12/3/90 and 12/15/90 (outliers)
- Moving average from previous day (lag 1)
- Autoregressive term from previous week (lag 7)

Cyclic Patterns in AR Models

It is relatively easy to model cyclic patterns (of period n) by including an autoregressive term for n periods ago. A typical monthly forecast looks like:

$$Y_t = \delta + \varphi_1 Y_{t-1} + \varphi_{12} Y_{t-12} + \varepsilon_t$$

The model says that the next month can be predicted from the current month and from the same month last year. Such a model will pick up regular monthly variations in traffic.

Similar models can be built to pick up weekly, daily, or (even) hourly variations in traffic levels.

Case Studies

Air Travel I: Brown and Watkins (1968)

One model from Brown and Watkins took the form:

$$\Delta \log(T) = 0.0725 - 1.307\, \Delta \log(F) + 1.119 \Delta \log(Y) - 0.038 \log t + \varepsilon$$

in which air passenger miles per capita T is a function of average fare F, real disposable income per capita Y and time in years t. In this equation Δ (delta) indicates differences between successive periods. This is a traditional linear regression model, as it does not contain any autoregressive or moving average terms. It is conceptually similar to an I (integrated) model. This model contains two causal variables, fare and income, and one trend term. Brown and Watkins looked at the differences of logs, so that the coefficients on the causal variables can be interpreted as elasticities.

An inspection of the model reveals:

- Dropping fare implies increasing travel;
- Increasing disposable income implies increasing travel;
- Future years, otherwise, will have less travel (or a declining rate of increase).

Air Travel II: Oberhausen and Koppelman (1982)

Oberhausen and Koppelman developed a rather elaborate AR model of monthly air passenger travel for a westbound trip to Hawaii.

$$Y_t = 0.36Y_{t-1} + 0.34Y_{t-2} + 0.62Y_{t-12} - 0.22Y_{t-13} - 0.21Y_{t-14} + 0.38Y_{t-24} - 0.14T_{t-25} - 0.13Y_{t-26} - 90.7F_{t-1} + 297.92 + \varepsilon$$

where F_{t-1} is the two-way fare and all other independent variables are earlier points in the time series.

The independent variable is passenger volume (not a difference), and they did not use any moving average terms. All autoregressive terms have coefficients less than one (in magnitude), as is typical for AR models.

The yearly cyclic pattern in the data is evident by inspecting the various terms. The largest coefficient is at lag 12, one full year ago. Passenger travel also seems to be influenced by a few other months about a year earlier and two years earlier. The multiple months at yearly intervals seems to be accomplishing a sort of moving average.

It is difficult to second guess these authors without acquiring and analyzing their original data, but this model contains a particularly large number of autoregressive terms. Other formulations in the ARIMA family might have produced a more elegant model. Unfortunately, Box-Jenkins software does not automatically select the best combination of terms. Judgement must be applied, resulting in models that are sometimes less than perfect.

Traffic Levels I: Maine VMT

A pure causal variable model was created by the State of Maine to estimate total VMT in the state.

$$VMT = 15L + 332G - 9600$$

where VMT is in millions of vehicle miles, L is thousands of licensed drivers, and G is gross state product in billions of dollars. Note the absence of any trend terms, properly reflecting the concept of travel being a derived demand.

Maine fit its VMT model with linear regression. The model fits the data almost perfectly (R-square = 0.995). The signs of coefficients for both independent variables are intuitively correct, even though the two independent variables are strongly correlated.

In order to use this equation, both the number of licensed drivers and the gross state product must be forecasted. Maine could do this themselves (perhaps with separate time series models) or by obtaining them from outside agencies or commercial services.[1]

Traffic Levels II: New Mexico Heavy Vehicle Traffic

This example from New Mexico forecasts heavy commercial vehicle traffic on a single road. The model was created with linear regression. It includes a trend term and three causal variables.

$$HC = -28000 + 15Y - 0.12D - 0.08G + 0.078C$$

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[1] Coefficients in the above equation have been rounded from the original model.

where HC is heavy commercial traffic on I-40; Y is year, D is US disposable income, G is US gasoline cost, and C is New Mexico's cost of residential construction. The overall fit was good (R-square of about 0.8).

The model exhibits problems of multicollinearity, due to the strong correlations between independent variables. The disposable income term (D) should be positively related to heavy vehicle traffic, but has a negative sign in the model. The negative sign for gasoline costs (G) seems reasonable. The term for cost of residential construction (C) is difficult to interpret. It may indicate the health of the New Mexico economy, or it could account for some aspect of consumer prices. The large negative y-intercept is due to using a 4-digit year in the trend term.[1]

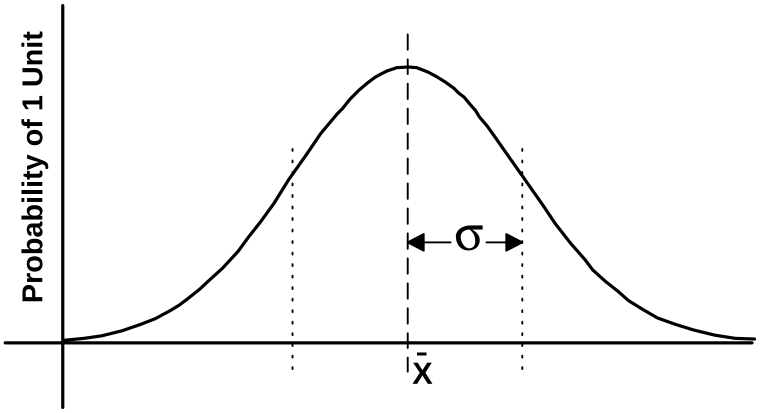
Appendix: Some Elementary Statistical Concepts

Time series analysis is inherently multivariate. The data item to be forecast (which behaves randomly) is related to other variables, some of them behaving randomly. Time, of course, is deterministic (i.e., not subject to random fluctuations). Random variables are expressed as a list of numbers, with a subscript denoting the position in the list. For example, traffic volumes on STH 43 might be given the variable X_i where i is the position in the list. In time series work, the lists are always ordered: for example, X_1 is the traffic in period 1 and X_n is the traffic in period n. A period can consist of a whole year, a month, a week, a day, an hour, etc.

Because of the randomness in the data, statistical analysis is appropriate. The statistical analysis allows someone to forecast without further consideration of the randomness in the data, and it allows that person to understand the accuracy of such a forecast. Typical statistics that describe data include the mean, the standard deviation, the coefficient of variation and correlation coefficients. Statistics that help understand accuracy include the t-statistic and R-square.

Normal Distribution. The normal distribution underlies much of the theory behind time series analysis. Any event that is influenced by a large number of random disturbances tends to be normally distributed.

Mean and Other Similar Statistics. The mean is the most probable value of a random variable, and it is estimated by taking a simple average of samples. The normal distribution is symmetrical about the mean. When data is categorized, the category with the largest number of samples is the "mode". The "median" value has half the samples above it and half the samples below it. The median is especially useful in determining central tendency when there are a few really strange samples that distort the mean.



Standard Deviation and Associated Statistics. The standard deviation is a measure of the dispersion (or spread) of the distribution. About 68% of the area under the normal curve occurs

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[1] Coefficients have been rounded from the original model.

within one standard deviation of either side of the mean. About 95% of the area under the normal curve occurs within 1.96 standard deviations of either side of the mean.

The square of the standard deviation in called the variance. A standard error is similar to a standard deviation, but relates to the dispersion of parameters (e.g., a mean or a constant in a model) that have been computed from many samples of data. The sample standard deviation, s, can be calculated by this formula:

$$s = \sqrt{\frac{1}{n-1}\sum_{i-1}^{n}\left(x_i - \overline{x}\right)^2}$$

T-Test. The t-test was developed to determine whether a statistic computed from a sample differs from a similar statistic computed from another sample or differs from some predetermined value. A typical use of a t-test in traffic engineering is to determine whether the mean speed after a change in the traffic environment (enforcement, geometry, etc.) differs significantly from the mean speed before the change. As a rule, t statistics become larger as more samples are included and accuracy improves. It is analogous to the signal-to-noise ratio for the statistic.

A t-test is also used to interpret the quality of an individual term in a time series model. A term consists of a model coefficient and a variable. The t-statistic is an output of regression analysis and similar techniques. The t-statistic for a model is found by dividing the value of a model coefficient by its standard error.

$$t = {}^{b}\!/_{s_b} > 1.96$$

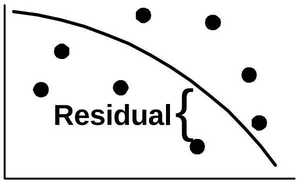
A t-statistic larger than 1.96 usually (with a sufficient number of data points) indicates that the coefficient is significantly different from 0 with 95% confidence. That is, 19 out of 20 times the coefficient will have the given sign (plus or minus) when a new sample is drawn each time. A significant t-statistic is often taken as evidence that the term is useful in explaining the data series.

A significant t-statistic does not imply that the value of the coefficient is correct. The analyst must look at the standard error of the coefficient to determine the accuracy of the term. Furthermore, a significant t-statistic does not by itself justify including a term in a model. There must also be good reasons for its inclusion from knowledge of travel behavior.

The formula above for the t-statistic shows how it is computed and interpreted when estimating coefficients of a model. The t-statistic is computed somewhat differently when comparing means of two samples. You should refer to a good text on statistics for more information on the t-test.

R-Square. R-square is the square of the correlation between the data and the estimate. It ranges between 0 and 1. R-square is often expressed as a percent and called “percent of variance explained”. It is the most often used measure of the quality of a model. Sometimes it is useful to adjust R-square for the number of coefficients in the model. An adjusted R-square gives a better indication of which of several alternative models is best.

A “residual” is the vertical (parallel to the axis describing the data series) deviation of a point in a data series from its estimate.



R-square can be calculated by comparing the standard deviation of the residuals to the standard deviation of the time series. Comparatively small residuals result in a large value of R-square.

Coefficient of Variation. The coefficient of variation reveals the compactness of a random variable. It compares the sample standard deviation to the size of the mean, as shown in the equation below.

$$V=\sigma/\bar{x}$$

Chapter 3. Passenger Forecasting

Introduction

Statewide passenger travel forecasts have been performed for many years in some states, but the models are not as fully developed as those used in urban forecasts. A few states, notably Michigan and Kentucky, have had long experience with statewide forecasts. However, the majority of states have not maintained statewide models. In many ways, statewide travel forecasting is more difficult than urban travel forecasting, and the need for accurate forecasts has been less compelling. Recent Federal legislation, including ISTEA and TEA 21, has highlighted the need for better statewide travel forecasts, so many states are now improving their models or developing new ones from scratch.

The purpose of this chapter is to introduce the standard passenger forecasting procedure as it relates to statewide travel forecasting. Primarily, this chapter concerns intercity forecasting. Corridor analysis is also briefly discussed.

The chapter first describes the differences between a statewide model and an urban model. Differences include the scale of the analysis, the types and frequencies of trips, available modes and data sources. An appendix at the end of this chapter discusses the basics of urban modeling.

Each step of the forecasting process, as implemented in statewide travel forecasts, is described. In some cases, alternative methods of performing the same step are presented.

More advanced passenger travel forecasting techniques are described in Chapter 5. This later chapter presents highly specialized and experimental methods, as well as means of collecting and processing statewide travel data.

Borrowed Methods

Many states have implemented passenger travel models that are derived from urban models. They perform many of the same steps with much the same mathematics. Besides the obvious differences in scale, other differences are subtler. Thus, this chapter will review the urban procedure and describe how it has been adapted to statewide travel forecasting. Many of the steps described here will reappear in Chapter 4 (freight) and in Chapter 5 (advanced passenger).

Advantages of Urban-Like Models

Building statewide models on the foundation of urban models has these advantages:

- Availability of commercial travel forecasting packages;
- Many refined algorithms;
- Well understood theories of travel choices; and
- Many active users to share knowledge.

Disadvantages of Urban-Like Models

However, building statewide models from urban principles carries some disadvantages:

- Convenience of the software may deter implementation of better methods;
- Urban models may be overly complex for many intercity applications; and
- Data requirements can be burdensome.

Many existing urban algorithms are deficient for statewide forecasts, for example:

- Traffic assignment methods rely on the notion of capacity to achieve good results;
- Methods for ascertaining the fraction of travel that is intrazonal trips are not good enough for statewide travel;
- Size of networks may overly burden the computational process;
- Sizes of some zones lead to very coarse traffic assignments; and
- Omission of many roads leads to excessive volumes on links near urban areas.

Urban v. Statewide Models

Network Detail. Urban models have highway networks that typically contain all freeways, freeway ramps, major arterials, minor arterials and a few collectors. Many urban models show freeway segments as pairs of parallel one-way links. By contrast, many statewide models greatly reduce the detail within urban areas. Included are all state and Federal highways and a selected number of other major arterials. Statewide networks will often omit interchange ramps and other details related to freeways.

Traffic Analysis Zone (TAZ) Size and Number. TAZ sizes vary considerably within urban areas, being smaller near CBDs and larger in suburban areas. The number of TAZs tends to increase with urban area size, but not proportionally. Small cities tend to have small TAZs; large cities tend to have much larger TAZs. Statewide networks do not vary TAZ sizes as much as urban models. Urban areas may be aggregated into just a few TAZs, so that timelines and computer resources can be kept to a reasonable level. Obviously, the zone system must at least cover the whole state. Michigan’s statewide model, for example, has 2300 TAZs and Kentucky’s model has 1500 TAZs. Both Michigan’s and Kentucky’s networks and zone systems extend considerably beyond their own borders.

Intercity v. Local Travel. Statewide models are designed to provide estimates of intercity travel. The details of travel within urban areas are of less interest.

Intrazonal Trips. Because it is difficult to assign intrazonal trips to networks, the number of intrazonal trips is usually kept small in urban area forecasts. Statewide models can have a large number of intrazonal trips in TAZs within urban areas.

Mode Split. Intercity travel involves different modes than urban area travel.

Processing Time. Large networks and large numbers of TAZs cause slow calculations. Slow calculations constrain the number of trial runs and increase the overall expense of producing a forecast.

Sources of Travel Data

A number of data sources used in statewide forecasting are available from federal government sources. This includes the National Personal Transportation Survey (NPTS) from FHWA and the Census Transportation Planning Package (CTPP) and the Journey to Work (JTW) survey from the Bureau of the Census.

The NPTS has proved to be the most valuable of these data sets for forecasting purposes. It was last performed in 1995. It is a 42,000 sample national survey of travel behavior conducted using travel diaries and phone interviews.

The CTPP does not provide trip data, but instead provides travel-related socioeconomic data for all regions of the country and has been prepared by the Bureau of the Census and AASHTO in a format designed for use in the transportation forecasting process. The related JTW survey provides origin-destination data for the home-based work purpose only, based on a 12.5% sample of households.

Surveys and Counts. More traditional sources of travel data are also applicable to statewide forecasting. These include special surveys and cordon counts. Special surveys can be conducted in a number of ways. Two of the most common survey methods are license plate surveys and home interviews.

License plate surveys involve observing the license plate numbers of vehicles passing or parked at particular locations. Addresses of ownership can be easily obtained. Alternatively, home interviews are conducted with a broad cross section of the population and involve the collection of travel and socioeconomic data by telephone or by mail survey.

Cordon counts or roadside surveys are surveys conducted by stopping vehicles on routes leading into or through a particular area and interviewing their occupants. This field work is often followed up with a mail-in or telephone survey. A 1995 Vermont study reported a cost of $17.50 per home interview sample versus $12.35 for a roadside survey.

Defining the Scope of the Model

Statewide Network Preparation

Of course, the network for a statewide model should connect all areas of the state between which travel is to be forecasted. In addition, the networks for some recent models have been extended as much as 200 miles into adjacent states. This might be especially useful in providing alternate paths for trips coming into the modeled state from distant regions. It is also possible to include a skeleton national network as a means of linking TAZs in distant regions to the statewide model. Such a national highway network would essentially consist of interstate highways.

Any highway or railway segments that are important to the type of analysis being done should be represented by links in the network. For a statewide passenger network this usually includes interstate highways and all major US and state highways. Where intercity rail or bus travel is being modeled, separate networks could also be included for these modes.

Zone Sizes. The TAZ sizes used in a statewide model should be limited by (1) the purpose of the model and (2) the geographical level-of-aggregation of the available data. For example, it may be desirable to use census tract-level data for corridor studies when sufficient data are available. For evaluation of the statewide effects of a localized system change, it may only be necessary to use data at a county level.

Different states have adopted different strategies for defining TAZs. Michigan, California and Texas each have more than 2000 TAZs; New Hampshire has just over 400; while Rhode Island has nearly 900. Missouri and Michigan are moving toward nested zone structures to be able to vary the zonal detail according to the specific needs of the analysis.

Special generators are used to represent land uses that generate travel, but are not adequately represented by conventional generation equations (i.e., equations based on population and employment figures). Examples include airports, state parks and universities.

Modal Categories

The number of modal categories that might be included in a statewide passenger travel forecasting model is heavily dependent on the objectives of the model itself. For instance, airplane trips would not typically be included in a model for a short distance intercity corridor. Similarly, it is sometimes useful to include modes that do not yet exist in a particular area (e.g., high speed rail) in an attempt to estimate the potential effects of future implementations.

A typical categorization of intercity passenger modes would have automobile (driver or passenger), intercity bus, conventional rail, high speed rail and airplane.

Purposes

Statewide and intercity travel forecasts have adopted different sets of trip purposes, depending upon the type of questions being asked. The trip purpose categories used for urban travel forecasts are not necessarily appropriate for statewide travel forecasts.

Trip purposes should be selected to match available data and to help address policies and access alternatives. More trip purposes may improve the precision of the model, but they cause increases in data collection costs and computation time.

Fundamentally, a trip purpose should contain trips that have similar characteristics:

- Any trip produced within a purpose must be allowed to travel to any attraction zone.
- All trips within a purpose share many of the same decision characteristics: mode split utility coefficients, automobile occupancy rates, time of day and direction of travel factors and gravity model parameters.

One particular set of trip purpose categories seems to work especially well for forecasts of intercity travel:

- Work related or business;
- Recreation/vacation; and
- Other nonbusiness.

Corridor studies should also include:

- Travel to work.

Network Structure

Sources of Networks. Statewide highway network data is often available from several sources. In urban areas, local MPOs typically maintain network models or GIS databases that can be modified for use in the statewide model. Network information is also available from federal government sources including the FHWA digital network (which is based on TIGER files), the BTS North American Transportation Atlas Data Bases CD-ROM and Oak Ridge National Laboratory.

It is important to check networks that are imported from other sources, since they may contain coding errors that went unnoticed in their original applications or that occurred as a result of translation across different software products.

Stitching. If the statewide network is assembled from a number of sources (e.g., the various local MPO models), the individual networks will need to be “stitched” together into a single network. In this case differences between adjacent local models must be resolved, including changes in network data format, renumbering of zones, transformation of coordinates, etc. A series of criteria – based on the network sources available and the intended uses of the model – must be developed to guide the “stitching” process.

For statewide modeling, the network’s level of detail in urban areas is generally less important than in MPO models. It therefore may be useful to condense the TAZs from local urban models into larger-scale TAZs. For instance, a statewide model’s TAZ could consist of a group of census tracts in an urban area and an entire county in a remote area.

Highway Network Attributes

Speeds: As with a network of any size, while delineating the statewide network structure it is important to include a description of the speeds (to be used in combination with link distances) or travel times associated with all links in the network. This information is critical to determining the shortest travel paths during the trip assignment step.

Including attributes to describe the directionality of traffic flow (i.e., “one-way” links) and turn prohibitions is generally less important in statewide models than for smaller-scale models.

Penalties. The use of penalties or delays may also be of value in representing signalized intersections or known capacity problems at intersections or interchanges. In a statewide model they may also be used for other purposes. For instance penalties could be assessed at state border locations to represent the reluctance of travelers to cross the state border for work trips. A similar situation could also exist at river crossings and toll facility locations.

Capacities. Since the travel data available for statewide modeling purposes does not usually lend itself to consideration of peak-hour conditions, the use of link capacities (often found in smaller-scale models) is also of limited value. For statewide modeling it may be more useful to assess delays to links where congestion is expected (typically in urban areas) or to adjust link travel times rather than to calculate speed reductions based on capacity restraints.

Other attributes that can be used to describe the highway network are of a more descriptive nature and can be used to examine links according to other categories that might affect their behavior. This includes classification according to count groups, functional classes, terrain types or geographical area groups.

Other Modal Networks

Sources. Among the most important non-automobile networks are those for rail, bus and airline service. Non-automobile network data is also available from a number of sources.

For rail, the Federal Railroad Administration (FRA) has developed a digital railway network for the United States. This can be used in combination with Amtrak or commuter rail maps and schedules to develop a statewide rail network.

Similarly, bus company schedule information can be used to determine what subset of the highway network is included in the bus network.

Airlines tend to be a more specialized case. Airport locations and airline schedule information could be used to develop an airline network. Much information about airline travel is national in scale and proprietary in nature, and airline networks may only be needed for statewide modeling to the extent that air travel is internal to the state or between the state and its neighbors.

As is the case for highway networks, any network data imported from other sources should be carefully checked for errors and inconsistencies.

Inclusion. Historically, statewide passenger models have had limited success in accounting for non-automobile modes of travel. This is primarily due to the overwhelming majority of instate trips that are made by automobile and the related difficulties in developing a statistically meaningful mode split model at the statewide level.

Meanwhile, mode split is an increasingly important consideration in corridor studies. Due to the more localized nature of corridor studies and to the likelihood that they include travel patterns in major urbanized areas, data is more readily obtained (from existing sources or localized surveys) for calibration of mode split models. Consequently, it is easier to model mode split for corridor study applications.

Zone Systems and Spatial Aggregation Issues

The level of aggregation of the TAZs used in the model is based on two major considerations. A first consideration is the level of aggregation of the available socioeconomic data (both current and forecasted). Since this data feeds the model, the model's structure must accommodate available data. For example, if socioeconomic data is available only at a county level of aggregation – which is not unusual for statewide modeling – there may be little value associated with developing a model using TAZs at a census tract scale.

Assignment. A second consideration is the proposed use of the model. If the model is to be used for small scale planning along an intercity corridor, then the TAZs should be small enough to reflect changes in the characteristics of that corridor in a meaningful way. For analysis of statewide trends, the TAZs can be much more coarsely modeled.

The use of smaller TAZs can have a beneficial effect on trip assignment, especially when an all-or-nothing assignment is used. In this case the smaller TAZ size serves to smooth out the assignment of traffic to the network, yielding results that may more closely resemble the gradual changes in traffic volumes observed on actual roadway segments. This same effect could be achieved by developing a simple disaggregation scheme for use during traffic assignment and by keeping the TAZ sizes as needed to match the socioeconomic data and model use considerations noted above.

The boundaries used for TAZs typically correspond to some common level of social or political division. Some typical sizes include (in generally decreasing size) counties, townships, census tracts and block groups.

Connectors. The characteristics of centroid connector links can be very important, especially for the large-scale TAZs. In large TAZs, the position of the centroid within the TAZ can cause its connector links to be inordinately long and have disproportionately large travel times associated with them. Also, with small-TAZ models, only one connector link may be needed, whereas multiple connectors may be required for larger TAZs.

Socioeconomic and Demographic Characteristics

The same sort of socioeconomic and demographic characteristics that are important in urban forecasting models are also important for use in statewide models. These include:

- Population;
- Household size;
- Employment;
- Income; and
- Auto ownership.

The data describing these characteristics are typically used as input to the trip generation step of an urban model, and the same is true for statewide models. Base year values for these data are used in combination with survey data to calibrate the trip generation equations. Forecast values for these data are then used in the generation equations to predict the number of trips that will be generated in future years.

Sources. The principal source for socioeconomic and demographic data used in travel demand modeling is the US census. The CTPP is particularly useful, since its tables are specifically configured to be used in transportation forecasting applications. The census, of course, only provides base year data. Population and employment forecasts – important for predicting future traffic – are often available from state government agencies or local universities.

Socioeconomic and demographic data is also available from a number of private sources, including McGraw-Hill, Woods & Poole and REMI. More importantly, forecasts of the same data are readily available from these same private sources.

Other Data Issues

Other issues are mainly associated with data collected as part of a traffic count or survey, or as part of a statewide traffic monitoring system.

With the increasing sophistication of traffic monitoring programs, time-of-day effects and direction-of-travel information can now be estimated even for rural highway links. This makes it possible to include these effects in a statewide model, just as they might be included in an urban model.

Cyclical Patterns. In addition, the clustering of counting stations and the continuous nature of counting programs also makes it possible to address the cyclical nature of travel on some highways. This includes the effects of travel on different days of the week, as well as seasonal patterns of travel (e.g., those patterns related to hunting season or summer vacations).

Trip Table Synthesis. For cases where only limited travel data is available, techniques have been developed to synthesize trip tables. The synthetic trip tables are developed through an optimization procedure, based on the existing count data. This will be discussed further in Chapter 5.

Model Steps

Trip Generation Issues

For statewide modeling, an important consideration is whether to generate all trips, including intrazonal trips, or to generate only the trips that are made between zones. Existing models tend to generate all trips, most likely because the available techniques for developing generation equations do not differentiate between intrazonal and interzonal trips. Instead, as will be discussed later, intrazonal travel times are adjusted within the trip distribution step to ascertain the correct number of intrazonal trips for individual zones.

There are also geographical variations in trip generation rates. Most importantly, small towns and rural areas tend to generate more trips per capita than urban areas. These effects are discussed in the next sections.

The time period of analysis must be considered when establishing trip generation rates. Urban models are mostly concerned with forecasting the amount of traffic on a typical weekday or within a single peak hour of a weekday. Statewide models have often been designed to forecast the amount of travel on an average day, including both weekdays and weekends. It should be noted that the peak hour for a rural road can occur on a Saturday or Sunday due to recreational travel.

The next sections discuss considerations when developing production and attraction models, deciding on how to deal with external trips and balancing the trip productions and attractions that result from the trip generation process.

Trip Productions

The number of trips produced in any particular TAZ is usually determined using trip production rates based on that TAZ's socioeconomic or demographic information.

Trip production rates can be developed from federal sources such as the NPTS, CTPP, or JTW data, or from local surveys. Different formulations may be required depending on the amount of data available for a particular state. One state, which had little NPTS coverage, made use of both NPTS and JTW trip production rates for the home-based work purpose in the following fashion:

HBW Rate = (National NPTS Rate) * (Local JTW rate) ÷ (National JTW Rate)

This formulation was used to take advantage of both (what the modelers viewed as more statistically reliable) national-level NPTS data and (the more locally available) JTW data.

Of course, traditional urban model production rates – such as those provided in *NCHRP Report #365* – may also be used as a last resort.

Purposes. The choice of trip purposes included in the model has an important effect on the way trip productions are estimated. Although many trip purposes are represented in the available data, there are generally only three purposes that must be modeled for intercity travel: business; non-business; and recreation. It is often necessary to condense the various trip purposes found in the available data into these three categories for use in a statewide model. Some models have included a fourth trip purpose for commute trips.

There is a comparative wealth of information available regarding business trips. For example, the JTW was specially designed to provide this sort of information for the home-based work trip purpose. To develop trip generation rates for other purposes, further assumptions are usually necessary, and both the quantity and quality of available data is more limited.

In the Michigan passenger model trip production rates are developed through the following process. First, using *NCHRP Report #365*, generation rates are obtained for the various cross-classification groups. There are 60 different classification groups for the Michigan model, based on five household sizes (1, 2, 3, 4 and 5+ persons), three household income levels (low, medium and high) and four geographical area sizes (small, medium and large cities and rural areas). For example, in a large urban area a low-income, single-occupant household will produce 3.7 trips per day.

Second, using the proportion of total trips devoted for each purpose from the NPTS, the generated trips are divided accordingly among the purposes. Again, for a large urban area, the following ratios are used for low-income, single-occupant households:

0.192 to home-based work
0.160 to home-based recreational
0.404 to home-based other
0.310 to non-home based work
<u>0.214 to non-home based other</u>

1.000 (100% of trips accounted for)

The resulting generation rates are obtained by taking the product of the two values. For instance:

0.192 * 3.7 = 0.71 trips per day for home-based work
0.160 * 3.7 = 0.59 trips per day for home-based recreational, etc.

The process is repeated for all 60 cross classification groups.

Trip Attractions

Determining trip attraction rates is even more troublesome than determining production rates. The same general methods used to develop production rates are also available to develop attraction rates. For instance, some statewide models have attraction rate equations that have been developed using federal data sources, including NPTS and JTW. Rates from *NCHRP Report #365* may also be of value. As with urban models, production rates are usually considered more trustworthy than attraction rates, so attractions are generally adjusted to match productions by purpose at the end of the trip generation step.

As is also done for production rates, attraction rates are determined by trip purpose. In this case a TAZ containing a national park would likely attract few business trips, but would attract many recreational trips.

Special Generators. Sites like national parks or military bases are sometimes represented in the network as special generators. Special generator sites are often modeled as trip attractors only, depending upon their characteristics; very site-specific information (from specialized surveys, for example) can be used to determine their attraction rates. If special surveys have not been undertaken, information from *NCHRP Report #365* can be used to set the trip attraction rates. For very small sites ITE's *Trip Generation* could also be used, but it is unlikely that many small sites would need to be included in a statewide model.

Michigan found that the weakest link in the whole model chain was trip attraction, so shortcuts at this stage of the modeling effort are inadvisable.

