Improving Existing Travel Models and Forecasting Processes: A White Paper

December 2013

TMIP
Better Methods. Better Outcomes.

U.S. Department of Transportation
Federal Highway Administration

FHWA-HEP-14-019

TMIP

Better Methods. Better Outcomes.

Improving Existing Travel Models and Forecasting Processes: A White Paper

Original: October 17, 2013

Final: December 18, 2013

Prepared by:

RSG

2200 Wilson Blvd., Suite 205

Arlington, VA 22201

Prepared for:

Federal Highway Administration

This page is intentionally left blank

Table of Contents

List of Figures

List of Tables

1.0 Introduction

Travel forecasts are critical inputs to transportation investment and policy decisions and help to introduce reason-based rigor into the planning process. Unfortunately, current practice in travel forecasting has several deficiencies that often diminish the value of these forecasts. These shortcomings are documented in NCHRP Special Report 288[1] and include:

- Inherent weaknesses of the models.
- Errors introduced by modeling practice.
- Lack or questionable reliability of data.
- Biases arising from the institutional climate in which models are used.

NCHRP Special Report 288 observes that "current four-step travel demand forecasting models are not well suited to applications that require the portrayal or analysis of detailed travel markets, decisions of individuals, effects of value of time and value of reliability, continuous time-of-day variations in travel, and goods movement." These limitations complicate analyses of many topics being considered by the transportation planning community including road pricing, non-motorized travel, time-specific travel, and freight.

NCHRP Special Report 288 acknowledges that many argue for more advanced models that more specifically represent the travel requirements of individual households over the course of a day. However, it also lists steps that can be taken to improve existing forecasting practice. These improvements are equally important to advanced practice models as they are to conventional four-step aggregate models. They range from general approaches for improving the practice of travel forecasting to specific actions to improve analytic tools. This paper discusses some of the most important steps for improving travel forecasts and models:

- Improve the practice of travel forecasting:
    - Apply forecasting procedures with full recognition of their limitations.
    - Assess and report uncertainty.
    - Review methodologies and findings with peers.
- Collect better data to support input assumptions and validation.
- Confirm the applicability of input assumptions.
- Improve the capabilities of forecasting tools:
    - Develop improved measures of arterial congestion.
    - Improve trip distribution models by considering the characteristics of travelers to allocate travel among destinations.
    - Include non-motorized travel.
    - Maintain consistency among all elements of the forecasting process.

[1] "Metropolitan Travel Forecasting, Current Practice and Future Direction" National Cooperative Highway Research Program Special Report 288. 2007.

- Confirm validity of forecasting tools.

This paper seeks to expand upon many of these topics and provides suggestions for how forecasters can improve practice with a series of relatively simple, implementable steps, most of which are equally applicable to advanced- and conventional-model architectures.

2.0 Improve the Practice of Travel Forecasting

The impetus for improving travel forecasting practice comes from the need to supply decision makers with information regarding likely outcomes associated with various policy and investment choices. As described in the introduction, and readily acknowledged by the forecasting community, travel forecasts often have significant weaknesses that limit their value.

This chapter begins by exploring the requirements that decision makers have for forecasts followed by a discussion of both limitations of the forecasting process and potential solutions for improving the usefulness of the resulting projections.

2.1 Focus on Forecast Requirements

Fundamentally, decision makers need projections that they can trust to show how future transportation conditions will evolve in response to a variety of policy or investment decisions. This requires that they have confidence that the forecasts, forecasters, and methodologies can reliably assess the impact of different strategies.

2.1.1 Understand the Needs of Decision Makers

Forecasters typically view a good forecast as one that is based on a methodology that is theoretically correct and replicates observed traffic flows, transit ridership, or other key transportation conditions. By contrast, users of projections look for forecasting results that can be relied on to support effective decision-making. Donnelly and Koppelman[2] conducted an informal survey in which they asked decision makers and modelers to describe the process used to assess the validity of a forecasting model and what could be done to increase their confidence in the projections. Their answers to these questions are presented in Table 1 and Table 2.

Table 1. Modeler and Decision Maker Response to Question about Model Validity.

Modelers	
Criteria	#Mentions
Replicates traffic counts	9
Theoretically plausible	5
Established practice	5
Matches calibration targets	5
Software verification	4
Sensitivity testing	2
Market understanding	2
Parallel studies	2
Peer review panel	2

Decision makers	
Criteria	#Mentions
Independent review	11
Confidence in analyst	11
Comparable forecasts	10
Squares with intuition	8
Free from obvious flaws	8
Agency/investor buy-in	6
Effective presentation	6
Established practice	3
Aligns with theory	2

Source: Donnelly and Koppelman, Travel Model Credibility as a Criteria for Design and Implementation, 2013.

[2] Donnelly & Koppelman, "Travel Model Credibility as a Criteria for Design and Implementation", TRB Transportation Planning Applications Conference, May 2013.

Table 2. Response to Question about Increasing Forecast Confidence.

Lose "replication tunnel vision"
Make risk and uncertainty explicit
Standards
Transparency • Delphi panel • Open models (data + assumptions + tools) • "Stakeholder access"
Reference class forecasting (outside view)
Independent review Crash testing
Model alignment

Source: Donnelly and Koppelman, Travel Model Credibility as a Criteria for Design and Implementation, 2013.

Together, the responses to these questions suggest that consumers of forecast information seek solutions that are:

- Effectively presented by an analyst whom they trust.
- Consistent with common sense.
- Transparent to allow for meaningful independent review.
- Checked using independent tools.
- Evaluated to understand the risks and uncertainties.

To be effective, the forecaster must develop and apply analytical methods that provide a clear explanation of why the projections can be trusted. Accepted practice, theoretical consistency, and validation are important insofar as they help inform the forecaster and provide confidence to the technician. Decision makers, however, expect the forecaster to distill forecast outcomes into a narrative that inspires confidence based on its connection to reality and the consistency of results to intuition.

With these requirements in mind, the forecasters should remember the following:

- ***Be mindful of the specific needs that the forecast must fulfill.*** In some settings, forecasts and tools must realistically estimate the overall demand for travel to support computation of future traffic volumes and emissions. In other contexts, highly specific estimates of project usage are required. In still other situations, impacts of pricing or other demand management policies are required. Before beginning the development of analytical methods, the forecaster should start with an understanding of the requirements.

- ***Consider the strengths and weaknesses of each potential analytical method.*** Some projects require an answer that can only be generated by a general-purpose regional travel forecasting model. In many cases, however, the regional model is not sufficiently accurate to address the particular needs of a project. Ad hoc, data-driven methods can be developed that describe current conditions, assess the response to external change, and report outcomes. It is important to remember that the best solution is not always a full regional travel forecasting model.
- ***Test everything.*** Models are very complex analytical engines and every aspect of the process is subject to error. This includes input data, each step of the modeling process, comparison (validation) data, and response to change. A serious flaw in just one of these elements could significantly diminish the credibility of the resulting forecast.
- ***Strive for transparency.*** Both decision makers and analysts depend on an understandable explanation of the key insights generated from the forecasts. Forecasters should always be able to explain these insights in simple, concise terms:
    1. What conditions exist today and where did this information come from?
    2. How well do our analysis tools grasp the important characteristics of the present?
    3. What external factors are projected to change, where did these assumptions come from, and how certain are they to occur?
    4. How will travel change if we didn't do anything? Are the magnitude and patterns associated with this change reasonable given the magnitude of change in the external factors?
    5. How will proposed actions alter these outcomes and are the magnitude of these changes consistent with the action?
    6. How might these outcomes change if the basic assumptions are different?

2.1.2 Develop Sufficient Methodological Capabilities to Meet Analysis Needs

Travel forecasting models were originally developed to support decision-making associated with capacity expansion programs, including the Interstate Highway System and fixed-guideway transit systems. Over time, other uses have emerged that add to the requirements that forecasting methodologies must satisfy. As documented in NCHRP Special Report 288, these include:

- Accurate representation of choices that travelers make in response to congestion, including shifting time of travel or utilizing non-motorized modes.
- Impacts of programs such as pricing, convertible traffic lanes, time shifting, telecommuting, transit vouchers, and land-use controls on both supply and demand.
- Estimates of the impacts of changes to the transportation system and its usage, including vehicle emissions, vehicle speeds, and induced travel.
- Assessment of benefits and impacts of different policies and programs on the population, in general, and on disadvantaged populations, in particular.
- Understanding of the economic development implications of transportation programs.
- Analysis of how all of these will change as the population of the United States becomes older and more likely to have immigrated to this country from elsewhere.

These requirements mean that our methods must:

- Have a finer-grained understanding of the characteristics of travel, including understanding who is making the trip, where trips begin and end, when travel occurs, and the degree to which any of these factors can change. At a minimum, this requires much more detailed representations of aggregate travel patterns and, many would argue, requires analysis of individual travelers and households.
- Consider the full range of potential responses to changes in the transportation system, demographic characteristics, or policy. In addition to typical forecast outcomes of trip generation, automobile versus transit shares, and route choice, forecasting methods must also estimate the degree to which travelers can shift their time of travel, choose to use non-motorized modes, or elect to forego travel.
- Include all types of transportation demand, including passenger and freight

Many believe that these solutions are best implemented within new model forms, most notably disaggregate, activity-based model systems. These models are being implemented across the United States, but are still in the process of establishing a record of accomplishment sufficient to demonstrate that their theoretical advantages outweigh their complexity.

Another approach to support decision making is to develop and apply ad hoc methods that make greater use of existing data on travel supply and demand and then apply simpler incremental techniques to project the impact of changes to background conditions on transportation usage.

Finally, in some cases, existing techniques can continue to be useful, provided that these tools have an accurate representation of supply and sufficient demographic, geographic, and temporal specificity.

As NCHRP Special Report 288 indicates:

> ***The committee finds that there is no single approach to travel forecasting or set of procedures that is "correct" for all applications or all MPOs. Travel forecasting tools developed and used by an MPO should be appropriate for the nature of the questions being posed by its constituent jurisdictions and the types of analysis being conducted.***

The remainder of this paper discusses improvements to model practice that can benefit all travel forecasting approaches.

2.2 *Remember the Limitations of Forecasting Tools*

Travel forecasting is as much "art" as it is "science." In part, this is because forecasters are attempting to represent the interaction of human behavior and transportation system performance; neither is static over time. Resurgence of urban cores, availability of car- and bike-sharing services, changing workplace requirements, evolving familial relationships, new shopping options, and online information and entertainment options have all profoundly affected both transportation supply and demand over the past 20 years. Travel forecasters must remember and communicate that forecasts are generally based on a snapshot of current conditions and that the future may unfold in a very different manner.

2.2.1 Recognize the Power and Limitations of Statistical Estimation

For the past 50 years, travel forecasting models have been developed by collecting survey information on travel usage and comparing these patterns to demographic data and numerical representations of transportation supply. A variety of statistical tools, ranging from simple regressions to complex likelihood maximization techniques, are used to develop rigorous tools that establish our understanding of the relationships that exist between the factors that generate demand for travel (the exogenous variables) and the resulting amount and type of travel that occurs (endogenous variables).

These statistical techniques rely on the identification of correlations between the exogenous and endogenous variables and infer potential causality. These findings offer useful insights into relationships among data, but they still require exercise of judgment. Forecasters must be mindful of several issues:

1. Successful parameter estimation requires variation in the observed values of both the exogenous and endogenous variables. For example, it is not possible to estimate the sensitivity of travelers to transit fare using cross-sectional survey data in a city with a flat transit fare. This does not mean that transit ridership is insensitive to fare—just that it cannot be estimated from revealed preference (RP) survey data in cities where transit fares are the same for all trips. Even if fares are not completely invariant (e.g., fares for transfers or express fares), there may not be sufficient variation to estimate fare sensitivity with any confidence.
2. The various exogenous variables should not be highly correlated if independent parameters are required for each variable. Even where transit fares are not constant, it is often problematic to estimate traveler response to the cost of transportation. Both automobile operating costs and transit fares are often highly correlated with travel distance (and time). In this situation, it is not possible to reliably estimate the sensitivity of travelers to both cost and time using RP survey data.

   Unfortunately, models with naïvely estimated values of time from RP data have been used to study pricing policies with the rationalization that "they are better than nothing." Given the potential damage to forecaster reputations, this is probably not true—a naïve forecast is worse than no forecast. A better solution is to examine similar projects in other locations and infer the likely usage based on logical analogies. Uncertainty (e.g., different outcomes in different cities or situations) should also be communicated.
3. The statistics that we typically use to determine whether to include or exclude a variable describe the confidence that a particular coefficient is different from zero. These statistics do not evaluate confidence in the magnitude of the estimated coefficient. As long as the result is meaningfully different from zero, a coefficient may earn a high T score even if the actual magnitude (and hence importance) of a variable is not reliably

known. It can be useful to estimate the confidence bands related to marginal rates of substitution (e.g., value of time). These often show significant uncertainties even when the individual time or cost coefficients have reasonably small standard errors.

4. Fundamentally, statistical estimation reflects correlation and not necessarily cause and effect. Of particular concern are cases of reverse causation. For instance, high levels of demand lead transit service planners to schedule frequent service. Car share services provide cars in areas with low auto-ownership. In these cases, what is cause and what is effect? Without careful thought, it is easy to construct models that misstate (or overstate) the impact of frequency on the decision to ride or the presence of car sharing services on the decision not to own a car.

Forecasters should always consider both the need for and likely success of statistical parameter estimation when constructing new travel forecasting models. If models are being built for situations quite similar to standard practice, then they should seriously consider utilizing parameters borrowed from existing models. The resources spent on model estimation could be more productively assigned to data collection, validation, and risk analysis.

In some cases, however, estimation is required. Models that have new terms in the utility expression or serve different roles (other than urban area mode choice) often have no guidelines regarding acceptable ranges for parameters. In these cases, practitioners should be prepared to extensively test the sensitivity of these models to changes in assumptions to confirm that they generate realistic results. The analyst must carefully consider whether the modeling process could confuse cause and effect or misstate model sensitivities.

