Maricopa Association of Governments

Toll Road Modeling Support: Final Report

Phoenix, AZ

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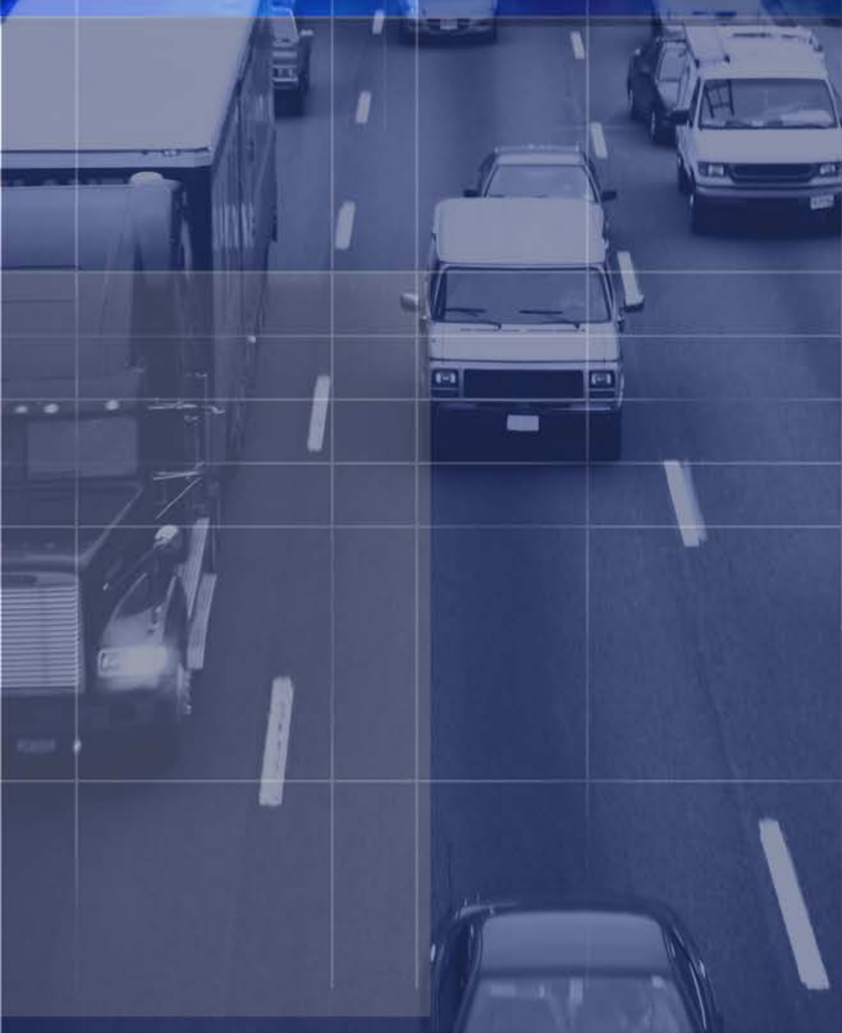

HDR

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1. INTRODUCTION

1.1 Overview and Purpose

In June 2011, the Maricopa Association of Governments (MAG) authorized HDR Engineering, Inc. (HDR), to review its capabilities and needs for modeling traffic and revenue (T&R) at a regional scale and to identify possible modeling improvements and data requirements.

This report synthesizes current and best practices in T&R modeling at a regional scale. It also examines current modeling practice at MAG and then discusses an analysis of the gaps between the existing MAG model—with respect to T&R modeling—and the state of practice in T&R modeling. Finally, the report recommends several modeling and data improvements for MAG's consideration.

It should be noted that this work should not be construed as a critique of MAG, its modeling capabilities, or its data sources. Rather, it is intended to address a specific need identified by MAG; namely, the need to upgrade its capabilities for modeling and forecasting alternative T&R scenarios and develop the supporting data—all to aid MAG in responding to potential future pricing initiatives by the Arizona Department of Transportation or other agencies. These initiatives are not yet defined and could take many forms; it is important to note that this task makes no implications in that respect—it simply focuses on the modeling tools and data, not on any potential applications.