In the Michigan passenger model special generators are modeled as attractors only. Attraction rates used are as follows.

Special Generator Type	Source of Rate	Rate Equation
Airports	1991 ITE Manual	exp[1.368 x ln(reg. aircraft) - 0.347] or [104.74 x operations /365]
Tourist Attractions	MDOT Travel & Tourism	2 x attendance
Campgrounds	1991 ITE Manual	0.79 x campsites
State Parks	1991 ITE Manual	0.50 x acres
Golf Courses	1991 ITE Manual	37.59 x holes
Marinas	1991 ITE Manual	(1.891 x berths) + 410.795
Motels	1991 ITE Manual	exp[0.713 x ln(0.44 x rooms) + 3.945]
Hospitals	1991 ITE Manual	exp[0.634 x ln(beds) + 4.628]
Shopping Centers	1991 ITE Manual	exp[A x ln(ksf) + B] where A = 0.756, B = 5.154 for > 570 ksf, and A = 0.625, B = 5.985 otherwise
Colleges & Universities	1987 and 1991 ITE Manuals	2.37 x students (for universities) or x students (for community colleges)

These rate equations are intended to show the types of ways rates can be created. They should not be used for forecasting purposes, as new data sources are available.

External Stations

There are two principal ways to include the effects of external travel in the model: using external stations or using a national highway network.

External Stations. External stations are located at the edges of the network and are used to generate trips produced or attracted from outside the area that the network covers. For statewide models, they are usually placed to correspond with locations where interstate highways and other major roads enter the network. Use of external stations requires good information about traffic entering the state at those locations, which should be obtained most readily from survey information.

National Network. Use of a national network provides an alternative method of modeling trips generated outside of the local network. For a statewide model, the national network would likely consist of the interstate system and TAZs representing states or groups of states away from the area being modeled. With a national network it is easier to make use of national data (e.g., NPTS) to generate trips from distant states and later to assign them into or through the local network. The use of a national network does not entirely eliminate the need for an external station OD survey, which is still useful for model validation.

Both states that use external stations and states that use national networks to help model external trips have found it beneficial to extend the local network into the surrounding states. In some cases this extended statewide network covers areas hundreds of miles into adjoining states. The extended network is used to provide both a more detailed accounting of trips generated in nearby states that may pass into or through the state being modeled and to provide a way of buffering the distribution of trips generated outside the local network and being fed into it through external stations or national network links.

Balancing Productions and Attractions

In general, the number of trips produced will not match the number of trips attracted. This is to be expected, since the numbers of trips produced or attracted are developed by entirely different sub-models.

Since the production equations are generally considered to be more reliable than the attraction equations, it is common to adjust the attraction values of each TAZ such that the number of trips attracted for the whole model is equal to the number of trips produced. This process is carried out separately for each trip purpose.

Trip Distribution: Gravity Model (Production Constraint)

Gravity models have been extensively used for statewide travel forecasting. A complete specification for one form of the gravity model is:

$$T_{ij} = P_i A_j f(t_{ij}) \Big/ \sum_k A_k f(t_{ik})$$

where:

T_{ij} is the number of trips from i to j;

P_i is the production in zone i;

A_j is the attraction in zone j;

t_{ij} is the impedance (time) from i to j; and

$f(t_{ij})$ is the friction factor from i to j.

This equation will always yield a trip matrix that is consistent with the number of productions in each zone, as calculated in the trip generation step. The trip matrix will not be consistent with the number of attractions. Thus, this form of the gravity model is often referred to as being "singly constrained".

The number of trips between any production zone i and any attraction zone j is proportional to the number of productions in i, proportional to the number of attractions in j and proportional to the measure of proximity, $f(t_{ij})$. The friction factor, $f(t_{ij})$, is larger for pairs of zones that are close to one another and smaller for zones that are distant from one another. Friction factors are determined empirically.

Friction Factors. Friction factors are a function of a measure of zone separation, t_{ij}. Travel time by automobile is commonly used for urban travel forecasting. For intercity travel, time and distance are almost directly proportional to one other, so either could be used to calculate friction factors. When there are two or more modes in the analysis, it is often desirable to use a composite time or cost that considers all available modes. This composite time is not a true average; it will be discussed more fully in Chapter 5.

The denominator of the expression (the sigma term) adjusts the trip table so that productions from the trip distribution step agree with productions from the trip generation step.

Singly-constrained gravity models are not recommended for statewide models because trip attractions from the trip generation step will not be preserved. A doubly-constrained model preserves both productions and attractions. Singly-constrained models are slightly easier to calculate than doubly constrained models. They are sometimes used for estimating the number of trips going to or coming from an entirely new activity site.

Doubly-Constrained Gravity Model

A doubly-constrained gravity model will preserve both productions and attractions, as calculated in the trip generating step. It has the following functional form:

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

To conserve productions, set the X's by

$$X_i = 1 \Big/ \sum_j A_j Y_j f(t_{ij})$$

To conserve attractions, set the Y's by

$$Y_j = 1 \Big/ \sum_i P_i X_i f(t_{ij})$$

Two "balancing factors" have been introduced, X_i and Y_j. There are as many of each as there are zones. These balancing factors do not provide any new information to the model; their only purpose is to assure that the trip generation results are not changed in the trip distribution step.

Xs and Ys must be calculated prior to calculating the number of trips between zones. An iteration process is required because each X_i requires knowledge of all Ys and each Y_j requires knowledge of all Xs. The iteration process is started by assuming that all Y's are 1. Then Xs are found, then Ys are found, then Xs are found again, etc. The process converges rapidly, typically in three to five iterations.

Friction Factors

Friction factors are found as a declining function of time, distance, cost or some combination of the three. Friction factors are commonly found from a lookup table, an exponential function, a power function, or a combination of exponential and power functions.

For example, Michigan defined its measure of separation as:

$$t = 0.75 \text{ Distance} + 0.5 \text{ Time} + 0.1 \text{ Toll}$$

The sum of two "gamma functions" was used for friction factors. For the home-base work purpose, the friction factor function looks like:

$$f(t) = 1258477t^{-1.565}e^{-0.123t} + 200t^{-0.441}e^{-0.012t}$$

They applied this function to all instate trips. Outstate trips had still another friction factor function. The complexity of the friction factors relates to the difficulty of obtaining a single function that properly reflects both short distance and long distance trip making.

Kentucky used tables of friction factors. They have three sets: work trips, short (≤60 minutes) nonwork trips and long (>60 minutes) nonwork trips. Long nonwork trips constitute about 1% of the total number of nonwork trips. Below are pieces of each table.

Time (min)	**Friction Factor, Work**
1	259360
2	203007
3	159242
118	2
119	2
120	2

Time (min)	**FFactor, Long Nonwork**
1	999999
2	367878
3	196955
58	2
59	2
60	2

Time (min)	**FFactor, Long Nonwork**
61	200
181	50
241	6
601	1
661	1
720	1

Trip Distribution: Application to Statewide Forecasting

Both Michigan and Kentucky had difficulty finding simple friction factor functions that match trip making for both long and short trips. Kentucky handled the problem by designating a separate purpose for long nonwork trips (>60 minutes). Michigan handled the problem by having a very complex friction factor function for intrastate trips and an entirely different friction factor function for interstate trips. Michigan also made extensive adjustments to the gravity model, trip-by-trip, with K factors. The experiences in Kentucky and Michigan suggest that the gravity model is not working well within the trip purpose categorization selected, which in both cases was similar to urban trip purposes.

Intrazonal Trips. The fraction of intrazonal trips is very important to statewide travel forecasting. A large error in these cells of the trip table can result in a large error in interzonal (i.e., intercity) trips. Within the gravity model, the number of intrazonal trips is controlled entirely by the size of the intrazonal trip time. This intrazonal trip time must be selected with great care. It should not be calculated by a "nearest neighbor" method that is available in some travel forecasting software packages. Still other software packages define friction factors for only whole minutes of trip time, so rounding can cause an appreciable error in the estimates of intrazonal trips.

Perhaps a better method of handling intrazonal trips is to exclude many of them from the gravity model. In fact, one of Michigan's early statewide models omitted intrazonal trips at the trip generation step. The number of intrazonal trips could be estimated for certain key zones, then subtracted from trip generation totals. The gravity models will eliminate intrazonal trips if the friction factor is set to zero (usually by setting intrazonal time to a very large number).

Mode Split

Mode Split Tables. The best single source of mode split information is the NPTS. However, the NPTS does not provide the data in a convenient form. Rather, each trip is separately reported. Thus, a considerable effort is required to develop the mode split tables. For intercity travel the tables should break out mode by both purpose and trip length. Other break outs are may be useful, depending upon the policies and alternatives to be tested. The NPTS modal categories are automobile, van, sport utility vehicle, pickup truck, other truck, RV (recreational vehicle), motorcycle, other POV (privately owned vehicle), bus, Amtrak, commuter train, streetcar/trolley, subway/elevated rail, airplane, taxicab, bicycle, walk, school bus and other non-POV.

A separate mode split table should be prepared for each trip purpose. The NPTS trip purpose categories are to work, work-related business, return to work, shopping, school, religious activity, medical/dental, other family or personal business, take someone somewhere, pick up someone, vacation, visit friends or relatives, went out to eat, other social/recreational, change mode of transportation, other and home.

Other mode split techniques are variations on logit analysis. The next sections will discuss multinomial logit and nested logit. Pivot point is illustrated in the chapter on freight forecasting.

Logit

The logit model allocates person trips to alternative modes. It does so by comparing the utilities of all alternative modes.

The proportion of trips made by mode k can be found from:

$$p_k = e^{U_k} \Big/ \sum_z e^{U_z}$$

where U_k is the utility of mode k, z is a dummy index that ranges over all modes and e is 2.718281…

Utility is a measure of the personal satisfaction of taking a trip, exclusive of the satisfaction of reaching the destination. Because travel consumes valuable personal resources, utility is most often a negative number. Utility is smaller (more negative) when trips are longer.

Utility is often expressed as a function of travel time, travel cost and convenience measures. The specific functional form is often found from statistical analysis of choices made by travelers.

Logit models possess an interesting mathematical property called “Independence of Irrelevant Alternatives” (IIA). The IIA property says that the ratio of mode shares between any two modes is unaffected by the presence or characteristics of a third mode. The IIA property is displeasing to many analysts because it can cause a bias toward technologies that have many distinct modes. For example, consider a mode split between automobile and conventional rail. Automobile has 80% of intercity traffic and conventional rail has 20% for a ratio of 4 to 1. Now assume the addition of a third mode, high speed rail, which grabs 20% of the ridership for itself. The new mode shares from a logit model would be 64% automobile, 16% conventional rail and 20% high speed rail (the ratio of automobile to conventional rail is still 4 to 1). It might be argued that conventional rail should lose a higher percentage of its ridership to high speed rail than does the automobile. After all, conventional rail and high speed rail have similar characteristics and compete directly with one another. However, the logit model does not recognize differences in competition across pairs of modes.

Utility is usually found from a linear equation that combines the effects of trip time, trip cost and trip convenience.

$$U_k = a_k + a_1 t + a_2 c + \cdots$$

where the a’s are empirical constants.

The utility function can be found from statistical estimation or from transferable parameters. Because longer and more costly trips are considered bad, the coefficients on time (t) and cost (c) are almost always negative.

The above equation defines a mode specific constant, a_k. This constant is arbitrarily set to zero for one mode. The value of a_k for the remaining modes may be positive or negative, depending upon how favorably travelers perceive that mode. A better mode would have a positive mode specific constant. A worse mode would have a negative mode specific constant.

Logit Example, Forinash and Koppelman (1993)

Forinash and Koppelman (1993) calibrated several mode split models for intercity travel in Canada. The data was taken from trips made between Ontario and Quebec. Some of the models were pure logit; others were nested logit (see later discussion). The modes considered were automobile, rail, bus and airline. One of the pure logit models is illustrated by the coefficients in the table below.

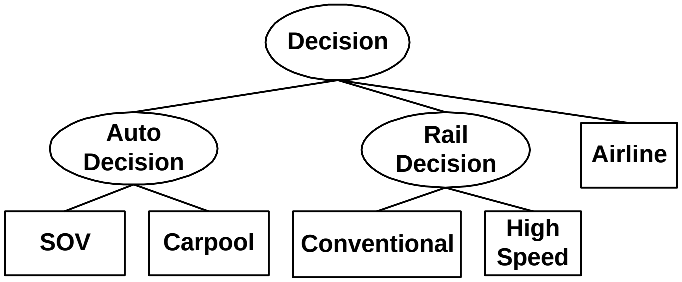
Significant independent variables in the model were: mode specific constants; large city dummies by mode; frequency; travel cost; in-vehicle time for high income; in-vehicle time for low income; out-vehicle time for high income; and out-vehicle time form low income.

Variable	Air	Bus	Auto	Train	All
Mode Constant	1.888	-2.756	2.203	0	
Large City	-0.7460	-0.1224	-1.1306		
Frequency					0.1022
Cost					-0.03265
In-Veh Time, High Income					-0.01382
In-Veh Time, Low Income					-0.003797
Out-Veh Time, High Income					-0.04053
Out-Veh Time, Low Income					-0.02635

The above table lists the coefficients of the utility functions. Be aware that not all coefficients appear in every mode's utility function.

The breakpoint between high and low income was $30,000 Canadian. The large city variable is 1 if either end of the trip is in a large city.

Nested Logit



Nested logit models organize modes into a hierarchy, like the one shown in the diagram on the right. The hierarchy implies that several decisions are made in the process of selecting a mode. For example, a decision is first made between SOV and carpool and between conventional rail and high speed rail. Finally, another decision is made between automobile, rail and airplane. Modes with similar characteristics are grouped together in a nest. A nested logit model helps the analyst to avoid the IIA property of a pure logit model.

The nested logit model has the ability to differentiate between pairs of modes that are complementary and pairs of modes that are competitive.

Nested logit models are calibrated in much the same manner as regular logit models, statistical estimation or adoption of default parameters. The statistical estimation process can also give a good indication of the best arrangements of modes and nests. However, professional judgement is required to assure that the model will give dependable results. Some nesting schemes that look good statistically can give strange forecasts.

A logit model is applied to each level in the hierarchy, but the model calculates utility somewhat differently than discussed previously. Specifically, the utility of a nest, U_n, is:

$$U_n = \phi_n \ln \sum_k e^{U_k/\phi_n} + \mu_n$$

where U_k is the utility of a mode one level below and ϕ_n and μ_n are constants for the current level. The utility of modes at the lowest level are calculated in the same way as a logit model, e.g., a linear combination of time, cost and convenience terms. The logsum term, specifically:

$$\phi_n \ln \sum_k e^{U_k/\phi_n}$$

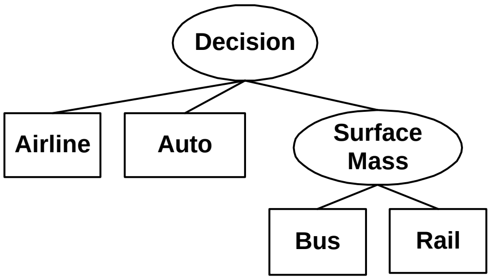
is simply a means of combining together the utilities of all the modes in the nest. This combined utility takes into account the increased opportunities to travel by having several modes in the nest. For example, to compute the utility of the automobile (refer to the previous hierarchy), the logsum would form the combined utility of the SOV and carpool modes. The coefficient on the logsum term ϕ_k is found by matching the model to data. The coefficient, ϕ_k, is usually between 0 and 1. A coefficient of 1.0 causes the nested logit model to behave as a standard logit model.

The nest bias coefficient, μ_k, performs the same purpose as the mode specific constant in the logit model. It raises or lowers the utility of the nest, depending upon the preference of users. The nest bias coefficient is arbitrarily set to zero for one nest at a level; the other nests' bias coefficients are set relative to the arbitrarily chosen nest.

It should be noted that some applications of nested logit omit the ϕ_k term where it divides utility in the exponent. Also, some nested logit models omit the nest bias term.

Nested Logit Example, More F&K

Forinash and Koppelman also tried several nested logit models on the travel data from Canada. One of their nesting schemes is illustrated on the right. The exact formulation of this nested logit model differs slightly from the general formulation described in the previous paragraphs. They did not include a nest bias term for the Surface Mass utility term when splitting trips across Airline, Auto and Surface Mass. The two formulations are nearly equivalent, but could produce slightly different coefficients for utility equations of the modes within the nest.



Variable	Air	Bus	Auto	Train	All
Mode Constant	-0.7359	-1.3140	0.5756	0	
Large City	-0.7697	0.1339	-1.242	0	
Household Income	0.03507	-0.03009	0.01303	0	
Frequency					0.09843
Cost					-0.02339
Out-Veh Time, High Income					-0.1977
Out-Veh Time, Low Income					-0.1830
Total Time, High Income					-0.01217
Total Time, Low Income					-0.00883

The coefficient, ϕ_k, on and within the logsum term had a value of 0.6488. The out-vehicle time term is computed as raw out-vehicle time divided by the natural logarithm of the distance.

Mode Split Issues

Lookup Tables. Lookup tables are particularly useful for splitting trips to minor modes or across finer divisions of modes. For example, a state wants to split trips across SOV and carpool categories. Rather than use a logit model, it might be more efficient to use a lookup table that shows typical splits as a function of distance.

Mode Specific Constants. A traditional logit model is calibrated from data about actual trip choices. When a new mode is planned, choice data for that mode are unavailable. All constants in the logit model that are specific to that single new mode cannot be estimated. It is sometimes possible to use psychometric techniques to estimate those constants. One such method asks travelers about their intention to take a new mode. This method, referred to as “stated preference”, is described in later chapters.

Collinearity. Many of the variables in the utility equation are roughly proportional to each other. For example, travel time is almost proportional to travel cost for most intercity modes. This proportionality is stronger for intercity trips than for urban trips. When two statistical variables are proportional in this manner, they are said to be collinear. Collinearity can result in strange values for estimated coefficients. If collinearity is present in the data, it is important to apply the calibrated logit model to situations where the same type of proportionality holds.

Nesting Structure. Quite different nesting structures can have almost the same statistical performance on data, but forecast very differently. Consequently, it is important to develop nesting structures that are logical, particularly by keeping like modes within the same nest. Professional judgement may be necessary.

Data Needs. Logit models require extensive data for calibration. Transferable parameters have not been developed for intercity mode split models, and it is inappropriate to take coefficients from urban models.

Trip Assignment

The least complicated technique for assigning trips to the links on the network is the all-or-nothing method. For all-or-nothing assignment, all of the trips between a particular origin-destination pair are assigned to the single shortest path of links between the pair. In reality traffic does not always travel along the shortest path.

Four possible reasons that travelers do not follow the single shortest path are (1) capacity restraints in the system, (2) random personal preference, (3) the lack of spatial detail associated with large TAZs and (4) the omission of many smaller-volume roads in a highway network. Capacity-restrained and stochastic assignment methods have been developed to address two of these reasons.

Capacity-restrained assignments, which include iterative and incremental techniques, involve increasing the travel time on links where high volumes of traffic are expected. These methods are commonly used in urban modeling situations in conjunction with the BPR equation:

$$t = t_o\ [1 + 0.15\ (q/q_{max})^4] \quad .$$

Urban models typically deal with peak-hour demand situations. However, for statewide modeling the necessary time-of-day information is often not available to estimate peaking of traffic; the data is instead available only in terms of 24-hour flows. This makes application of capacity restraint techniques difficult at a statewide level.

Stochastic assignment techniques involve assigning some of the trips between a given origin and destination to the second- or third-shortest path, as well as to the shortest path overall. This is done to account for the preferences for certain routes that drivers might have, independent of travel time considerations and the imprecision associated with large zones or arbitrarily small networks. Assignment to the various paths is done by estimating the probability that a traveler will chose that particular path.

Unfortunately, states that have tried various traffic assignment techniques have been disappointed with the results. It seems that all-or-nothing assignment works as well as the others. All-or-nothing traffic assignment can produce quite lumpy results when there are comparatively few TAZs and the network omits a high percentage of minor roads.

Therefore, it is important to retain some degree of spatial detail when performing all-or-nothing assignments. TAZs should be kept small, and a large number of minor roads should be included to provide a reasonable approximation of the actual path choices. However, small zones and many links increase both data preparation and computational needs.

Computer resources are likely to be less of a problem in coming years. Currently, Michigan’s model (at 2300 zones) is approaching the practical size limit computationally.

A large number of zones implies an increased burden of data preparation and input data forecasting. A suggested method of reducing this burden is to adopt two levels of spatial aggregation, districts and zones. Districts could correspond to the spatial units most often used in socioeconomic forecasts, typically counties. Most data preparation and data forecasting tasks could then be performed at the district level. Data from the districts could be disaggregated to zones using a constant set of factors for each district. Special generators could be associated with particular zones, as needed.

Integrating Freight. Freight represents a significant proportion of vehicles on roads and an even larger percentage of passenger car equivalents (from the *Highway Capacity Manual*). Thus, a full evaluation of highway performance must consider freight. Freight is discussed in the next chapter.

Calibration and Validation

Calibration versus Validation. Calibration is the process of setting the various model parameters of the various model steps to match existing trip making behavior. Validation is the process of determining whether the calibrated model, as a whole, accurately forecasts current conditions, usually assigned traffic levels. Thus, calibration is normally a lengthy process, with extensive use of statistical estimation techniques and many trials and errors. Validation should occur rather quickly once the validation data set is assembled.

It is important to maintain the distinction between calibration and validation. All too often the validation data is used in the calibration process, thereby undercutting their value for validation.

Statistical methods (linear regression, maximum likelihood estimation) are preferred calibration techniques for all steps except traffic assignment. There are no widely accepted techniques for calibrating the traffic assignment step in a statewide model.

Sources of Validation Data. The set of validation data consists of traffic counts. Statewide models should be validated only on links where network detail is reasonably representative of reality, usually in rural areas.

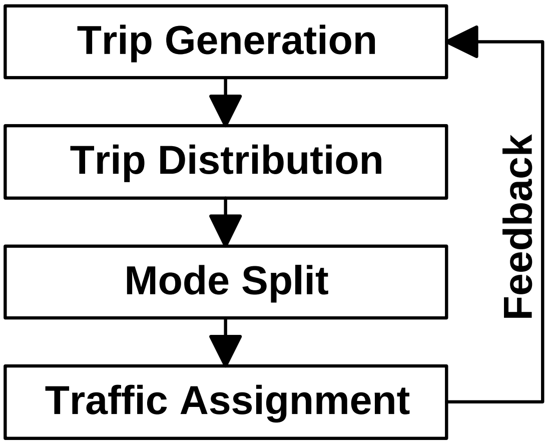
When two or more duplicative data sets are available, it is possible to calibrate a model step with one of them and validate with the other. For example, calibrations made with home interview data could be validated with CTPP or NPTS data. Cross validation data may be reported at a different level of spatial aggregation than the original calibration data.

How good? Models need not be any better than the quality of the traffic data in the validation data set. Since the quality of traffic counts is poor on low volume roads, all roads with less than 2000 vehicles per day (AADT) should be excluded from the validation. If a large number of such low-volume roads exists in a portion of a state and a validation is important, they should be combined into a cutline.

Appendix: Overview of Four Step Models

The four major steps of the urban transportation modeling process are shown below. The steps are executed sequentially. A feedback loop is now considered best practice; it assures that congestion and delay are treated consistently throughout the model.

When strictly highway policies are being analyzed, the mode split step is often omitted. Thus, a three step model consists of trip generation, trip distribution and traffic assignment.

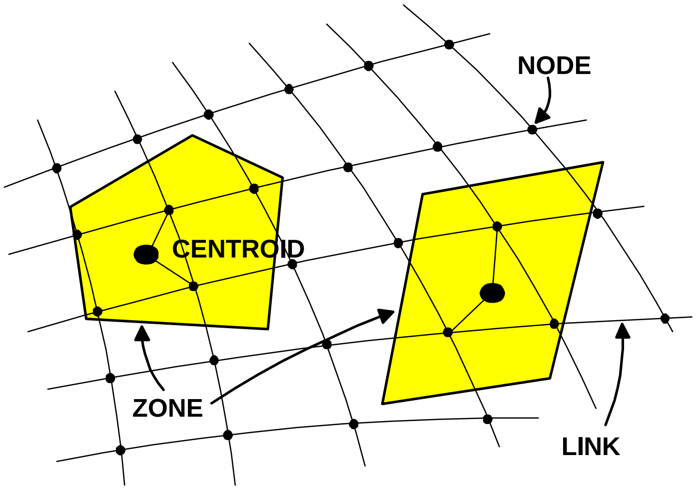


In actuality, there are many more steps to the modeling process. Some of these steps are quite important. A typical modeling sequence might involve:

- Find highway trip times;
- Find disutilities for nonhighway modes;
- Activity allocation;
- Trip generation;
- Trip distribution;
- Vehicle occupancy;
- Time of day and direction of travel;
- Highway traffic assignment;
- Trip assignment to nonhighway modes;
- Highway volume averaging;
- Highway delay calculation; and
- Feedback.

Network Basics

Networks. A network holds nearly all data used in a travel forecast. A network consists entirely of nodes and links and the values of their attributes. Networks are drawn with a specialized program, called a network editor, or they can be taken from a GIS. Already prepared networks can be obtained for many statewide and corridor applications. Networks must satisfy two important continuity requirements:



- All links must connect to two distinct nodes (referred to as “A” and “B”);
- For a node to be useful, it must connect to one or more links.

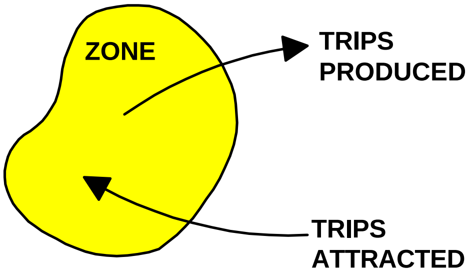
Links. A link is a straight line segment representing a portion of a travel path. Often links are identified as being one-way or two-way. Traffic on one-way links flows in the A to B direction. Links have attributes, including distance, travel time, speed and capacity.

Nodes. Nodes are primarily used to represent places where trips begin, end or change direction. Most nodes represent intersections or bends in a road. In a traditional urban model, trips begin or end at a special type of node called a centroid. Centroids usually represent areas of the city identified by travel analysis zones (TAZs). Intersection nodes do not have many attributes, but centroids contain attributes that describe the socioeconomic and demographic characteristics of the zone. Many travel forecasting models require that centroids be connected to the arterial portions of the network with a special type of link, called a centroid connector. One type of centroid is an external station. External stations represent large areas beyond the region of interest.

Path. A path is a sequence of nodes and links, starting at an origin centroid and ending at a destination centroid. There are many paths between most origins and destinations. Usually, the models identify the shortest path by some criterion, typically time or distance or some combination of the two.

Trip Generation Basics

Overview. The trip generation step determines the total number of person trips that begin or end in a zone, usually over a 24-hour period. Trip totals for any zone are separately tabulated by trip purposes and by whether they are productions or attractions. A typical set of trip purposes for urban travel forecasting is home-based work (HBW), home-based other (HBO), nonhome-based (NHB) and specialty purposes. Trips identified as being home-based have the home as either the origin or destination. Whether a trip end is a production or an attraction depends on how the trip purpose is satisfied. Trips are produced where the trip is conceived. Trips are attracted to where the trip purpose is satisfied. The following rules apply within most urban models:



All home-based trips are produced at the home;
All home-based trips are attracted to the end that is not the home; and
The network-wide total of productions must equal the total of attractions for each purpose;

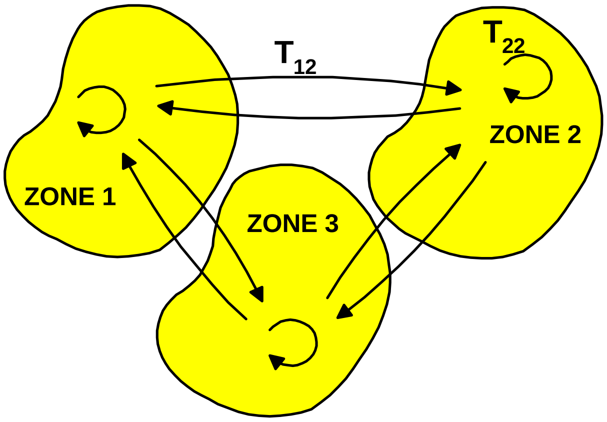
Nonhome-based trips are treated in a variety of ways. Many urban models generate a total amount of nonhome-based trips, then split them evenly between productions and attractions.

Trip productions and attractions are computed with separate empirical relationships. These relationships include the socioeconomic and demographic characteristics of zones, but rarely include any travel characteristics of zones.

Productions. Productions are most often calculated by multiplying a trip rate for a category of households by the number of households falling into that category. Categories are typically organized by number of persons in the household, number of automobiles in the household or household income.

Attractions. Attractions are most often calculated by a linear equation, where the dependent variables are demographic characteristics, such as retail employment, nonretail employment and households.