2.2.2 Remember That All Models Are Abstract Representations of a Complex Reality

No matter how complex or sophisticated a model becomes, it is still a simplified representation of an even more complex reality. Depending on the application, these simplifications can generate counterintuitive or incorrect results. It is the responsibility of the forecaster to review important markets for the situation being studied to confirm that the model grasps that market. Several examples:

- **Example 1**. Choice models typically add up the impedance associated with each option to generate a total generalized cost. The probability of selecting an option depends on the relative cost and an error term to account for the fact that different travelers value each aspect of a trip differently. This structure works well in many cases, but it will not handle some situations where two options are generally similar but one always takes slightly more time and costs slightly more than the other. In this case, models may split the demand more evenly among the choices than seen in the real world. As shown in Table 3, the typical model form may not be able to represent situations in which modes sometimes trade-off attributes while other times a mode is superior to its competition for all characteristics.

- **Example 2**. In some cases, a model may accurately represent the overall probability distribution while still significantly overstating the chance of low-probability events as illustrated in Figure 1. Even carefully estimated models may overstate the demand in low-probability situations if the perception of a mode is not linearly related to impedance. In this illustration, the model would predict seven times the actual number of trips for cases in which the relative impedances are less than negative 100 minutes. If a project has many potential trips in this region of the curve, then traveler response could be overestimated.

Table 3. Example Mode Share Computation for Hypothetical Case with and Without Time-Cost Tradeoffs.

Mode	Time	Cost	Total Impedance	Modeled Share	Observed Share
Case 1: Ferry and Rail Offer Tradeoff Between Time and Cost					
Bus	45	$1.00	51	28%	20%
Ferry	20	$3.00	38	53%	55%
Rail	30	$2.50	45	29%	25%
Case 2: Ferry Superior to Rail in Both Time and Cost					
Bus	45	$1.00	51	28%	20%
Ferry	20	$3.00	38	53%	75%
Rail	24	$3.50	45	29%	5%

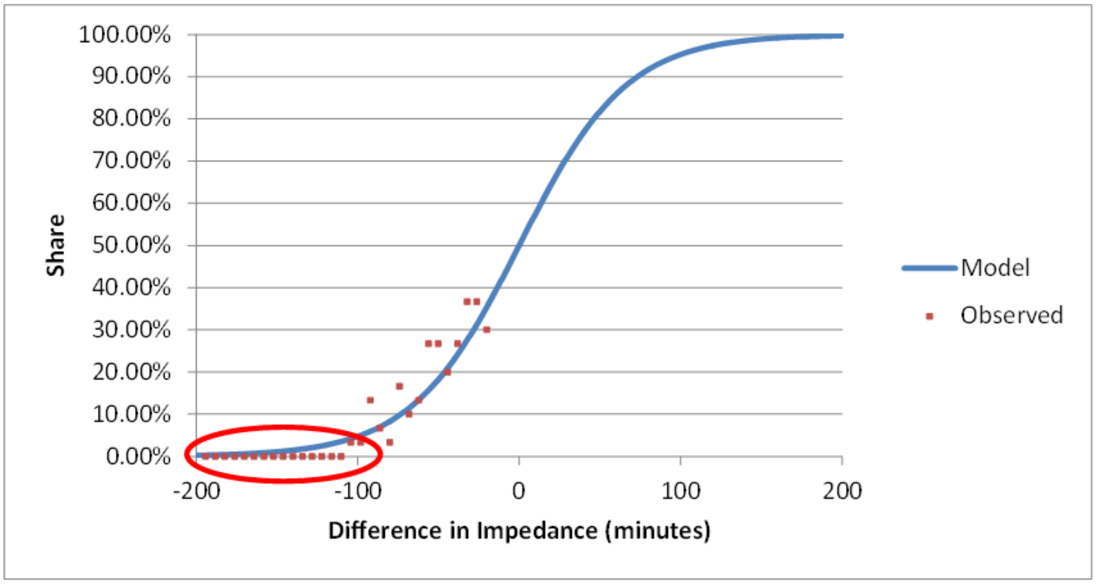


Figure 1. Model Overestimates of Shares in Low-Probability Situations.

The key message with both of these examples is that there are no guarantees that traveler response will necessarily follow the profile of a traditional logit curve using a simple set of utility expressions constructed from linear combinations of time and cost. The analyst developing model relationships must carefully examine model performance as compared to observed values over a wide range of conditions to confirm that the model has a complete understanding of the factors that affect choice.

2.3 Consider Data-Driven Techniques

Except in research settings, the principal reason for developing forecasting methods is to provide information to support policy or program decisions. In many cases, the people making these decisions want an indication of likely future impacts that is reasonable, grounded in fact, and explainable. In many cases, solutions generated from data may provide a superior, cost-effective alternative to traditional models. This is particularly true in situations where conventional travel forecasting procedures struggle to generate realistic results. These include

- Forecasts of future transit ridership;
- Analyses of pricing policies; and
- Projection of Toll or High-Occupancy Toll (HOT) facility usage.

Each of these applications demand that forecasting models have an accurate representation of total person trip flows, mode shares, specific fees to use the project, and a traveler-specific understanding of the tradeoffs between various components of travel time and cost. Regional forecasting models seldom achieve the level of accuracy required to support these kinds of planning analyses.

Fortunately, these projects are frequently constructed in areas where existing data on travel demand patterns may be used to forecast future outcomes directly. These data-driven approaches work as follows:

1. Conduct a large-scale Origin-Destination (OD) survey of potential users. Collect data from 5% to 10% of existing transit users and/or highway users in the corridor to determine origin/destination location, trip purpose, socioeconomic characteristics, and trip routing.
2. Use the data from the previous step to construct a mode-specific person trip table (or trip enumeration listing). In essence, directly collected survey data are used to generate a file that is equivalent to the base year output of a conventional mode choice model, but with a higher confidence that it represents real travel patterns.
3. Develop detailed representations of corridor transportation facilities. This can be done using conventional travel forecasting networks and software, traffic simulation or Dynamic Traffic Assignment networks, and/or transit schedule data in General Transit Feed Specification (GTFS) format.
4. Assign the person-trip tables from Step 2 to the networks from Step 3 to confirm that observed volumes are replicated. As necessary, repeat with adjustments to survey weighting and/or network routing until simulated volumes match observed volumes.

5. Obtain demographic information for the base and forecast year.
6. Scale OD survey information to represent future conditions as follows:
    a. Use demographic data to scale survey data to represent the growth in trips expected from corridor population and employment growth.
    b. Use changes in zone-to-zone impedance from the network-processing step to scale survey data to account for the impact that future-year transportation system improvements will have on demand. This scaling can done using simple elasticities or incremental logit choice models to reflect changes in mode and, potentially, destination.
7. Utilize the elasticity or incremental logit choice models from Step 6b to evaluate alternative future-year transportation options.
8. Utilize network assignment procedures to report volumes/ridership for individual facilities.

Steps 6 and 7 both involve applying forecasted ***changes*** in demand to existing data on demand flows; therefore, these techniques are often called "incremental" forecasting models. There are many methods that can be used to apply forecast changes to existing data. The traditional incremental logit formulation is one such technique that computes the change in mode share given changes in conditions. This technique can only be applied in cases where observed data is non-zero and where the modeled choice is available in both the existing and alternative cases.

An alternative approach is to run the forecasting model in a synthetic mode for both the base and alternative case, and apply either a factor or the absolute difference from the model results to the base table according to the rules (applied separately for each combination of zone and time periods) shown in Table 4.[3]

[3] Daly, Andrew; Fox, James; Patruni, Bhanu; Milthorpe, Frank. "Pivoting in Travel Demand Models." Astralasian Transport Research Forum, September 2012.

Table 4. Application of Synthetic Mode for Both the Base and Alternative Case.

Base Data (B)	Synthetic Base (S_b)	Synthetic Future (S_f)	Predicted
0	0	0	0
0	0	>0	S_f
0	>0	0	0
0	>0	>0	Normal growth:0 Extreme growth: $S_f - X_1$
>0	0	0	B
>0	0	>0	$B + S_f$
>0	>0	0	0
>0	>0	>0	Normal growth: $B*S_f / S_b$ Extreme growth: $B*X_2/S_b + (S_f - X_2)$

Notes:

$X_1=k_2*S_b$

$X_2=k_1*S_b + k_2*S_b*\max(S_b/B, k_1/k_2)$

Common values for k_1 and k_2 are $k_1=0.5$ and $k_2=5$

Source: Daly, Fox, Patruni and Milthorpe, Pivoting in Travel Demand Models, 2012.

The key to the data-driven approach is to collect sufficient OD survey data, and have sufficiently precise networks, so that a trip table created from the survey can be assigned to the transportation networks and generate accurate estimates of volume.

In the case of traffic forecasting, OD survey data may also be supplemented by observed traffic count data on the network through the use of OD matrix estimation techniques. This approach can be very powerful, particularly when it can take advantage of rich traffic-count data. However, great care is necessary with matrix estimation to ensure the resulting matrix represents a reasonable OD flow pattern that respects, and does not distort, the original survey OD data. Matrix estimation also relies on the accuracy of network data and modeled travel times.

Most of the effort with data-driven procedures is expended in adjusting/correcting the OD matrix, network data, and network processing procedures to generate assignments that are sufficiently accurate to meet the needs of the project. Although not a trivial task, the level of effort is typically much less than that required to calibrate and validate conventional models.

When the models are calibrated, there is a direct relationship between:

- Observed data and the modeled representation of current conditions.
- The effect of demographic growth on travel conditions.
- The effect of background transportation system changes on travel.
- The effect of alternative policy and/or infrastructure improvements on travel.

Some users of travel forecast data, most notably the Federal Transit Administration (FTA) and the UK Department for Transport, welcome data-driven techniques as an equal (and often superior) substitute to forecasts generated by conventional travel forecasting models.

2.4 Adopt a Step-by-Step Build-Up Forecasting Protocol

Users of forecast information have expressed the desire for a more transparent forecasting process that helps them build confidence in the judgment of the forecaster and evaluate the reasonableness of results.

A simple step-by-step build-up forecasting protocol can be used to generate the information needed to develop answers to each question described in Section 2.1.1. The protocol begins with data—information about current conditions that are obtained through direct or indirect observation—and then provides a series of analysis results that shows how well the methods understand conditions today and how these procedures envision conditions changing in the future. Each step of the process is structured so that only a limited number of changes are introduced from the previous step; reducing the number of "moving parts" and allowing the analyst and decision maker to assess the reasonableness of the outcomes and understand the specific contribution of different assumptions to final results.

Table 5 shows one potential structure for a step-by-step build-up of data and analyses. The left column shows each analysis step, starting with data on current conditions and continuing through a build-up of model runs that begins with current conditions and ends with future projections. The right side shows the specific questions that are answered with each step in comparison to the prior step.

Table 5. Approach for Building-Up Forecasting Analysis.

<table>
<tr><th>Analysis Step</th><th>Question Answered</th></tr>
<tr><td rowspan="2">Data on existing traffic volumes, ridership counts, traveler surveys, etc.</td><td>What conditions exist today and where did this information come from?</td></tr>
<tr><td rowspan="2">How well do our analysis tools grasp the important characteristics of the present?</td></tr>
<tr><td rowspan="2">Analysis/model representation of current conditions</td></tr>
<tr><td rowspan="3">What external factors are projected to change and where did these projections come from?
– and–
How will travel change if we didn't do anything? Are the magnitude and patterns associated with this change reasonable given the magnitude of change in the external factors?</td></tr>
<tr><td>Analysis/model with future year land-use and current transportation system</td></tr>
<tr><td rowspan="2">Analysis/model with future year land-use and programmed transportation improvements (No-Build/Do-Nothing/No-Action)</td></tr>
<tr><td rowspan="2">How will proposed actions alter these outcomes and are the magnitude of these changes consistent with the action?</td></tr>
<tr><td rowspan="2">Analysis/model with future year land-use and programmed transportation improvements, and alternative policies/projects (Build/Action/Alternatives)</td></tr>
<tr><td rowspan="2">How might these outcomes change if the basic assumptions are different?</td></tr>
<tr><td>Analysis/model with future year land-use and programmed transportation improvements, alternative policies/projects, and alternative external assumptions (Sensitivity tests on price of fuel, cost of parking, demographic growth, etc.)</td></tr>
</table>

Ideally, numeric information is accompanied by a narrative that describes the contribution of each factor that results in a material change to transportation conditions. A simple illustrative example of a narrative is as follows:

- The Central Expressway currently has five lanes in each direction and carries an ADT of 320,000. HOV accounts for 10% of this traffic. It operates at capacity for 12 hours per day.
- The model shows a current ADT of 300,000 and matches the observed share of HOV users.
- In the forecast year, corridor population shows growth of 25% and employment growth of 50% (much of which is located in the developing suburbs). Since the corridor is transitioning from a bedroom community to a diversified activity center, suburb-to-CBD corridor trip making is projected to grow by only 15%.
- If no other improvements are made, the volumes on the Central expressway will add 15,000 vehicles per day and another 30,000 cars will be added to parallel arterials. Given the fact that these facilities are already at capacity, travel times will likely degrade from an average speed of 45 mph in peak periods to 38 mph and the congestion will occur for 14 hours each day. HOV usage will remain at 10%.

- Addition of a median HOT lane will cause Central Expressway HOV usage to grow by 12% and about half (19,000) will be making trips that can use the HOT lanes. During congested hours, another 10,000 toll-paying cars can be accommodated while still maintaining free-flow speeds. When this happens, 20,000 of the cars shifted to the arterials will return to the Central Expressway, and the general-purpose lanes of the expressway will carry 304,000 ADT, slightly more than it attracts currently. Together, the HOT and general-purpose lanes will carry 324,000 vehicles per day.

This is obviously a simplistic example, but it serves to illustrate how forecasting results can be coupled with facts about the existing conditions and expected changes to create an understanding of how each factor contributes to the overall forecast outcomes. All of this is made possible by the build-up sequence of runs that isolates the impact of each element of the forecast scenario.

2.5 Understand and Document Uncertainty

All projections of the future are uncertain. Travel forecasts are no exception. Many of the steps described in this paper are intended to reduce the likelihood of model error, but these steps will not result in diminished uncertainty related to the other reasons that cause actual outcomes to deviate from projections. Instead, the forecaster must invest time and effort to understand potential uncertainties and communicate this knowledge to decision makers.