For the purposes of this task, the term "T&R modeling" essentially describes how auto or commercial travelers behave when monetary costs (i.e., prices) are imposed on their trips.[1] That being said, however, T&R modeling could take many different forms. For example:

- Point tolls at a specific location, such as a bridge
- Distance-based tolls, such as a rate per mile traveled
- Variable tolls by time of day or day of week
- Dynamic tolls, which fluctuate according to prescribed criteria, as a means of managing the speed and flow of traffic
- Cordon or other pricing schemes; that is, across a range of facilities (e.g., all expressways) rather than on a specific facility or corridor
- Managed lanes; that is, individual lanes on specific facilities (which otherwise are not tolled)

In addition, the nature and objectives of the application and forecasting requirements could take different forms, from policy studies to long-range transportation plans, sketch plans, corridor studies, and investment-grade T&R forecasts.[2] Each of these has its own

[1] Although auto drivers could choose to switch to transit or other non-auto modes in the face of a toll, the imposition of costs on these other modes is not considered as part of this task.
[2] A 2005 guideline from the Texas Turnpike Authority (TTA), a division of the Texas Department of Transportation (DOT), identifies four levels of analysis for T&R studies:

requirements. Related to all of these are the questions being asked, or the objectives of the studies, as well as the perspective of the study, for example:

- Purpose of the proposed tolled improvement – e.g., to generate revenues or mitigate congestion (the responses are not necessarily the same)
- Subject of the study – e.g., to test alternative pricing schemes or rates and/or test the impact of a new capacity expansion and/or test alternative network configurations (and so on)
- Use of the study – e.g., to test engineering designs, examine alternative operational configurations, or use as the basis for funding decisions
- Perspective – e.g., the owner, other levels of government, a potential concessionaire, a lender, bond insurer, etc.

Finally, this task focuses on MAG's existing four-step model, which is the agency's operational model. The task is not considering MAG's activity-based model, which now is being developed.

As a result, although this review covers a range of subjects within the practice of T&R modeling, it necessarily is generic. This review, then, provides a base to support subsequent detailing of specific models or data, which would be required in order to address specific initiatives or studies as they arise.

1.2 Structure of Report

The report is organized into nine chapters. Chapter 2 discusses the key issues relevant to T&R modeling and data. This sets the stage for the subsequent review of practices. Chapter 3 inventories the T&R practices and sources that were found in the conduct of a literature review, which was the main source of information for the task. Chapter 4 then elaborates on these findings to develop a synthesis of T&R practices that could serve as the basis for designing a T&R model or add-ons for MAG. This is followed by Chapter 5, which presents ways of addressing uncertainty in T&R forecasts. Chapter 6 reviews the current MAG four-step model, insofar as its treatment of T&R (costs) is concerned. Chapter 7 draws together the preceding material to identify gaps and opportunities. Chapter 8 then proposes recommended modeling and data approaches to enable MAG to develop its T&R forecasting capabilities. Finally, Chapter 9 presents an annotated list of sources.

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1) Conceptual, which determines the potential for a toll road project to support bonds. (Expected durations of each type of study were provided: they are listed here as an indication of the level of effort and detail. The conceptual level had an estimated duration of 1–4 weeks).
2) Sketch, which is a project-specific estimate of costs, demand and revenues (6 weeks duration).
3) Intermediate, which refines the previous analysis, including a tolling plan. It is expected that demand projects would be derived from a travel demand model (4–6 months duration).
4) Investment grade, which is an "extensive and detailed" analysis "to determine its value in anticipation of proceeding to the bond market" (12–18 months duration).

Source: "Guidelines for Conducting TTA Traffic and Revenue Studies," Technical Memorandum 2005-2, Texas Turnpike Authority, Austin, 2005. As cited in *Estimating Toll Road Demand and Revenue*, NCHRP Synthesis 364.