Trip Distribution Basics



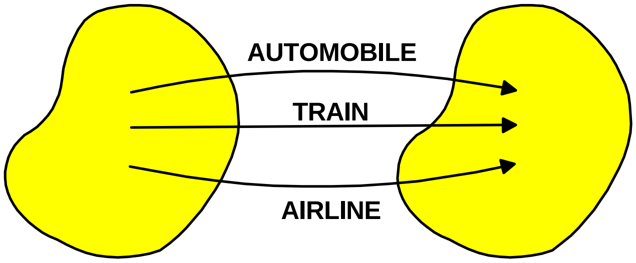
Overview. Trip distribution finds the number of person trips that go between all pairs of zones. Usually, 24-hour person trips are distributed separately for each trip purpose. The diagram on the right shows three zones, yielding 6 interzonal trip interchanges and 3 intrazonal trip interchanges. The direction of each arrow is from the production end to the attraction end of the trip. Each trip is identified by subscripts, with the first subscript representing the production zone and the second subscript representing the attraction zone. The results of the trip distribution step can also be shown in the form of a matrix, with as many rows and columns as zones. Each row represents a production zone and each column represents an attraction zone. In the trip table shown at the right, there are 776 trips between production zone 2 and attraction zone 3.

		A's		
		1	**2**	**3**
P's	**1**	183	784	939
	2	890	141	776
	3	920	748	197

Trip Distribution Technique. Trip distribution is most often performed in urban area models by a technique called the gravity model. The principles of the gravity model are quite straightforward:

- There is a large number of trips between pairs of zones when the trip productions in the pair are large;
- There is a large number of trips between pairs of zones when the trip attractions in the pair are large; and
- There is a large number of trips between pairs of zones when there is little separation between zones (as measured in time or space).

Mode Split Basics



The mode split step finds the number of trips using each available mode between a production/attraction pair. As with trip distribution, mode split is typically performed on 24-hour person-trips. The figure on the right illustrates three intercity modes: automobile, train and airline.

The mode split step is most often found in forecasting models for large urban areas. Small cities tend to have low transit ridership, which is either ignored or treated as a fixed percentage of all trips.

Mode split models assume that travelers choose the best mode for themselves by weighing the characteristics of the trips for all available modes. The measure of trip goodness is called "utility". Since trips consume valuable resources, the value of utility is most often a negative number. The actual utility is unknown, as there are many personal factors and perceptions that influence each traveler's decision. However, major objective factors in the choice, such as travel time and cost, can be ascertained with some degree of accuracy. The mode split model takes these objective factors as inputs, but recognizes that the actual utility is known imprecisely when calculating mode shares.

Some mode split models include socioeconomic factors in their expression of utility. Still other mode split models take into consideration factors related to access and the lack of one or more alternative modes for subgroups of travelers.

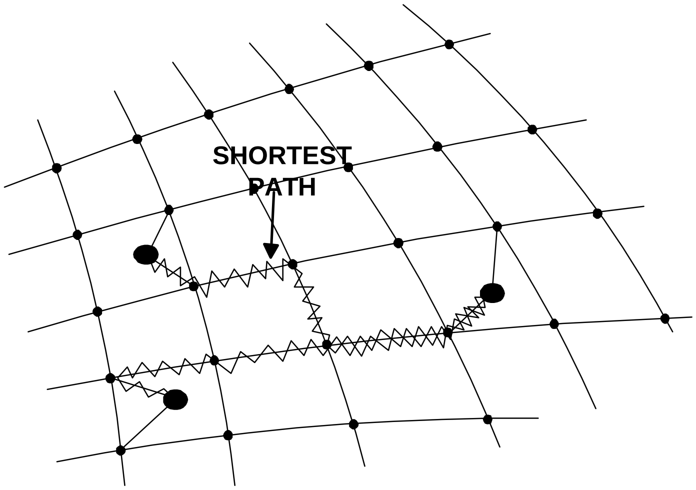
Most urban models containing a mode split step use a variation of the logit model for mode split. Two of these variations are discussed in the main portion of this chapter.

Traffic Assignment Basics

The major outputs of the traffic assignment step are volumes on all links, turning movements at selected intersections and the delays from congestion.

Trip Table Preparation for Assignment. The output of the mode split step is still in terms of 24-hour person trips in the production to attraction direction. For automobiles, the trips must be converted to vehicles. For all modes, the trips must be factored into a specific time period (e.g., peak hour) and given a physical direction of travel (i.e., origin to destination). For example, a morning home-based work trip will have its origin at home and its destination at work. Conversely, an evening home-based work trip will have its origin at work and its destination at home.

All-or-Nothing. All-or-nothing assignment loads all trips between an origin and a destination to the shortest path between the origin and destination. This assignment is done separately for each OD pair, then the results for all OD pairs are summed. All-or-nothing assignments do not recognize the capacity of individual links or nodes, but can account for known delays on links, turn restrictions and turn penalties at intersections.



Capacity-Restrained Equilibrium. Capacity-restrained equilibrium assignment recognizes delays that may occur due to congestion. Algorithms that perform this form of assignment try to spread trips from a single pair of origins and destinations over many paths such that all used paths are shortest (or tied for shortest) and the delay along any link or at any node is consistent with the amount of traffic on the link or passing through the node.

Stochastic. A stochastic assignment finds the shortest path between an origin and a destination and also finds several alternative paths that are somewhat longer. The algorithm then assigns the largest fraction of trips for that origin-destination pair to the shortest path and lesser fractions to the longer paths.

Chapter 4. Freight Forecasting

Introduction

The purpose of this chapter is to present a unified methodology for forecasting commodity flows and vehicular volumes on intercity and rural portions of our transportation systems.

Freight forecasting is dependent upon knowledge of:

- Industrial structure of the economy;
- Existing and projected commodity flow;
- Technological characteristics of modes;
- Potential actions of carriers and shippers; and
- Modal networks.

Factors affecting freight demand are complex, involving:

- Presence of factors beyond the planner’s control;
- Variety in type and value of commodities;
- Multiple measuring scales for goods; and
- Variation in type of service (e.g., specialized services).

Forecasting requires extensive use of existing data sources (commercial or public), other local knowledge and experience gained elsewhere.

Methods presented here have been adapted from forecasts done for Wisconsin, Michigan, Indiana, Kentucky and Kansas. The methods follow a process that is similar to four-step models for passenger forecasting, but details vary considerably due to the unique aspects of commodity movement.

Freight Model – Basic Steps

Building a freight model involves several steps that will be discussed in detail later. These steps are as follows:

1. *Obtain Freight Modal Networks.* Networks are required for freight models. Networks consisting of mathematical descriptions of routes, links and intersections are required for each mode receiving complete analysis. Networks are drawn from scratch or modified from existing sources.
2. *Develop Commodity Groups.* Vehicle traffic levels are derived from the movement of commodities. Thus, a good understanding of commodities is necessary. Because there are a very large number of commodity categories, commodities are grouped to facilitate the analysis. A large number of groups gives precision, but increases the complexity of the modeling process.
3. *Relate Commodity Groups to Industrial Sectors or Economic Indicators.* Separate economic indicators should be adopted for production and consumption of each commodity. It is easier to relate commodities to industrial indicators at the production end of the shipment. Input-output (IO) tables can bridge the relationship to consumption of commodities.
4. *Find Base Year Commodity Flows.* Origin and destination data for commodities must be obtained to build a factual model. These data are collected irregularly. For example, the Commodity Flow Survey was last performed in 1997. Local data sources would most often have other dates of completion.

5. *Forecast Growth in Industrial Sectors.* Growth forecasts are best done by economists who specialize in industrial forecasting. Forecasts can be obtained from a variety of governmental, private and educational organizations. Growth forecasts are best if they are disaggregated to the TAZ (traffic analysis zone) level.
6. *Factor Commodity Flows.* These industrial forecasts can be used to forecast commodities. These forecasts can be applied to production, to consumption or to a whole commodity flow table.
7. *Develop Modal Cost for Commodities.* Mode split is determined, to a large extent, by cost considerations. The cost of any given shipment is complex, relating to the full logistics stages of shipping. Detailed cost models (e.g., NCHRP Report #260) have been developed for mode split purposes. A cost model is the primary way to determine the impact of public policies on modal choice.
8. *Split Commodities to Modes.* There are three categories of methods for splitting commodities to modes.
    - *Mode Split Models:* Mode split models estimate mode shares by comparing the relative costs of shipment between alternatives. The logit model, an often used mode split model for passenger forecasting, has occasionally been used for commodities.
    - *Tables:* Historical mode split tables for individual commodities are readily available. These tables are especially useful when cost is not a determining factor or when testing policies without significant cost implications.
    - *Expert Opinion:* Tables or models may not be available for entirely new modes or services. In these instances, persons very familiar with goods movement can provide information that may lead to reasonable estimates of mode shares.
9. *Find Daily Vehicles from Load Weights and Days of Operation.* Commodity flow data are given in terms of tons per year. Planning studies often require model outputs in the form of vehicles per day. Thus, it is necessary to determine the amount of goods carried in a vehicle and the number of vehicle days in a year.
10. *Assign Vehicles to Modal Networks.* Flow matrices, by themselves, are of limited value for planning. More important are the number of vehicles that use each link, intersection and terminal. This information is provided by a traffic assignment algorithm.

Key Freight Data Sources

Commodity Flow Survey

The Commodity Flow Survey (CFS) is a sample of shipment information from 100,000 businesses. The CFS only provides summary tables of the raw data, but these tables are extensive. The CFS can give good estimates of external-to-internal and internal-to-external flows for states. For the most part, it cannot provide commodity flow tables for points within a single state, and it cannot provide through (overhead) flows. No vehicular data are provided. The CFS excludes shipments from farms, most retail and service establishments, oil and gas extraction, transportation and government. It does not provide data for flows passing through the US that originated outside its borders.

Perhaps the most useful part of the CFS for statewide forecasting is its commodity mode split tables. These tables give the percentage of weight or value for each commodity on each mode.

Average trip lengths are also given. The Wisconsin mode split by weight (tons) and average trip lengths (miles) for food and kindred products (STCC 20) from the 1993 CFS are shown on the right. Modes with small or no amounts of these commodities are omitted from this table.

Mode	Tons	Trip Length (Miles)
Parcel	19	NA
Private Truck	13509	56
For Hire Truck	11843	385
Rail	3058	901
Truck and Rail	115	1718
Other or Unknown	362	NA

The CFS also provides for each state tables for mode by trip length and commodity by trip length. These tables may be helpful in preparing mode split tables that vary by distance shipped. At the national level tables of mode by commodity and trip length are available. Commodities in the 1997 CFS are organized by SCTGs, not STCCs.

Vehicle Inventory and Use Survey (VIUS)

VIUS (formerly TIUS, Truck Inventory and Use Survey) is a large sample of trucks, their physical characteristics, their ownership characteristics and their operations. VIUS comes with software for comparatively easy access to data. Each data record in VIUS is for a single truck, containing about 400 fields. Characteristics of a data record within VIUS include:

- Extensive description of vehicle and ownership characteristics;
- Empty weight, average gross weight and maximum gross weight;
- Weeks operated;
- Annual mileage and percentage of mileage by trip length (<50, 50-100, 100-200, 200-500, >500);
- Percentage of mileage by product; and
- Commodities reported in 33 categories (roughly two-digit STCC), including passengers and empty.

Commercial Freight Data Sources

Commodity flow data are available from Reebie, DRI/McGraw Hill and GIS/Trans, who are co-developing the Intermodal Freight Visual Database. This database is derived from TRANSEARCH. The database shows commodity volume by mode and lane (OD pair). Origins and destinations are as small as counties. Assignments to modal networks are possible in terms of vehicles, weight, VMT ton-miles and dollars. Modes include truck, rail, water and air. Commodities are identified by four-digit STCC. Imports and exports are also identified.

This description of this product is not intended as an endorsement, but as examples of types of data available.

Other Interesting Data Sources

County Business Patterns. County Business Patterns reports for each county and for each four-digit SIC the number of employees, annual payroll, number of establishments and size of establishment. The data is available online or by CD-ROM.

1992 Census of Agriculture. This survey helps fill in information missing from the CFS and contains information on farm-based shipments.

Other Commercial Forecasts. Several companies provide demographic and industrial forecasts at the county level. These forecasts are often broken down into many industrial categories, more than enough for the two-digit precision of STCCs (or SCTGs) and SICs that are typical for planning models. Forecasts are sometimes available from other state agencies, banks, utility companies and universities. Forecasts more aggregated than the county are of less value.

North American Transportation Atlas Databases (NORTAD). Some of the more aggressive state models have national scope, but are focused on the state. Thus, national networks are required. The NORTAD from the Bureau of Transportation Statistics contains many modal networks, including highway, rail and water.

Other Specialized Databases. There are many specialized data sources documented in NCHRP Report #388. These include information on:

- Exports/imports;
- Specific modes;
- Railroad, truck, water and air;
- Commodities; and
- Fruits and vegetables, coal, grain, petroleum and natural gas

Specialized databases have unique ways of listing or aggregating data. Consequently, a considerable amount of analysis may be required to put the data into a usable form. For example, rail waybill information may be assigned to a network to give traffic volumes on rail lines (ALK Associates performs this type of analysis). Some of these data sources may help to plug holes in the CFS.

Local Surveys of Note

Classification and Other Counts. Freight forecasting requires counts of vehicular flows on enough facilities to validate the forecast. Publicly operated terminals or links (e.g., airports, water ports, toll roads, toll bridges, locks and US Customs offices) should be able to readily provide levels of traffic for their facility. Privately operated terminals may or may not be willing to supply traffic information. The participation of carriers and shippers in counts of vehicular movement is also uncertain. Classification counts on highways are needed to separate truck traffic from passenger car traffic. The classification must be specific to a location and up-to-date. Classification factors developed elsewhere should not be applied to ADT data.

Single Station OD Surveys. More extensive data on shipments may be obtained by surveying trucks at weigh stations or other convenient points. Several well-chosen locations can give a good picture of trucking in a state. Data on gross weight, payload, origin, destination, commodity, vehicle type, time and other aspects of use can be obtained in this manner. Michigan’s truck forecast was largely based on data of this type. It should be noted that sampling at weigh stations is biased toward long haul shipments and appropriate corrections are required.

Defining the Scope of the Freight Model

Establish Goals for Model

Before embarking upon a modeling effort, it is important to clearly identify the desired outputs.

- What policy decisions are going to be made, and should the model be sensitive to these decisions?

- What level of accuracy is needed, and what is the desired level of precision for TAZs, commodities and modes?

- Can development of the model be accomplished in useful phases, when lessons can be learned and applied in future developments?
- How can expert opinion be best integrated into the modeling effort?

Spatial Units

One of the most important decisions when building a model is the fundamental level of spatial aggregation. Should zones be constructed from townships, counties, states, BEA regions, NTARs, or some combination? Most statewide freight models have adopted TAZs based on counties within the state, plus an additional zone for each of the remaining (contiguous 48) states and external stations at US border crossings.

Disaggregating to smaller than county level presents methodological problems, as economic data and forecasts are often not available for smaller areas. Thus, a series of assumptions are required to further disaggregate the model.

Wisconsin included some counties in neighboring states. This technique is especially helpful when there are large industrial centers just outside the state. Wisconsin traffic is heavily influenced by the Chicago metropolitan area and the Twin Cities.

The adoption of county-sized TAZs means that vehicular volumes will only be reasonable for intercity facilities. Also, capacities may be greatly exceeded for links within major metropolitan areas.

Michigan, which only performs forecasts of truck travel, adopted a fine grained zone system (approximately townships in the Lower Peninsula) to be consistent with their passenger forecasts.

Selecting Modes

Mode split models can become excessively complicated when there are many modes and even more complicated when there are intermodal combinations. However, mode split models need not be applied to every commodity and to every mode serving each commodity. Since the CFS provides mode split tables by commodity group, there is some advantage in retaining a large number of modes throughout the analysis. After traffic assignment, vehicular volumes may be aggregated into the four major modes of truck, rail, water and air.

In the CFS not every commodity uses every mode. Here is a list of CFS modes.

- Parcel, US Postal Service, or courier
- Private truck
- For-hire truck
- Air
- Rail
- Inland water
- Great Lakes
- Deep sea water
- Pipeline
- Private truck and for-hire truck
- Truck and air
- Truck and rail
- Truck and water
- Truck and pipeline

- Rail and water
- Inland water and Great Lakes
- Inland water and deep sea
- Other and unknown modes

Different states have adopted different modal categories. For example, Indiana defined its modes consistent with the CFS. Michigan, Kansas and Kentucky used only trucks. Wisconsin adopted four modal categories: truck; rail; air cargo; and water

Network Development

The network (for all states except Alaska and Hawaii) should cover the 48 contiguous states but focus on the state of interest. Canada and Mexico may also be included. Within the state there would be smaller zones (see previous discussion), and the level of detail for the network will be greater. The networks beyond state borders should consist of only those links with substantial interstate traffic (e.g., interstate highways). Even so, networks can be quite large. For example, the small national railroad network from the FRA contains over 16,000 links, although a considerable amount of cleaning is possible.

Experience with these large networks indicates the possibility of numerous coding errors. The networks need to be checked for continuity, for duplicate links, for looped links (links looping back to the same node) and for multiple nodes at the same location. Not all elements of the national networks can be checked, so efforts should be concentrated on parts of the network nearest the state.

The state networks are likely to be derived from a different source than national networks, so problems can be encountered when splicing them together. For example, a strategy must be developed for handling loose ends of roads that pass through state borders, but do not appear on the national network.

Commodities

For many reasons it is best to derive commodity groups from standard categories. Many existing models have used two-digit STCCs (or SCTGs), which seems to provide enough detail without overburdening the computations. Most data sources report commodities in ways that can be consistent with two-digit STCCs, and two-digit SICs are roughly comparable.

Special commodity groups need to be established for waste and deadheading to account for all types of freight vehicle movement.

Different data sources report the amount of goods by different measures. To reconcile the various scales, conversion factors must be developed. The CFS provides data in both tons and dollars, so it can be used to develop those conversions factors for listed commodities.

A truck-only model may bypass the notion of commodities entirely. However, this method is best suited to urban areas.

Developing a Flow Matrix

There are a number of means available for developing a flow matrix.

1. Adjustment factors can be applied to an existing matrix or the matrix can be expanded by splitting large zones into smaller ones.

2. Alternatively, a gravity model can be constructed and calibrated on state-to-state data, then applied at the county-to-county level, as was done for Indiana.

Further adjustments to flow matrices may also be needed to account for information not already included. For instance, the CFS does not include information about commodities originating outside of the US. Furthermore, the CFS does not contain all commodities.

Import information can be separately obtained (and forecasted). Michigan used the model INFORUM (from the University of Maryland) to forecast imports. Import data were obtained from the Transborder Surface Transportation Project of USDOT and from data collected under Section 6015 of ISTEA.

Trip Generation for Gravity Model

When the gravity model is used for building flow matrices, it is necessary to obtain information on the amount of production and consumption for each TAZ and for each commodity group. Production rates can be established in terms of tons per employee or tons per person, depending upon the category. For some commodities, these rates can be formed by simply dividing the tons of goods produced in a group by the number of people employed by industries involved in this group. When there is less than a perfect match between commodity groups and industrial categories, it is necessary to establish production rates by statistical means, such as linear regression.

Relating commodity production to employees or population is important when forecasting future flows, as forecasts for these particular input variables are readily available.

For example, Indiana found trip generation rates by linear regression of CFS data. Michigan found the following relationships from state data in 1983 CTS (Commodity Transportation Survey).

Commodity Group	Annual Tons per Employee
1 Animals and vegetables	222.5
2 Mining	2897.7
3 Chemicals	435.3
4 Rubber and Plastics	31.0
5 Wood, pulp, paper	273.4
6 Textiles	16.3
7 Stone, glass, clay, concrete	1242.6
8 Metal products	68.6
9 Machinery and electronics	11.8
10 Transport equipment	15.3
12 Other	5.1

Indiana found the following statistical relationships between production in commodity groups and industrial sectors or population:

STCC1	Farm Products	SIC7
STCC11	Coal	SIC11
STCC14	Nonmetallic Minerals	SIC2 + SIC3

STCC20	Food and Kindred Products	SIC20
STCC22	Basic Textiles	SIC22
STCC23	Apparel	SIC23
STCC24	Lumber and Wood Products	SIC24
STCC25	Furniture and Fixtures	SIC25
STCC26	Pulp and Paper Products	SIC26 + 0.54*SIC24
STCC28	Chemicals and Allied Products	SIC28 + 7.8*SIC29
STCC29	Petroleum and Coal Products	SIC29
STCC32	Stone, Clay and Glass Products	Population
STCC33	Primary Metal Products	SIC33
STCC34	Fabricated Metal Products	SIC33 + 2.6*SIC34
STCC35	Machinery, except Electrical	SIC35
STCC36	Electrical Machinery	SIC33 + SIC34 + 0.75*SIC36
STCC37	Transportation Equipment	SIC37
STCC40	Waste and Scrap Material	Population
STCC50	Other Manufactured Products	Population

Forecasts of consumption are also required but are more difficult to obtain. A preferred method is to use the information in an input-output (IO) table.

Michigan's IO table was organized by commodity, presumably by associating industries with commodity groups. There were 11 commodity groups and two nonproducing sectors, nonmanufacturing and households. The IO table originated with the Bureau of Economic Analysis. Part of Michigan's IO Table is shown below.

Commodity Group	3	4	5	6	Non-Manuf	HH's
3 Chemicals	48500	18261	11024	2351	76398	318561
4 Rubber&Plastics	6919	23183	8740	12226	23057	11824
5 Wood Products	4056	2821	88721	1064	66861	75532
6 Textiles	86	1870	3655	47109	6421	89649

IO tables usually are organized by industrial sectors, not commodities. For the purpose of understanding commodity consumption, the IO table should be modified so that the producing sectors (rows) are commodity groups. Consumption (columns) can be left as industrial sectors, consistent with economic forecasts.

The individual cells in the IO table are value-added, not total sales. The size of shipments is better measured by total sales. Thus, an important assumption must be made: weight of a commodity is proportional to the value-added, regardless of the consuming sector.

IO analysis can also provide an answer to the question: What will be the change in all sectors due to growth in a single sector? Extensive mathematical manipulation of the IO table must be accomplished to answer this question.

Gravity Model for Freight

The gravity model for commodities is similar to a gravity model for person travel, except that flows are distributed from a production zone to a consumption zone and that friction factors are a function of distance.

$$V_{ij} = P_i A_j X_i Y_j f(d_{ij})$$

V_{ij} is the commodity flow from i to j;

P_i is the production in zone i;

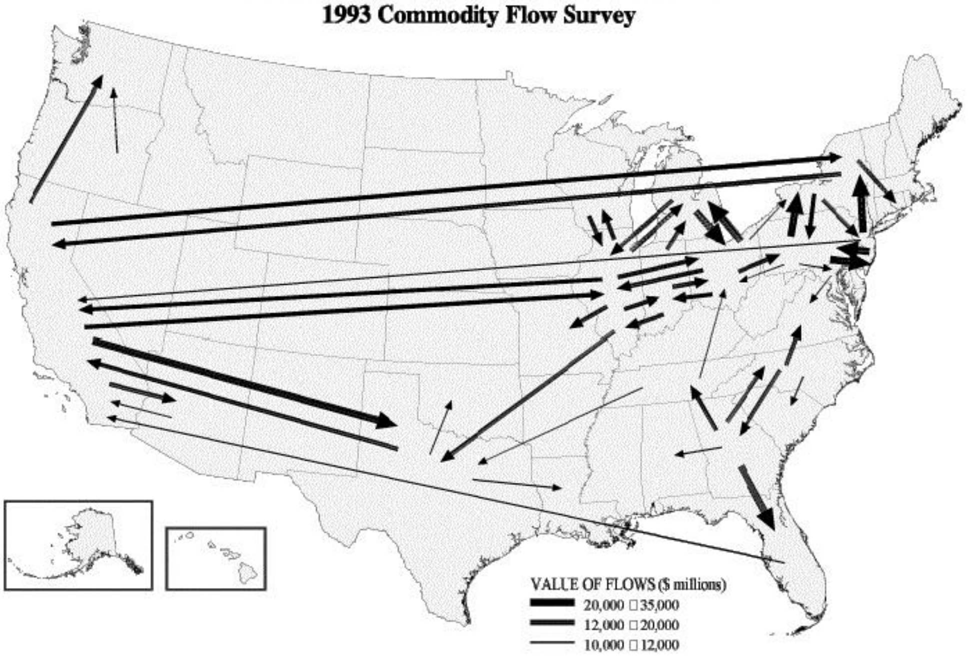
A_j is the consumption in zone j;

X_i, Y_j are balancing factors; and

d_{ij} is the distance from i to j.

The gravity model distributes commodities in tons. The map below from the CFS showing the 50 largest flows in the US is a visual confirmation of the principles of a gravity model. Notice that the largest flows occur between moderate sized states that are adjacent (e.g., Michigan-Ohio, Georgia-Florida) and between large states, regardless of the distance (e.g., California-Texas, California-New York).

TOP 50 INTERSTATE FLOWS BY VALUE
1993 Commodity Flow Survey



SOURCE: U.S. Department of Transportation, Bureau of Transportation Statistics, Commodity Flow Survey Data, 1997.

Friction Factors. As with person travel, friction factors can be set in a number of ways. Indiana used:

$$f(d_{ij}) = \exp[\beta d_{ij}]$$

although the choice was somewhat arbitrary. d_{ij} was taken to be distance in miles. The single parameter, β, varied considerably by commodity, its magnitude being roughly inversely related to length of ton haul.

It is suggested that β be set by trial and error until average trip length from the model matches average trip length from data. It is necessary to eliminate bias due to shipment sizes by calculating average ton length rather than using average shipment length already provided in the CFS. Average ton length may be found by dividing ton-miles by tons.

Application: During application of the gravity model, P_i and A_j are production and consumption measured in tons. The balancing factors (X_i and Y_j) are computed by the software and do not carry any useful information. The balancing factors just assure that flow is conserved at both ends of the trip. Kansas used the gravity model for external-to-internal flows, only. The Kansas model had external stations at state borders and forecasted agricultural commodities, only.

Mode Split Methods

Mode Split Tables. Extensive aggregated data on mode split are available from the CFS and other sources. Mode split tables can be readily developed. For example, Indiana developed mode splits by commodity and distance. Distance is a significant factor in mode split, as the average length of rail hauls greatly exceeds the average length of truck hauls for most commodities.

Diversion Models/Elasticities. Various organizations have developed diversion models for estimating the shift of shipments between truck and rail. These include the Intermodal Competition Model (ICM) from the AAR, the Truck-Rail, Rail-Truck Diversion Model from the FRA and the Strategic Choice Model from Mercer Management Consulting. These models can be used to generate elasticities that may be applied to individual OD pairs and commodities in a statewide forecast. Example elasticities are shown later.

Expert Opinion. Expert opinion is often necessary to evaluate the effects of new technologies. Experts can be asked to give mode splits directly or to provide reasonable assumptions to permit forecasts by mode split models. For example, Wisconsin used an expert panel to estimate parameters of forecasts of future truck-rail intermodal traffic in the state.

Mode Split Models. Experience with mode split models in statewide forecasts has been limited. The major factors in mode split models are intended to respond to policy issues. These factors include:

- Commodity characteristics;
- Cost;
- Time, dependability and frequency of shipment;
- Quality; and
- Access.

Mode split models include aggregate demand formulations, logit, pivot point and simple elasticities. Pivot point and elasticities will be discussed later. A typical aggregate demand model for truck volume (VT) (due to Friedlaender and Spady) looks like:

$$VT = SR^{a}LR^{b}ST^{c}LT^{d}VAL^{e}TR^{f}TT^{g}$$

where SR is the average rail shipment size, ST is the average truck shipment size, LR is the average length of a rail haul, LT is the average length of a truck haul, VAL is the average value of the commodity, TR is the rail unit cost and TT is the truck unit cost. The lower case letters are all calibrated constants. A similar equation was developed for rail shipments.

Regardless of whether the model is aggregate or disaggregate, extensive calibration is required.

Model from NCHRP Report #260. The most complete treatment of mode split is found in NCHRP Report #260. Because of extensive changes in technology, commodities and markets since this report, its results are not directly applicable to forecasts done today. NCHRP Report #260 recommended an all-or-nothing mode split. That is, on comparison of costs all OD flow of a particular commodity would be assigned to the least cost mode. A very detailed cost model was provided. This report developed cost relationships for rail, truck and barge. Modal costs are also given extensive treatment in NCHRP Report #388.

Use of Mode Split Models. Obtaining cost data for interstate OD pairs may be quite difficult, especially considering the size of zones (states, NTARs). A solution may be to limit analytical mode split analysis to shipments entirely within the state. External flows would then be split by table.

Given the difficulty of calibrating models for each commodity, a comprehensive mode split model covering each mode and each commodity is not recommended. Special analysis may be performed for those commodities of greatest interest.

A mode split model should be selectively applied to those commodities expected to be sensitive to the policies being tested.

Pivot Point

One technique for mode split of commodities is pivot point. Pivot point is derived from a logit model, but requires somewhat less information to operate and is less sensitive to errors of calibration. Pivot point models are as valid as logit models, but only allow the variation of one term in the utility function. Since the mode split of commodities is largely determined by cost, this limitation is not serious. The existing mode shares are required inputs.

$$p_j = \frac{p_{bj} \exp(\alpha \Delta c_j)}{\sum_k p_{bk} \exp(\alpha \Delta c_k)}$$

In the above equation:

p_j is the forecasted share for mode j, as a fraction;
p_{bj} and p_{bk} are the existing shares for modes j or k;
α is a calibrated coefficient which varies by commodity; and
Δc_j and Δc_k are the changes in the full costs of transporting a ton of goods on mode j or k.