A full discussion of model uncertainty appears in a companion paper, "Uncertainty and Risk in Travel Forecasting," and is not repeated here. The travel forecaster should always understand the key contributors to uncertainty, which include:

- ***Travel forecasting procedures that misrepresent existing conditions.*** When applied to future conditions, these tools may result in unrealistic estimates of usage or impacts. This element of model uncertainty is the result of an error in the forecasting process and is largely preventable if the steps described elsewhere in this document are followed.
- ***Input information (demographic or transportation supply) describing future conditions does not occur as assumed.*** In the past, toll road volumes have been overestimated because future suburban development did not occur according to the forecasted timetable. Other forecasts did not consider construction of parallel free roads. Transit ridership forecasts have been overestimated due to aggressive demographic projections or optimistic assumptions regarding level-of-service. Careful research can eliminate some uncertainty. However, demographic forecasts are always subject to change given underlying regional and national economic conditions. In addition to careful research, forecasts should be prepared with a range of background supply and demand assumptions so that the dependence of forecast outcomes on underlying assumptions is fully known.
- ***The future represents a situation beyond the range of anything that exists today.*** As mentioned above, models are calibrated so that they respond to the range of conditions that exists today. To the maximum extent possible, inputs representing future conditions should be constrained to fall within the range of the experiences used in developing the forecasting model. If very different conditions (e.g., very high fuel costs or parking limitations in suburban activity centers) are an integral part of the analysis, then these elements should be portrayed as an alternative scenario with explicit caveats that

alert the user to the fact that traveler response to these conditions are particularly speculative.

- ***The future is different from today.*** Even if forecasting procedures are carefully checked, input variables occur as projected, and the model is being applied well within its calibration parameters, the future may still be materially different from forecasts. Societies and the environments in which they exist are dynamic and there is no certainty that transportation will be used in the future the way that it is today. Depending on the circumstances, it may be useful to consider and discuss the impact of societal megatrends on transportation outcomes. Changing workplaces, family structures, online shopping, and social media are affecting all aspects of our economy, transportation included. Absent quantitative information on the effects of these changes on transportation, forecasts might include a qualitative assessment of their impact. As an example, the biggest driver of change in travel demand in the second half of the twentieth century was the entrance of women into the workforce—a trend that was not incorporated into travel models until well after it occurred but could have been foreseen as these changes were beginning to emerge.

The common theme to each element of uncertainty is that the forecaster should recognize the factors that drive uncertainty and communicate both the quantitative and qualitative dimensions of the range of potential outcomes to users of forecast information.

2.6 Peer Review Methods and Results

Peer review is becoming an increasingly accepted element of the forecasting process and agencies are regularly convening panels prior to major model development projects. These panels are tasked with identifying opportunities for updating forecasting tools to be consistent with the state-of-the-practice. As described above, decision makers view the peer review process as a key element of their own assessment of the reliability of forecasts and suitability to support policy and investment plans.

As currently implemented, the peer review process focuses on modeling approach and consistency with best practice. They are often conducted at a time (prior to model update) when peer suggestions can be implemented as part of the ongoing model development program.

Forecasters should consider expanding the peer review program to other elements of the forecasting process that are equally important to the quality of the projections. These include:

- Validation of all aspects of forecasting methodologies.
- Review of key external inputs to the forecasting process.
- Assessment of the reasonableness of results.
- Analysis of forecast uncertainties.

With the extension of the peer review program into model application, forecasters and decision makers can develop enhanced confidence that travel projections are a useful contribution to the transportation planning process.

3.0 Collect Better Data

Reliable information is the key to preparing effective travel forecasting methods and requires the longest lead time of any activity in the development process. Too often, the cost of collection forces analysts to skip this step and rely, instead, on simulation results or historic data. Neither is an adequate substitute. Effective forecasting models require accurate input information and extensive calibration/validation data to properly represent circumstances faced by each traveler and to evaluate whether the model understands the resulting travel choices.

Five types of basic data are required and described below.

3.1 Demographic Information

Information on population, households, and employment for each modeled geographic subdivision (Traffic Analysis Zones) and for various stratifications (income, auto ownership, household size/composition) are basic elements of all travel forecasting models. Data for population and households by residence location is obtained every 10 years from the Census. Employment data requires more effort to prepare and is often obtained either directly or indirectly from employer data files obtained from state unemployment offices or from private sector marketing firms. Unfortunately, these data sources have a variety of problems, including inconsistencies due to changes in the data collection/processing protocols over time; disclosure proofing of Census products; and the so-called “headquartering” effect in which all of a firm’s employees—who actually work in several locations—are reported in one location, which is generally the firm’s headquarters.

When collecting base-year information, it is important to remember that all elements in the current year dataset that are used in the model must also be forecasted into the future. These projections must be consistent with the base year in terms of definitions of each data item and the procedures used to estimate population, households, and employment by stratum.

Be particularly mindful of input information denominated in monetary terms such as dollars. The value of a dollar is not constant over time. Monetary quantities are typically expressed in constant dollar terms (e.g., year 2013 dollars).

Care is also required regarding how data are assigned to individual Traffic Analysis Zones (TAZs). Since many workplace addresses are located on streets that serve as TAZ boundaries, small inconsistencies in street or TAZ boundary files can lead to data being assigned to incorrect zones. If the cartographic files change (even slightly) over time, then a comparison of existing and future TAZ employment may reveal significant (and spurious) changes in demographic conditions that reduce the credibility of the modeling process.

3.2 Transportation Supply

Most regions have access to automated network representations of the roadway system that are in a form ready for use by travel forecasting software. Most larger metropolitan areas also have access to transit network data. The quality of these network representations is often insufficient to support effective travel forecasting models. Typical problems (and solutions) include:

- Highway networks:

- Inaccurate data on the number of lanes, distances, free-flow speeds, or link-to-link connectivity that are either errors, represent older conditions that have since been changed, or are the remnants of earlier misguided attempts to improve calibration by manipulating input conditions.
- Centroid connections that concentrate too much traffic at the wrong places in the networks.
- Reliance on functional class as the sole determinant of facility speed and capacity.
- Lack of information on observed travel times.
- Representation of arterial capacity and travel times as functions only of link attributes, without adequate representation of intersections.

> Spend the time on network quality control at the beginning of the project. Check network attributes for accuracy and recode centroid connectors to multiple mid-block locations rather than fewer intersections. Be sure that the physical nature of the facility is coded (e.g., signal spacing, medians, turn bays, grade, etc.) since these attributes have a significant impact on capacities and operating speeds. Finally, strive to collect as much information on congested travel times as possible to allow careful calibration and validation.

- Transit networks:
  - Inaccurate representation of routing, stop locations, headways by time-of-day, and fares.
  - Centroid connections that misrepresent the ability of travelers to walk to nearby transit services.
  - Incomplete representation of fare.

> If transit is a meaningful element of the existing or future transportation system in a region, equal attention must be paid to the quality of both the transit networks and the highway networks. Transit systems in smaller cities can be easy to represent since routes operate end-to-end and on regular headways throughout the day. In these areas, each route is coded according to the stops that it makes and period-specific (e.g., AM peak or midday) headways computed as follows:
>
> $$Headway = \frac{Period\ Duration, in\ minutes}{Number\ of\ trips\ operated\ in\ period}$$
>
> Larger urban areas often have transit services that are vexing to the network coder, including: tripper runs, route deviations or short turn-backs, and limited stop semi-express services. The coder must apply judgment to balance the need to accurately

represent specific services against the need to represent the aggregate performance of the route. Often this tradeoff is affected by the purpose of the analysis and the specific capabilities of the travel forecasting software.

Centroid connectors are a particular problem in transit networks and are handled in many different ways depending on the capabilities of the software, the desire to rely on automatic linkages or to require human intervention, and the particular modeling challenges faced in each region. No single best way is applicable to each situation. Instead, consider the following objectives:

1. Do not design a process that relies on the first link (i.e., centroid to first highway node) coming from the highway network unless that network has been checked to confirm that its centroid connectors are, in fact, suitable for that purpose.

2. Do develop a system in which travelers can walk to any reasonably nearby transit service. Avoid arbitrary rules such as: "Walking is permitted up to 0.5 miles" or "Connections are made to the five nearest transit routes." These may have been appropriate when most people walk to a local bus stop no more than 0.5 miles away. However, many agencies plan to provide improved services in selected corridors and customers may be willing to walk up to a mile to reach these facilities. The models should be prepared for such plans by allowing access all transit within one mile.[4]

3.3 Usage (Counts)

Data on usage have been a key part of the transportation analysis profession for many decades. As long as these counts have existed, travel forecasters have found them to be problematic. Nevertheless, they are necessary to confirming the proper operation of travel models. Data include:

- Period-specific, directional traffic counts, accurately positioned on the highway network.
- Route and station-level transit boarding and alighting counts by period, direction, and mode of access.

[4] FTA guidance requires that all access to transit be treated similarly. The choice to walk longer distances to some forms of transit (e.g., rail) should not be coded as an access rule. Instead, this behavior should emerge as the result of the path-building process. When properly configured, the shortest path will walk further to better transit when the value of the improved service exceeds the impedance of the longer walk.

Highway usage data is often collected for a subset of all links in the network due to the costs associated with assembling this information. Wherever possible, more data is preferred over less data. Most count datasets contain a small number of miscounts or incorrect geographic locations. These errors can be difficult to detect without having nearby counts that can be used to determine consistency.

It is critical for agencies to maintain a count database in digital electronic form (not PDF images) with consistent conventions in terms of the coding of directions and the locations of count stations so that directional count information can be reliably attached to the model's highway network in an automated fashion. Substantial coverage of the network with reliable classification counts is necessary for any reliable forecasting of truck volumes.

Transit ridership information is increasingly available from Automated Passenger Counting (APC) systems that are collected for each route in the system. Wherever possible, data should be maintained separately for each route by direction and stop. Mode of access information is less easily obtained. In many cases, transferring passengers or arriving cars must be counted by hand at key locations.

3.4 Traveler-Demand Patterns (Surveys)

Traveler surveys are often the only source of information on the nature of travel that we seek to represent within travel forecasting models. To control costs, survey sample sizes are often kept relatively small. An overview of survey methods prepared in 1996 for TMIP[5] observed that guidance on recommended sample sizes typically focuses on the minimum number of responses necessary to estimate a quantity such as average household income or trip rates per segment, given the mean and standard deviation and desired precision and confidence. As noted in NCHRP Report 571[6], choice model estimation generally requires at least 300 responses for each separate choice in each separate model. Clearly, the number of survey responses can vary dramatically based on the complexity of the proposed model (e.g., number of purposes, number of choices, and degree of segmentation) and on how many survey responses are required to obtain the necessary information.

It is evident that no real consensus has emerged on sample sizes for home interview surveys. In the United States, survey sample sizes have ranged from a few hundred to 20,000 households. Likewise, transit on-board survey sampling approaches have included route-based frames where sample sizes are selected according to the need to estimate means within specified precision and confidence intervals (several hundred responses per route) to larger-scale surveys where 10% of all customers are sampled.

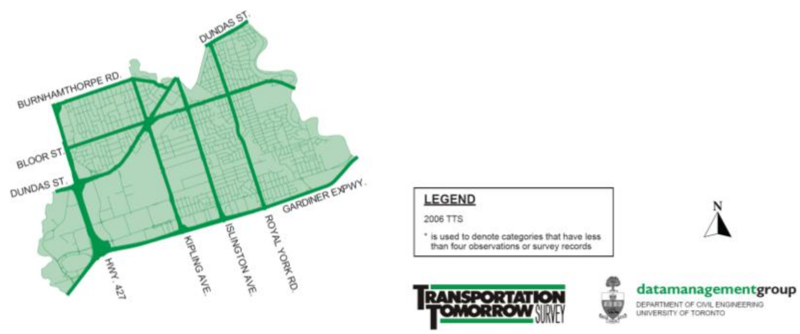
As both reports note, purpose dictates required sample sizes. Some purposes for the collected data are defined by statistical precision requirements for estimating parameters for pre-determined models (e.g., trip generation rates by household composition and auto ownership). In these cases, the sample sizes identified above may be sufficient.

[5] Cambridge Systematics, "Travel Survey Manual", TMIP, July 1996.

[6] "Standardized Procedures for Personal Travel Surveys" National Cooperative Highway Research Program Report 571, 2008.

A potentially more important use, however, is to develop a more complete understanding of how travel patterns vary across a metropolitan area. The need for this understanding is demonstrated by the fact that forecasting models often need large fixed geographic adjustments for trip tables and mode split models to adequately represent observed flow patterns. These factors are rightly criticized for being crude adjustments that may not be stable over time. Significantly more data is required to understand current travel patterns and identify modeling approaches for replicating these patterns.

A good example of a large-scale household survey in North America is the Transportation Tomorrow Survey conducted every five years in the Greater Toronto-Hamilton area of Ontario, Canada. The 2011-2012 version of this survey collected travel information from 150,000 households—a 5% sample. This large-scale survey enables the development of district-to-district tables of travel (see Figure 2 for an example from 2006) and detailed snapshots of



specific areas of the region (see

Figure 3 for a sample snapshot from 2006).

The patterns revealed by this type of survey data can be important for demonstrating that the model represents key aspects travel in a region. As the district-to-district table shows, most travel—13 million out of 16 million trips—are intra-district. Comparing travel to two adjacent areas in the center part of the region (City of Toronto and Region of York), some areas have a greater affinity for Toronto (Peel, City of Hamilton, Region of Niagara) while other areas have a stronger affinity for York (County of Simcoe, or City of Barrie). Detailed snapshots of the region show that residents of Ward 5 of the use transit 17 percent of the time while travelers to Ward 5 use transit only 12 percent of the time. Travel forecasting models must be able to replicate big picture characterizations of travel patterns like these.