The report summarizes the three phases of the work. Chapters 2–7 address Task 1, which was a review of best practices in T&R modeling and a synopsis of MAG's current four-step model vis-à-vis toll modeling. Chapter 8 is a high-level list of directions for proposed modeling improvements and supporting data collection activities for consideration by MAG and possible implementation on subsequent task orders.

The report is accompanied by three appendixes. Appendix A presents values of time (VoTs) from T&R studies elsewhere in the United States. These can be used as benchmarks and references for MAG as it develops its own values of time. Appendix B includes the consultant's presentation slides from MAG's toll road model workshop, held at the agency's offices on October 24, 2011. There are two presentations: the first provides a general perspective, while the second is a more technical discussion. Appendix C provides two memoranda that describe—at a generic level—the content and conceptual design of stated preference (SP) surveys that are used to capture VoTs.

2. ISSUES

2.1 Analytical Attributes of a T&R Model and Forecast

The complexity of T&R modeling, as outlined in Section 1.1, means that a first step in identifying best practices should be to list key T&R issues that are common to the practice, and then categorize them in order to set up the response (which follows in subsequent chapters). We do this, first, by identifying the key attributes of a T&R model and forecast and, second, by listing specific issues. These are done in this section and the next section, respectively.

As discussed in HDR's work plan for this task order, the requirements can be seen as two-fold: At its core, the essential requirement is *analytical*, to enhance the existing treatment of *costs* or *pricing* into the model; that is, to account more precisely for how traveler behavior is influenced by tolls or by other public-private partnership (P3) pricing mechanisms. This enhancement could entail:[3]

- Detailing and updating of VoT parameters, detailed appropriately to account for different trip purposes and vehicle "classes." The VoT parameters convert monetary values to travel time equivalents, so these data and this relationship lie at the core of the analytical requirements. VoT parameters may have been included in a model's distribution, assignment, and mode choice modules; however, in the absence of specific surveys, they often are derived from broad regional indicators such as income.
- Development of a new toll choice model to model the travel behavior of a new tolled facility or a managed lane. Commonly, a logit model is developed for this within the trip assignment stage, but the toll choice also can be considered in mode choice, especially if the impact of tolls on mode choice is expected to be significant. The toll choice or "diversion" mechanism is the analytical basis of the model.
- Assurance of consistency between the treatment of costs in different model components (e.g., between assignment and mode choice, but also trip distribution). It is important to ensure that VoTs are applied consistently throughout the process, while ensuring that they do not have any unintended impacts on the individual model steps. Moreover, some models have calibrated a particular value as part of the model development process; meaning that—in absolute terms—the actual value of the parameter may not be realistic, even though it is sufficient for calibration. Finally, and perhaps most important, the treatment of costs/prices in a regional travel demand model may have been, at best, of secondary concern: that may not be enough to respond to today's cost/pricing issues.
- Assurance that all appropriate toll choice forecasting parameters have been taken into account in the model, both for calibration and also to allow for forecasting (and ensuring also that the parameters can be forecasted). Studies have found that the propensity to use tolled facilities, especially in an area for which tolls are new to the traveling public, has been linked to several factors in addition to VoT. These include personal disposable

[3] The ensuing paragraphs expand on a discussion that first appeared in HDR's workplan for this task order.

income and its expected growth, general congestion levels, start-and-stop conditions on alternate routes, vehicle operating costs, and the method of toll collection.

- Ensuring that complementary data are developed to support T&R analysis. In particular, origin-destination data are required at a sufficient level of geographic detail, sample size, etc., to capture the would-be users of a tolled or priced facility. SP surveys are widely used to capture values of time. Traffic counts and screenline classification and occupancy counts may be required at a finer level of geographic detail to complement existing counts. Finally, up-to-date and precise travel time data are required; this supports the need to ensure that speeds are modeled accurately in the model, on a route level rather than the more typical matrix-/network-level totals. The object is to simulate reliably the route choices that are available to travelers, between the tolled and non-tolled alternatives.