The single coefficient of the pivot point model, α, can be calibrated by knowing mode shares and average modal costs at two points in time. It can be calibrated to match known cross elasticities between modes (see later discussion). The coefficient could also be calibrated by analyzing surveys of behavioral intention of shippers.

Because of the difficulties in calibration, it is recommended that the number of modes be kept to a minimum: truck, rail, water and air. Tables can be used to further refine these categories, if desired.

Elasticities

An elasticity is the fractional change in output divided by the fractional change in input. Elasticities can be used to measure the effect on demand of any other important variable. For transportation services it is possible to use elasticities to quantify the effect on demand of headway, vehicular size, speed, the degree of competition, etc.

For some commodities, mode split may be best accomplished with cross elasticities. For example, a cross elasticity between truck and rail might be the percent change in rail demand given a 1% change in truck costs.

Detailed Elasticities. The following table was drawn from NCHRP Report #388. It contains cross elasticities between truck and rail in Canada, as predicted by the Intermodal Competition Model (ICM) developed by the Association of American Railroads. Each elasticity is the estimated percent increase in rail ton-miles for each one percent increase in truck costs. The average cross elasticity is about 0.5. These elasticities include all factors, including access.

Commodity	Low Elasticity	High Elasticity
Bulk Farm Products	0.02	0.03
Finished Farm Products	3.5	3.7
Bulk Food Products	0.62	0.83
Finished Food Products	2.0	2.2
Lumber and Wood	0.57	0.73
Furniture	4.0	4.7
Pulp and Paper	0.71	0.93
Bulk Chemicals	0.49	0.67
Finished Chemicals	3.2	3.5
Primary Metals	1.2	1.5
Fabricated Metals	5.2	7.3
Machinery	3.7	4.8
Electrical Machinery	4.1	4.8
Motor Vehicles	0.21	0.28
Motor Vehicle Parts	1.1	1.4
Waste and Scrap	0.17	0.22
Bulk All Else	0.14	0.19
Finished All Else	3.9	4.5

Commodity Density and Load Weights

Converting commodity flows into vehicular flows usually requires two sets of conversion factors. The first factor is used to convert annual tonnage to daily tonnage and the second factor is used to convert tonnage to vehicular loads (trucks, containers, cars, etc.)

Truck Days. In order to convert annual flow to weekday flow, it is necessary to estimate the number of equivalent weekdays in a year. Indiana calculated 5.8 (weekday-equivalent) flow days per week or 300 per year.

Load Weights. Michigan found that most trucks on intercity trips carried about 40-50 thousand pounds. Major exceptions were:

	Commodity Group	Tons per Truck
0	Empty	5.4
1	Animals and vegetables	20.2
2	Mining	36.2
3	Chemicals	24.0
4	Rubber and Plastics	23.9
5	Wood, pulp, paper	29.4
6	Textiles	7.2
7	Stone, glass, clay, concrete	26.1
8	Metal products	27.6
9	Machinery and electronics	15.0
10	Transport equipment	15.6
12	Other	12.7

empty; textiles, clothes, furniture and electrical machinery. Michigan allows larger trucks than many states do, so some average payloads were considerably higher, especially bulk commodities. Michigan eventually used the load weights on the previous page in their forecast.

Wisconsin developed load weights for commodities in two-digit STCC. These are shown in the table below. A comparison of Wisconsin to Michigan would suggest that load weights are rather constant for some commodities but vary considerably by state for other commodities.

STCC		Tons/ Truck	STCC		Tons/ Truck
1	Farm Products	24	32	Clay, Concrete, Glass, Stone	23
8	Forest Products	13	33	Primary Metal Products	19
9	Fish or Marine Products	6	34	Fabricated Metal Products	24
10	Metallic Ores	24	35	Machinery, Not Electrical	9
11	Coal	24	36	Electrical Machinery	8
13	Crude Petro, NG, Gasoline	14	37	Transportation Equipment	12
14	Nonmetallic Minerals	19	38	Instruments, Photo or Optical	5
19	Ordinance or Accessories	24	39	Misc. Manufacturing Products	2
20	Food or Kindred Products	18	40	Waste or Scrap Materials	16
21	Tobacco Produces	5	41	Misc. Freight Shipments	23
22	Textile Mill Products	5	42	Shipping Devices Returned	4
23	Apparel, Finished Textile	3	43	Mail and Express Traffic	3
25	Lumber or Wood Products	15	44	Freight Forwarder Traffic	4
26	Furniture of Fixtures	3	45	Shipper Association Traffic	3
27	Printed Matter	9	46	Misc. Mixed Shipments	7
28	Chemicals	22	47	Small Package Freight	4
29	Petroleum or Coal Products	19	48	Hazardous Waste	16
30	Rubber or Misc. Plastic	4	49	Hazardous Materials	18
31	Leather or Leather Products	3	99	Unknown	12

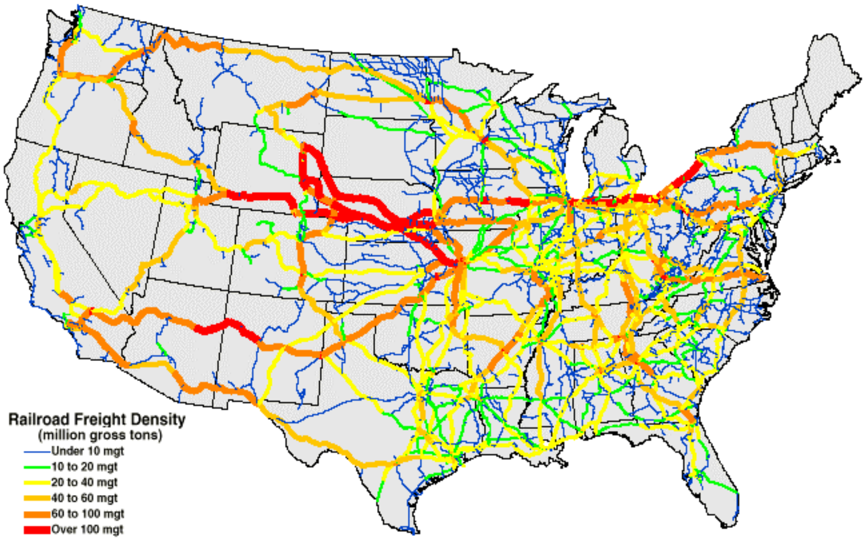
Traffic Assignment

All-or-Nothing. All-or-nothing assignment (all trips between an origin and a destination are placed on the single shortest path) has been the preferred method of assignment by those doing statewide freight forecasts. Unfortunately, all-or-nothing assignment is very sensitive to speeds, tending to load most highway traffic on interstate highways. Furthermore, it is difficult to simulate rail routing decisions with a shortest path paradigm. Extensive adjustments to impedances (times, costs) on links is required to get acceptable assignments.

Other Methods. Other techniques that have been considered are capacity restrained equilibrium and stochastic multipath. Capacity restraint techniques are particularly difficult because freight vehicles, by themselves, rarely exceed the capacity of links. In addition, highway capacity becomes useless as a modeling concept in urban areas, where only a small percentage of roads are included in the network. Railroads experience considerable economies of scale by routing traffic on mainlines, thus violating a major premise of capacity restrained assignment.

Stochastic multipath assignment shows promise, but there is comparatively little experience with the technique for statewide freight forecasting. A stochastic multipath assignment sends some trips along the shortest path and smaller proportions to other reasonable paths.

Rail Issues. The figure on the right illustrates the importance of mainlines of Class 1 railroads for major commodity movement. Because of the method railroads charge shippers for freight transport, railroads do not have a strong incentive to either minimize time or distance. (Railroads are compensated according to fraction of distance carried.) Still, many rail shipments involve multiple carriers. Thus, a shortest path is only a rough approximation of the true path. The network must clearly designate points where shipments change carriers. As readily seen in the figure, many counties do not have rail access. The pure rail mode would not be a possibility for shipments produced or consumed in these counties.



Source: U.S. Department of Transportation, Federal Railroad Administration, Carload Waybill Statistics, 1995

Highway Issues. Evidence suggests that for statewide models there is little need to consider multistop tours. Michigan found that 92.5% of intercity truck trips were direct (no intermediate destinations). 99% had 0 or 1 intermediate stops.

Assignment Fixes

In the absence of better algorithms, there are a number of fixes that can be applied to achieve better assignments.

Highway Impedance. Kansas performed three different traffic assignments, each with a different impedance measure, and then took a weighted average of the volumes from the assignments. The three impedance measures were based on time, distance and cost. This method created a smoother loading than might have been obtained otherwise. The averaging weights were developed subjectively.

Indiana used travel time as its primary measure of impedance, but modified the speed used in the travel time calculation to provide less of a disadvantage for non-interstate routes. The following formula was used:

$$\text{speed} = (\text{true speed}) + 2\,(65 - \text{true speed})^{0.5}$$

Railroad Impedance. Indiana accounted for railroads' tendency to assign traffic to mainlines by adopting the following measure of impedance:

$$I = L\,(1/(D + 1))$$

where L is the length of the link and D is the traffic density in millions of gross ton-miles per year.

Assignment of Intermodal Flows. Intermodal shipments in the CFS are identified by pairs (e.g., truck-rail or truck-air), without identifying the order of the modes. Thus, a truck-rail intermodal shipment may logically be by truck-rail, truck-rail-truck, or rail-truck (ignoring drayage). Strictly speaking, each of these three modal combinations should be given separate treatment in the assignment process. The problem of too many intermodal combinations can be simplified by assuming that all intermodal shipments are interstate or international. Thus, rail terminals in the state can be either the production end or consumption end of intermodal flow. Without further information, it is only possible to assume 50% of each. Some states, like Indiana, have so little intermodal traffic that it makes sense to simply lump these flows into one or both of the component modes.

Other Freight Forecasting Issues

Combining Passenger and Freight Forecasts

The *Highway Capacity Manual* (1997 revision) gives passenger car equivalents (PCEs) for trucks as a function of grade. The lowest heavy truck PCE is 1.5 (level) and the largest is 15 (6% grades in excess of 1 mile when there are only 2% trucks in the traffic stream). The effect of a single truck on delay can be considerably greater than the effect of a single passenger car. If good estimates of delay are needed, trucks should be appropriately weighted to account for their larger effect:

Delay = f(passenger cars + PCE*trucks)

There are two ways to account for trucks in the traffic stream: (1) apply an average PCE factor to the whole truck trip table; or (2) apply the PCE factor to trucks on each link individually.

Whole Trip Table. If equilibrium assignment is the desired technique for traffic assignment, then it is easiest to multiply the whole truck trip table by a single PCE factor that represents average conditions. The algorithm would assign PCEs rather than vehicles to links, so it would be difficult to determine how many trucks use each link.

Link-by-Link. Each link (indeed, each link direction) theoretically has a different PCE factor for heavy trucks. Truck PCEs may be assigned to links ahead of the assignment of passenger vehicles. In so doing, it is possible to account for the larger effect of trucks on steeper uphill segments. An equilibrium assignment for just the passenger cars could then be pursued to obtain final delay estimates.

Forecasting Inputs to a Freight Forecast

Industrial and Population Forecasts. Production and consumption of commodities depends on forecasts of employment (or sales) for industries and forecasts of population. It is recommended that these forecasts be obtained from specialists.

IO Analysis. Input-output analysis is a technique for forecasting the effect of industrial growth in a single sector (or few sectors) on the overall economy. IO analysis starts with an IO table, as illustrated previously. The IO table tells who sells to whom and how much. The analysis finds the total value added for all industrial sectors given an increase in consumption for a single sector. The only difficult part of IO analysis is getting the IO table. The Bureau of Economic

Analysis publishes an IO table for the whole US economy. IO tables are also included with proprietary software packages. Once an IO table has been obtained, the mathematics is simple enough to be performed on a spreadsheet. Regional IO analysis, an extension of traditional IO analysis, allows identification of the effects of industrial growth on a state or urban area.

Value per Ton. Value per ton may change in the future due to (1) shifts in the types of commodities produced within a commodity group or (2) or a decrease in the actual value of a given commodity. Forecasting these effects is difficult and should be reserved for those commodity groups of special interest.

Productivity. If the forecast of a commodity is based on growth in employment, then an adjustment is required for anticipated increases in worker productivity. Forecasts of productivity increases for various economic sectors are available from proprietary data sources.

Load Weights and Shipment Sizes. There has been a recent decline in both shipment densities and in shipment sizes. These variables affect the load weights and the choice of premium modes.

Chapter 5. Specialized Methods for Passenger Forecasting

Introduction

This chapter is concerned with a number of topics that enhance or replace parts of the traditional four-step model for passenger forecasting. These topics relate to the following.

- *Surveys.* Single station OD surveys, truck travel surveys, freight truck OD surveys, external travel surveys and survey techniques.
- *Stated Preference.* A method to help calibrate mode split models when they must include modes that do not yet exist in the corridor or state.
- *Steps in between Steps.* Time of day issues, external trips, vehicle occupancy and interfacing with urban models.
- *Total Corridor Demand.* Estimating the amount of travel in a corridor, regardless of mode, without running a complete statewide simulation.
- *Trip Table Refinements.* Using traffic counts to re-estimate a trip table that might have been created through surveys or a gravity model.
- *Pivot Method.* A method for project-level forecasting that combines the best features of a simulation and time-series analysis.
- *Calibration.* Philosophy of calibration, techniques for calibrating model steps, including linear regression, analysis of variation (ANOVA), nonlinear regression and maximum likelihood estimation.
- *Validation.* Understanding validation data sources, especially the Highway Performance Monitoring System (HPMS), in developing a coherent validation database determining the quality of a validation.

Data Collection

Validation Data Sets: HPMS Element of the Traffic Monitoring Program

HPMS constitutes a valuable source of validation data at the statewide level. HPMS is a consolidated data set containing information on every major public road within the state, such as the category the road belongs to (interstate, major, minor, etc.), the area where the road is located and volume of traffic it carries. HPMS can be used to prepare traffic volume samples, either in terms of AVMT (average vehicle miles of travel) or AADT (average annual daily traffic) for use by the state during the validation phase. The methods adopted for the calculation of AADT and AVMT estimates are briefly described below.

- *AVMT Estimation*: This process is based on counting periods not usually exceeding a day. AVMT estimations are sometimes based on longer periods of 48 hours; however, longer periods become laborious and time-consuming. The actual calculation requires multiplying each section's AADT by the section length and an expansion factor. The resulting AADTs for all expanded sections are then summed.
- *AADT Estimation:* Like the AVMT, the AADT is, for the most part, based on daily counts. Correction factors such as seasonal adjustment factors, day of week factors and axle correction factors are applied in the calculation of the AADT estimate.

Additional detail in the validation data may be attained by applying vehicle classification information in HPMS volume samples. The FHWA has adopted 13 vehicle classifications based on the physical characteristics of the vehicles: motorcycles; passenger cars; other 2-axle, 4-tire single unit trucks; buses; 2-axle, 6-tire, single unit trucks; 3-axle single unit trucks; 4- or more axle single unit trucks; 4- or less axle single trailer trucks; 5-axle single trailer trucks; 6- or more axle single trailer trucks; 5- or less axle multitrailer trucks; 6-axle multitrailer trucks; and 7- or more axle multitrailer trucks. This vehicle classification scheme exceeds the requirements of travel forecasting.

Traffic Monitoring Guide Recommendations for HPMS Data Collection: The Traffic Monitoring Guide makes several recommendations about how count data should be collected and processed for HPMS. Not all states follow these recommendations, but they give a good indication of the quality of data within HPMS. There are basically three types of counts adopted by states to maintain traffic volumes. They are *continuous counts*, conducted throughout the year to record daily traffic volumes, *seasonal counts* to keep track of the seasonal factors affecting these volumes and *coverage counts* to record more specific information on a particular road or highway segment. Recommendations include the following:

- For coverage counts a 48-hour monitoring period should be repeated once every three years. Recording truck weight at the same time is also recommended.
- Both directions of travel should be monitored. Where this is not done the usefulness of the data for validation purposes is greatly limited.
- Samples should be scheduled throughout the year to minimize seasonal biases.
- Samples should also be well distributed spatially, so that geographic biases can be minimized. Randomness of samples should be maintained with regard to both season and location.
- Growth factors may be used to interpolate counts taken every three years to yearly estimates
- Day-of-week factors should be applied to the raw count data to eliminate daily variation. Moreover, the application of axle correction factors helps to main statistical consistency.

Shortcomings of HPMS Data: The data needs of each state may be different from others. Thus, it is important to note that although HPMS should be a very consistent data set across states, each state varies its procedures to account for its own unique geography, such as population, climate and size of cities.[1]

Example, Traffic Counting in Wisconsin: Wisconsin has a well established counting system set up on all the major highways in the state. Wisconsin adheres closely to the recommendations in the Traffic Monitoring Guide. It has a total of 142 continuous counting stations located mostly on high volume roads. Coverage counts are made on a three-year cycle at 30,000 separate locations. Seasonal, day-of-week and axle correction factors are accounted for in the estimation of AADTs. Such a comprehensive database would allow validation of both statewide and corridor models.[2]

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[1] Traffic Monitoring Guide, FHWA, Publication No. FHWA-PL-92-017, 1992

[2] Adapted from Wisconsin Highway Traffic Volume Data, March 1996 and Wisconsin Automatic Traffic Recorder Data, March 1997

Single Station Origin-Destination Surveys

The Michigan Department of Transportation (MDOT) is known for conducting several types of origin-destination surveys over the last 30 years, covering all major state trunklines and interstate highways. The data set collected from single station origin-destination surveys (SSODs) is probably one of their most extensive sources of information on passenger traffic in the state of Michigan and represents more than 800,000 “expanded” survey trips. About 300 surveys have already been conducted.

Information was mainly collected through roadside interviews conducted by MDOT personnel throughout the state. These data included time of day, month and year that the trip was made, the type of vehicle (or mode of travel), number of persons per vehicle and the origin, destination and purpose of the trip. Most of the interviews were conducted during a 12-hour time frame (usually starting at 7 a.m. and ending at 8 p.m.), but the sample was eventually expanded to represent a whole day. One or both directions of travel were recorded. This information was further supplemented using a vehicle classification counts over a 24- hour period. Since 1985, 129 sites in 49 of Michigan’s 83 counties have been surveyed and recorded[1].

Since most of the information for these surveys is obtained through direct personal interviews, the data gives a very realistic picture of the travel patterns throughout the state. The main advantage of conducting SSOD surveys is that they are capable of capturing atypical trips, such as vacation trips during the summertime by state residents and non-residents. In this regard, conventional household surveys have shown poor results. SSOD surveys also pick up long trips that are too infrequent to be seen in reasonable numbers in a household survey. Another advantage is that the SSOD survey information can be used in conjunction with select link analysis for validation purposes. This procedure will be dealt with in more detail later in this chapter.

Due to several reasons, the SSOD data that was collected could not be directly applied towards model development in Michigan. Some of these reasons are listed below:

- The SSOD surveys are conducted only during the summer months and on weekdays. As a result, they may not always relate to the average annual flow.
- They do not distinguish between residents and non-residents of the state.
- There are inconsistencies in the trip purposes, and most often conflicting with the trip purpose breakdown used by the model. A typical example was the Mackinaw Bridge Survey conducted for MDOT, where 61% of the trips were for vacations. In contrast, the Michigan model was calibrated with NPTS data, which showed less than 1% of the total trips as vacation trips. This is another troublesome outcome of conducting these types of surveys during summer months alone.
- The model shows an average trip length shorter than that indicated by the SSOD data. This is due to the influence of the trip purpose breakdown on the average trip length and the fact that longer trips have a greater chance of being counted.

Based on this experience, Michigan recommended several possible modifications to SSOD survey procedures.

- Future SSOD surveys should distinguish between residents and non-residents of the state.

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[1] KJS Associates, Inc., Statewide Travel Demand Update and Calibration: Phase II, Michigan Department of Transportation, April 1996

- Additional SSOD surveys should be conducted for control purposes in other travel months to help develop seasonal adjustment factors.
- All the SSOD surveys conducted in the future should incorporate commercial traffic flow along with private vehicles.
- Inconsistencies with the model, such as the trip purpose definition, should be eliminated.
- SSOD data sets should be built in a manner that enables their effective use for the model development phase.[1]

Truck Travel Surveys

Truck travel surveys are done to record more specific information on commercial vehicles, unlike the SSOD surveys that cater to all vehicle types. Ports of entry and truck weighing stations on all major highways, carrying large daily volumes of commercial vehicles, in the state are generally designated as survey stations. Survey time can extend from anywhere between 12 and 24 hours. An advantage of this survey method, unlike an SSOD study, is that it less biased by the geographical location of a single station. An unbiased sample can be collected at a controlled sampling rate.

Michigan. A good example is the 1994 Michigan Truck Survey conducted by the Michigan Department of Transportation. This survey was fairly extensive and included more than 5,000 surveys. The surveys were conducted at 10 different locations within the state. MDOT personnel used survey forms to record the information. Once the data was checked, it was stored in database format. Several coding errors were also eliminated in the process. Details gathered on vehicle classification were consolidated into the 13 categories recommended by the FHWA Traffic Monitoring Guide. MDOT applied expansion factors to all the survey locations and to the 13 vehicle classifications. The main function of the expansion factors was to weight each sample so that the total sum of these factors would give the total volume of trucks surveyed. For example, if the various truck classifications were to be ignored, then the expansion factor would be given by dividing the total volume of trucks by the total number of observations made at the survey station.[2]

The commodity groups that were specified for the Michigan truck survey were based on a two-digit STCC. The data collected included the actual number of observations for each commodity group. This information was then expanded to yield estimates of the number of trips made and the vehicle miles of travel per group. In order to calculate these expanded numbers, the expansion factors were multiplied by the actual trip distance.

In addition to classifying the collected information by commodity groups, to assure a statistically valid database trips were further classified into three specific categories depending on whether they crossed the border or not. The three categories used were:

- Intrastate (no border crossings);
- Interstate; and
- International (to account for the larger number of trips made across the US-Canadian border).

During the actual survey, up to three trip chains between the *ultimate* origin and destination were noted. However, it was found that 92.5% of the trips did not have trip chaining at all.

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[1] KJS Associates, Inc.

[2] Ibid.

Hence, the idea of separately categorizing those trips with an intermediate stop was discarded. However, for later analysis, two origin-destination pairs were considered:

- One pair with an ultimate origin and destination;
- Another pair taking into consideration only that portion of the trip through the survey station.

The final application of the model itself is the chief determinant in deciding which of these O-D pairs to use.[1]

Washington. In 1993, Washington State Department of Transportation (WSDOT) conducted a truck survey. This survey was unique as it collected statewide freight data throughout the state through personal interviews of truck drivers. Again, as with the Michigan Truck Survey, the main focus was on all the major commercial corridors within the state. Truck and commodity flows were recorded over 24 hour periods keeping in consideration important seasonal factors.

A total of 25 truck weigh stations and ports of entry were designated as survey locations. The survey procedure was similar to that followed by the Michigan Department of Transportation. Here, the goal was to obtain at least 300 surveys during a full day at one location. The I-5 corridor in Washington is particularly known for its heavy commercial traffic. In order to keep the survey process within reasonable limits, the sample was restricted to one out of every 10 trucks on this highway. For the other highways, smaller samples were taken based on the actual daily truck flow.

Other Survey Methods

Stateline Cordon Survey. Stateline Cordon Surveys are intended to gather information on those trips originating or ending outside the state. Hence, these surveys should monitor traffic on all major interstate facilities as well as intrastate highways with a fairly high traffic volume that contribute to interstate travel.

Most stateline cordon surveys are required to monitor both directions of travel. The most important data items to be collected include:

- Time of interview, such as time of day, month and year (to keep track of any daily or seasonal variations in the travel patterns);
- Type and registration details of vehicle (for trucks, the classification could be based on the guidelines given by the FHWA Traffic Monitoring Guide);
- Occupancy per vehicle;
- Details of origin and destination of the trip, both within the state and outside; and
- Trip purpose (whether HBW, HBO, NHB, Recreation, Vacation, Business, etc).[2]

License Plate Surveys. License plate surveys are particularly useful on heavy traffic corridors as it does not slow down the traffic. To efficiently conduct this survey, it is essential to have access to computerized automobile registration files. However, a problem could, arise if these files are not updated on a regular basis. Also, it is difficult to trace vehicles from other states. Complete automation is a definite advantage of this system, making it very safe, easy to execute and comparatively accurate.

Household and On-Board Surveys. Some of the most practical survey techniques used at the statewide level are mail or telephone surveys and on-board surveys. Mail or telephone surveys

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[1] KJS Associates, Inc.

[2] Adapted from FHWA, *Statewide Travel Demand Forecasting*, US Department of Transportation, 1973

are more economical than conducting home interviews. The sample size can also be expanded. Again, for efficiency, like the license plate surveys, auto registration files or telephone directories with names and current mailing addresses can be used. Care must also be taken to account for households without cars or telephones, although small in number. The usual response rate for these surveys is anywhere between 20 to 50%. Telephone surveys usually assure a better response rate, since direct contact is made and follow-up, when necessary, is easier. Telephone surveys are often used as the second stage in mail surveys.

A good example is the mail survey conducted for the Kentucky Department of Transportation for both household and truck travel data. The household survey focused on households owning an automobile in the state. The total sample consisted of nearly 15,000 households (an average of 60 households per county). A 45% response rate was achieved.

On-Board Surveys. These surveys usually focus on public modes of transportation and provide more comprehensive information than can be obtained from records of collected tickets. Care should be taken to keep the questionnaires brief and to the point, as travelers must complete the survey enroute. These surveys help to cover information that cannot be effectively collected through household surveys for infrequently used modes. Typical questions include the point of origin, point of destination, access mode, transfer points, trip purpose and traveler characteristics. The time of day, carrier and vehicle information are usually completed by the person administering the survey.[1]

Validation Quality

Validation involves comparing a base-year forecast to actual traffic counts. There are three primary questions that must be answered.

- Are the forecasts of total traffic volumes (total volumes, VMT or VHT) sufficiently close to those measured?
- Are the differences reasonable, link-by-link, between the forecast and actual volumes?
- Is the forecast spatially unbiased?

Good estimates of speeds are not a major consideration in statewide travel forecasts, although it is important that inputs relating to speed are reasonable.

For many years, urban models have been validated according to the 1/2 lane rule. That is, traffic estimates should be accurate to within + or – one-half the amount of traffic that could be carried by a single lane at its design capacity, usually LOS C. Roughly speaking, this rule would mean that urban streets (which are signal controlled) should be accurate to some number between 300 to 500 vph and freeways and multilane highways should be accurate to some number between 600 to 700 vph. For all practical purposes, links with volumes of less than 300 vph in the peak period should be ignored. The 1/2 lane rule, if followed, assures that the model will not cause a major blunder in sizing some future facility.

Perhaps a better means of judging validation quality is to insist that the model be about as good as the traffic counts to which it is being compared. If the RMS error in traffic counts is known to be e, then the maximum acceptable RMS error in a model validation should be about 1.4e. RMS error is calculated as follows.

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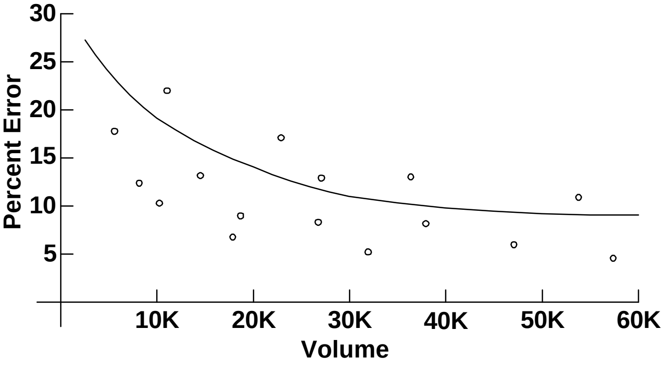
[1] Adapted from FHWA, op. cit.

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(V_{\text{counted}} - V_{\text{estimated}}\right)^2}$$

Acceptable Error Plots



The curve in the figure on the right shows a typical relationship between link volume (24 hours) and the RMS error between a base-year forecast and ground counts. The points on the chart are hypothetical, but illustrate the important statistical principle that about 68% of all errors should fall below the line and about 32% of the points should fall above the line. Road segments with less than 2000 vehicles per day in a single direction should be ignored, as they are highly unlikely to require more than one lane per direction under any standard design criteria. (Design criteria include peak hour in week, 30th highest hour, or 100th highest hour.)

Validation in Low Volume Areas. If validation is required in a portion of the state where there are many low-volume roads, it is acceptable to validate the total of these roads, as if they formed a single link.

Spatial Validation. Validation should be achieved across the state to assure that forecasts will not be spatially biased. There are no well established procedures for performing a spatial validation. Some considerations are:

- Good agreement with VMT within several big districts that cover the state;
- Good agreement with screenline counts across major travel corridors; and
- Good agreement with VMT in counties constituting major activity centers.

Stated Preference

Stated Preference is a survey technique that can overcome problems with using only revealed preference (actual behavior) in calibrating models. For example, Wisconsin DOT wanted to investigate the demand for a high speed rail alternative. Existing modes in the corridor consisted of conventional passenger rail, automobile and airline. WisDOT believed that the characteristics of high speed rail could be significantly different than conventional rail. Thus, it was necessary to investigate users' perceptions of the new mode and to approximate its coefficients within a logit model. As an end product they would need to ascertain a mode bias coefficient for high speed rail and to determine whether the coefficients on travel attributes (time, cost, etc.) needed to be modified. There are three general methods of obtaining stated preference information.