From: \ To:	CITY OF TORONTO	REGION OF DURHAM	REGION OF YORK	REGION OF PEEL	REGION OF HALTON	CITY OF HAMILTON	REGION OF NIAGRA	REGION OF WATERLOO	CITY OF GUELPH	COUNTY OF WELLINGTON	SUB-REGION TOTAL
CITY OF TORONTO	4,222,100	111,700	413,400	305,600	51,400	13,300	5,900	6,300	3,000	1,600	5,134,300
REGION OF DURHAM	112,000	925,700	35,100	8,700	1,400	600	800	600	300	100	1,085,300
REGION OF YORK	413,500	35,000	1,220,800	65,200	7,800	2,300	1,200	1,900	700	300	1,748,700
REGION OF PEEL	310,400	8,900	66,200	1,743,700	109,200	15,300	5,100	9,800	4,200	4,200	2,277,000
REGION OF HALTON	51,100	1,600	7,700	109,100	690,900	66,900	8,900	6,500	4,200	4,600	951,500
CITY OF HAMILTON	13,400	500	2,200	14,700	66,500	854,800	26,200	7,900	2,700	800	989,700
REGION OF NIAGRA	5,700	800	1,300	4,500	9,100	26,400	939,200	1,400	200	200	988,800
REGION OF WATERLOO	6,600	500	1,700	9,500	6,500	7,800	1,200	1,027,400	24,200	8,500	1,093,900
CITY OF GUELPH	3,000	300	600	4,100	4,300	2,500	300	24,200	223,900	18,400	281,600
COUNTY OF WELLINGTON	1,400	100	300	4,300	4,400	800	200	8,600	18,200	46,600	84,900
SUB-REGION TOTAL	5,139,200	1,085,100	1,749,300	2,269,400	951,500	990,700	989,000	1,094,600	281,600	85,300	14,635,700

Figure 2. Example District-to-District Table.

Source: University of Toronto, Transportation Tomorrow Survey, 2006 (Excerpt)

CITY OF TORONTO - WARD 5

DEMOGRAPHIC CHARACTERISTICS

TOTAL NUMBER OF HOUSEHOLDS: 24,100

Dwelling Type	House	Townhouse	Apartment
	58%	5%	38%

Household Size (persons)	1	2	3	4	5+
	26%	37%	16%	13%	7%

No. of Available Vehicles	0	1	2	3	4+
	16%	51%	26%	6%	1%

Household Averages	Persons	Workers	Drivers	Vehicles	Trips/Day
	2.4	1.2	1.6	1.2	5.3

TOTAL POPULATION: 57,800

	Population	Transit Pass	Licenced Drivers	Student	Employment Status: Full time	Part time	Work at Home F/T	Work at Home P/T
Male	26,900	8%	73%	20%	42%	5%	5%	1%
Female	30,800	10%	59%	19%	31%	9%	3%	1%
On survey day: Made work trip					87%	48%	35%	26%

Age	Median	0-10	11-15	16-25	26-45	46-64	65+
	44.4	11%	5%	10%	25%	27%	22%

Daily trips/Person (age 11+): 2.5

TRAVEL PATTERNS

TRIPS MADE BY RESIDENTS OF CITY OF TORONTO - WARD 5

Time Period	Trips	% of 24 hr.	Trip Purpose Category: HB-W	HB-S	HB-D	N-HB	Mode of Travel: Auto Driver	Auto Passng.	Local Transit	GO Train	Walk & Cycle	Other
6 - 9 a.m.	25,900	20.4%	54%	19%	19%	8%	56%	10%	25%	0%	7%	1%
24 hours	127,300		29%	9%	45%	17%	61%	16%	17%	0%	5%	1%
Median Trip Length (km)							5.1	4.1	10	11.5		

Percentage of trips made within district: 6-9 a.m. = 19% 24 hours = 30%

TRIPS TO CITY OF TORONTO - WARD 5

Time Period	Trips	% of 24 hr.	Destination Purpose: Work	School	Home	Other	Mode of Travel: Auto Driver	Auto Passng.	Local Transit	GO Train	Walk & Cycle	Other
6 - 9 a.m.	38,700	20.2%	66%	11%	2%	21%	68%	10%	16%	0%	4%	1%
24 hours	191,000		20%	2%	28%	50%	67%	16%	12%	0%	3%	1%

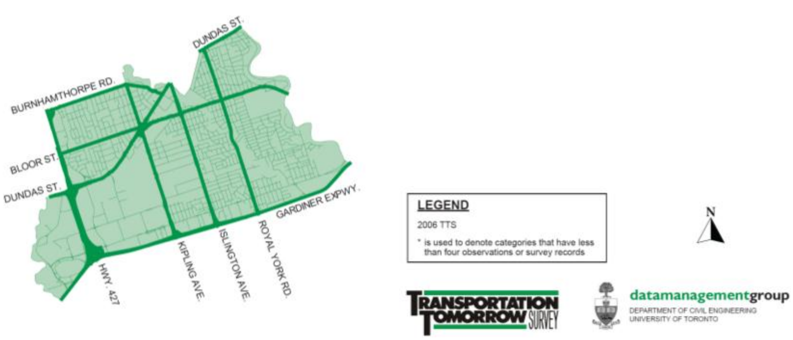


Figure 3. Sample Sub-Region Snapshot.

Source: University of Toronto, Transportation Tomorrow Survey, 2006.

As noted above, transit surveys in the United States regularly collect data on a sizable proportion of trips (5 to 10%). The Census Transportation Planning Package tables of Journey-to-Work flows are equivalent to large-scale surveys of travel flows for work-related travel. The American Transportation Research Institute (ATRI) has recently begun providing truck trip tables based on large-sample GPS data. Other sources of passively collected data offer promise of improved availability of detailed spatial demand data in the near future. The availability of large-scale databases of travel flows opens up the potential for conducting some transportation analysis and forecasting using data driven tools and techniques as well as for better understanding and improving traditional models.

3.5 Check Data before Beginning Methodology Development

The process of developing models or methodologies is similar to scientific research in which the analyst develops hypotheses about what mathematical formula might replicate a particular travel pattern and then tests it against the data to determine whether it does or does not work well. This effort is wasted if the input data or the validation data are flawed. Worse, it may lead the analyst to draw incorrect conclusions that must be eradicated from the thought process after the error is discovered. Once allowed into the forecasting process, incorrect "data" is difficult to remove.

It is important to confirm that input and validation data are as accurate as possible before beginning development of travel forecasting analysis methodologies. The following are some suggested steps that can verify input data prior to its use in travel forecasting models:

- Highway networks:
  - Build zone-to-zone estimates of travel time for free-flow conditions. Spot check against travel-time estimates generated from the National Performance Management Research Data Set (NPMRDS), floating car travel time studies, and other commercially available roadway datasets that include travel time information.
  - Validate count data to identify implausible situations:
    - Where counts locations are nearby, look for cases where counts cannot be reconciled with one another. For example where ramp counts and link-by-link freeway counts exist, are there cases where the following applies?

$$Vol_{upstream} - Vol_{exiting} + Vol_{entering} \neq Vol_{downstream}$$

    - Where counts locations are spaced, can the difference between the upstream and downstream counts be explained by traffic serving nearby land uses or entering/exiting traffic from intersecting roadways?
  - In places with relatively large surveys (more than 5,000 respondents), use the CTPP in concert with the home interview survey data to synthesize zone-to-zone work trip tables. Supplement with non-work trip tables derived from district-to-district tables allocated to zones using relative zonal trip productions and attraction relationships. Adjust to match external estimates of vehicle miles traveled (VMT) and assign. Compare assigned volumes to counts. Compare congested speed estimates to estimates derived from NPMRDS. Review significant differences to determine whether differences are caused by inaccuracies with the trip table or problems with the network.

- Transit Networks:
    - Compare estimated transit running speeds to timetable information and/or Automatic Vehicle Location (AVL) data.
    - Review centroid connection process to confirm reasonableness of transit access representations.
    - In cases where transit origin-destination surveys collected data on 5% or more of travel, develop zone-to-zone transit trip tables and assign to networks. Compare assignment results to counts. Where differences occur, determine whether the discrepancy is a result of inaccuracies in the transit trip tables, transit networks, or transit path-building procedures.
- Socioeconomic Data:
    - Compare current year population and employment to Census and CTPP data.
    - Compare key household attributes (e.g., household size, household income, auto ownership) to Census and CTPP data.
    - Check the internal consistency of demographic data. For instance, confirm that the number of resident workers in each zone is less than the total number of residents, etc. TMIP is currently developing a spreadsheet tool to assist with these types of checks.
- Other Key Data:
    - Review plausibility and consistency of parking cost data and other representations of local area characteristics. Be sure to note the precise definition of this data (e.g., timeframe-hourly/daily, units-dollars/cents and year of dollar, and total cost vs. per-trip cost).

4.0 Confirm the Applicability of Input Assumptions

Travel forecasts are the result of a process that, at its core, relates current-year travel patterns to underlying assumptions regarding population, employment, land use, and the transportation system. In general, these underlying assumptions are treated as exogenous variables that are used by mathematical models to generate the demand for transportation and predictions of how this demand will be satisfied by the transportation system. Forecasters strive to develop forecasting methods that represent these relationships as accurately as possible so that future transportation demand can be projected based on anticipated changes to the input conditions.

The application of travel forecasting methodologies with future demographic and transportation system information is one of the principal reasons that planning agencies invest in these tools. However, the use of future-year projections as input to travel models also represents a very different paradigm from model development. The model development phase is data- and validation-focused and provides the careful analyst with frequent opportunities to observe problems or errors, research their cause, test solutions, and implement enhancements. Model application with future-year forecasts offers fewer opportunities to identify problems and develop solutions since comparison data is not available. The user can still observe illogical model outcomes between similar alternatives; otherwise, the testing protocols associated with model development are not available.

As mentioned above, a step-by-step build up of forecasts allows the analyst to understand the impacts of each change in the exogenous variables and provides an opportunity to observe counterintuitive results and to research their cause.

Another tactic is to carefully review each exogenous assumption to confirm that it represents appropriate inputs to the travel models. Two types of problems should be detected and resolved:

1. Input assumptions that may be reasonable but create conditions outside the range of the data used to develop the model.
2. Input assumptions that are inconsistent or infeasible.

Each aspect is discussed below.

4.1 Input Assumptions Outside Calibration Conditions

Travel models are calibrated so that they understand traveler responses to observed variations in conditions. Part “a” of Figure 4 shows a case where transit mode shares are related to the cost of parking, which varies between $0 and $5 per day. A standard logit curve can be fit to represent this data and shows that the transit shares will vary between 0 and 0.3 with a strong correlation to parking cost.

Suppose, however, that parking cost was also a proxy for downtown activity patterns and that these patterns are highly correlated with parking cost up to a value of about $5. Thereafter, assume that the density of activity patterns has reached the point of diminishing returns and no longer rises in parallel with parking costs. If that is the case, then future transit shares with higher parking costs might actually look like Part “b.” As this plot shows, the modeled and actual estimates of transit share begin to diverge at higher levels of parking costs

a. Calibrated response of transit to parking price (maximum observed price=$5)

b. Underlying relationship between transit share and price

Figure 4. Potential Problems with Applying a Model Beyond Range of Calibration Data.

This example offers two key warnings to forecasters:

1. The most obvious problem (and well-known to analysts) is that when causal variables are projected to grow beyond observed variations, even the most carefully calibrated travel forecasting models can misstate the potential response.
2. The second problem is less intuitive. When causal variables are correlated with one another it is not always possible discern which is responsible for a particular traveler response. If one of these causal variables (e.g., parking cost) appears in a new setting (e.g., suburban activity center without downtown amenities), the model may generate an exaggerated and unrealistic response.

It is important to verify that all forecasting input variables are consistent with both the range and context of existing conditions. Input variables that are outside of observed existing ranges or appear in a different context can generate results that are, at best, uncertain and, potentially, highly unrealistic. For this reason, FTA has historically required project sponsors to maintain key exogenous variables (with the exception of demographic projections) largely constant. Current FTA project evaluation methodologies weight current year data more heavily than projections to account for the uncertainties associated with demographic forecasts.

4.2 Input Data Implying Significant Changes to Travel Patterns

Demographic projections are important contributors to forecasted demand. The magnitude and location of future population and employment can have a significant impact on the need for and nature of transportation. The various components of future-year demographic projections may reveal major changes which will have a profound impact on the structure of regional travel. In some cases these changes are an expected consequence of the demographic forecasts. In other cases, the demographic forecasts are inconsistent with regional plans and expectations. The forecaster is responsible for determining which situation applies.

Examples of demographic changes that should be reviewed include:

- Estimated growth in regional employment that is much higher (or lower) than growth in population/households/labor force.
- Substantial changes to socioeconomic class variables such as income.
- Projected locations of future employment and residence that require very long (and unlikely) trips to balance.
- Changes to transportation supply that are inconsistent with projected demographic growth

These variations can have an important impact on travel forecast outcomes, even when they are realistic. For example, employment in the Washington, D.C., region was expected to grow from 4 million in 2010 to 5.6 million in 2040, a 40.7 percent increase.[7] In the same timeframe,

[7] Metropolitan Washington Council of Governments. Round 8.1 Forecasts by TAZ, 2012.

population was expected to grow by just 30.7% and households by 35.4%. These data suggest that household sizes will continue to drop, labor force participation will rise, and additional workers residing outside the region will be filling Washington-area jobs.

The City of Washington is expected to have a job growth of 25.4% and slightly higher growth in households and population (27 to 28%). In both the present and future cases, the number of jobs in Washington, D.C., exceeds the population, which suggests that commuting from suburban areas to the city will continue to be important. However, the growth in the Washington, D.C., population suggests that internal travel will increase even more rapidly.

In many metropolitan areas, the forecasted patterns show much greater variations from current conditions than those described for Washington, D.C., and may not be realistic or may cause problems with the forecasting models. Travel forecasters should always review demographic projections prior to use and develop an understanding of their key characteristics and reasonableness.

Even if the demographic inputs to the forecasting models are deemed reasonable, the modeling treatment must still be assessed. Many models balance trip generation results by adjusting attractions to match productions. If this approach is applied in Washington, then the growth in work travel may be limited to 35% even if employment growth is 40%. In built-out parts of the region with small growth in employment, the balancing process may result in a 3 to 4% drop in work travel that may not be realistic. These outcomes may suggest a need to adopt a different trip-generation-balancing approach or reconsideration of the socioeconomic data.

If the demographic and economic growth assumptions imply growth in commuting into and out of a region, then inputs to the external travel model components should be checked to verify that they portray a similar scenario.

5.0 Improve Capabilities of Existing Forecasting Tools

The previous elements of this report have focused on improvements to the practice of travel forecasting. This section shifts the emphasis to simple steps that can be taken to improve the travel forecasting tools themselves. The actions described in this section can be applied to existing forecasting methods, are easy to accomplish, and usually generate superior results.