All of these analytical considerations are discussed in the ensuing Chapters 3, 4 and 5.

The second requirement is *procedural*. This refers to the application of the T&R model in planning decisions. This is discussed further in Chapter 7.

2.2 Specific Issues

The National Cooperative Highway Research Program (NCHRP) Synthesis 364, *Estimating Toll Road Demand and Revenue*, provides a useful means to identify more specific issues. The synthesis reviewed the state of T&R modeling and forecasting practice. It identified and examined several issues. This 2007 research paper, written by HDR staff, identified 12 categories of issues—these complement or expand the list of issues discussed in the previous section.[4]

1) Model inputs – ensuring, in particular, that the demographic and socioeconomic factors that "drive" forecasts of the market for travel reflect realistic conditions and trends.

[4] Kriger, D., S. Shiu, and S. Naylor, *Estimating Toll Road Demand and Revenue*, Synthesis 364: National Cooperative Highway Research Program, 2007. It is widely acknowledged in the P3 and alternate delivery industry that the track record of T&R forecasts—the basis for financing—has varied significantly. The synthesis was intended to understand the shortcomings associated with investment-grade T&R forecasts, and to identify best practices to address these deficiencies. In particular, the synthesis was intended to improve the *accuracy*—that is, the *reliability* and *credibility*—of T&R forecasts, from the perspectives of both the engineering/planning community that generates the forecasts for design and analytical purposes and the financial/insurance community that generates funding for the project. The synthesis compared forecast and actual traffic for several toll roads throughout the United States. It reviewed a number of T&R studies, and found a range of shortcomings: from inappropriate use of an existing travel demand model to inadequate treatment of trucks and—most commonly—a lack of transparency as to the source data, assumptions, and even the modeling process. The synthesis conducted a nationwide survey of DOTs and tolling authorities to ask them about their T&R modeling and data practices, whether their needs were met, deficiencies, and best practices. Interviews also were conducted with practitioners around the world.

2) Travel characteristics – the need for accurate, reliable, and up-to-date travel data that are specific to the endeavor, including origin-destination surveys, traffic counts, and travel time surveys.
3) VoT/willingness to pay – recognizing that these values represent a range or a distribution and not a single value (even, sometimes, a given purpose), and ensuring again that the values reflect local conditions and the specifics of the issue at hand.
4) Tolling "culture" – accounting for local potential biases or motivations that would encourage or discourage the use of the tolled facility.
5) Truck forecasts – the need for a full-scale truck modeling capability that captures all aspects of the market. The model must be integrated into the full modeling process, in particular, in the trip assignment and in the travel time (skim) matrices that are fed back to the (passenger) demand models.
6) Ramp-up – accounting accurately for the first few years after the facility opens, as traffic grows. Critical issues are how well the base year model is calibrated, how well the short-term traffic forecasts reflect actual demographic or socioeconomic growth, and how to account for short-term fluctuations in business cycles or economic conditions that have severe impacts on traffic. Econometric models, as discussed below, have improved the reliability and accuracy of short-term T&R forecasts.
7) Time of day modeling – the need to accurately depict different times of day as well as peak spreading, as discussed in the previous section.
8) Risk – the need to incorporate risk analysis into the model forecasts, as well as ensuring that sensitivity analyses go beyond the "typical" high/low variations to the same parameters individually, and move instead toward more realistic stress tests that account for exogenous and endogenous factors in combination (i.e., the way the real world would behave).
9) Optimism bias – accounting for external factors that might promote the need for a given facility, even if the numbers do not make the case.
10) Model calibration – ensuring that rigorous calibration criteria are applied to the model, to make it appropriate for use for modeling the given project (e.g., that calibration screenlines match the location and scale of the corridor in question, and in particular that travel times and speeds are accurately simulated in the model [in addition to trip tables]).
11) Model validation – using "air tight" validation criteria to ensure that the model is appropriate for the specific purpose and is not simply an application of an existing tool, and using the more rigorous validation tests and criteria supported by the international toll lending community. The importance lies in ensuring that although the travel demand forecasting model was not originally intended for T&R studies when the four-step model was introduced over half a century ago, its outputs can now be used to develop a business case that will be accepted by the financial community.
12) Peer reviews – it is common that investment-grade T&R forecasts are subjected to multiple reviews by external advisors. In addition, however, it is important to ensure that the client team participates fully in the development of the model, data, and forecasts (because the team will provide important insight into what originally was its model and because the team ultimately will own the model). It also is important that the modeling process, inputs, assumptions, and outputs be documented fully and transparently to allow model analysts and financial analysts alike to understand the process. The importance lies in promoting credibility and reliability.