Method A, Ask about Choices. This method describes two alternative modes for a trip already experienced by the respondent. The respondent is asked whether the new mode would be chosen, if it is implemented. The respondent's current mode need not be included among the choice set. A logit model can be calibrated to the data, giving, among other things, the mode bias of the new mode relative to existing modes.

Method B, Ask about Tradeoffs. Tradeoff methods ask respondents to judge the value of one attribute against another. For example, a popular tradeoff method rates attributes in terms of their monetary (dollar) value. A typical question would be: "How much more fare (toll) would you be willing to pay to avoid 10 minutes of travel time on this trip?" This method can yield a value of time for the new mode.

Method C, Direct Disutility Estimation. Respondents can be shown characteristics of trips and asked to rate the disutility of the trip on an open-ended scale. Each respondent can be asked about many trips, so the sample size can be small. The ratings, along with the trip data, can be statistically analyzed to obtain most of the coefficients of a utility function. To obtain stable ratings, the respondents should initially be told the ratings of two arbitrary trips. One trip is described as having no length and no disutility (and thus a 0 rating). The other trip is a typical trip and is given an arbitrary rating (e.g., 100).

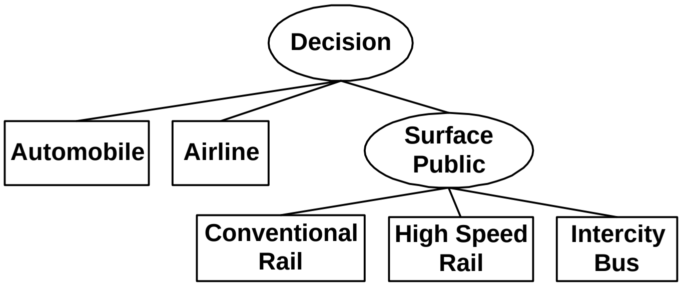
Wisconsin's High Speed Rail Study illustrates method A. Respondents were given four sets of pairwise choices under various automobile LOS conditions, purposes and end points:

- automobile v. conventional rail;
- automobile v. bus;
- automobile v. air; and
- automobile v. high speed rail.

These stated preferences were included into a nested logit model calibration with revealed preferences (actual choices). There were far more stated preference data points than revealed preference data points.

The survey form did not force a definite response to the stated preference questions. The respondent could indicate one of five possible answers to any comparison (definitely choose mode A, probably choose mode A, indifferent between A and B, probably choose mode B, definitely choose mode B). Data points were weighted, depending upon the strength of the response (0.9 for definitely, 0.7 for probably and 0.5 for indifferent).

The final nesting structure is shown on the right.



Service quality was measured primarily in terms of in-vehicle time, out-vehicle time, cost and frequency of service. At first the calibration did not result in good estimates of all parameters for service-related variables. Subsequent calibrations held constant the ratios of parameters for the service-related variables, based on earlier studies. Thus, the model estimated parameters for this combined service quality index, a Chicago Loop (downtown) dummy variable, an income variable for rail and bus modes, mode specific constants and the logsum constant for the surface-public nest.

The model was further adjusted by hand to replicate existing mode shares and to deal with aggregate data (e.g., average zonal income) instead of household data. The final set of coefficients is shown in the table on the next page.

The nest utility is calculated by the equation below. The nest bias constant (seen in a previous chapter but eliminated here) is redundant, given that each of the modes in the nest have their own mode specific constant.

$$U_n = \phi_n \ln \sum_k e^{U_k/\phi_n}$$

Variable	Commute	Business	Recreation	Other
Total Travel Time	-0.0126	-0.0097	-0.0103	-0.0103
(Out-Vehicle AET)/Distance	-1.2557	-0.9648	-1.0292	-1.0292
(Travel Cost)/(HH Income)	-1.5672	-1.0034	-1.6055	-1.6055
Inverse Frequency	-6.67810	-2.6051	-5.5576	-5.5576
Chicago Loop – Bus	1.2729	-0.2583	2.2886	2.2886
Chicago Loop – Rail, HSR	0.9523	1.0450	0.3603	0.3603
Income – Rail, Bus	-0.0161	-0.0122	-0.0290	-0.0290
Distance < 75 mi - Bus	-0.0335	-0.0218	-0.0397	-0.0397
Distance < 75 mi – nonBus	-0.4488	-0.1725	-0.4046	-0.4046
Air Constant	-14.1117	-0.3723	-2.1906	0.8380
Rail Constant	2.9360	0.5231	1.8201	1.6875
Bus Constant	0.0452	-1.5935	0.9536	0.8126
HSR Constant	1.4067	0.7545	1.3868	1.2501
Logsum – Surface/Public Nest	0.8769	0.8769	0.8769	0.8769

Value of Time and Value of Frequency -- Tri-State

Wisconsin participated in another high speed rail study with Illinois and Minnesota. Again, stated preference techniques were used. The Tri-State study conducted a stratified random sample of travelers by all modes in the corridor. Respondents were given a series of trip choices, systematically varying time, frequency and cost. There were separate questions for each mode and purpose. The data was analyzed by binary logit. The table on the right illustrates a comparison between the Tri-State study and three earlier rail corridor studies for values of time (dollars per hour).

Mode and Purpose	Tri-State	New York	Ontario-Quebec	Illinois
Air Business	65	51	58	54
Air Other	34	32	32	19
Rail Business	40	26	25	28
Rail Other	28	21	19	13
Auto Business	43	26	25	23
Auto Other	26	26	18	13
Bus Business	25	--	17	--
Bus Other	22	32	12	--

Single Mode Vehicle Occupancy: Michigan

Michigan did not use a formal mode split model for statewide travel forecasts. Rather, it converted person trips to vehicle trips (all relevant modes) by a vehicle occupancy factor. NTPS (1990) data were used to ascertain vehicle occupancy rates as a function of household characteristics and trip length. Michigan used vehicles/person (VP) as its primary measure of occupancy. Michigan's relationship between VP and distance was determined by linear regression for both work and nonwork purposes:

Work:

$$\text{adjustment} = 0.8679\ D^{0.05561}\ \exp(-0.002045\ D)$$

Nonwork:

$$\text{adjustment} = 1.100\ D^{-0.052769}\ \exp(-0.001346\ D)$$

These equations suggest that VP declines with distance (or vehicle occupancy increases with distance). The distance adjustment is applied to a table of vehicle-to-person ratios, one ratio for each combination of income and household size categories. Michigan found the OD pair VP ratio by averaging the ratios for the two involved zones. The income and household size categories are consistent with the trip generation step.

Time of Day Considerations

If there is a need for an hourly forecast, then provisions must be made for the unique nature of intercity travel. A distinction should be made between statewide and urban models. Time of day is handled in different ways in different urban models. There are two principle techniques. First and easiest, trips are generated and distributed for a specific hour in the day. Assignments are made hour by hour. Second, trips are generated and distributed for a full 24-hour period. The 24-hour assigned volumes are allocated to hours and directions by a table of factors for each link.

These urban methods will not work in statewide models (unless the state is quite small), because trips found on rural roads are quite long. Long trips (greater than two hours in length) will likely impact a link one or more hours after its generation. The peak hour of any given link will not necessarily correspond to the peak hour of zonal trip generation. Tables of factors for each link are unavailable, difficult to acquire and difficult to estimate. Under HPMS guidelines states are likely to have time of day information for only a small fraction of their counting stations.

Urban models do not attempt to distinguish between long and short trips when applying time-of-day factors, because average trip lengths are considerably shorter than the smallest time period of analysis (typically, one hour or greater). However, those trips on the rural portions of a statewide network that are quite long in duration are more likely to start in the early parts of the day. Thus, a statewide model may find it beneficial to develop separate time-of-day factors for trips of different durations.

A Solution, Dynamic All-or-Nothing Traffic Assignment. Dynamic assignment takes into consideration the length of trip when assigning it to a network. Dynamic assignment can be quite difficult to implement when analyzing congested urban networks, but it is conceptually much easier with less congested statewide networks that would otherwise be analyzed with all-or-nothing traffic assignment.

Only a modest change is necessary to existing traffic assignment algorithms in order to implement a dynamic all-or-nothing (AON) assignment. The following procedure should be performed.

1. Ascertain the maximum length trip in the network, N hours.
2. Run a special AON assignment for the current hour and each of the N-1 previous hours. The special AON assignment only records link volumes that are between J and J+1 hours in

length, where J is the number of hours prior to the current hour. In essence, only a fragment of each trip will be assigned to the network.

3. Sum the AON assignments.
4. Validate the base-year assignment against traffic counts for several hours in the day and for both directions of travel.

Many existing travel forecasting packages are now incapable of performing this type of assignment.

Interstate Trip Rate

Regression analysis conducted by the Michigan Department of Transportation (MDOT), with regard to their statewide travel demand model, has indicated that the trip rate for trips with at least one trip end outside the state is inversely proportional to the area of the state in square miles. Or in other words, the proportion of “interstate” trips will be smaller if the state itself is large. The MDOT analyzed interstate trip rates with regard to total household trip rates. The main conclusion from this analysis was that the outstate trips were far less relevant than the trips made within the state, especially when considering the major highways within the state. Another interesting feature of the outstate trip generation approach in the Michigan model is that trip productions and trip attractions are computed by the same model, thereby assuming that the TAZs outside the state produce and attract nearly the same number of trips. However, this assumption is not valid for the smaller TAZs within the state itself.[1]

Development of Outstate Trip Generation for the Michigan Model

The 1990 NPTS data were used by Michigan for calculating outstate trip generation rates for the Michigan model. These data were drawn from respondents who were asked to report only those trips with destinations at least 75 miles from home during a stipulated 14-day period. The process was based on the following steps:

- Identification of intrastate versus interstate trips;
- Segregation of trips by trip purpose;
- Calculation of interstate trip rates for households based on both the NPTS and the 1990 census;
- Calculation of trip rates for states not found in the NPTS data, a total of 16 states plus Canada and Mexico; and
- Generation of trip ends by applying household trip rates to households.[2]

External Travel for Other State Models

Calculation of Through Nonwork Auto Travel for KySTM (Kentucky Statewide Traffic Model). In 1995, Kentucky calculated the total number of productions and attractions for through “nonwork” trips as a percentage of the total traffic entering and exiting the area under consideration. One of the disadvantages of using a gravity model to estimate the number and distribution of through trips is that it is based on accessibility, which has little influence over through trip travel patterns. For the preliminary distribution of these trips, it was assumed that those through trips were less likely to change their direction of travel. A spreadsheet-based method was developed following

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[1] KJS Associates, Inc.

[2] Ibid

this assumption. The productions and attractions at all the external stations were then balanced using the Fratar method. This method produced a reasonable number and distribution of through nonwork trips on all the major corridors at the edge of the modeling area.[1]

External Trip Generation for Florida Statewide Model. The external trip generation model for the Florida Statewide model was based on external trip tables developed from roadside interviews conducted as part of the Florida Department of Transportation (FDOT) Statewide Origin-Destination Survey. The Statewide model considers all trips with an origin or destination outside Florida to be external. Future year projections are made by applying Fratar factoring to this trip table.

The Florida Statewide Model has assumed a separate trip purpose for outstate trips with one end in Florida. The attractions for this separate trip purpose were set proportionally to the attractions for other trip purposes. The outstate trip attractions at statewide zones were also assumed to be roughly inversely proportional to the distance from the nearest border.[2]

Composite Utilities for Trip Distribution

There does not seem to be a truly satisfying method for adjusting trip distribution to account for the availability of alternative modes. The need for such adjustment should be obvious when the different distributions for airline and automobile trips are considered. Airline trips tend to be long; automobile trips tend to be short. A larger mode split to airlines would imply a lengthening of trips or a spreading of the distribution. Because typical four-step models calculate distribution ahead of the mode split step, it is not possible to cleanly account for multiple modes in trip distribution. There are two approaches that may be tried.

Approach #1. It may be possible with custom software to perform trip distribution and mode split simultaneously. In essence, a multinomial logit model is calibrated to estimate shares going to each destination and each mode. Such a model involves many choices, n*m, where n is the number of zones and m is the number of modes. It is also possible to use a nested logit model, where the trip distribution decision is made after the mode split decision.

Approach #2. It is possible to include a composite utility term in the trip distribution model to better account of the availability of alternative modes. The theory underlying composite utilities suggests that destinations are more attractive when there are many available modes between the origin and destination.

The use of composite utilities in urban models is considered to be only a small refinement. Because of the widely varying modal technologies for intercity travel, the use of composite utilities in statewide models is considerably more important.

A two mode form of a composite utility function is shown below.

$$t_{ij} = \frac{1}{\alpha} \ln\left[\exp(\alpha t_{ij1}) + \exp(\alpha t_{ij2})\right]$$

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[1] Wilbur Smith Associates, Kentucky Statewide Traffic Model Final Calibration Report, Kentucky Transportation Cabinel, April 1997

[2] The Corradino Group, Statewide Highway Traffic Forecasting Model, Technical Report 3, Florida DOT, August 1990; Post, Buckly, Schuh and Jernigan, Final Technical Report -- Validation and Refinement of 1990 Statewide Model, Florida DOT, August 1994

where t_{ij1} is the utility of mode 1 between i and j, t_{ij2} is the utility of mode 2, and α is a calibrated coefficient.

This equation can be extended to more than two available modes by adding more “exp” terms inside the square brackets.

The value of t_{ij} is used in the gravity model as the measure of spatial separation. The coefficient α is calibrated, but many planners have found that a good value of α can be taken from the coefficient on in-vehicle time from the mode split model.

The composite utility is always less than or equal to the smallest utility among the available modes.

Total Travel in Corridor: Wisconsin Model

Wisconsin used the following equation to forecast volume increases for all traffic in a corridor, regardless of mode.

$$\frac{V_f}{V_b} = \left(\frac{P_f}{P_b}\right)^{\alpha} \left(\frac{E_f}{E_b}\right)^{\beta} \left(\frac{I_f}{I_b}\right)^{\gamma} \left(\frac{L_f}{L_b}\right)^{\varepsilon}$$

where V is volume, P is population, E is employment, I is income, L is level of service, f denotes future year and b denotes base year. Greek letters are calibrated parameters. The level of service variable, L, is computed as the composite utility of all modes in the corridor.

This equation was used by the Wisconsin Department of Transportation to estimate demand for a high speed rail alternative in the Chicago-Milwaukee corridor. WisDOT calibrated this model for each of four trip purposes, as illustrated in the table below.

Variable	Commute	Business	Recreation	Other
Population	0.5621	0.3662	0.5081	0.4371
Employment	0.9046	0.5894	0.5478	0.2878
Per Capita Income	0.3007	0	0.3711	0.0104
Level of Service	0.1865	0.1898	0.3499	0.3606

Tri-State Total Demand Model

The Tri-State study also created a total demand model for a corridor. It had the form:

$$T_{ijp} = e^{B_{0p}} \left(E_{ijp}\right)^{B_{1p}} \left(C_{ijp}\right)^{B_{2p}}$$

where

T_{ijp} is the OD volume for a purpose;

E_{ijp} is a socioeconomic variable, dependent on trip purpose;

C_{ijp} is the generalized cost of travel; and

B_{0p}, B_{1p}, B_{2p} are calibrated coefficients.

The three trip purposes were business, commuting and other. The socioeconomic variables chosen for the trip purpose was:

- business -- E = (Employment)(Annual Household Income)
- commuting, other -- E = (Population)(Annual Household Income)

Generalized cost of travel is found from the following equation.

$$C_{ijmp} = IT_{ijm} + 2\left(OT_{ijm}\right) + P_{ijm} + {TC_{ijmp}}\big/{VOT_{ijmp}} + {\left(VOF_{mp}\right)\left(OH\right)}\big/{\left(VOT_{mp}\right)\left(F_{ijm}\right)}$$

where:

IT_{ijm} = in vehicle time between zones i and j and mode m (hours);

OT_{ijm} = out vehicle time between zones i and j and mode m (hours);

P_{ijm} = interchange penalty in units of time (hours);

TC_{ijmp} = travel cost between zones i and j, mode m and purpose p (1990$);

VOT_{mp} = value of time for mode m and purpose p (1990$);

VOF_{mp} = value of frequency for mode m and purpose p ($ per hour between departures);

OH = operating hours per week (hours); and

F_{ijm} = frequency of departures per week between zones i and j and mode m;

Value of time (VOT) and value of frequency (VOF) were found using stated preference techniques.

The model was calibrated using linear regression on travel survey data, resulting in the calibrated coefficients shown in the following table.

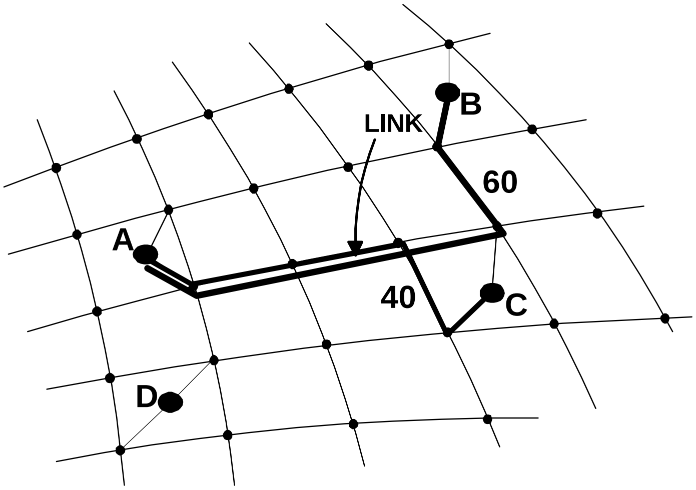
Purpose	B_0	B_1	B_2
Business	-0.709	1.169	-2.750
Commuting	0.241	1.080	-2.814
Other	-1.186	1.136	-2.596

Hybrid Technique: Pivot Analysis

Four step models are often unsuitable for project level analysis. Errors in link volumes can be large, both in the base year and for alternatives. However, it is possible to use results from a four-step model to “pivot” about known levels of traffic. Select link analysis can be used to obtain a relationship between zonal activity and traffic levels. Consequently, forecasts of zonal activity from time series methods can be directly related to traffic levels for a chosen facility.

This method is particularly well suited for project level analysis, where only a few links are being analyzed and where highly accurate forecasts are essential for each facility. The method applies to any situation where traffic will not be redistributed due to major network changes or capacity restraint. An advantage of this technique is that is requires only one base-case run of a four-step model. There is no need to adjust and rerun the model for future scenarios.

Review of Select Link Analysis



The conventional form of select link analysis reports the OD flow matrix for a single direction on a single link. The figure on the right illustrates a select link analysis. There are four zones for a possible 12 interzonal OD pairs. Two of the OD pairs (AB and AC) send trips along paths that use the selected link. These OD pairs and their associated volumes are listed in a select link analysis. In this case, the AB flow is 60 trips and the AC flow is 40 trips. In a large network with many zones, a huge amount of data may be generated by a select link analysis. To achieve an understanding of the results, it is usually necessary to restrain the number of selected links and to filter out OD flows that are trivially small. A select link analysis, properly executed, will tell the analyst which zones and OD pairs contribute most to a link's volume.

Some software packages also implement a form of select link analysis where it is possible to determine the number of vehicles using a pair of links. For example, an analyst might want to determine the number of vehicles traveling on First Street (northbound, between Oak and Maple) and later on Ninth Street (northbound, between Elm and Spruce).

A related technique is select zone analysis. This method finds the number of vehicles using each link that have either their origin or destination in a given zone. Select zone analysis is particularly helpful when trying to determine the impact of site developments on surrounding streets.

It is important that the select link analysis be compatible with the method of traffic assignment. Some forecasting packages compute their selected link flows from an all-or-nothing assignment, which is of limited value when equilibrium assignment is the chosen method.

Pivot Steps

The pivot method may be implemented in seven steps.

Step 1. Obtain good average volumes for the link of interest. Counts should be repeated to assure that statistical variation, day-of-week and seasonal factors have been eliminated. Ideally, stock adjustment factors should not be used. Counts should be taken for both directions of travel and by hour of the day.

Step 2. A reasonably well calibrated four-step model should be available. A "reasonable" level of calibration means that the model provides good estimates of overall system performance, has an RMS error in link volumes no more than twice what would be anticipated from traffic counting variation alone and includes all links in the project. In addition, the links in the project show good agreement between actual volumes and the base-case forecast. "Good agreement" is subjective, but the pivot technique would be difficult to defend when the base-case forecast is in error by more than 50% (high or low) on a given link. In the network shown earlier, the volume on the project link is 130 vehicles, which is considered acceptably close to the 100 vehicles from the base-case forecast.

Step 3. The fraction contribution of all OD pairs should be obtained from the select link analysis. From the drawing, there are two OD pairs contributing volumes: AC contributes 40 vehicles, or 40%, and BC contributes 60 vehicles, or 60%. All other OD pairs are ignored.

Step 4: Assuming that the fraction contribution of OD pair to the link's volume is accurate, it is possible to estimate the amount of actual traffic associated with each OD pair. In this example, the 130 vehicles can be split 60/40 across the two OD pairs. Thus, 52 vehicles come from AC and 78 vehicles come from BC.

Step 5. The growth in activity in an individual zone is forecasted by a time series. As indicated previously, a measure of zonal activity closely related to intercity travel is total personal income. Forecasting the growth in an OD pair requires an assumption about the interaction between two zones. The gravity model would suggest that the growth factor for an OD pair is related multiplicatively to the growth factor for each zone. For example, if zone B is expected to grow by 55% and zone C is expected to grow by 38%, then the growth factor for the OD pair can be found from:

BC growth factor = (1+0.55)*(1+0.38) = 2.139 or a 113.9% growth

The growth in zone A is 46%, so the AC growth factor is 201.5%.

Step 6. The forecasted vehicles for AC is 105 (52*2.015) and the forecasted vehicles for BC is 165 (78*2.139).

Step 7. The forecasted link volume can found from summing the contributions from all OD pairs. In this example, the forecast is 270 vehicles (105 + 165).

These steps should then be repeated for the other links in the project.

Pivot Method Refinements

Use Larger OD Pairs. A selected link can have contributions from many OD pairs, especially when an equilibrium assignment or a stochastic multipath assignment has been performed. Many OD pairs contribute very small amounts of traffic to a link. It is possible to eliminate many of those smaller contributions, concentrating on a few of the largest OD pairs.

Forecasting OD Flows, Revised. The multiplicative assumption of the previous example would not hold when large portions of the state are growing at about the same rate. In this case, growth in traffic for the OD pair should be roughly related to the average growth rate of zones. A workable compromise is to assume that an OD pair growth equals the regional average growth times a factor calculated from the degree to which the OD pair exceeds the regional growth. The following calculations illustrate this concept.

In the previous example, the regional average growth rate is 41%. The growth factors for each zone in the example can be easily split into regional and local components:

A growth factor = 1.41*1.035 = 1.46
B growth factor = 1.41*1.10 = 1.55
C growth factor = 1.41*0.98 = 1.38

Consequently the OD factors can be easily found:

BC growth factor = 1.41*1.10*0.98 = 1.52
AC growth factor = 1.41*1.035*0.98 = 1.43

With these revised growth factors, the forecasted volume on the project link is:

volume = 52*1.43 + 78*1.52 = 193

which is considerably less than the 270 vehicles calculated earlier.

Calibration and Validation

Calibration and validation are separate tasks, although many transportation planners try to do both at the same time. Calibration applies to each step in the modeling process, while validation applies to the model as a whole.

Calibration. Each model step has one or more parameters that can be adjusted to assure that the step is replicating known travel behavior. Calibration is the process of performing that adjustment. Very often calibration is performed by statistical methods, such as linear regression or maximum likelihood estimation. In some cases, it is possible to refine by hand one or two parameters in a step by adjusting them to match known aggregate measures of travel. To perform such a hand refinement, it is usually necessary to adopt the remaining parameters from an earlier study in the same city or from a similar study in another city.

Validation. Validation primarily involves comparing a base-year forecast to known traffic levels. A poor quality validation would indicate the need for additional calibration. There is no formal provision in the validation process to improve the accuracy of the model.

A Muddle. Many transportation planning agencies have adopted a joint validation/calibration strategy to increase the perceived accuracy of the model. These agencies use the validation data in the following ways:

- Use measures of total travel on a network to adjust the trip production equations;
- Use link volumes near special generators to establish trip generation relationships for those generators;
- Use link volumes on major roads to introduce K-factors into a gravity model; and
- Use individual link volumes to adjust free speed on links.

The desire to meld the validation and calibration process is understandable, but the results are less valid than if a good calibration had first been achieved.

National Defaults

The calibration process can be greatly accelerated if parameters are adopted from national databases, such as NPTS or ATS, or studies performed elsewhere. Defaults can give good starting points for calibration exercises or can eliminate the need for some locally-collected data. At this writing, a dependable source of default parameters for statewide travel forecasting does not exist. Some states have tried to use the parameters of NCHRP #187 (superceded by NCHRP #365), but these parameters have been created for urban applications.

Some states have applied results from national databases (e.g., NPTS or CFS) to their statewide model with good success. The use of the NPTS is facilitated because the raw data is available on CD-ROM. Unfortunately, the CFS data is aggregated by state or NTAR.

At this time, only few states have calibrated statewide models. However, as more models become operational, the potential to share parameters increases.

Trip Table Estimation from Traffic Counts

A good statewide trip table can be difficult to approximate from a gravity model. For instance, (1) friction factors may vary considerably across the state; (2) errors in estimating the number of intrazonal trips may unduly influence the accuracy in interzonal trips; and large biases can be introduced by barriers to travel, such as bridges and state borders. Common practice has been to adjust the gravity model with "K" factors to account for sizable discrepancies in the gravity model. An alternative method worth investigating is to statistically adjust an estimated trip table to match traffic counts. A small-scale test of this concept has been tried in Wyoming.

Several methods of estimating OD tables have been described in the literature; the details of these methods are beyond the scope of this guidebook. One method, entropy maximizing, can be adequately described by its inputs:

V_a = volume of traffic on link a;

p_{aij} = proportion of trips from origin i to destination j carried by link a; and

t_{ij} = prior trip table of trips from origin i to destination j

The method finds the "maximum entropy" trip table given these input data. The prior trip table could be taken from surveys or estimated by a gravity model or Fratar model, and the volumes are taken directly from traffic counts.

The proportion of trips between i and j on link a, p_{aij}, needs further explanation. They must satisfy the requirement:

$$V_a = \sum_i \sum_j p_{aij} T_{ij}$$

where T_{ij} is the final trip table. These proportions are most easily found by traffic assignment. When all-or-nothing assignment is performed, the p's are Boolean (0 if the link is not used, 1 if it is used). With any multipath techniques (including equilibrium), fractional values are possible.

SSOD in Validation

SSOD data is an important input in the validation phase of the model. This is done by means of select link analysis. The selected link assignment output from the model can be directly compared with the SSOD survey data, either as individual links or as groups of links. The Michigan Department of Transportation has used recent SSOD weekday surveys in the validation phase of their model, as SSOD data was not directly used in the model's development. To do so, Michigan assigned the SSOD trip table back to the network, then compared the resulting assignment with a select link analysis. A major shortcoming in the MDOT model's selected link analysis was that only one link could be selected per run of the model, whereas the complete SSOD data set involved many "stations" and, thus, several links.[1]

Michigan's application of this procedure would be better classified as a calibration tool, because it focuses entirely on the assignment step. For validation, it would have been better to have assigned the full trip table as calculated in the trip distribution step, thereby testing all steps in the model together.

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[1] KJS Associates, Inc.

Integration of Statewide and Urban Models

Statewide and urban models use different types of data and different algorithms. Generally speaking, urban models show greater geographic and geometric detail and should be far more accurate within the urban area. Consequently, urban model results should be used for links within urban areas, with the results from the statewide models used elsewhere.

In order to assure that the urban models are properly using statewide model results, the statewide model must be capable of performing link-to-link select link analysis. This type of select link analysis gives the OD flows between many pairs of links. If the selected links in the statewide model correspond exactly to the external stations in the urban model, the select link OD flows are theoretically equivalent to the E-E (external-to-external) trip table in the urban model.

Some fixing is usually necessary to account for errors in the statewide model. A common problem is that the forecasted traffic from the statewide model in the base year fails to match the known traffic counts. Errors of this sort can be overcome by Fratar factoring the trip table.

Another problem is numerous zero-valued cells in the OD matrix. This problem arises when the statewide model uses all-or-nothing assignment. To the extent possible using local knowledge of existing travel pattern, the number of zero-valued cells should be reduced by manual adjustments of the trip table.

Appendix: Review of Calibration Methods

Ordinary Least Squares (Linear Regression)

Ordinary least squares, or linear regression, analysis is the primary method for calibrating statewide travel demand models.

Trip Attractions. The estimation of trip attractions requires little more than an elementary knowledge of linear regression analysis and can be easily performed on a spreadsheet. Trip attraction equations are typically of the form:

$$A = a_0 + a_1 x_1 + a_2 x_2 + \cdots + a_n x_n$$

where the x's are measures of zonal activity (population, employment, etc.) and the a's are calibrated coefficients. It is important to tell the statistical software to set the constant term ("a_0" in the above equation) to zero in order to force the line through the origin. Otherwise, zero activity in a zone would not be associated with a zero amount of trip making.