5.1 Refine Geographic Units of Analysis

Nearly all travel forecasting models subdivide the modeling region into geographic units of analysis, which are known as Traffic Analysis Zones (TAZs). In aggregate models, TAZs serve as the finest unit of geographic resolution for most parts of the model. Disaggregate models can perform some operations on individual trips with specific latitudes and longitudes, but may still utilize transportation level-of-service (skim) data that are organized by TAZ.

In both aggregate and disaggregate models, it is important that estimates of time and distance accurately reflect the options available to all travelers. This means that TAZs should be sufficiently small that the use of zone centroids to represent origins and destinations will not change estimated travel times enough to affect the choice of route, mode, or destination.

A good set of guidelines for the size and structure of TAZs was prepared for the Florida Department of Transportation[8] and is included below:

- The number of people per TAZ should be greater than 1,200, but less than 3,000, for the base and future years.
- Each TAZ should yield less than 15,000 person trips in the base and future year.
- The size of each TAZ should be between 0.25 to 1 square mile in area.
- There should be a logical number of intrazonal trips in each zone, based on the mix and density of the land use.
- There should be no irregularly-shaped TAZs.
- Each centroid connector load should be less than 10,000 to 15,000 vehicles per day in the base and future year.
- The study area should be large enough so that nearly all (over 90%) of the trips begin and end within the study area.
- The TAZ structure should be compatible with the base- and future-year highway and transit networks.
- The centroid connectors should represent realistic access points onto the highway network.
- Transit access should be represented realistically.
- The TAZ structure should be compatible with Census, physical, political, and planning district/sector boundaries.

[8] Cambridge Systematics Inc., and AECOM Consult, “A Recommended Approach to Delineating Traffic Analysis Zones in Florida,” Florida Department of Transportation Systems Planning Office, September 27, 2007.

- The TAZs should be based on homogeneous land uses, when feasible, in both the base and future year and consider future DRIs.
- Special generators and freight generators/attractors should be isolated within their own TAZ.

Additional amplification may be helpful for areas with substantial numbers of non-motorized or walk-to-transit trips. In both cases, the traveler leaves the home on foot or bike and is often assumed to be traveling at only 3 miles per hour. As shown in Figure 5, a traveler starting at point "A" in a zone that is 0.5 mile by 0.5 mile could have a 1 mile (20-minute) walk to reach a bus stop (or destination) located in the same zone at point "B." This distance is generally the maximum distance that most travelers are willing to walk to reach transit. If the zone is much larger than this size, then the centroid representation of travel could result in an overstatement of the accessibility of transit to potential users. This means that in places where walk-to-transit or non-motorized modes are prevalent, zone sizes should generally not exceed 0.5 by 0.5 miles. In dense areas with significant trip making, even smaller dimensions are preferred.

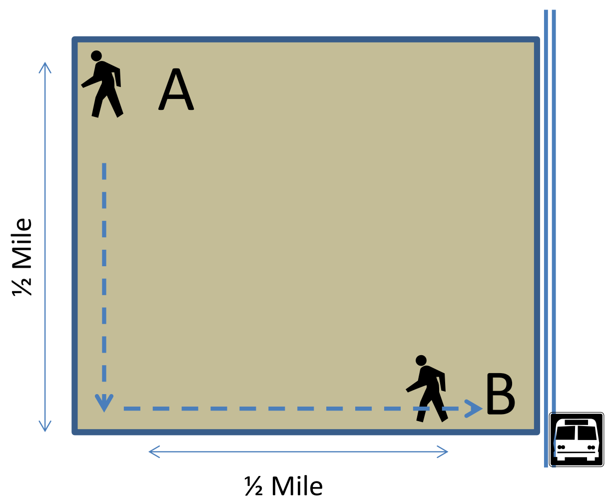


Figure 5. Example of Maximum Walk Distance in a TAZ.

Beyond the overall size of TAZs, the FDOT guidelines also suggest that land use, highway access, and transit access also are important to TAZ design. Figure 6 presents an illustration of land uses and transportation near Tysons Corner, Virginia. Commercial areas are nearer to the major arterials and are more likely to have direct access to these arterials. Residential areas that are located away from the arterials connect to the collector roadway system. This geography is represented with separate zones for each land use and access connectors that reflect the specific opportunities available to travelers in that zone.

Transit access procedures should be designed so that highway connectors are provided everywhere where access can occur and then allow use of walkable highway links to reach transit stops even if the stops are outside the limits of the zone.

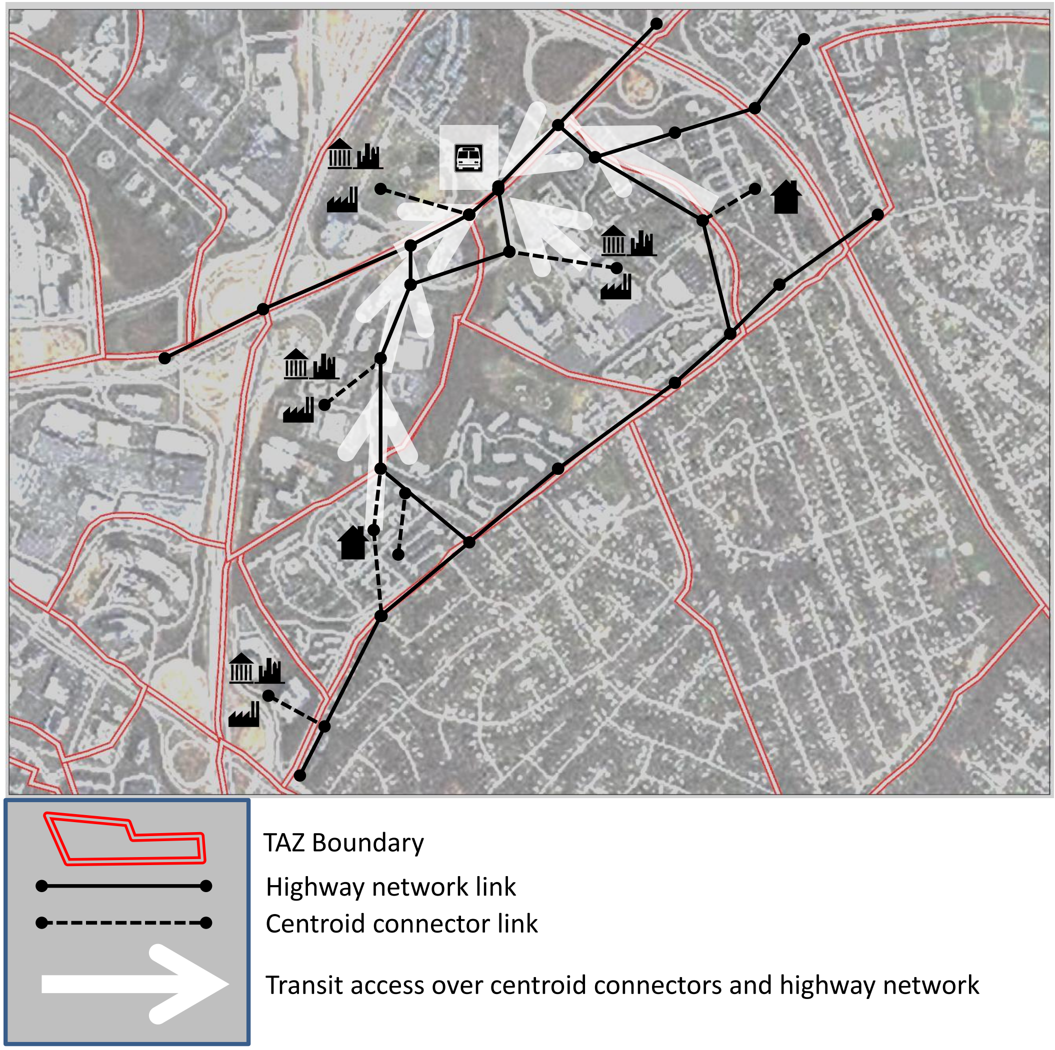


Figure 6. Interaction Between Land Use, Zone Size and Network.

5.2 Stratify Models According to Time-of-Day

As discussed above, estimates of time and cost should represent the actual conditions faced by travelers. In most metropolitan areas, time of travel is another dimension that must be considered when estimating travel times and distances. Peak periods are characterized by slower automobile travel times due to highway congestion and higher levels of transit service than similar trips made in the off-peak period.

These time-of-day differences should be represented consistently throughout the travel forecasting process. One simple way of accomplishing this objective is by structuring the model as follows:

- Generate demand for travel on a daily basis (i.e., daily trip or tour generation).
- Select the time of day of travel (i.e., time-of-day choice).

- Choose destinations and stopovers based on the transportation impedances that are specific to each period of travel (i.e., period-specific destination choice or distribution).
- Determine choice of mode by period of travel (i.e., period-specific mode choice).
- Subdivide highway travel to more detailed time periods, if necessary.
- Assign travel to the appropriate routes.

Selecting the most appropriate time subdivisions is a matter of considerable judgment. It is not always true that more time subdivisions are superior to fewer. In many larger urban areas, trips can easily exceed one hour of travel time and many will begin in one time period and end in another. Most software packages do not consider the span of travel when assigning trips to time periods and most transit path-building packages cannot easily generate paths for trips in which the travelers return to a park-ride lot to pick up their car and drive home.

Both problems are usually manageable when initial time periods (prior to destination and mode choice) are defined as peak and off-peak. After mode choice, automobile trips can be subdivided further to represent more specific periods for assignment purposes. This structure is shown in Figure 7. Additional highway stratifications can (and often are) used beyond those described in this illustration.

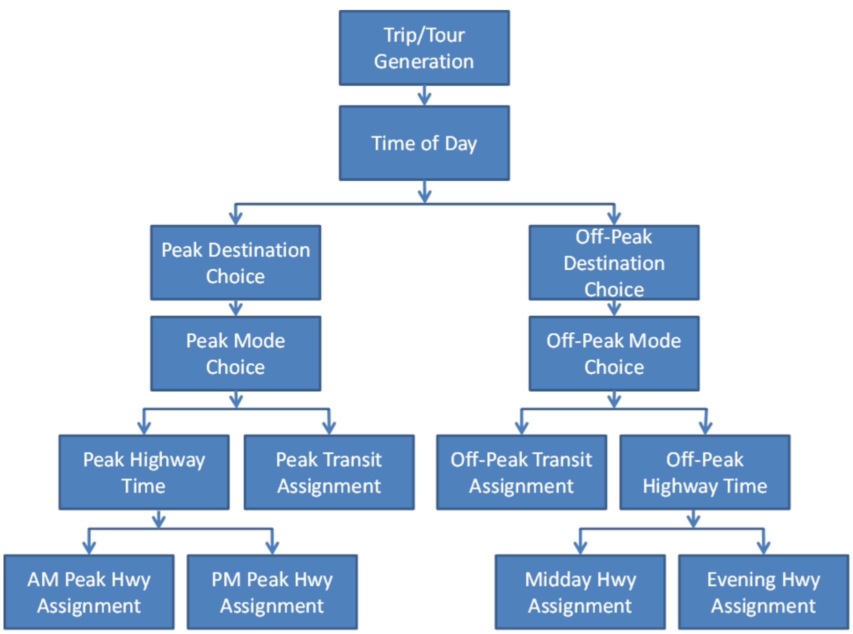


Figure 7. Simple Time-of-Day Stratification

The peak/off peak subdivisions may not be sufficient for some situations where the peaks of the peak period have different characteristics from shoulders of the peak; this is also true if the AM and PM periods are significantly different. This can happen in cases where highway travel is highly peaked, or if the transit agency offers express tripper service only during the peak hour. In that case, additional subdivisions may be necessary; however, this must also be balanced against potential problems being introduced for travel that occurs in more than one time period.

The process described above is an elementary means for introducing time of day into the travel forecasting process. It has the advantage that major differences in supply characteristics are represented in distribution and mode choice. It does not, however, capture the effects that congestion has on travel, which requires more elaborate procedures.

5.3 Stratify Models by Socioeconomic Group

Many aggregate travel forecasting models generate travel separately for different socioeconomic strata and then (to varying degrees) merge them together prior to conducting succeeding steps. This is most typically seen in older trip-based aggregate models where estimates of trips by purpose are computed separately for each combination of household size, workers, income, and/or auto ownership. Once computed, trip ends are merged together prior to distribution. More disaggregate procedures generally retain information on individual characteristics throughout the forecasting process, but these still utilize common sets of impedance matrices for distribution and mode choice.

Trip-based models will generally perform better if trip ends for each SE class are not merged prior to destination choice. By keeping these tables separate, less-wealthy areas with fewer jobs are less likely to dominate travel to nearby activity centers (often CBDs) and will instead reflect a more realistic distribution.

Both aggregate trip-based and disaggregate models may benefit from separate impedance matrices if travelers in these groups are revealed to have very different perceptions of the different elements of time and cost. For instance, if higher-income travelers are found to have a higher value of time, they may be more likely to use toll roads or travel by premium-fare transit services than lower-income travelers. If the mode choice model values these parameters differently for each traveler class, then the path choices must also reflect those differences[9].

5.4 Maintain Consistency among All Forecasting Elements

Travel forecasting models make extensive use of time and cost matrices representing the impedance between every TAZ-pair in the metropolitan area. This information is used to predict the shares of trips using each mode, the choice of destination, and sometimes to estimate the amount of travel generated. Typically, each of these models assigns a different weight to each component of time or cost. For instance, many models weight out-of-vehicle travel times (walking or waiting) as being two to three times as onerous as in-vehicle time (i.e., riding in a car, bus, or train). Likewise, these models assign a value to out-of-pocket cost to convert dollars to equivalent minutes of in-vehicle time.

These relative weights appear in multiple parts of most models including:

- Procedures used to find the network shortest paths and build zone-to-zone impedance matrices.
- Mode choice.
- Some destination choice or distribution models.

[9] Separate paths are not necessary if the various weights are not sufficiently different to make a material change to paths.

- Some trip-generation procedures, if accessibility is used to adjust trip rates.

It is often argued that each phase of the model represents a different part of the travel decision-making process; thus, there is no certainty that travelers will value different elements of the travel experience similarly when deciding routing, mode, or home-work relationships.

Even if the preceding statement were true, the use of different weights in different model elements results in a problematic tool for use in forecasting—particularly when the tool is used to analyze the relative performance of different transportation alternatives.