Trip Productions. The estimation of trip productions is most often accomplished by category analysis or by cross classification. In both methods the parameters can be estimated using a dummy variable to represent each possible category or cell. A related method, analysis of variance (ANOVA) can used to determine whether a categorization or a classification scheme is appropriate. The ANOVA routines found on spreadsheets are inappropriate, because they do not allow an unequal number of observations in cells.

Trip Productions with a Covariate. When the parameters of a trip production model are estimated with linear regression analysis, it is possible to include continuous variables into the model. For example, a trip production model might consist primarily of a cross-classification procedure with cells representing all combinations of household size and automobile ownership.

The model might be enhanced by including an accessibility term, such as distance to the nearest regional shopping mall. All parameters would be estimated at the same time.

Linearization. Acceptable fits of nonlinear relationships can often be achieved by transforming them so that their parameter can be estimated with linear regression analysis.

Consider the total demand model from the Tri-State High Speed Rail Study:

$$T_{ijp} = e^{B_{0p}} \left(E_{ijp}\right)^{B_{1p}} \left(C_{ijp}\right)^{B_{2p}}$$

The parameters of this equation were estimated by first taking the natural logarithm of both sides of the equation:

$$\ln\left(T_{ijp}\right) = B_{0p} + B_{1p} \ln\left(E_{ijp}\right) + B_{2p} \ln\left(C_{ijp}\right)$$

This equation is now linear in the logarithmically transformed variables. Logarithmic transformations disturb the distribution of errors of the dependent variable, so linearization may not always be the best strategy for obtaining unbiased parameters. As discussed in an earlier chapter, logarithmic transformations are entirely appropriate when the size of the error is proportional to the size of the dependent variable.

Nonlinear Regression

Nonlinear regression is implementable on a spreadsheet using a "solver" feature. In nonlinear regression, the following expression is minimized by varying the parameters of the model, $Y_{i,estimate}$. That is,

$$\min \sum_{i} \left[Y_{i,actual} - Y_{i,estimate}\right]^2$$

where each i represents a data point.

Maximum Likelihood Estimation

Certain model steps that involve estimating probabilities are often calibrated with maximum likelihood estimation. These steps include mode split (logit and nested logit) and trip distribution (gravity model with complex friction factor functions and attractiveness factors). Like regression analysis, maximum likelihood estimation finds the parameters of a model. However, maximum likelihood estimation is designed to find predictive equations for choices and does not attempt to find the best line to fit a set of data. Maximum likelihood estimation sets parameters of the model so that the probability of exactly replicating by chance the observed pattern of choices is the highest. Usually, there are many possible choices in a data set and the probability of an exact replication is extremely low, regardless of the parameters.

Maximum likelihood estimation begins by specifying a "likelihood function", L, which computes the probability of seeing an exact replication of observed choice patterns.

$$L = \prod_{n=1}^{N} \prod_{j=1}^{J} P_{jn}^{\delta_{jn}}$$

Here P_{jn} is the estimated probability of any given traveler n choosing mode j, as given by the choice model (containing assorted variables and parameters to be estimated). Also, δ_{jn} is a Boolean (0,1) variable that is set equal to 1 if the traveler n had chosen mode j and set to zero otherwise. This equation is difficult to work with, because it usually evaluates to a very small number. Thus, statisticians commonly try to maximize the logarithm of the likelihood function -- an equivalent and much easier task.

$$\max \quad L^* = \sum_{n=1}^{N} \sum_{j=1}^{J} \delta_{jn} \ln P_{jn}$$

It is readily seen that all terms in the log likelihood function that represent unchosen modes are zero, and all other terms are negative numbers (i.e., the logarithm of a number less than 1 is negative). Thus, maximizing the log likelihood function involves making it less negative by reducing its magnitude. The means of performing the maximization vary, depending upon the software. The “solver” capability of a spreadsheet is one possible method.

Fast Trip Distribution Calibration

When there is a single parameter in a gravity model friction factor function, that parameter can be set so that the model yields the same average trip length as observed in reality. That is,

$$\bar{t} = t^*$$

where t “hat” represents the model’s average trip length and t “star” represents the actual average trip length. Single parameter friction factor functions include the power function:

$$F_{ij} = {}^{1}\!/\!{}_{t_{ij}^{\alpha}}$$

and the exponential function:

$$F_{ij} = e^{-\beta t_{ij}}$$

The parameter is estimated by repeatedly running the model and adjusting the parameter up or down. If the estimated average trip length is too small, then the magnitude of the parameter (exponential or power) should be made smaller. If the estimated average trip length is too large, then the magnitude of the parameter (exponential or power) should be made larger.

The choice between the power function or the exponential function (or any other convenient one-parameter function) must be made by comparing the differences between the estimated and observed trip length frequency distributions.

The true average trip length can be ascertained by questionnaire or by analysis of NPTS.

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APPENDIX: The State of the Art in Statewide Travel Demand Forecasting

A.1. Introduction

The belief has long been held that the characteristics of travel on a statewide scale are in many ways different than those of travel within an urban area. Thus, encouraged by early progress in the development of urban-area models, attempts have been made over the last 35 years to formulate models and techniques to forecast transportation activities on a statewide scale. Many states expended a significant amount of time and expense – especially in the late 1970s and early 1980s – to develop statewide models. Some succeeded in developing a working model, but most did not.

At present, most states do not have a forecasting process in place at a statewide level – whether due to past difficulties in developing and maintaining a statewide model, or due to a cynicism bred by the often highly political process of transportation planning. However, a formalized statewide forecasting process offers a rational basis for making planning decisions. The use of travel forecasting models can assist with decisions regarding future facility needs, budget projections and the assessment of the large scale effects of alternative projects. Statewide models help to tie the decision-making process to a knowledge of the interaction between transportation systems and socioeconomic structures at a statewide scale.

Most recently, in reaction to the requirements of the 1990 Clean Air Act Amendments (CAAA) and the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA), there has been renewed activity in travel forecasting at a statewide level. In fact, implementation of most of the 23 “planning factors” (see Figure A.1) outlined in the ISTEA legislation [1.1] can be assisted greatly by a statewide forecasting effort.

Statewide forecasting can have a significant impact on at least six of these “factors” including:

1. Transportation needs for non-metropolitan areas;
2. Connectivity between metropolitan areas;
3. Recreational travel and tourism;
4. Preservation of rights-of-way for future projects;
5. Long-range needs of the state transportation system; and
6. Methods to enhance the efficient movement of commercial goods.

These planning factors have been consolidated in TEA 21, but the need for a statewide model remains. More specifically a statewide forecasting effort can, as one report noted [1.2]:

1. Assess demand by specific customer/market segments;
2. Forecast passenger and commodity flows for a 20-year horizon;
3. Provide an improved tool for trunkline planning and analysis;
4. Enable multimodal analysis along major intercity corridors;
5. Provide quantitative data input to management systems; and
6. Integrate with and provide input to urban models.

The purpose of this appendix is to present a review of the state of the art travel forecasting at the statewide level and to identify possible avenues for improving the forecasting process.

1. The results of required management systems.
2. Any federal, state, or local energy use goals, objectives, programs or requirements.
3. Strategies for incorporating bicycle transportation facilities and pedestrian walkways.
4. International border crossings and access to ports, airports, intermodal transportation facilities, major freight distribution routes, national parks, recreation and scenic areas, monuments and historic sites and military installations.
5. The transportation needs of nonmetropolitan areas.
6. Any metropolitan area plan.
7. The connectivity between metropolitan areas within a state or with metropolitan areas in other states.
8. Recreational travel and tourism.
9. Any state plan developed pursuant to the federal Water Pollution Control Act.
10. Transportation system management and investment strategies to make the most efficient use of existing facilities.
11. The overall social, economic, energy and environmental effects of transportation decisions.
12. Methods to reduce traffic congestion and to prevent congestion from developing.
13. Methods to expand and enhance transit services and to increase the use of such services.
14. The effect of transportation decisions on land use and land development.
15. Strategies for identifying and implementing transportation enhancements.
16. The use of innovative mechanisms for financing projects.
17. Preservation of rights-of-way for construction of future transportation projects.
18. Long-range needs of the state transportation system for movement of persons and goods.
19. Methods to enhance the efficient movement of commercial motor vehicles.
20. The use of life-cycle costs in the design and engineering of bridges, tunnels or pavement.
21. The coordination of transportation plans and programs developed by MPOs.
22. Investment strategies to improve adjoining state and local roads that support rural economic growth and tourism development, federal agency renewable resources management and multipurpose land management.
23. Concerns of Indian tribal governments.

Figure A.1. Summary of ISTEA Statewide “Planning Factors”

It should be noted that the title of this appendix deals with the “state of the art” in travel forecasting. Some previous research [1.3] has attempted to differentiate between the “state of the art” and the “state of the practice”. This appendix, however, makes no such distinction. The approach followed here assumes that the knowledge that is elsewhere divided into “art” and “practice” is, in fact, merely part of the same continuum.

Method of Research

In order to assemble information for this appendix, two distinct research methods were applied. First, a search was made through the nearly-complete set of Transportation Research Board (TRB) bulletins and reports, National Cooperative Highway Research Program (NCHRP) reports and syntheses and other published materials available in the collection of the Center for Urban Transportation Studies at the University of Wisconsin-Milwaukee. This search was supplemented by an examination of the references found in applicable TRB and NCHRP literature and through online searches of the Northwestern University library. Surprisingly little information that applies specifically to statewide travel forecasting was discovered in these searches. Instead, much of the available information describes “intercity” models, which (as discussed in section A.2) bear many relationships to statewide models.

The second method of research consisted of direct contact with various state department of transportation (DOT) officials. For as many states as possible, contacts were initiated using the Internet. Many DOT officials were directly accessible via e-mail or could be easily reached through a general information e-mail addresses at their respective DOT web sites. Other contacts could be made through access to DOT phone lists that are also available online. As shown in Table A.1, attempts at contact were made with 45 states. Alaska and Hawaii were not contacted because of their geographical separation from the lower 48 states, Rhode Island and Delaware were not contacted because of their small size, and Mississippi was not contacted because its DOT did not support a home page on the internet. As also shown in Table A.1, an overwhelming majority of the states contacted replied via e-mail or telephone, and many sent documentation of their individual statewide forecasting models and procedures. A similar, electronically-based procedure was followed in contacting several commercial sources that provide the population and economic forecasts that are often used as inputs to the transportation forecasting process.

Organization of Appendix

The following sections of this appendix present a review of the information gathered during the research process described above and some observations and recommendations about the state of the art as portrayed by that information. Section A.2 and Section A.3 provide a review of the literature of intercity models for passenger travel and freight transportation, respectively. The formulation of intercity models, in general, historically preceded the development of statewide models. Thus, the intercity models are presented first. The information in these sections is drawn principally from TRB and NCHRP publications. Similarly, Section A.4 and Section A.5 provide a review of statewide forecasting methods for passenger travel and freight transportation, respectively. Much of the information reviewed in these sections was collected from the DOT sources. Section A.6 presents a review of two statewide passenger models now under development: the Michigan Statewide Travel Demand Model and the Kentucky Statewide Traffic Model. Section A.7, likewise, presents a review of two statewide freight models now under development: Multimodal Freight Forecasts for Wisconsin and Transport Flows in the State of Indiana. Finally, Section A.8 provides some recommendations for “best practice” based on the observations made in the preceding sections.

Table A.1: Contact with State Departments of Transportation

DOT	Contact Made	Reply Rec’d	Items Sent
AL	Yes	No	----
AK	No	----	----
AZ	Yes	Yes	No
AR	Yes	No	----
CA	Yes	Yes	Yes
CO	Yes	Yes	----
CT	Yes	Yes	Yes
DE	No	----	----
FL	Yes	Yes	Yes
GA	Yes	Yes	No
HI	No	----	----
ID	Yes	Yes	No
IL	Yes	Yes	No
IN	Yes	Yes	Yes
IA	Yes	Yes	No
KS	Yes	Yes	Yes
KY	Yes	Yes	Yes
LA	Yes	Yes	Yes
ME	Yes	Yes	Yes
MD	Yes	Yes	No
MA	Yes	Yes	No
MI	Yes	Yes	Yes
MN	Yes	Yes	Yes
MS	No	----	----
MO	Yes	Yes	No
MT	Yes	No	----
NE	Yes	Yes	No
NV	Yes	Yes	No
NH	Yes	Yes	Yes
NJ	Yes	Yes	Yes
NM	Yes	Yes	Yes
NY	Yes	Yes	Yes
NC	Yes	Yes	No
ND	Yes	Yes	No
OH	Yes	Yes	No
OK	Yes	Yes	No
OR	Yes	Yes	No
PA	Yes	Yes	No
RI	No	----	----
SC	Yes	Yes	No
SD	Yes	Yes	No
TN	Yes	No	----
TX	Yes	Yes	Yes
UT	Yes	No	----
VT	No	----	Yes
VA	Yes	Yes	No
WA	Yes	Yes	No
WV	Yes	Yes	Yes
WI	Yes	Yes	Yes
WY	No	----	Yes

A.2. 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 [2.1, 2.2], 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 (O-D) 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 [2.3, 2.4, 2.5, 2.6, 2.7] 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 makes use of the socioeconomic data for the O-D pairs in the model and can also include the service characteristics of the modes of travel between them. Disaggregate data goes 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 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 [2.6]. The most famous of these was Quandt and Balmol’s abstract mode model [2.8]. The reader is referred to the reviews referenced in the previous section (especially Koppelman et al [2.6]) 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 [2.9]. 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 [2.10]. Here, as part of two single-purpose (business and non-business) 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 [2.11] and Kaplan et al [2.12] 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.

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 [2.13]. 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. Due 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 [2.14, 2.15]. Again, Koppelman et al [2.6] provides a review of many of the earlier disaggregate mode choice models. In addition, Miller [2.16], Forinash [2.17], and Forinash and Koppelman [2.18] 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 instance, present multimodal models (one for vacation travel and one for business) with the hierarchical structure shown in Figure A.2 [2.19]. Similarly, Koppelman [2.20] and Koppelman and Hirsh [2.21, 2.22] present a multimodal model with a structure shown in Figure A.3. Morrison and Winston make use of the 1977 National Travel Survey (NTS) data, while Koppelman and Hirsh use both the NTS and the 1977 National Personal Transportation Survey (NPTS) data. Both pairs of researchers seek 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 [2.23, 2.24, 2.25]. 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, but since 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.

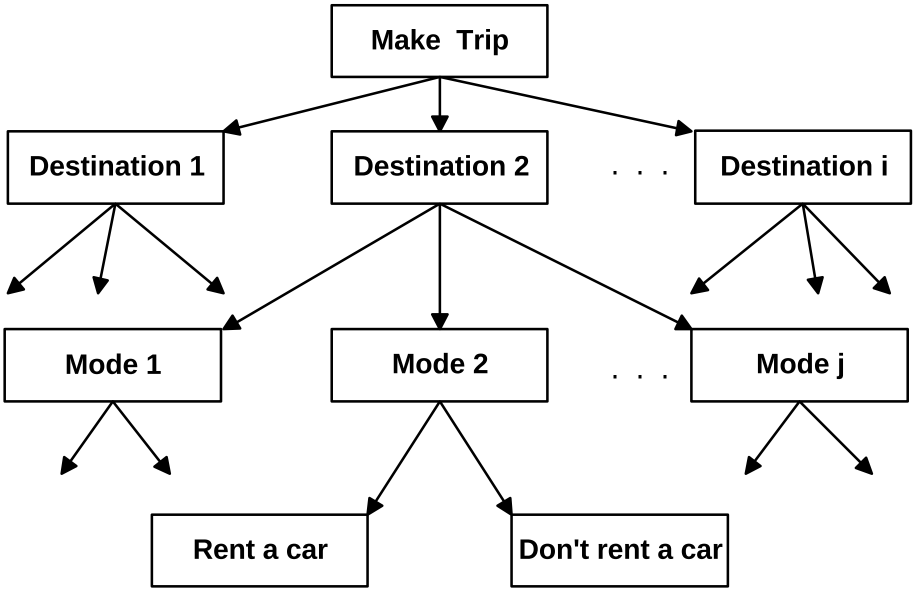

Figure A.2. Structure of Morrison and Winston's Model

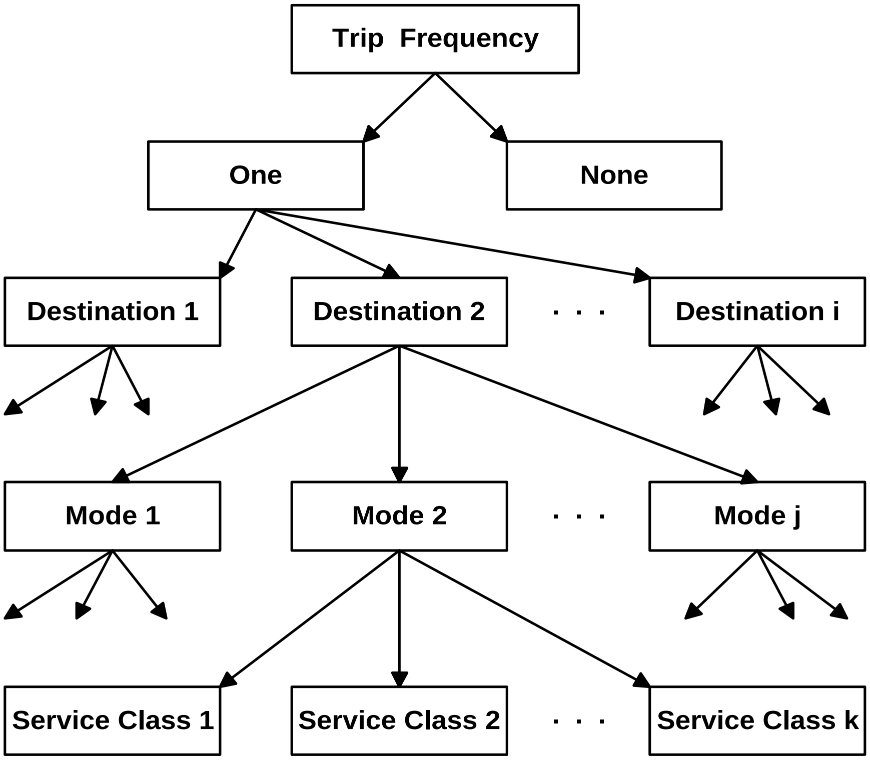

Figure A.3. Structure of Koppelman and Hirsh's Model

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 proved to be difficult [2.26] and examples of intercity bus models are rare. One interesting bus model is presented by Neumann [2.27]. 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 [2.28] addresses this issue with simple linear regression techniques. A later paper by Oberhausen and Koppelman [2.29] 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 [2.30] 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 [2.31] and an elaborate direct-demand model of intercity air travel based on quality-of-service measures by Ghobrial and Kanafani [2.32].

Finally, the one other single-purpose intercity model worth noting is the disaggregate model of recreational travel presented by Gilbert [2.33]. 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 A.4. 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 due to the strong traditions of and training in the four-step modeling process, but it is also due to 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 is 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 (annual VMT or emissions, for instance) to forecasts of socioeconomic data.

A.3. Intercity Freight Literature

Introduction

Intercity freight models are similar to intercity passenger models in their attempt to model traffic – in this case, freight traffic – between spatially distant locations. Compared to the amount of literature available about intercity passenger forecasting, the amount of intercity freight forecasting literature is rather small. The history of inter-regional input-output analysis – which is closely related to some models of freight transportation – dates back to the 1930s, but serious attempts to forecast freight movements at a national or regional level were generally begun only after the first intercity passenger models were developed in the middle 1960s.

Reviews of Intercity Freight Models

As in the case for passenger models, several reviews have been published about the history of intercity freight modeling. A paper by Smith [3.1] divides previous models into six categories based on their structure: (1) market share, (2) input-output, (3) inventory theoretic, (4) gravity, (5) abstract mode and (6) linear programming. Smith concludes that either a gravity model or an abstract-mode model would be best for use in the situation where the available data are limited. In a 1983 paper, Winston [3.2] divides freight models into two categories familiar to passenger modelers: aggregate and disaggregate. He observes that models based on aggregate data might be better for regional level freight flows. He also recognizes the difficulties inherent in collecting the immense amounts of data required to calibrate disaggregate models. Friesz et al [3.3] also present an overview of early freight modeling efforts, with conclusions concentrating on work performed at the University of Pennsylvania. That work is discussed briefly below. Meanwhile, Bronzini [3.4] traces the development of various multimodal freight transportation models at the national level. The models described include those developed by the Inland Navigation Systems Analysis project, the Transportation Systems Center and the National Energy Transportation Study. An important conclusion of Bronzini's review is the need for a "comprehensive interregional commodity flow data base" – something that has been under development in the intervening years by many sources and will be discussed further in Section A.5. Another important observation by Bronzini regards the benefits of using an equilibrium assignment for non-highway modes. His investigations indicate that using an equilibrium assignment tends to redistribute traffic to cause more efficient use of a particular modal network, rather than cause a switch of traffic to a competing mode.

Intercity Freight Models

One of the earliest intercity freight studies was published by Morton in 1969 [3.5]. In it he applies a linear regression analysis to develop equations for national rail freight volume and truck freight volume based on GNP, rail shipping rates and truck rates. Apart from national-level models, however, little appears to have been written regarding workable intercity freight transportation models until the late 1970s. In 1977 Jones and Sharp [3.6] published research on demand modeling for undeveloped rural regions of the United States. Their model explicitly did not have any predictive function, but it did recognize that:

> In underdeveloped regions… the patterns of economic development cannot be predicted by past trends because past trends lead nowhere. (p. 523)

Like others in the 1970s, Jones and Sharp noted the lack of available commodity flow data that could make their model useful.

Throughout the 1980s researchers at the University of Pennsylvania concentrated on the differences between freight modeling and passenger modeling [3.7, 3.8]. They formulated a model that recognizes the special situation of shippers and carriers and attempts to account for the different information available to each group. Their model takes O-D pairs determined at the shippers' level and optimizes the flow for the carriers' network, in a model structure shown in Figure A.4. Other intercity freight modeling efforts, including Canadian research in the late 1980s and early 1990s, bears a closer resemblance to statewide modeling practice and will be discussed in Section A.5.

Intercity Freight Mode-Split Models

In addition to the models that address the full extent of the freight transportation process, several address only mode-split. Some attempts have been made to examine statewide freight flows for single modes; recent studies have included air freight [3.9] and special-use trucks [3.10]. However, a primary concern of freight modeling is the division of the freight flow between competing modes, usually between truck and rail. A clear example of the importance of mode-split models for intercity freight transportation is provided in Lindesmeyer's paper [3.11] about the drastic effects on rural freight trucking in Nebraska that were brought about by changes rail freight practices.

A number of methods have been employed in the effort to understand how freight traffic becomes divided among the available modes. The methods used have included discriminant analysis [3.12] and a diversion matrix method [3.13], as well as the probabilistic methods more familiar to urban mode-split modelers [3.14, 3.15, 3.16]. Of these studies, the most interesting is the diversion matrix study. Although it was written before the recent explosion of truck/rail intermodal business and is based on an uncomplicated analysis, the study suggests that only about one quarter of total manufactured-goods cargo is really subject to competition between modes. The choice of modes for the vast majority of manufactured-goods, the study concludes, is instead determined by the weight of the shipment and the length of its haul, or by other factors, such as shipper prejudices toward one mode or another.

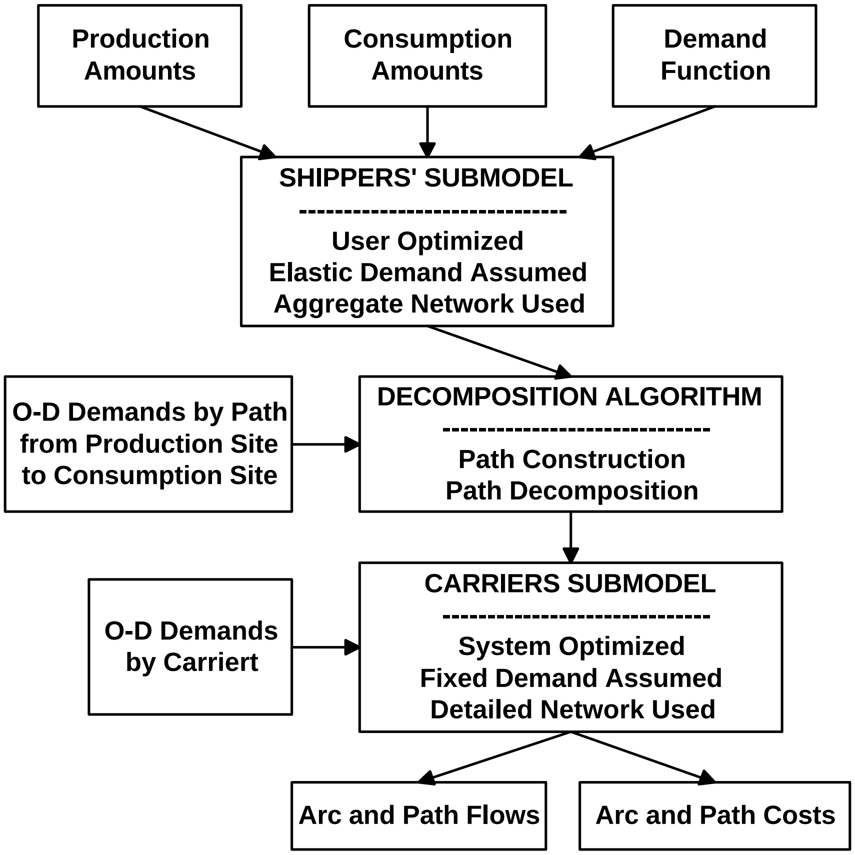

Figure A.4. University of Pennsylvania Shipper-Carrier Model

Discussion

Research on intercity freight transportation appears to have been minimal, apart from the specifically statewide research that will be discussed in the Section A.5. Research into shipper-carrier problems clearly addresses an important behavioral link in the freight transportation process, but there may be other, easier ways to address this complicated interface. One way might be to employ expert panels (as will be discussed in Section A.7) that include shipper and carrier representatives to examine traffic forecasts from their individual perspectives.

A.4. Statewide Passenger Forecasting Literature

In spite of 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 (see Table A.1) 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 wholly 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 [4.1], and by 1972 at least 19 different states were using or preparing statewide models [4.2]. Modeling activities were evidently so popular that in 1973 the Federal Highway Administration (FHWA) perceived the need to standardize the thinking about statewide modeling and issued a guidebook on the subject [4.3] – 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 due to funding cuts or to frustration with the model results, and little activity seems to have taken place (studies in Florida and Kansas are an exception [4.4, 4.5, 4.6]) 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 (CAAA and ISTEA), several states were rethinking their strategies. New Mexico [4.7] and Texas [4.8] 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 proposals (RFP) 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 A.2, and these are discussed below.

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 [4.9] and continue to be conducted at the statewide level [4.10, 4.11].

However, they are relatively expensive to conduct and must be supplemented by other data. Two other options make use of data that is already available: Federal survey data and statewide traffic counts. US census data have always been valuable as inputs to travel modeling. The 1990 census improved upon this by including a journey-to-work (JTW) survey and by introducing the Census Transportation Planning Package (CTPP) [4.12]. The JTW has proved especially useful in estimating home-based work trips on a statewide level, but has been criticized for its lack of information about other purposes [4.13]. The CTPP provides transportation-related information at a transportation analysis zone (TAZ) level, which can be readily aggregated into township or county level data for statewide modeling. Another federal data source is provided by the US Department of Transportation, which conducted its most recent National Personal Transportation Survey (NPTS) in 1995. The NPTS data, which measures 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 is 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 [4.14, 4.15, 4.16] 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 the FHWA's *Traffic Monitoring Guide* in 1985 [4.17], Pennsylvania [4.18], Washington [4.19, 4.20, 4.21] and New Mexico [4.22, 4.23] began to re-evaluate 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 O-D pairs being examined. To get around this difficulty, optimization methods have been developed to synthesize trip tables from available traffic count information [4.24, 4.25, 4.26]. These methods have subsequently been applied to statewide analyses in Wyoming [4.27, 4.28]. Attempts have also been made to synthesize trip tables from census data at a sub-state level in New Jersey [4.29].

Trend Analyses of Passenger Travel

As noted above, 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 [4.30], but such documentation seems to be the exception. Some indication of the possibilities of trendline analysis is given in a paper by Harmatuck [4.31] 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 the FHWA's 1992 *Traffic Monitoring Guide* [4.32], 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 underdevelopment is presented in Table A.2. This includes work done in Connecticut [4.33, 4.34], Florida [4.35, 4.36], Indiana [4.37], Kentucky [4.38], Michigan [4.39], New Hampshire [4.40], New Jersey [4.41, 4.42], Vermont [4.43], Wisconsin [4.44] and Wyoming [4.27, 4.28]. In addition to the states shown in Table A.2, California has a statewide model, but it is being redesigned, so documentation is currently unavailable for it. Oregon is also in the early stages of developing a comprehensive forecasting model that will include a land use element [4.45]. Several other states are currently in the very beginning stages of modeling projects – issuing RFPs to interested consultants.

As can be seen from Table A.2, most of the models consider a large number of trip types (as many as 5 or 6), 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 TAZs. The Florida and New Jersey models are also interesting in the degree to which they have attempted to incorporate existing MPO 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. Section A.6 examines both of these models in greater detail. Recreational Travel Models

As early as 1963 recreational trips were considered an important enough purpose to warrant separate study [4.46]. In fact, in the late 1960s and early 1970s the NCHRP [4.47], Indiana [4.48, 4.49], Kentucky [4.50, 4.51] and other states [4.52, 4.53] conducted studies of the special characteristics of recreational travel. Strangely, although Americans seem to have dedicated an increasing amount of time to pursuing recreational activities, the last of these studies was published more than twenty years ago. Since many state economies depend heavily upon 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. Further discussion of the structure of typical statewide passenger models is presented in Section A.6.

Table A.2. Current Statewide Passenger Models

STATE	TAZs	MODES	PURPOSES	COMMENTS
Connecticut	1300 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. HB other 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	2392 total	Auto only	1. HB Work/Biz. 2. HB Soc./Rec./Vac. 3. HB Other 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 5000 pop.	1. SOV 2. HOV2 3. HOV3+ 4. Bus 5. 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	2762 internal 51 external	----	----	• Model created by merging 5 MPO models.
Vermont	622 internal 70 external	Highway vehicles only	1. HBW 2. HB Shop 3. HB School 4. HB Other 5. NHB 6. Truck	• Based on extensive statewide survey.

Table A.2. Current Statewide Passenger Models (continued)

STATE	TAZs	MODES	PURPOSES	COMMENTS
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

A.5. Statewide Freight Forecasting Literature

Introduction

For various reasons, it has been suggested that forecasting freight transportation flows is more complex than modeling passenger travel volumes [5.1]. This is partly because of the numerous parties involved in shipping the large variety of commodities that are regularly moved by the several modes available. The development of freight forecasting techniques, therefore, has historically lagged behind the development of passenger techniques. At the same time, the methods of analyzing freight traffic at a statewide level have remained similar in form to those used in predicting passenger travel. There are essentially two ways that state DOTs forecast freight traffic: (1) by analyzing truck traffic or (2) by using a commodity flow model [5.2].

There are two techniques generally applied to truck traffic analysis. The first technique is a simple trendline analysis similar to that described in Section A.4 for passenger travel forecasting. The other technique is to include truck trips as a separate trip purpose in the passenger model, based on survey data or on counts of truck traffic on various links in the highway network. In either case the similarity to passenger forecasting is obvious.

Forecasts that are based on commodity flows bear a resemblance to passenger models in the way they are structured. They are typically employed in a “four-step” sequential process that employs a gravity-model distribution, a cursory mode-split step and some sort of simple assignment. The only significant difference is that the trip generation step is often based on freight flow data (usually classified by industry groups), instead of regression equations for employment and population, as with passenger models.

Data for Freight Forecasting

Freight data, especially for truck analysis techniques, can be collected by survey methods, as has been done recently by the Washington DOT [5.3], but increasingly models are using commodity flow data as their basis. NCHRP released two reports in the late 1970s [5.4, 5.5] that began to address the data requirements of statewide freight modeling. These two reports present 228 different sources of data that could be used for freight forecasting. More recently, *NCHRP Report 388* [5.1] has provided an update to the list of data sources. Meanwhile, the Bureau of the Census’s 1993 Commodity Flow Survey has been used by several states to develop their own commodity flow interactions. A number of private firms also offer (for a fee) access to their collections of historical and forecast data, not only for population and general employment data, but for employment and commodity flows by industry. Reebie's TRANSEARCH database has been a popular source, but many others are available [5.1] or are under development. Much of the currently available data is unfortunately provided only at a Bureau of Economic Analysis (BEA) region level, which is generally too big for statewide analysis. The data must therefore be disaggregated to at least a county level before use. Some databases under development by the FHWA (with Reebie and Colography, another private firm, for instance) are aimed at directly providing county-level data.

Statewide Models for Freight Forecasting

Likely influenced by deregulation in the railroad industry, there seems to have been a flurry of interest in statewide freight forecasting in the early 1980s. At that time *NCHRP Report 260* [5.6] and papers in *Transportation Research Record 889* [5.7, 5.8, 5.9] presented organized methods of modeling freight traffic at a statewide level. The modeling techniques described are of two types: (1) calculation of growth factors (by commodity) to be applied to existing traffic patterns [5.8] or (2) use of forecasts of future freight flows (by commodity) distributed by a gravity model. Aside from isolated examinations of specific issues [5.10], most proposals for statewide freight modeling have closely followed the pattern of these early 1980s papers.

Documentation for a few statewide freight models was obtained as part of the research for this appendix, and their features are summarized in Table A.3. Of these models, only Louisiana's [5.11] is of the growth factor type noted above. It is a relatively simple example, but it is also the most explicitly multimodal model provided. The report of a recent FHWA project [5.12] offers recommendations on how to apply similar growth factor methods with increasing degrees of sophistication. The Indiana [5.13] and the Wisconsin [5.14] models are both of the commodity forecast type noted above, and the comparatively coarse structure of their models – an order of magnitude fewer TAZs than for a typical passenger model – is evidence of the reduced ability to disaggregate freight data to a less-than-county level. Both the Indiana and Wisconsin models are reviewed in greater detail in Section A.7. The Michigan [5.15] and New Jersey [5.16] models are, as can be seen from Table A.3, truck models and share an identical network structure with their respective statewide passenger models (see Table A.2).

Related Models

Some work done in the late 1980s with models for Alberta and Brazil by Canadian researchers is also applicable to statewide freight modeling in the United States. In papers describing their model for the Province of Alberta, Ashtakala and Murthy [5.17, 5.18] present a sequential model with a gravity-style trip distribution based on commodity flows. Its useful features include a Box-Cox procedure to calibrate the friction factors for the gravity model and a "Commodity Haul Frequency Diagram" to visually assist in calibration of the gravity model. Their related work with a logit mode-split model has already been noted in Section A.3.

Another notable effort from Canada is the STAN system developed by the Centre de Recherche sur le Transports at the Universite of Montreal [5.19, 5.20, 5.21]. The STAN model was developed from the EMME/2 passenger modeling set of programs and includes a sophisticated "multimode multiproduct" model [5.21], which assigns traffic to the various modes and links according to the solution to an optimization problem. Application of STAN was made to a large region of Brazil, and ample evidence is provided of the graphical output made available by STAN.

Table A.3: Current Statewide Freight Models

STATE	TAZs	MODES	PURPOSES	COMMENTS
Indiana	145 total	1. Truck 2. Rail	21 Commodity Groups	• Based on 1993 Commodity Flow Survey. • Distribution by fully-constrained gravity model.
Louisiana	----	1. Truck 2. Rail 3. Water 4. Air	11 Commodity Groups	• Based on commodity-specific growth factors applied to existing traffic volumes.
Michigan	2392 total	Truck only	11 Commodity Groups	• Trip generation regressed by commodity using (1) employment and (2) tons shipped. • Michigan truck survey, BEA commodity flows and US-Canada trade flows (FHWA) used.
New Jersey	2762 internal 51 external	Truck only	----	• Based on four-digit STCC code commodity flow analysis.
Wisconsin	106 internal 34 external	1. Truck 2. Rail	39 Commodity Groups	• Internal TAZs at a county level. • Consideration of rail-to-truck intermodal diversion scenarios.

Discussion

Statewide models for freight transportation appear to be structured with a strong sense of the limitations inherent in forecasting at a large geographical scale. This is reflected in their documentation which is generally more straightforward than that for passenger modeling. This may be because freight forecasting models have developed independently enough from the four-step urban modeling process that they can begin to address problems (such as data availability) that are unique to their statewide nature. Further discussion of the characteristics of statewide freight forecasting models is presented in Section A.7.

A.6. Two Recent Passenger Models

This section provides a closer examination of the recent statewide passenger modeling efforts for the states of Michigan and Kentucky. As discussed in Section A.4, both Michigan and Kentucky have comparatively long histories of statewide modeling, and both have produced documentation describing their most recent modeling efforts. This documentation provides some indication of the difficulties involved in producing a workable statewide model and the significant number of assumptions and adjustments that often must be made in the statewide modeling process.

The Michigan Passenger Model

The Michigan model [6.1] is a traditional statewide model, in the sense that it retains the characteristics of an urban model (many TAZs, many purposes), but on a much larger scale. The Michigan model is a “four-step” model that, as can be seen in Table A.2, forecasts travel for five trip purposes between 2392 TAZs. A graphical depiction of the Michigan network can be seen in Figures A.5, A.6 and A.7. Most of the TAZs appear to be at the township-level, with smaller TAZs in large urban areas and larger TAZs in rural areas and the Upper Peninsula. The vast majority (2307) of the TAZs are within Michigan while the remaining 85 represent the other 47 contiguous United States, Canada and Mexico. In addition, the model includes thousands of special generator sites, divided into 10 general categories by type of facility (airports, tourist attractions, campgrounds, state parks, golf courses, marinas, motels, hospitals, shopping centers and colleges).

Michigan's modeling procedure starts by using socioeconomic data developed at a county level from a Regional Economic Model, Inc. (REMI) model. This information is then disaggregated to a TAZ-level using data from the Michigan Employment Security Commission. Census data from the Public Use Microdata Sample (PUMS) and the CTPP are then used to develop cross classification tables based on five different household sizes (1, 2, 3, 4 and 5+ persons per household) and three income groups (low, medium and high) for a total of 15 categories. It should be noted that the PUMS data is available at the Public Use Microdata Area (PUMA) level. Since there are 67 PUMAs in Michigan, a PUMA is essentially equivalent to a county in its level of aggregation. For forecasts of future travel activities, REMI-generated county-level growth factors are applied to all TAZs in a particular county.

The trip production step for internal trips involves the use of equations for trip production from the as-yet-unpublished update to *NCHRP Report 187*. These production rates are distributed to the five trip purposes according to proportions based on NPTS data and are applied to the 15 cross-classification categories noted above, further classified by five geographical categories (four for different city sizes and one for rural areas). Figure A.8 shows some example calculations for the production rates that are used. Equations for internal trip attractions are based on an evaluation of alternative rates generated from NPTS data, metropolitan area studies in Michigan and available data from the San Francisco area. Table A.4 shows the final attraction rates. Total productions and attractions are then the result of entering TAZ-level household socioeconomic data into these equations.

The numerous special generator sites are evaluated as having attraction value only. The Institute of Transportation Engineers' *Trip Generation* was used (along with local surveys) to develop the attraction equations. Table A.5 shows the information used in developing these attraction rates. The trips attracted to the special generator sites are only for the home-based social/recreational and home-based other purposes, since a preliminary analysis revealed that attractions for the other purposes were inconsequential. For trips with ends outside of Michigan, production and attraction equations were developed using NPTS data for trips greater than 75 miles in length. Trips from any state not represented in the NPTS data are estimated as a function of the state's area.

Trip distribution is accomplished using a gravity model. Friction factors for the gravity model are calculated using a gamma function of the generalized cost of travel (see Figure A.9). The gamma function was chosen to provide maximum flexibility in accounting for both very short and very long trips that are possible in a statewide model. The gravity model was calibrated using NPTS data and validated using CTPP and traffic count data. Three types of "geographic adjustment" factors (K-factors) are also used in calibrating the gravity model. These K-factors are based on information regarding existing (1) county-to-county, (2) major city-to-city and (2) outstate/instate traffic flows and the values of the K-factors listed in the documentation range from as low as 0.10 to as high as 9.67. Unlike previous statewide models for Michigan, this most recent model includes intrazonal trips. The impedances for intrazonal trips are calculated separately from the network, however, to avoid complications due to the arbitrary placement of TAZ centroids with respect to highway links.

Figure A.5. Instate TAZs from Michigan Model

Figure A.6. Instate Highway Network from Michigan Model

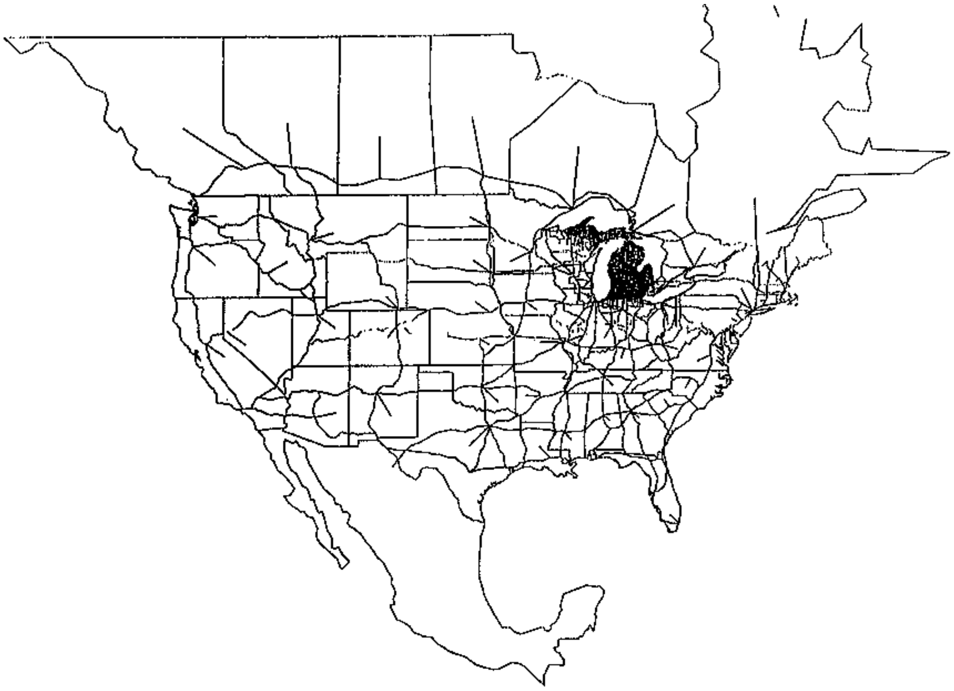

Figure A.7. Outstate Highway Network for Michigan Model

Table A.4a. Attraction Rates from Michigan Model, Urban Areas

		Employment Category					
Purpose	**Total**	**Retail**	**Whole-sale**	**Service**	**Mfg.**	**Other**	**House-holds**
HBW	1.486	---	---	---	---	---	---
HB Rec	---	1.300	---	0.260	---	---	0.522
HB Other	---	6.360	2.650	1.802	---	0.530	---
NHB Work	---	0.797	---	0.232	0.097	---	---
NHB Other	---	4.123	---	1.207	---	0.583	0.350

Table A.4b. Attraction Rates from Michigan Model, Rural Areas

		Employment Category					
Purpose	**Total**	**Retail**	**Wholes ale**	**Service**	**Mfg.**	**Other**	**House -holds**
HBW	1.486	---	---	---	---	---	---
HB Rec	---	0.522	---	0.087	---	---	0.522
HB Other	---	10.07	2.650	1.802	---	0.530	---
NHB Work	---	0.728	---	0.212	0.088	---	---
NHB Other	---	3.748	---	1.097	---	0.530	0.318

First, using the *NCHRP 187* update, obtain generation rates for the various cross-classification categories. For instance, in a large urban area (population greater than 1 million), a low-income, single-occupant household will produce 3.7 trips per day.

Second, from the NPTS, apportion the trips produced to the Michigan model's purposes according fixed ratios. Again, for large urban areas the following ratios are used for low-income, single-occupant households:

0.192 to home-based work (HBW),
0.160 to home-based recreational,
0.404 to home-based other,
0.310 to non-home based work and
<u>0.214 to non-home based other.</u>
1.00 (100% of trips accounted for)

Next, multiply these factors. For instance, (3.7 x 0.192) = 0.71 HBW trips from each low income, single occupant household. Similarly, (3.7 x 0.160) = 0.59 home-based recreational trips, etc.

Finally, repeat the process all combinations of urban (and rural) areas, income groups, household sizes and trip purposes.

Figure A.8. Sample Production Rates Calculations from Michigan Model

The mode-split step is really a vehicle occupancy step, since a more sophisticated intermodal model has proved difficult to develop. The vehicle occupancy step consists of three sub-steps. First, a county-level transit share is developed for work trips based on average CTPP shares and extended to other purposes by using work/non-work ratios from the NPTS. The resulting shares are applied to every TAZ in the county. Second, person trip and vehicle trip data from the NPTS are used to develop average occupancy rates by trip purpose for each of the 15 cross-classification categories noted earlier. Representative minimum and maximum values are shown in Table A.6. Finally, adjustment factors are developed to account for trip length, based again on NPTS data. A graph of the resulting factors is shown in Figure A.10. After applying these occupancy factors, the trips are then assigned to the network using an all-or-nothing procedure.

It should be noted that the model documentation describes experiments made during model development with proprietary software for synthesizing trip tables based on single-station origin-and-destination surveys and for employing a "stochastic user equilibrium" algorithm for trip assignment. Both experiments proved unsatisfactory and are not included in normal operation of the model.

Table A.5. Special Generator Attractions from Michigan Model

Special Generator Type	Source of Rate	Rate Equation
Airports	1991 ITE Manual	exp[1.368 x ln(reg. aircraft) - 0.347] or [104.73 x operations /365]
Tourist Attractions	MDOT Travel & Tourism	2 x attendance
Campgrounds	1991 ITE Manual	0.79 x campsites
State Parks	1991 ITE Manual	0.50 x acres
Golf Courses	1991 ITE Manual	37.59 x holes
Marinas	1991 ITE Manual	(1.891 x berths) + 410.795
Motels	1991 ITE Manual	exp[0.713 x ln(0.44 x rooms) + 3.945]
Hospitals	1991 ITE Manual	exp[0.634 x ln(beds) + 4.628]
Shopping Centers	1991 ITE Manual	exp[A x ln(ksf) + B] where A = 0.756, B = 5.154 for > 570 ksf and A = 0.625, B = 5.985 otherwise
Colleges & Universities	1987 and 1991 ITE Manuals	2.37 x students (for universities) or 1.55 x students (for community colleges)

Gamma function formulation for friction factors:

$$f = a\,T^{b} \times \exp(c\,T)$$

where:

f = friction factor
T = travel time (or generalized cost of travel)
a, b and c = constants of calibration

Figure A.9. Gamma Function for Friction Factors from Michigan Model

Table A.6. Maximum and Minimum Occupancy Rates from Michigan Model

	Trip Purposes				
Occupancy Rates	**HBW**	**HB Rec**	**HB Other**	**NHB Work**	**NHB Other**
Minimum	1.07	1.20	1.13	1.12	1.22
Maximum	1.13	1.76	1.57	1.19	1.55

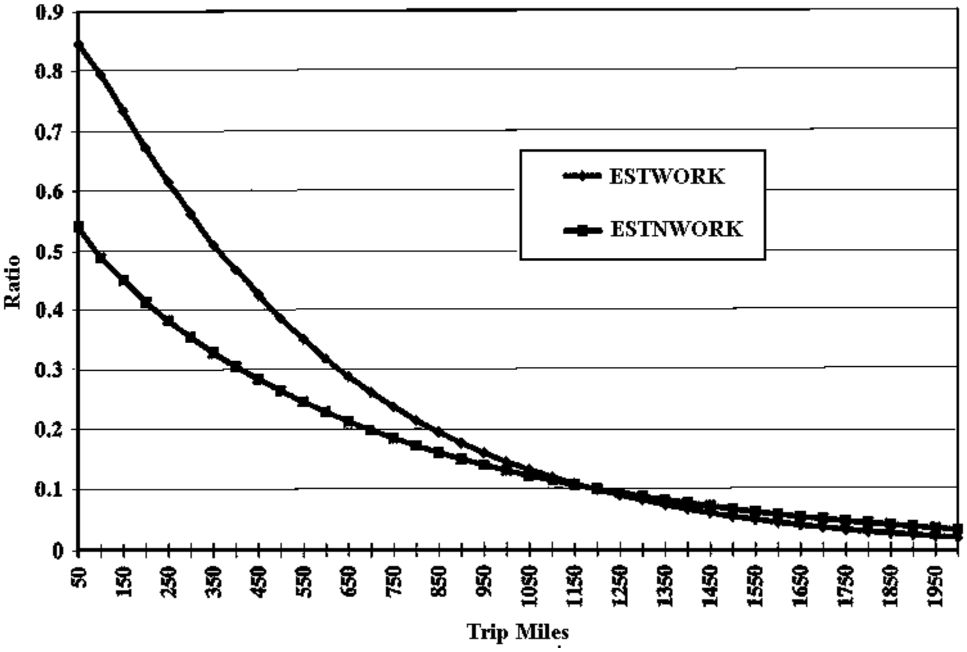

Figure A.10. Trip Length Occupancy Factors from Michigan Model

The Kentucky Passenger Model

The most recent Kentucky model [6.2] forecasts travel for three trip purposes (plus trucks) among nearly 1500 TAZs, almost half of which are outside of the state. The large number of TAZs outside of the state borders is a distinctive feature of the Kentucky model. The model's network actually extends to include almost all of Tennessee, more than half of West Virginia, Ohio and Indiana, as well as significant proportions of the other surrounding states. The TAZs inside the state consist of individual census tracts in rural areas and groups of census tracts in urban areas. In addition to the census-based TAZs, special generator TAZs are included at 40 significant recreational areas and military bases and 29 external station TAZs are included to model travel into the network from the remainder of the United States (mostly via the interstate highway system). A graphical depiction of the Kentucky network is shown in Figure A.11.

Except for special generator and external station TAZs, the trip generation step uses projections of population and employment provided by a commercial source, Woods & Poole. Trip generation rates for home-based work (HBW) trips are developed in a spreadsheet that calculates county level trip generation rates by multiplying the national NTPS production rates (for large urban areas and for other areas) by a ratio of county-specific to national production and attraction rates based on JTW data. The national rates used from the 1990 NPTS are shown in Table A.7. The Kentucky model's documentation indicates that the JTW rates vary between 0.246 and 0.435 trips produced per person and between 0.532 and 0.744 trips attracted per employee, depending upon the county examined. Total HBW attractions are then adjusted to match productions.

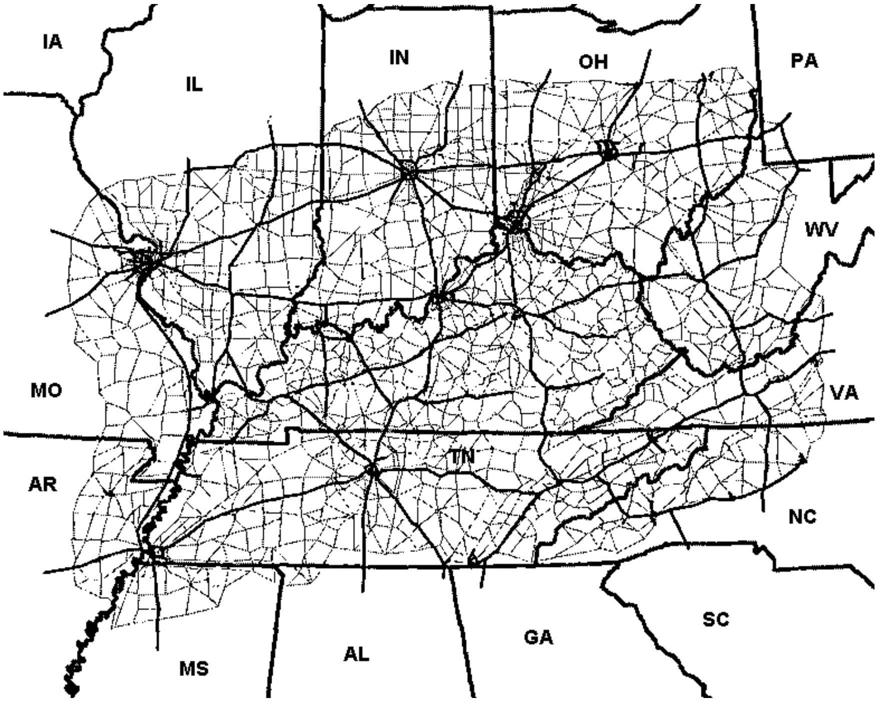

Figure A.11. Network Structure from Kentucky Model

Table A.7. NPTS Trip Rates Used in Kentucky Model

NPTS Trip Purpose	Rate for Large Urban Areas (trips per person)	Rate for Other Areas (trips per person)
HB Work	0.5390	0.5236
HB Business	0.0364	0.0414
HB Shop	0.3261	0.3346
HB Social-Rec	0.4420	0.4282
HB Other	0.5969	0.6313
Non Home Based	0.6041	0.6122
Total	2.5445	2.5714

Less guidance is available from census sources regarding nonwork trips, which in the case of the Kentucky model include home-based other (HBO) and non-home based (NHB) purposes. Instead, nonwork trips are divided into three categories: (1) “short” trips – those less than 60 minutes in length; (2) “long” trips – those longer than 60 minutes in length; and (3) through trips. Starting from national-level NPTS generation rates, it is assumed that 99% of nonwork trips are short trips and that 70% of all nonwork productions are HBO. Attraction rates are taken from *NCHRP Report 187*, assuming that retail employment in all areas is 20% of total employment. Again, for nonwork trips, attractions are adjusted to match productions.

Recreational special generator TAZs are classified as either “local” or “national”, with the assumption that 67% of the nonwork trips generated are “short” trips and 33% are “long” trips for “local” areas and vice versa for “national” recreation areas. For military special generators only work trips are considered, and it is assumed that 20% of the work trips generated are intrazonal trips and are not assigned to the network. A Fratar model is used to predict nonwork trips passing through the network. There is no mode-split or auto-occupancy step, and traffic assignment is evidently done using an all-or-nothing technique, since no other details are provided in the documentation.

The trip distribution step is accomplished using a gravity model. However, limitations in Kentucky's software used to calibrate the friction factors, require that HBW trips over 120 minutes in length be eliminated from the process. Kentucky judged this to have a beneficial effect on model performance, since a few very long trips can have a disproportionately large effect on the average trip length calculated for calibration. Friction factors for HBW trips are developed from JTW survey information, but intrazonal travel times are deliberately kept small (a maximum of 15 minutes) in order to keep intrazonal trips off the statewide network. For nonwork trips, friction factors are developed from the previously noted unpublished update to *NCHRP Report 187*, but friction factors for "long" trips are synthesized to give a "reasonable" trip frequency distribution. A summary of the various friction factors in their final form is presented in Figures A.8 and A.9. K-factors are also used at a county level to adjust the distribution of HBW trips, but the documentation does not indicate a range of values used. The friction factors and K-factors are subsequently adjusted to provide a good fit with known screenline counts and average trip length frequency data from the JTW survey.

A further procedure described as "trip table calibration" is mentioned in the documentation, but described only as "similar to the Fratar process". An appendix to the documentation further describes it as an iterative adjustment procedure where the modeled volumes on network links are matched to corresponding traffic counts on the roads they represent. Of course, the end result is a better fit between the model and the base year traffic. Unfortunately, since accessibility effects are not considered in this data synthesis procedure, the gravity model cannot be used to forecast future volumes when the "trip table calibration" procedure is used. The Kentucky model's documentation instead recommends that if accessibility changes are expected in the future, the following three-part procedure be followed: (1) a "fratared" forecast should be prepared using the "trip table calibration" results, (2) a gravity model forecast should be produced that includes accessibility changes and (3) a final forecast should be manually generated to resolve any inconsistencies.

Discussion

As noted above, one similarity between the Michigan and Kentucky passenger models is their fine geographical level of detail in comparison with statewide freight models and with several other statewide passenger models (see Tables A.2 and A.3). The 756 instate TAZs for Kentucky are, on average, twice as big as the 2307 instate TAZs for Michigan (52 sq. mi. per TAZ versus 25 sq. mi. per TAZ, respectively), but are relatively close in terms of average population per TAZ. Based on 1990 population figures, the Kentucky TAZs average slightly more than 5000 residents each, while the Michigan TAZs average 4100 residents each. Selection of the "grain-size" for the model should be made considering its intended use. If forecasts of general trends are being sought, perhaps fewer, larger TAZs will suffice. Similarly, if project-specific planning capabilities are desired using the statewide model, a more "fine-grain" model may be useful. In either case it would appear that using a large number of TAZs precludes the use of any but the most basic data from any individual TAZ. The likelihood that meaningful adjustments could be made to the model based on detailed knowledge of activities in any particular TAZ is therefore diminished. It should also be noted that many calculations (involving generation rates, growth factors, K-factors, transit shares, etc.) are already made using only county-level data in both of the models examined.