Example: Illogical Outcomes When Consistent-Weights Are Not Used

Assume path-building weights out-of-vehicle time at 2:1 compared to in-vehicle time and the mode choice model weights out-of-vehicle time at 3:1. Assume also that an existing local bus route takes 45 minutes to make a trip, requires a short 5-minute walk at each end of the trip, and involves a 10-minute average wait.

To improve transit service, planners are considering adding an express bus in the same corridor. To achieve speed improvements, the express bus will skip many stops. It will operate at the same frequency as the existing local bus (which will continue to operate at the current frequency). Travel time for the express bus trip will take only 20 minutes, but walking time to the express stops will increase to 10 minutes on each end. Waiting time will continue to be 10 minutes.

Path-Building (Identification of the Shortest Routing)

Existing path: 45 min. local bus ride time + 20 min. walk & wait x 2 = 85 min. total weighted time

Build path: 20 min. express ride time + 30 min. walk & wait x 2 = 80 min. total weighted time

Result: Existing path will use bus since the express bus is not present. Build path will use express bus since the much faster travel time outweighs the longer walking time.

Mode choice (Evaluation of the Shortest Routing Previously Identified by Path-Builder)

Existing path: 45 min. local bus ride time + 20 min. walk & wait x 3 = 105 min. total weighted time

Build path: 20 min. express ride time + 30 min. walk & wait x 3 = 110 min. total weighted time

Result: Build path is evaluated as worse than the existing path leading to a modeled decline in transit ridership even though real travelers would have continued to select the local bus option in the build alternative with no change to the perceived service quality.

Full consistency may require more path-building steps than are currently built into many models. In particular, different socioeconomic strata may value time and cost separately. If these values are significantly different, then it may be necessary to build separate paths for each socioeconomic group.

5.5 Develop Effective Highway and Transit-Time Functions

Transportation travel times and costs are the underpinnings of forecasted travel demand. It is important that they accurately represent current conditions to facilitate effective model development. They should also realistically reflect changes in highway and transit speeds that are expected to occur in the future. The following approaches can help achieve these objectives:

- Code highway links so that initial estimates of free-flow speeds and capacities are as accurate as possible. Free-flow speeds and capacities are a function of many factors, including speed limit, physical configuration, signal spacing, and signal progression. These factors can be related to area type (degree of urbanization), roadway functional class (collector, arterial, freeway), and roadway physical configuration (access control, signal spacing, grade, lanes, presence of median, and presence of turn lanes). To the maximum degree possible, utilize link-specific values for speed limit and physical attributes. As an example, the Ohio Department of Transportation network coding procedures include the following physical variables on highway networks[10]:
    - Posted speed
    - Operational functional class
    - Area type
    - Lanes
    - Width
    - Turn lanes
    - Terrain (e.g., level, rolling, mountainous)
    - Intersection type (e.g., pre-timed signal, interconnected signal, two-way stop, uncontrolled, all-way stop)
- Consider use of junction or intersection delay procedures to separately estimate the travel times associated with traversing each link and each intersection. This capability allows network assignment and path-building routines to base intersection delays on both the characteristics of the roadway used by each traveler and the amount of cross-traffic at intersections. Be mindful of the fact that some attempts at adding intersection delay have resulted in assignment instability in highly congested networks.
- Estimate transit travel times using an approach that represents the factors that cause transit vehicles in mixed traffic to travel more slowly than automobiles. A small part of the difference may be due to the performance characteristics of buses compared to cars; therefore, bus speeds (when in motion) may be 10% slower than automobile speeds. The remainder of the time difference is a function of buses stopping to receive and discharge passengers. Bus travel times should be adjusted to account for stop frequency and dwell time per stop that are generally a function of the area type where the stop is located.

5.6 Run Highway Assignment Models to Full Convergence

The last element of most travel forecasting procedures is a step called “assignment.” In this step, the routing for each transit and highway trip is determined based on the shortest path

[10] Ohio Small/Medium MPO Travel Demand Forecasting Model, Network Coding Training, 2006.

(according to the traveler valuation of each component of time and cost). Nearly all highway assignments (and some transit assignments) take the effects of congestion into consideration. As links become more congested, their travel times degrade, leading some travelers to seek alternative routes.

Highway-assignment procedures borrow from the economic framework of (non-cooperative) equilibrium. Under this assumption, routing adjusts until no traveler can change routes to a lower-cost/faster path. There are a number of different algorithms and techniques for producing this solution. The traditional (Frank-Wolfe) technique iteratively assigns the demand matrix to a network using a series of all-or-nothing shortest paths and, at the end of each iteration, it updates the generalized cost to reflect the effect that current volumes have on link (and potentially intersection) travel times. Results of each iteration are combined into a total estimate of volume using weights that minimize the overall costs. Iterations continue until a stopping criterion is achieved—generally a maximum number of iterations or achievement of a relative gap[11] below a user-specified value.

It is important that equilibrium assignment be allowed to run until a near-equilibrium solution is found. According to Boyce,[12] a relative gap of 10^{-4} is generally sufficient to achieve link stability.

Caliper[13] conducted assignment stability tests for three large and congested networks. As shown in Table 6, larger relative gaps (e.g., 10^{-2}) result in assignments concluding before generating a stable set of volumes. In Philadelphia, link volumes varied by up to 3,596 vehicles during the last assignment iteration. This variation could easily appear between two similar model runs, even for links far from the projects being studied. Spurious variations can cast doubt on all model results and should be avoided. Furthermore, when these differences appear in early cycles of a feedback process, they can lead to much larger differences in later iterations of the overall model.

Gaps set to 10^{-4} reduce this variance to a maximum of 86 vehicles difference during the last iteration cycle—a value much less likely to be problematic when reporting link volumes. Even this level of variation could lead to problems if amplified during the feedback process.

[11] Relative gap is a measure of the difference between the total cost of the current assignment and the total cost if all travelers were to use the shortest path. One formula for computing this quantity is: $1 - \frac{\sum_{OD} V_{OD}\pi_{OD}(x)}{\sum_{ij} X_{ij} t(X_{ij})}$, where the numerator measures the sum of all origin-destination volumes multiplied by the all-or-nothing travel time; the denominator represents the sum of all assigned link volumes multiplied by the link travel time. Both all-or-nothing and link travel times are computed using the current assigned volumes.

[12] Boyce, David; Ralevic-Dekic; and Bar-Gera, Hillel. “Convergence of Traffic Assignments. How Much is Enough?” National Institute of Statistical Sciences Technical Report 155. 2004

[13] Slavin, Howard; Brandon, Jonathon; and Rabinowicz, Andres, “An Empirical Comparison of Alternative User Equilibrium Traffic Assignment Methods,” Caliper Corporation, 2006.

Table 6. Maximum Link Flow Change at Different Levels of Convergence.

Relative Gap	Chicago	Philadelphia	Washington, D.C.
0.01 (10^{-2})	352	3,596	1,555
0.001 (10^{-3})	56	630	191
0.0001 (10^{-4})	4	86	48

Note: Flow change is the difference in estimated link volume between the second to last and last iterations. It is an indication of how much the resulting line volume would change with one more iteration. All tests from results reported for 2.2GHz Athlon.

Source: Caliper Corporation, An Empirical Comparison of Alternative User Equilibrium Traffic Assignment Methods, 2006.

6.0 Confirm Model Validity

In common practice, model validity is determined by comparing modeled and observed volumes at the link, screenline, and transit-route level. Two common approaches for assessing modeled highway volumes involve:

1. Comparing modeled VMT by functional class or area type to observed values and confirming that the modeled results fall within a predetermined standard. Typical standards are shown in Table 7.
2. Compute the root mean square error (RMSE) and percent root mean square error (%RMSE) for a set of links grouped by volume range and compare to a predetermined standard as shown in Figure 8. RMSE and %RMSE are computed using the following formulae:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}[(Count_i - Model_i)^2]}{N}}$$

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

Some models also compute error statistics for freeways and other major corridors in the region. This is generally a good practice and it is particularly important for any existing corridors with known proposed improvements that the model will be used to study.

Transit ridership is typically validated by comparing modeled linked trips by access mode and transit sub-mode to observed estimates of these quantities. The number of boarding customers by route and the number of transit trips crossing selected screen lines are also frequently used to confirm the validity of the transit-forecasting procedures.

Additional error statistics, such as the mean absolute percentage error (MAPE) and the GEH statistic,[14] are being increasingly used and can be helpful in understanding a model's validation.

The GEH has become the standard statistic for evaluating model error in the United Kingdom and the MAPE has become a common statistic in many other forms of computer modeling. The GEH has the attractive property of having similar ranges of "good" values (< 5) across a wide range of volumes. Unlike the RMSE and MAPE statistics, the GEH statistic is generally used for individual observations rather than groups of observations. Validation criteria are generally specified as a percentage of observations with a good GEH (e.g., 85% of observations with a GEH < 5).

The MAPE complements the RMSE in that the RMSE treats larger volumes as more important (i.e., it is most important to correctly calculate interstates, but local streets are less important); This is compared to the MAPE, which treats all observations/errors equally. Therefore, in many

[14] GEH Statistic is named for Geoffrey E. Havers.

cases in travel modeling, the %RMSE will be lower than the MAPE, indicating that the model performs better on larger facilities.

$$MAPE = \frac{\sum_{i=1}^{N} \left| \frac{Count_i - Model_i}{Count_i} \right|}{N}$$

$$GEH = \sqrt{\frac{2(Model - Count)^2}{Model + Count}}$$

While these tests are important and necessary comparisons, they are not sufficient to establish the model's ability to represent regional travel. At least three other tests are required to establish the fact that the model is adequate for use in supporting decision making:

- **Test 1**. Confirm that the modeled representation of transportation supply is accurate.
- **Test 2**. Assess the accuracy of the modeled representation of travel flows.
- **Test 3**. Review the sensitivity of modeled demand to changes in supply or demographic conditions.

Each of these elements is discussed below.

Table 7. Typical Standards Used to Assess Modeled vs. Counted Estimates of VMT by Link Type.

Stratification	Modeled vs. Counted VMT Percentage Difference				
	Ohio[a]	Florida[b]		Michigan[c]	FHWA-1990[c]
		Acceptable	Preferable		
Functional Class					
Freeways/Expressways	±7%	±7%	±6%	±6%	±7%
Principal Arterials	±10%	±15%	±10%	±7%	±10%
Minor Arterials	±10%	±15%	±10%	±10%	±15%
Collectors	±15%	±25%	±20%	±20%	±20%
All Links		±5%	±2%		
Area Type					
CBD	±10%	±25%	±15%		
Fringe	±10%	±25%	±15%		
Urban	±10%	±25%	±15%		
Suburban	±10%	±25%	±15%		
Rural	±10%	±25%	±15%		

Source: Travel Model Validation and Reasonability Checking Manual, Second Edition. Travel Model Improvement Program, FHWA, 2010

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

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

c The FHWA Travel Model Improvement Program Workshop over the Web, The Travel Model Development Series: Part I–Travel Model Estimation, prepared by Cambridge Systematics, Inc.,

June 9, 2009, Slide 11, http://tmip.fhwa.dot.gov/sites/default/files/presentation_8_with_notes.pdf, accessed November 29, 2009.

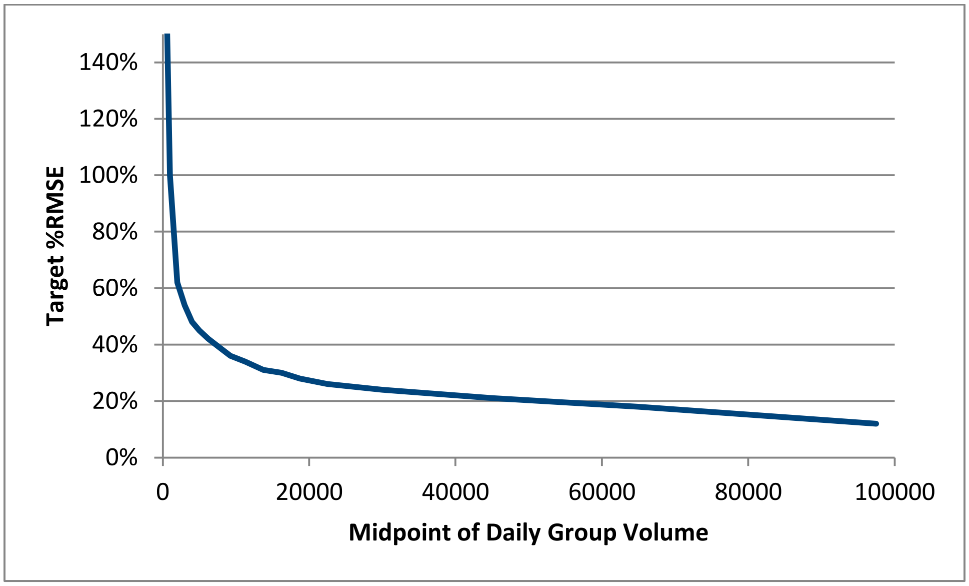


Figure 8. Ohio DOT Percent RMSE Guidelines.

Source: Ohio Department of Transportation, "Traffic Assignment Procedures," August 2001.

6.1 Review the Accuracy of Modeled Transportation Supply

All current forecasting models use the characteristics of the transportation system to estimate the demand for travel. The demand for travel, in turn, affects the amount of congestion expected on each facility. The process of assessing the supply, computing demand, and updating estimates of congestion continues until the process converges on an estimate of both travel demand and facility congestion.

Estimates of time, speed, and cost for each mode of travel generated by this process are critical for forecasted estimates of the following:

- Connection between home locations and various destinations, including work, shopping, school, and other activities.
- The choice of mode (highway or transit) and subdivisions of these choices, including toll roads or fixed-guideway transit.
- The choice of routing.
- Assessment of impacts such as mobility and emissions.

Despite its importance, many travel models have been developed without clear evidence that travel time estimates are realistic. In fact, some model developers have altered travel times away from observed values in order to obtain more accurate estimates of modeled traffic volumes. Even if traffic volume is the only performance measure that matters, these adjustments are unlikely to produce satisfactory results for future-year forecasts. Since most measures of mobility also involve an assessment of travel times, these adjustments could generate results that are unusable for supporting key planning or policy decisions.