Table A.8. HBW Friction Factors from Kentucky Model

Travel Time (min.)	Friction Factor	Travel Time (min.)	Friction Factor	Travel Time (min.)	Friction Factor	Travel Time (min.)	Friction Factor
1	259,360	**31**	4675	**61**	257	**91**	24
2	203,007	**32**	4177	**62**	236	**92**	22
3	159,242	**33**	3737	**63**	218	**93**	20
4	125,178	**34**	3348	**64**	200	**94**	19
5	98,609	**35**	3003	**65**	184	**95**	17
6	77,840	**36**	2697	**66**	170	**96**	16
7	61,572	**37**	2426	**67**	157	**97**	15
8	61,572	**38**	2184	**68**	144	**98**	13
9	61,572	**39**	1969	**69**	133	**99**	12
10	61,572	**40**	1777	**70**	123	**100**	11
11	61,572	**41**	1605	**71**	114	**101**	11
12	53,244	**42**	1452	**72**	105	**102**	10
13	46,129	**43**	1315	**73**	97	**103**	9
14	40,040	**44**	1192	**74**	90	**104**	8
15	34,818	**45**	1082	**75**	83	**105**	8
16	30,333	**46**	982	**76**	76	**106**	7
17	26,472	**47**	893	**77**	71	**107**	6
18	23,143	**48**	813	**78**	65	**108**	6
19	20,268	**49**	740	**79**	60	**109**	5
20	17,780	**50**	675	**80**	56	**110**	5
21	15,624	**51**	616	**81**	52	**111**	4
22	13,752	**52**	563	**82**	48	**112**	4
23	12,123	**53**	514	**83**	44	**113**	4
24	10,705	**54**	470	**84**	41	**114**	3
25	9468	**55**	431	**85**	38	**115**	3
26	8386	**56**	394	**86**	35	**116**	3
27	7439	**57**	362	**87**	32	**117**	3
28	6609	**58**	332	**88**	30	**118**	2
29	5880	**59**	304	**89**	28	**119**	2
30	5239	**60**	280	**90**	26	**120**	2

The most immediately visible difference between the Michigan and Kentucky models is their treatment of the geographical areas outside of their respective state boundaries. The Michigan model's roadway network is built with connections to outstate areas at relatively few discrete points (see Figure A.6). In contrast, the Kentucky model's highway network extends more than 200 miles into the surrounding states (see Figure A.11). While limiting border crossings to a few very select locations may be acceptable for a peninsular state like Michigan, it is a bit more troublesome for a landlocked state like Kentucky. It should also be noted that, since the Kentucky model does not include a national network (as Michigan's does), it must include external stations to generate travel between the network and external areas. The cushioning effect of the 200-mile wide outstate network makes the precise trip generation values for the external stations less important. The Kentucky modeling strategy, to include TAZs and network links well outside its state boundaries, poses a similar problem to that posed by using a large number of instate TAZs. That problem is the need to know detailed information about hundreds of TAZs and road segments outside of Kentucky.

Table A.9. Nonwork Friction Factors from Kentucky Model

“Short” Non-Work Trips			
Travel Time (min.)	**Friction Factor**	**Travel Time (min.)**	**Friction Factor**
1	999,999	**31**	639
2	367,878	**32**	557
3	196,955	**33**	486
4	122,954	**34**	425
5	83,497	**35**	372
6	59,802	**36**	326
7	44,435	**37**	285
8	33,916	**38**	250
9	26,425	**39**	220
10	20,925	**40**	193
11	16,788	**41**	170
12	13,616	**42**	150
13	11,144	**43**	132
14	9192	**44**	116
15	7632	**45**	103
16	6374	**46**	91
17	5351	**47**	80
18	4512	**48**	71
19	3821	**49**	63
20	3247	**50**	56
21	2768	**51**	49
22	2367	**52**	44
23	2029	**53**	39
24	1744	**54**	34
25	1503	**55**	30
26	1297	**56**	27
27	1122	**57**	24
28	972	**58**	21
29	844	**59**	19
30	734	**60**	17

“Long” Non-Work Trips	
Travel Time (min.)	**Friction Factor**
1	1
60	1
61	200
181	50
241	6
301	3
361	1
421	1
481	1
541	1
601	1
661	1
720	1

Travel data used to construct both the Michigan and Kentucky models comes primarily from three US government sources, specifically the NPTS, the CTPP and the JTW survey. Perhaps the most troubling aspect of the Kentucky model is its extensive use of national average values derived from these sources in combination with assumed ratios of travel characteristics (99% of nonwork trips are “short”, 70% of nonwork trips are HBO, etc.) that are also based on national averages. According to the Kentucky documentation, this dependence on national average figures is due to the dearth of readily available data for Kentucky.

A similarly troubling feature of the Michigan model is its extensive use of K-factors to adjust the gravity model results. As noted above, the Michigan model makes use of three overlapping sets of K-factors – one set at a county level and two other sets for specific destination TAZs – to modify the distribution of travel predicted by the model. The K-factors appear to be produced in a mechanical fashion, without consideration of any behavioral basis for factoring (e.g., reluctance to cross a state line for work or social differences between regions). The very large and very small values of the K-factors developed (see earlier discussion) seem to indicate that some simplification of this process would not compromise the modeled results. The Kentucky model also makes use of K-factors, but in a less aggressive fashion. It is also important to note that Kentucky attempted to develop rationally-based K-factors, but those efforts proved problematic and were abandoned.

One final contrasting element of the Michigan and Kentucky models is their treatment of special generator sites. Michigan's lengthy list of special generator sites continues for 51 pages of small print type, including individual hotels, shopping centers and golf courses. It would appear that merely maintaining the database for these thousands of locations would be a significant task in itself. It is unclear what advantage this provides for statewide modeling. Kentucky's approach, using only 40 of the most significant special generator sites, is more limited and presumably more in keeping with modeling at a statewide level.

A.7. Two Recent Freight Models

As a complement to the passenger models discussed in the previous section, this section provides a closer examination of two statewide models for freight traffic forecasting. The models examined – Wisconsin and Indiana – represent typical examples of recent thinking in freight forecasting. Both models are constructed to operate in a sequential fashion, similar to passenger models, but their TAZ structures are much more coarse. As with the statewide passenger models, these freight models show the number of simplifying assumptions must be made to facilitate model development.

The Wisconsin Freight Model

The Wisconsin freight model [7.1] estimates the freight traffic carrying the products of 39 important commodity groups between 140 TAZs by four modes: air, water, truck and rail. Of the 140 TAZs, 106 are counties. Each of Wisconsin's 72 counties is represented by a separate TAZ, while the remaining 34 county-level TAZs represent counties in adjacent states. The other 34 TAZs are composed of multiple BEA regions that represent other states. Figures A.12 and A.13 show the TAZ structure for the Wisconsin model. Table A.10 lists the 39 commodity groups that are considered important for Wisconsin and are used in the modeling process.

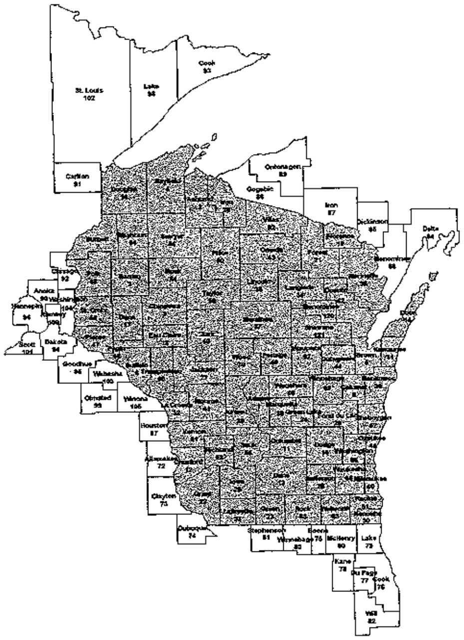

Figure A.12. Local TAZs from Wisconsin Model

The principal data on which the Wisconsin model is taken from Reebie's TRANSEARCH. The TRANSEARCH data, which is provided at a BEA region level of aggregation, is supplemented by some commodity flow data specific to Wisconsin. No generation equations for freight flow are developed, instead the TRANSEARCH flows are simply distributed at the county level in a four step process as follows. First, the <u>total flows</u> are determined from the base-year TRANSEARCH data for each important commodity group. Second, freight <u>origins</u> are identified and are assigned to the county-level TAZs based on county employment data. Third, based on a national input-output table, it is determined which proportion of each commodity group's flow is destined for industrial consumption and which is destined for household consumption. Finally, county-level destinations are allocated based on employment (for industrial consumption) and population (for household consumption). Factors are also calculated for “secondary” trucking volumes as a function of the primary freight flows. These factors represent the additional movements for freight distribution and drayage from intermodal yards.

Forecasts of future freight flows are made using econometric models that include employment forecasts obtained under a contract with WEFA (another private firm) and productivity forecasts made using information from REMI. This constitutes what is called the “trendline” forecast. Adjustments are made to the “trendline” forecast by enlisting the services of various expert panels, who add a “market driven” element to the forecast values. Since the forecast flows would project the current modal shares into the future, Wisconsin also developed an approach which uses another panel of experts to identify alternative rail-truck modal splits based on shipment distance and frequency of rail service. This approach is less formalized than that used in the “trendline” model, but is important to making policy decisions based on the model results.

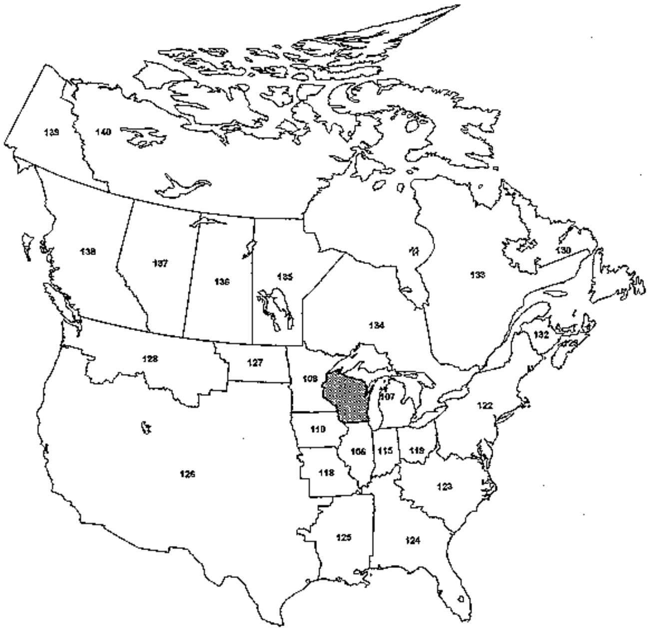

Figure A.13. Outstate TAZs from Wisconsin Model

Once the freight flows (by weight) are determined, they are converted into an equivalent number of vehicles. Initially weight-per-vehicle ratios of 100 tons per railcar and 24 tons per truck were used for all commodities. Tons-per-truck values were subsequently modified by commodity group to the values shown in Table A.4. Daily flows are determined by dividing the total number of vehicles by a value of 312 working days per year, based on a six-day work week. The resulting daily flows are then assigned to the appropriate modal networks. The truck assignment is done all-or-nothing. For rail each shipment is designated as having a “most likely carrier”, and the shortest path using that carrier alone is assigned the shipment. Air and water traffic are not assigned.

The Indiana Freight Model

The TAZ structure for the Indiana freight model [7.2] is very similar to that used in the Wisconsin model. The Indiana model predicts both truck and rail traffic volumes for a network that includes a TAZ for each of Indiana’s 92 counties and 53 more TAZs that represent the remaining 47 contiguous states and the District of Columbia. (There are three TAZs for Ohio and two each for Illinois, Kentucky and Michigan. All other states and the District have one TAZ each.) Both the truck and rail networks were developed from US DOT sources. Figures A.14 and A.15 graphically depict the Indiana freight network. It should be noted that, as for the Kentucky passenger model, the detailed roadway network for the Indiana freight model extents to about 200 miles beyond the state’s border.

Table A.10. Important Commodity Groups and Traffic Densities

		Wisconsin Model	**Indiana Model**	
STCC	**Description**	**Tons per Truck**	**Tons per Truck**	**Tons per Railcar**
1	Farm Products	24	38	96
8	Forest Products	13	--	--
9	Fish or Marine Products	6	--	--
10	Metallic Ores	24	--	--
11	Coal	24	40	100
13	Crude Petroleum, Nat. Gas, Gasoline	14	--	--
14	Nonmetallic Ores	19	39	97
19	Ordinance or Accessories	24	--	--
20	Food and Kindred Products	18	32	80
21	Tobacco Products	5	See note 1	See note 1
22	Textile Mill Products	5	7	18
23	Apparel or Finished Textile Products	3	4	10
24	Lumber or Wood Products	15	29	72
25	Furniture or Fixtures	3	6	15
26	Pulp, Paper or Allied Products	16	25	62
27	Printed Matter	9	See note 1	See note 1
28	Chemicals	22	35	88
29	Petroleum or Coal Products	19	26	66
30	Rubber or Misc. Plastics Products	4	See note 1	See note 1
31	Leather or Leather Products	3	See note 1	See note 1
32	Clay, Concrete, Glass or Stone Products	23	32	81
33	Primary Metal Products	19	34	86
34	Fabricated Metal Products	24	8	20
35	Machinery - Other than Electrical	9	11	28
36	Electrical Machinery, Equip., Supplies	8	7	17
37	Transportation Equipment	12	9	23
38	Instruments - Photo. or Optical Goods	5	See note 1	See note 1
39	Misc. Manufacturing Products	2	See note 1	See note 1
40	Waste or Scrap Metals	16	31	78
41	Misc. Freight Shipments	23	--	--
42	Shipping Devices Returned Empty	4	--	--
43	Mail and Express Traffic	3	See note 2	See note 2
44	Freight Forwarder Traffic	4	--	--
45	Shipper Association Traffic	3	--	--
46	Misc. Mixed Shipments	7	--	--
47	Small Packaged Freight Shipments	4	--	--
48	Hazardous Waste	16	--	--
49	Hazardous Materials	18	--	--
99	Unknown	12	--	--
Other		--	35	87

Notes:
1. For Indiana model, “Other” includes STCC groups 21, 27, 30, 31, 38, 39.
2. For Indiana model, US mail and express mail groups are analyzed separately.

The actual workings of the model are very similar to a UTP model. For each of 21 commodity groups that are considered important to Indiana (see Table A.10), trip generation equations were developed based on a regression of data available from the 1993 CFS. Forecasts for

Indiana county productions and attractions are then based on county-level employment and population projections commercially available from Woods & Poole. Table A.11 shows the trip generation equations that were developed. For areas outside of Indiana, forecasts are based on national growth factors.

Following trip generation, freight shipments are distributed by a gravity model that is also calibrated using the CFS data. Special care is taken to match the average shipping distance per ton for each commodity group. This prevents an inappropriate weighting for many short-distance lightweight deliveries versus a few long-distance heavyweight shipments that might be included in the same commodity group. The mode split step also utilizes the 1993 CFS, projecting the 1993 national shares into the future.

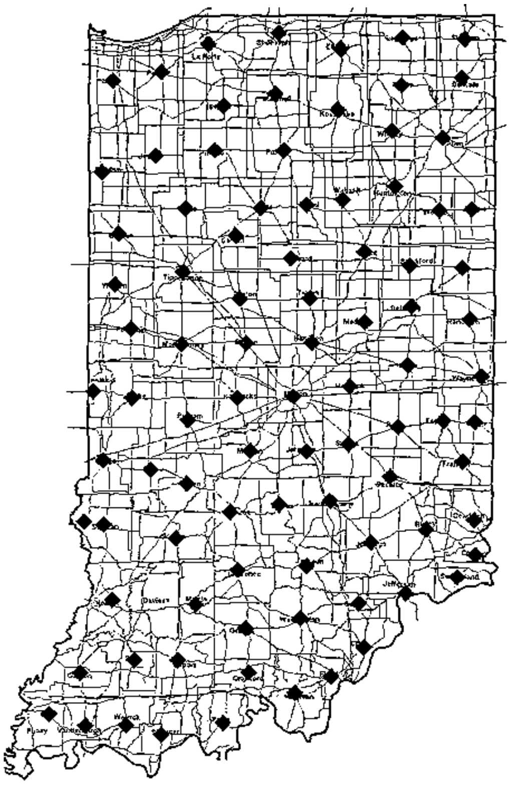

Figure A.14. Instate TAZs from Indiana Model

Before assigning traffic to the network, the Indiana model (like the Wisconsin model) divides the freight tonnages into an equivalent number of vehicles, with tons-per-vehicle rates determined separately for each commodity group. The rates are based on values (by commodity group) from the ICC Rail Waybill sample and the assumption that each truckload carries 40% of the load carried by a railcar. The tons-per-truck and tons-per-railcar values used are shown in Table A.10. A daily traffic conversion is also made for the Indiana model, assuming 5 working weekdays and (from the *Highway Capacity Manual*) 0.44 working days for each weekend day. This results in a 5.88 day work week or a 306 day shipping year.

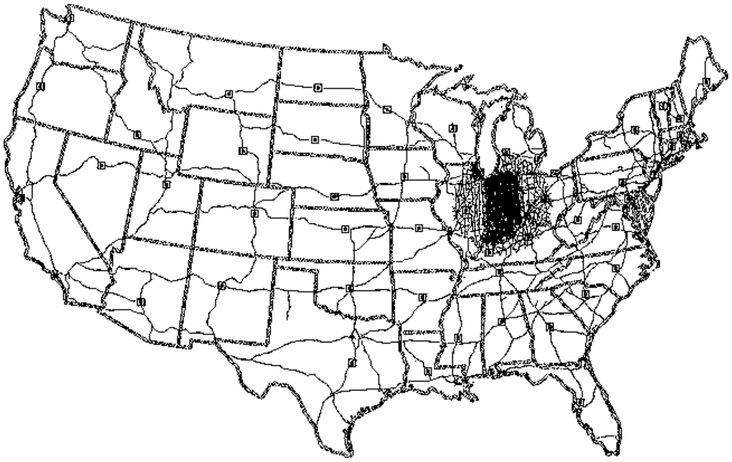

Figure A.15. Out-of-State TAZs for Indiana Model

Finally, the traffic is assigned to the network using an all-or-nothing process. Since a straight all-or-nothing assignment typically loads too many trips onto the interstate highways, a procedure to adjust the link speeds for non-interstate highway segments is provided. The adjustment involves calculating new speeds for non-interstate links using the equation shown in Figure A.16. This serves to draw more trips from the interstate roads to the competing US and state highways that run parallel to them.

$$S_{adj} = S_{prev} + [2 \times (65mph - S_{prev})^{0.5}]$$

where:

S_{adj} = the adjusted link speed
S_{prev} = the previously used link speed (usually the speed limit on the link)

Figure A.16. Link Speed Adjustments from Indiana Model

Table A.11. Trip Generation Equations from Indiana Model

Commodity Group (by STCC)[1]	Trip Generation Equations[2] (tons produced or attracted)
1	P = 1445 - 0.523(ag services) + 0.0048(ag cash) A = 0.819 P
11	P = 7.6 (coal) A = 3.1(coal) + 5.3(mining)
14	P = 0.078(manufacturing) A = 0.997 P
20	P = 0.282(food) A = 0.832(population) + 0.162(food)
22	P = 0.016(textiles) A = 0.003(apparel) + 0.0001(all)
23	P = 0.004(apparel) A = 0.002(apparel) + 0.011(population)
24	P = 0.668(lumber) A = 0.728 P
25	P = 0.017(furniture) A = 0.033(population) + 0.002(furniture)
26	P = 0.103(pulp) + 0.056(lumber) A = 0.085(pulp) + 0.259(population)
28	P = 0.150(chemicals) + 1.164(petroleum) A = 0.077(chemicals) + 0.455(petroleum) + 0.683(population)
29	P = 6.857(petroleum) A = 4.007(petroleum) + 1.881(population)
32	P = 2.882(population) A = 2.914(population)
33	P = 0.085(metals) A = 0.093(metals) + 0.061(fabrication)

Table A.11. Trip Generation Equations from Indiana Model (continued)

Commodity Group (by STCC)[1]	**Trip Generation Equations**[2] **(tons produced or attracted)**
34	P = 0.013(metals) + 0.034(fabrication) A = 0.035(fabrication)
35	P = 0.013(machinery) A = 0.010(machinery)
36	P = 0.004(metals) + 0.004(fabrication) + 0.003(electrical) A = 0.005(fabrication) + 0.034(population)
37	P = 0.040(transportation) A = 0.027(transportation)
40	P = 0.00048(population) A = 0.0067(manufacturing)
Other	P = 1.097 A A = 0.254 (population)

Notes: 1. See Table A.10 for description of groups.

2. population = total population
all = total employment
ag services = employment is SIC 7
ag cash = gross receipts (in $1000) from farming
coal = employment in SIC 11
mining = employment in SIC 14
manufacturing = employment in SIC 2 and SIC 3
food = employment in SIC 20
textiles = employment in SIC 22
apparel = employment in SIC 23
lumber = employment in SIC 24
furniture = employment in SIC 25
pulp = employment in SIC 26
chemicals = employment in SIC 28
petroleum = employment in SIC 29
metal = employment in SIC 33
fabrication = employment in SIC 34
machinery = employment in SIC 35
electrical = employment in SIC 36
transportation = employment in SIC 37

Discussion

As noted above, both the Wisconsin freight model and the Indiana freight model use a county-level TAZ structure. This appears to be the accepted level of geographical detail for freight modeling for two reasons. First, essential commodity flow information has been widely available only at the BEA region level of detail, which is too large a geographical area for meaningful use in a statewide model. Use of this information at a county level involves only one step of disaggregation. In contrast, using smaller scale TAZs (e.g., at the census tract or township level) typically involves additional disaggregation steps and additional layers of assumptions about the characteristics of the commodity flows. Second, a large amount of economic information is available (e.g., *County Business Patterns* data) or will soon be available (e.g., the

Reebie and Colography databases mentioned in Section A.5) at a county level for use as inputs to a statewide freight model.

As it is, the Indiana model depends heavily upon CFS data, which still must be disaggregated once to get to the county level. The CFS is then supplemented with information that includes important commodity flows that are not covered by the CFS, such as certain agricultural products or solid waste. On the other hand, Wisconsin's model makes use of a commercially available commodity flow database. In doing so, it loses some sense of where the data is coming from and what assumptions have been made in supplementing it.

The most obvious difference between the two models is the techniques each uses to generate and distribute the predicted freight flows. The Wisconsin model does not have a conventional trip generation step. Instead, future freight flows are forecast by a growth factor procedure, where the growth factors (one for employment growth and one for productivity growth) are calculated by econometric models developed by specialized consultants. These factors are then applied to the base year flows. The Indiana model, in more a typical four-step fashion, uses regression equations developed from the CFS to generate its freight flows and a gravity model to distribute them. The method used in the Wisconsin model seems appropriate for use in a state where little change is expected in the transportation network over the forecast period. However, the Indiana model offers greater flexibility for considering the effects of changes in the network (e.g., a new highway corridor with reduced travel times).

In the end, both models use very similar processes to divide the predicted freight flows into an equivalent number of vehicles and assign them to the network. Many of the tons-per-truck values are higher for the Indiana model, but both models use comparable days-per-year factors. The Wisconsin model gives less attention to the tons-per-vehicle considerations for railcars, but that is likely a function of the Wisconsin DOT's primary goal of estimating future highway demand. An unfortunate part of the assignment step for both models is the failure to address the possibility of congestion due to the presence of a large number of passenger vehicles sharing the road. Attention to congestion considerations (and related issues such as the development of factors for seasonal or even hourly flows) should not be difficult given available forecasting software.

A.8. Recommendations and Conclusions

Some general advice on constructing statewide travel forecasting models (or models for any geographical area) is contained in the documentation for the Indiana freight model [8.1], which states:

> There is a temptation to evaluate the … forecasts. It should be obvious that this is not possible until the forecast dates have been reached … One's acceptance of the forecasts should be based on the quality of the methods used in the analysis of the [current] flows and the accuracy of the methods in replicating existing conditions. (p. 141)

Keep the process sound and rational, the Indiana report seems to say. To this might be added two more common sense suggestions: use methods of modeling that are appropriate to the results desired and keep the process simple. Any recommendations for "best practice" in travel forecasting should be based on these principles. Thus, a good model should be easy to explain to an informed audience and easy to justify to an interested public (who will likely be funding the modeling efforts). The following eight recommendations are directed toward developing just such models for use in statewide travel forecasting.

Recommendations for Statewide Travel Demand Forecasting

1. *Use a statewide model for analysis of statewide effects of system or socioeconomic changes or for statewide corridor planning only.* This is a philosophical decision that drives the rest of the modeling process. The statewide passenger models examined for this appendix appear (because of their continued manipulation of information at a small scale) to be aimed at examining flows at a project level. Use of a statewide model for small-scale or project-specific purposes is dubious, due to the increased necessity for adjustments (K-factors) and the reduced ability of a statewide modeler to be aware of localized conditions across the state. Separate methods should be used for forecasts at the smaller scale, where more specialized and local knowledge can be applied.

2. *Build the statewide model in a form consistent with available data.* This second recommendation logically follows from the first. As demonstrated in the passenger and freight models reviewed in this appendix, the majority of transportation (as opposed to merely demographic) information is generally available only at the county level. Further steps to artificially disaggregate the information involve assumptions that are probably not necessary for modeling at a statewide level. These assumptions are too easy to forget when adjustments are made to try to match the base year traffic flows. With county level modeling, there is less temptation to match flows at a small (census tract) level, when the model is really based on information from a much larger (county-level) scale. At the county level of aggregation it is also more likely that a sufficient number of data samples can be found to calibrate logit-style models and other more “advanced” modeling structures similar to those discussed in reference to intercity modeling.

3. *Examine, simultaneously, alternative methods of modeling.* Concurrent use of alternative modeling techniques is, as noted in Section A.6, the procedure suggested at the close of the Kentucky model’s documentation. There are obviously a large number of techniques available for use in developing a statewide forecast, including various disaggregate behavioral models. Examinations could also be made to determine whether it is worthwhile to extend the network into other states to buffer external station effects or to include a national network or to experiment with the number of purposes. If several different model structures are available, then a better sense can be gained of the sensitivities of the various techniques and the possible range of forecasts for future travel.

4. *Re-examine the structure of any “traditional” UTP methods used.* If “advanced” techniques are not warranted or do not prove fruitful, then “traditional” techniques may require some overhaul. A principal example is the use of K-factors for adjusting the gravity model. The K-factors used in the models examined appear to have been developed mostly in an effort to adjust the gravity model results to match the base year traffic, rather than through behavioral principles. Behavioral methods might be better for increasing or decreasing trips between particular TAZs. For instance, if it is desired to represent the reluctance of residents of one state to work in another, adding a short slow-speed (high-disutility) link at a border crossing might work just as well.

5. *Make use of existing government and commercial databases.* Most of the data used to develop the models reviewed in Section A.6 and Section A.7 came from a few government (NPTS, CTPP, CFS) sources or similarly few commercial (Reebie, REMI, WEFA, Woods & Poole) commercial sources. This data, judiciously supplemented and modified by local information, proved sufficient to develop workable statewide models. New database products under development (at the only the county level for freight) will make the process still easier.

6. *Make use of existing statewide traffic monitoring programs.* Aside from the obvious value in assessing the reasonableness of model results, the information gathered by statewide monitoring programs can be useful in developing daily and seasonal factors for various roadway types and geographical areas in the state, thereby contributing to the accuracy of the model. Monitoring data could also be used to assist in making modifications to national rates used for special generators and external stations. The use of traffic monitoring data would be greatly assisted by the use of time series techniques of data analysis, such as the Box-Jenkins methods noted in Section A.2.
7. *Plan for future data collections that will enhance an existing model.* Although statewide forecasting model may have been built primarily from existing data sources, it could be improved with additional, locally-collected data. Examples are data that may allow spatial disaggregation below the county level and data on recreational travel, expecially on the weekend.
8. *Make use of expert panels in the modeling process.* Expert panels can be very useful in filling gaps in existing socioeconomic data, assisting with model assumptions and disaggregating model results to smaller divisions of zones. The Wisconsin freight model is notable for its use of expert panels, and it shows how assembling groups of people with direct experience in freight can be used to take some of the burden away from individual modelers (or small groups of modelers) and open up the forecasting process to knowledgeable people outside of the DOT.
9. *At future dates, assess the performance of the model(s) used.* In all of the material reviewed for this appendix, there is one subject that is glaringly absent: comparison of model results with subsequent traffic demands. At the time a model is developed it is obviously impossible to guess how effective it will be in predicting future traffic. Without some effort at future dates to assess how well previous models have worked, modelers may be doomed to repeating the same mistakes. It might also be possible to determine how much modeling effort is sufficient to generate forecasts for the particular transportation decisions being made.

Conclusions

The full arsenal of available techniques discussed in the literature of intercity and statewide travel forecasting is not being brought to bear in existing statewide models. One of the primary reasons is the lack of data available in sufficient quantities to build and calibrate “fine grain” models at a statewide level. Another reason is a general lack of confidence in the value of developing a statewide model in the first place. This is attested to by the vast majority of states that do not perform any travel forecasting at the statewide level and by the states that built models in the past, but have not continued to use them. Early efforts in statewide model building were handicapped by rapidly changing political and economic environments.

The increasing availability of more user-friendly computer programs for travel forecasting and the increasing availability of travel and socioeconomic data to feed these programs should begin to alleviate some of the problems that caused states to abandon their statewide forecasting efforts. The card-punch technologies that existed during the first wave of statewide modeling in the early 1970s are long gone. In addition, a continued federal government focus on planning issues that can be addressed by statewide modeling – as begun with ISTEA and the CAAA – should provide an impetus for state DOTs to once again explore the possibilities of forecasting travel demand at a statewide level. A continuing development of databases useful for calibration of models (especially behavioral models) at a statewide scale would also be helpful.

As an additional impetus to model building, state DOTs are now being pressured to address traffic congestion by programming transportation improvements. Improvements in intercity and interregional corridors are best analyzed with statewide models.

Future research might include an investigation of the proprietary forecasting techniques employed by private transportation firms that operate over large geographical areas. This includes railroads, airlines, trucking companies and express delivery services. Other future research might be aimed at understanding the underlying causes in the socioeconomic trends that drive the forecasting models.

As this appendix has sought to point out, there are a number of techniques available to prospective modelers – from the familiar four-step models and growth factor techniques to more advanced probability-based or optimization methods. There is an enormous opportunity to combine and overlap the available techniques and to explore the benefits of travel demand modeling at a statewide level. The challenge is now to put these techniques to the test of use.

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