The aforementioned is well known and has been accepted in the travel forecasting community for many years. However, this guidance is often not followed due to the absence of reliable data to allow checking of modeled travel times. Fortunately, a new data source is now available to state departments of transportation and Metropolitan Planning Organizations—the National Performance Management Research Data Set (NPMRDS). This dataset includes information on historic travel times for 5-minute intervals for each link in the National Highway System (NHS) as defined in MAP-21. Data is available for passenger vehicles, freight vehicles, and all traffic and is collected from a variety of sources, including mobile phones, personal navigation devices, and the American Transportation Research Institute (ATRI). This data became available in September 2013 and it allows the user to compare modeled and observed travel times on a link-by-link basis. With additional processing, it should be possible to develop point-to-point observed travel times for origins and destinations connected by the National Highway System. If necessary, this data can be supplemented with information collected by floating car travel time runs on other major roadways or by purchasing commercially available travel-time data.

Figure 9 provides an example of how the NPMRDS could be used to compare travel times. In this exhibit, AM peak truck travel times on Interstate routes from ATRI are shown as a "string of beads" along each interstate route. Times to the CBD are color shaded into 5-minute bands. The same shading scale is used to show AM Peak modeled travel times from each zone to the CBD. As this chart shows, travel times in most locations are similar between model and the ATRI database. The key exceptions are:

- Modeled travel times to downtown from the far east of the model area are higher than ATRI data by about 5 minutes
- Modeled travel times to downtown from the far west of the model area are lower than ATRI data by about 10 minutes

These differences should be examined to determine whether the speed data is accurate and what, if anything, should be done to adjust modeled estimates of travel times in these areas. When NPMRDS data becomes available, additional checks should be performed for all links in the NHS to multiple destinations.

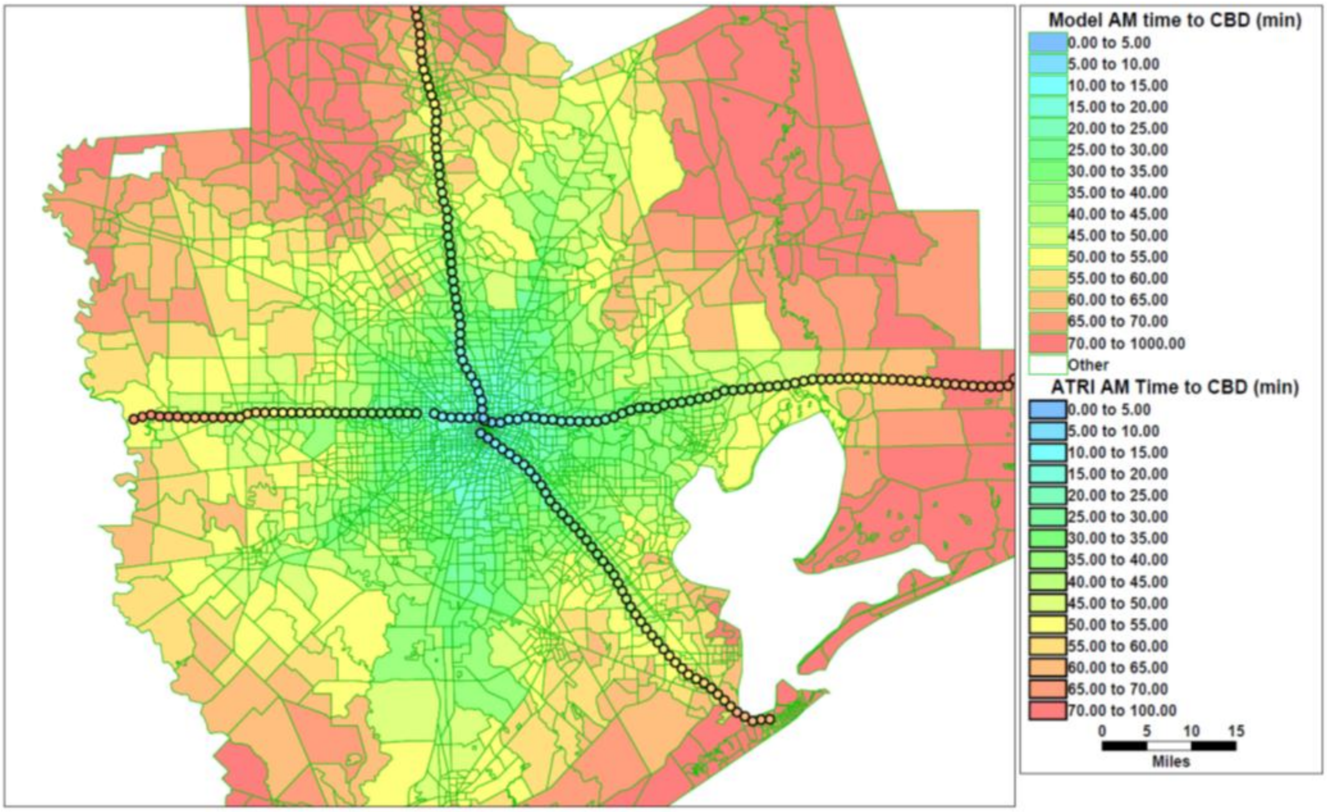


Figure 9. Illustrative Comparison of Modeled and Observed AM Peak Highway Travel Times.

Transit-travel-time data is also available from several sources. In particular, most transit agencies have online route planners that can be used to spot check OD times and routes that are generated by travel forecasting models. This can be done by navigating to the trip-planning section of the transit agency's website and specifying one or more sets of origins and destinations that correspond to modeled zone-to-zone trips. Larger tests can be run using the FTA's Simplified Trips-on-Project Software (STOPS). This model requires the user to obtain the local General Transit Feed Specification (GTFS) dataset, which is a series of computer files containing the operating agency's schedule. Zone-to-zone skims that are generated by STOPS can be compared to modeled zone-to-zone times to confirm the accuracy of these inputs.

6.2 Confirm Geographic Distribution of Travel

The geographic distribution of travel is one of the most important outcomes of the travel forecasting process and, unfortunately, one of the least accurate. Travel forecasting models typically start at each home (or group of homes) and use a variety of techniques to determine whether and where each individual works, goes to school, shops, or participates in other activities. Techniques vary between different models, but the essence is similar:

- Demand for travel is developed at the home location based on the number and characteristics of households.

- Destinations are selected based on a function of the number of attractions (e.g., employment, shopping, etc.) and the travel impedance from home.
- Travel to and from each zone may be constrained to match home and non-home input assumptions (doubly constrained). If not, models are generally constrained to assumptions regarding the home end of travel.

The procedures used to generate geographically-specific estimates of travel (origins and their linkage to destinations) tend to generate smooth distributions of travel that may or may not align with actual travel patterns. Figure 10 shows maps comparing the modeled proportion of trips traveling to the CBD from each production zone to a similar statistic from the Year 2000 CTPP. Note that the CTPP data is less uniform and the principal CBD corridors appear to the east and west of downtown. The model has more north-south travel to the CBD.

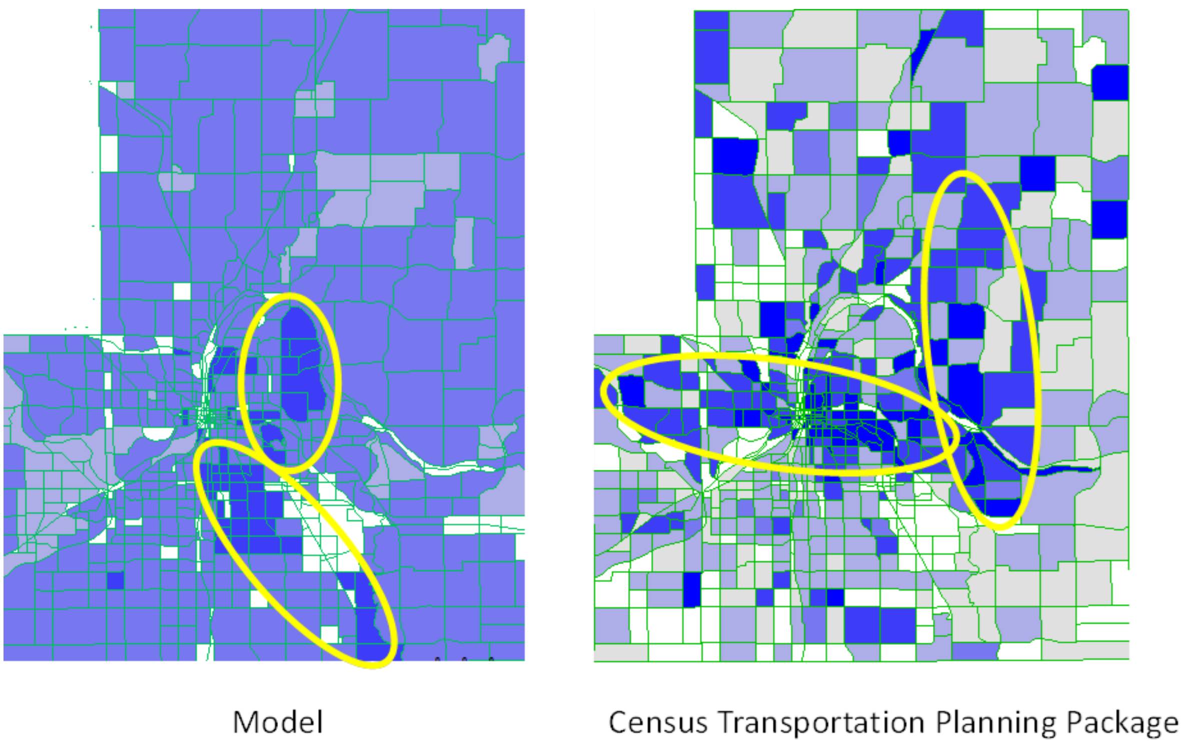


Figure 10. Comparison of Modeled and CTPP Fraction of Person Trips to CBD.

Source: AECOM, TMIP Webinar: Shining a Light Inside the Black Box, 2007.

Table 8 shows a sample district-to-district comparison that highlights differences in both attraction trip ends and certain cell-to-cell movements. If a project were intended to serve travelers from the suburban district to the CBD, then its usage could be underestimated by 80%—the amount that total travel in this corridor is underestimated—unless this model outcome is detected and corrected.

As these examples suggest, model developers must obtain data, map trip ends, and tabulate district-to-district flows to find and correct these problems. Reproducing average trip lengths, or even entire observed trip length frequency distributions, is *not* sufficient to demonstrate validation of a distribution model. The keys to proper validation include the following:

1. Gather sufficient data at the beginning of the model development effort to support district-to-district comparisons. Census Transportation Planning Package data is useful for work-related travel. Survey data is needed for other trip purposes.
2. Take the time to review destination choice outputs. Both production zone mapping to selected attraction districts and district-to-district flow tables are useful to help uncover serious model deficiencies.
3. Apply these checks for major stratifications of the person trip table. In one metropolitan area, the total demand for travel estimated by the forecasting model closely matched the CTPP. An examination of travel among different socioeconomic groups, however, revealed that trips by low-income persons were overestimated in wealthier parts of the region. This caused significant distortions to elements of the model that are affected by household income.

Table 8. Comparison of Modeled and CTPP District-to-District Home-Work Person Trips.

Estimated Demand/Travel Patterns

	CBD	Urban	Suburbs	Tech Center	Rural	Total
CBD	1,000	1,000	-	-	-	2,000
Urban	40,000	1,000	-	1,000	-	42,000
Suburbs	7,000	1,000	10,000	35,000	2,000	55,000
Tech Center	1,000	3,000	3,000	1,000	-	8,000
Rural	1,000	19,000	7,000	3,000	-	30,000
Total	50,000	25,000	20,000	40,000	2,000	137,000

Observed Demand/Travel Patterns

	CBD	Urban	Suburbs	Tech Center	Rural	Total
CBD	1,000	-	-	1,000	-	2,000
Urban	7,000	10,000	21,000	3,000	1,000	42,000
Suburbs	35,000	1,000	5,000	12,000	2,000	55,000
Tech Center	2,000	-	1,000	4,000	1,000	8,000
Rural	5,000	-	-	20,000	5,000	30,000
Total	50,000	11,000	27,000	40,000	9,000	137,000

Source: AECOM, TMIP Webinar: Shining a Light Inside the Black Box, 2007.

The Census's introduction of Traffic Analysis Districts (TADs) may be helpful in facilitating and standardizing district-to-district comparisons. It may be helpful to evaluate the validation of the distribution model using classic statistics such as correlation coefficients between observed and predicted district-to-district flow matrices. This would present a far more robust and meaningful criterion than coincidence ratios or average trip lengths. It is possible to produce a trip table with precisely the observed trip-length frequency distribution, but which in no way resembles the pattern of observed OD flows. Moreover, there is some evidence that over calibration to precisely reproduced observed average trip length can, in fact, result in a model that is less able to reproduce the observed pattern of OD flows[15].

6.3 Confirm Mode Choice Patterns

Many regional models include a procedure to split person-travel estimates among automobile, transit, and non-motorized modes. Mode choice procedures typically use a nested logit model to divide person trips between automobile and transit and between various transit access and line-haul sub-modes. Disutility functions are either estimated or borrowed from other cities and consist of a coefficient on in-vehicle time between -0.020 and -0.030 applied equally to all modes. Out-of-vehicle time is typically valued at 2 to 3 times the value of in-vehicle time, and costs are valued anywhere between $10 and $20 per hour.

Relatively simple models are often adjusted so that they match regional linked-trip totals by mode using automatic calibration procedures. Adjustments are accomplished by altering mode-specific constants until the total number of linked trips by mode generated by the model match observed control totals. In conventional practice, model validity is established by confirming that linked trips by mode closely agree with the control totals. Sometimes, route-specific ridership estimated by the model is compared to observed boardings. Only rarely do route-level model results match observed ridership.

Unfortunately, the standard practice described above does not necessarily result in a model that is useful to support transit planning. Models must also be checked to confirm that they properly represent the nature and location of the strongest transit markets.

The checking process starts with the recognition that the market for transit is not uniform across socio-economic segments or geographies. Transit ridership in most urban areas comprises less than 10% of all trip making. Some markets, however, have much higher market shares and it is vital that transit-forecasting models understand the circumstances in which transit is able to attract larger shares and where the market penetration is less.

[15] Ye, X., W. Cheng and X. Jia. Synthetic Environment to Evaluate Alternative Trip Distribution Models. Transportation Research Record Number 2302, Transportation Research Board, 2012.

Table 9 shows an approach that can be used to understand existing transit market patterns. This example subdivides trips according to where the traveler lives (each row), where they work (each column), and whether they live in a zero-car household or a car-owning household [16]. Trips are also subdivided by mode (e.g., auto, walk-to-transit, and drive-to-transit).

As this table illustrates, the principal markets for transit include the following:

- Zero-car households throughout the region.
- Car-owning households traveling to or from the CBD.
- Drive-access trips from suburban areas to the CBD.

Table 10 shows how a model might compare to observed volumes for car-owning households.[17] Overall, this model shows a reasonably close correlation to the observed volumes and matches overall transit volumes to within 3% of observed ridership.

Like many models, this model properly understands that the principal markets are zero-car households (not shown in this view) and travel to and from the CBD. At the same time, this model has some deficiencies that might make it unusable to support transit planning. Key problems include the following:

- The model understates transit travel from suburban areas to the CBD by 46%.
- The model overestimates transit travel from suburban areas to urban (non-CBD) areas by 98%. The model overestimates both walk-to-transit and drive-to-transit ridership for this market by 1,500 trips, each.
- The model underestimates transit for reverse commute trips from the CBD and urban areas to suburban areas.

Whether or not this model can be used in its current condition will depend on its intended uses. Even though the overall patterns match well, key markets that are off by a factor of two could easily result in project forecasts that are 50% below, or twice as high as, a more refined forecast of ridership.

A full discussion of potential steps to ameliorate these problems is beyond the scope of this paper. The basic approach is to identify problems (beginning with the analysis above), attempt to understand the root causes (e.g., drive-to-transit usage not sufficiently tied to areas with high parking costs), implement potential solutions, and test the model. This process is often highly iterative as solutions are identified, tested, and revised multiple times.

[16] In an actual analysis, travel should be subdivided into more districts, socioeconomic groups, and modes.

[17] Similar checks should be performed for each socioeconomic group.

Table 9. Example of Observed Mode Share Patterns.

0 Car Households | **Car-Owning Households** | **All Households**

Auto	CBD	Urban	Suburban	Total	*Auto*	CBD	Urban	Suburban	Total	*Auto*	CBD	Urban	Suburban	Total
CBD	500	300	300	1,100	**CBD**	700	400	700	1,800	**CBD**	0.0%	0.0%	0.0%	0.0%
Urban	3,000	20,000	10,000	33,000	**Urban**	4,000	18,000	11,000	33,000	**Urban**	0.0%	-10.0%	10.0%	0.0%
Suburban	4,000	9,000	10,000	23,000	**Suburban**	2,800	12,000	9,000	23,800	**Suburban**	0.0%	33.3%	-10.0%	3.5%
Total	7,500	29,300	20,300	57,100	**Total**	7,500	30,400	20,700	58,600	**Total**	0.0%	3.8%	2.0%	2.6%

Walk-to-Transit	CBD	Urban	Suburban	Total	*Walk-to-Transit*	CBD	Urban	Suburban	Total	*Walk-to-Transit*	CBD	Urban	Suburban	Total
CBD	5,000	2,000	1,000	8,000	**CBD**	3,000	1,500	900	5,400	**CBD**	0.0%	0.0%	0.0%	32.5%
Urban	10,000	20,000	5,000	35,000	**Urban**	12,000	22,000	4,200	38,200	**Urban**	20.0%	10.0%	0.0%	9.1%
Suburban	7,000	6,000	3,000	16,000	**Suburban**	6,000	5,000	4,000	15,000	**Suburban**	-14.3%	-16.7%	0.0%	-6.3%
Total	22,000	28,000	9,000	59,000	**Total**	21,000	28,500	9,100	58,600	**Total**	-4.5%	1.8%	1.1%	-0.7%

Drive-to-Transit	CBD	Urban	Suburban	Total	*Drive-to-Transit*	CBD	Urban	Suburban	Total	*Drive-to-Transit*	CBD	Urban	Suburban	Total
CBD				-	**CBD**				-	**CBD**	0.0%	0.0%	0.0%	0.0%
Urban	5			5	**Urban**				-	**Urban**	0.0%	0.0%	0.0%	0.0%
Suburban	10			10	**Suburban**	1,000			1,000	**Suburban**	0.0%	0.0%	0.0%	0.0%
Total	15	-	-	15	**Total**	1,000	-	-	1,000	**Total**	0.0%	0.0%	0.0%	0.0%

Total Person Trips	CBD	Urban	Suburban	Total	*Total Person Trips*	CBD	Urban	Suburban	Total	*Total Person Trips*	CBD	Urban	Suburban	Total
CBD	5,500	2,300	1,300	9,100	**CBD**	3,700	1,900	1,600	7,200	**CBD**	0.0%	0.0%	0.0%	-20.9%
Urban	13,005	40,000	15,000	68,005	**Urban**	16,000	40,000	15,200	71,200	**Urban**	23.0%	0.0%	1.3%	4.7%
Suburban	11,010	15,000	13,000	39,010	**Suburban**	9,800	17,000	13,000	39,800	**Suburban**	-11.0%	13.3%	0.0%	2.0%
Total	29,515	57,300	29,300	116,115	**Total**	29,500	58,900	29,800	118,200	**Total**	-0.1%	2.8%	1.7%	1.8%

Transit Share	CBD	Urban	Suburban	Total	*Transit Share*	CBD	Urban	Suburban	Total	*Transit Share*	CBD	Urban	Suburban	Total
CBD	90.9%	87.0%	76.9%	87.9%	**CBD**	81.1%	78.9%	56.3%	75.0%	**CBD**	-10.8%	-9.2%	-26.9%	-14.7%
Urban	76.9%	50.0%	33.3%	51.5%	**Urban**	75.0%	55.0%	27.6%	53.7%	**Urban**	-2.5%	10.0%	-17.1%	4.2%
Suburban	63.7%	40.0%	23.1%	41.0%	**Suburban**	71.4%	29.4%	30.8%	40.2%	**Suburban**	12.2%	-26.5%	33.3%	-2.0%
Total	74.6%	48.9%	30.7%	50.8%	**Total**	74.6%	48.4%	30.5%	50.4%	**Total**	0.0%	-1.0%	-0.6%	-0.8%

Table 10. Comparison of Observed and Modeled Mode Share Patterns.

Car-Owning Households

OBSERVED | **MODEL** | **Percent Different for Cells over:** 5000

Auto	CBD	Urban	Suburban	Total	*Auto*	CBD	Urban	Suburban	Total	*Auto*	CBD	Urban	Suburban	Total
CBD	500	2,000	1,500	4,000	**CBD**	700	1,800	3,000	5,500	**CBD**	0.0%	0.0%	0.0%	0.0%
Urban	30,000	25,000	30,000	85,000	**Urban**	25,000	20,000	40,000	85,000	**Urban**	-16.7%	-20.0%	33.3%	0.0%
Suburban	40,000	200,000	1,000,000	1,240,000	**Suburban**	40,000	220,000	980,000	1,240,000	**Suburban**	0.0%	10.0%	-2.0%	0.0%
Total	70,500	227,000	1,031,500	1,329,000	**Total**	65,700	241,800	1,023,000	1,330,500	**Total**	-6.8%	6.5%	-0.8%	0.1%

Walk-to-Transit	CBD	Urban	Suburban	Total	*Walk-to-Transit*	CBD	Urban	Suburban	Total	*Walk-to-Transit*	CBD	Urban	Suburban	Total
CBD	3,000	1,000	700	4,700	**CBD**	700	1,500	900	3,100	**CBD**	0.0%	0.0%	0.0%	0.0%
Urban	12,000	2,000	3,000	17,000	**Urban**	12,000	1,500	2,000	15,500	**Urban**	0.0%	0.0%	0.0%	-8.8%
Suburban	1,000	2,000	10,000	13,000	**Suburban**	1,500	3,500	12,000	17,000	**Suburban**	0.0%	0.0%	20.0%	30.8%
Total	16,000	5,000	13,700	34,700	**Total**	14,200	6,500	14,900	35,600	**Total**	-11.3%	30.0%	8.8%	2.6%

Drive-to-Transit	CBD	Urban	Suburban	Total	*Drive-to-Transit*	CBD	Urban	Suburban	Total	*Drive-to-Transit*	CBD	Urban	Suburban	Total
CBD				-	**CBD**				-	**CBD**	0.0%	0.0%	0.0%	0.0%
Urban	1,000	50		1,050	**Urban**	4,000			4,000	**Urban**	0.0%	0.0%	0.0%	0.0%
Suburban	6,000	500		6,500	**Suburban**	2,000	2,000		4,000	**Suburban**	0.0%	0.0%	0.0%	-38.5%
Total	7,000	550	-	7,550	**Total**	6,000	2,000	-	8,000	**Total**	-14.3%	0.0%	0.0%	6.0%

Total Person Trips	CBD	Urban	Suburban	Total	*Total Person Trips*	CBD	Urban	Suburban	Total	*Total Person Trips*	CBD	Urban	Suburban	Total
CBD	3,500	3,000	2,200	8,700	**CBD**	1,400	3,300	3,900	8,600	**CBD**	0.0%	0.0%	0.0%	-1.1%
Urban	43,000	27,050	33,000	103,050	**Urban**	41,000	21,500	42,000	104,500	**Urban**	-4.7%	-20.5%	27.3%	1.4%
Suburban	47,000	202,500	1,010,000	1,259,500	**Suburban**	43,500	225,500	992,000	1,261,000	**Suburban**	-7.4%	11.4%	-1.8%	0.1%
Total	93,500	232,550	1,045,200	1,371,250	**Total**	85,900	250,300	1,037,900	1,374,100	**Total**	-8.1%	7.6%	-0.7%	0.2%

Transit Share	CBD	Urban	Suburban	Total	*Transit Share*	CBD	Urban	Suburban	Total	*Transit Share*	CBD	Urban	Suburban	Total
CBD	85.7%	33.3%	31.8%	54.0%	**CBD**	50.0%	45.5%	23.1%	36.0%	**CBD**	-41.7%	36.4%	-27.5%	-33.3%
Urban	30.2%	7.6%	9.1%	17.5%	**Urban**	39.0%	7.0%	4.8%	18.7%	**Urban**	29.1%	-7.9%	-47.6%	6.5%
Suburban	14.9%	1.2%	1.0%	1.5%	**Suburban**	8.0%	2.4%	1.2%	1.7%	**Suburban**	-46.0%	97.6%	22.2%	7.6%
Total	24.6%	2.4%	1.3%	3.1%	**Total**	23.5%	3.4%	1.4%	3.2%	**Total**	-4.4%	42.3%	9.5%	3.0%

6.4 Confirm Model Response to Change

Ultimately, models are designed to represent the expected evolution in travel patterns that will result from changes to other conditions. Forecasting-analysis tools are calibrated with the assumption that insights can be derived from the examination of existing relationships between demographics, supply, and demand that can help understand how changes in these factors will influence future travel.

Even carefully calibrated models may not perform well when initially applied to future conditions. The most common problems are related to the fact that for all their complexity, travel forecasting tools are still just approximations of complex behaviors. These tools do not always generate appropriate responses to changes in input variables, even if individual changes are reasonable and thought highly likely to occur. Judgment on the part of the forecaster is required to assess whether the model is or is not behaving properly when stressed with sizable increases in population and employment and modest (or no) improvements to the transportation system.

This judgment is best applied by constructing a series of tests that attempts to stress the model by changing input conditions one at a time and in combination to determine whether the model response is reasonable. Wherever possible, reasonableness should be based on real-world experience with similar changes inside the forecaster's metropolitan area or in other similar regions (e.g., use the model to "backcast" to an earlier time and confirm that the model properly represents both current and earlier travel patterns). Even if no similar experiences exist, it is still important to test the model response to anticipated changed conditions.

The list of changed circumstances that could generate questionable model results is long. Table 11 provides a list of potential problems that have been observed in application and model responses that should be evaluated for reasonableness.

Table 11. Potential Tests of Model Sensitivity.

Situation	Potential Model Responses to Evaluate
Demographic forecasts show that the central city is relatively stable. Inner suburbs show little population growth but strong employment growth. Outer suburbs show strong population growth.	Residents of outer suburbs take an increasing share of CBD employment. Inner suburban residents increasingly take jobs in inner suburbs. Together, these factors decrease inner suburb-to-CBD travel significantly. Even though logical, this change often is different from observed trends and difficult to defend.
Massive new exurban development built next to rural two-lane road, often loaded with single centroid connector.	LOS on rural road collapses and computed speeds approach 5 miles per hour. Buses traveling on these roads slow to 3 miles per hour. This situation is also difficult to defend since it is unlikely that this development could occur without improvements to the rural road or connections to other roadways.
Increased population and employment lead to substantial increases in highway demand and changes to the relative use of freeways and arterials.	Although the original calibration reveals a good balance between freeways and parallel arterials, the future year shows unrealistic levels of arterial usage. Potential problems may exist with highway capacity and/or volume delay functions that were not revealed in current, less congested scenarios.
Imposition of parking costs or auto operating costs that	Increase in transit ridership far in excess of observed increases during recent fuel price increases. Price

are much higher and broadly applied than today.	sensitivity may need to be adjusted.
Implementation of express transit service from a limited number of stops.	Greater attractiveness of express services than is warranted by the limited stop coverage. Often caused by insufficient geographic detail that overstates the ability of travelers to reach the new stops.

7.0 Conclusion

In the end, a successful set of forecasts is the product of the person who utilizes knowledge of current conditions, tools (such as models) to show what may happen, and judgment to develop the actual projections of future travel demand and its impacts on mobility. Each aspect of this process is important—successful projections cannot be developed without data, effective analysis procedures, and judgment. In each, the person responsible for assembling projections plays a key role. The forecaster must actively review each element of the forecasting process to confirm that the data are accurate and that the results make sense. Forecasts that have not been scrutinized by the forecaster and by independent reviewers are only raw numbers. It is the combination of internal and external review that transforms these numbers into useful projections.

NOTICE

This report is being distributed through the Travel Model Improvement Program (TMIP).

Federal Highway Administration