The synthesis identified best practices for each of these topics. Equally important, HDR has applied these practices into investment-grade T&R forecasts that we have developed, resulting in a reputation for credibility, reliability, and transparency.

3. REVIEW OF BEST PRACTICES

This chapter summarizes practices in T&R modeling from recent reports, studies, and guidelines on the subject from both North America and Europe. A total of 32 sources were reviewed (not counting duplicate or irrelevant material), with a complete annotated list provided in Chapter 9. Fifteen of the 32 were selected for detailed review here. These represent the most recent (within 5 years) and/or comprehensive studies and focus on practical applications rather than abstract techniques.

The reports reviewed in this chapter are divided into three categories: T&R studies and road pricing surveys, econometric modeling, and managed lane modeling. Each of these is described, summarizing the key points contributed by that source. The information is then carried forward to Chapter 4, where it is used in the summary of modeling practices that forms the core of this report.

3.1 T&R Studies and Road Pricing Surveys

3.1.1 Guidelines and Syntheses

The first three sources, rather than analyzing a specific facility, provide general guidelines and recommendations for use in models. These are useful for providing descriptions of methodologies, information that needs to be collected through surveys or other means, and approximate parameters for values of time and for sensitivity ranges.

Oregon DOT Synthesis of Travel Demand Models[5]

Report	Tolling White Paper 3: Travel Demand Model Sufficiency
Author	Parsons Brinckerhoff/David Evans/Stantec
Location/Year	Oregon (reviews across USA), 2009
Key Points	• assesses opportunities provided by road pricing in generating revenue and managing congestion • reviews modeling practices and modeling requirements • evaluates capability of existing models to provide T&R forecasts • identifies essential/desirable model features, including route selection, departure time, mode, and destination • identifies quality of validation and recommends risk-analysis program • recommends that vehicle classes for assignment should be modeled consistently with VoT classes

[5] Parsons Brinckerhoff, David Evans, Stantec, *Tolling White Paper 3: Travel Demand Model Sufficiency*, Oregon DOT, 2009. Accessed from <www.oregon.gov/ODOT/TD/TP/docs/LRPU/twp3.pdf>.

United Kingdom Department for Transport Road Pricing Procedures[6]

Report	DfT Transport Analysis Guidance Module 3.12.2: Modelling Road Pricing
Author	Department for Transport (United Kingdom)
Location/Year	United Kingdom, 2007
Key Points	• explains guidelines for how to model road pricing schemes • segments trips by business (income/mode) and non-business (purpose and income) for pricing • derives and applies VoT, and also explains how to calculate marginal social cost for an additional vehicle using a link • uses national studies to derive VoT values • recommends that data on household income and mileage travelled collected in segments be adopted • VoTs average £4.85/hour commute (approximately $8 at September 2011 exchange), £4.33 non-work related (approximately $7), £21 business (approximately $34)

Mexico/SDG Toll Road Model Guidelines[7]

Report	Modelación de demanda para carreteras de cuota (Toll road model manual)
Author	Luis Willumsen and Steer Davies Gleave
Location/Year	Mexico, 2006
Key Points	• provides general recommendations for designing and applying toll road demand models • recommends segmenting demand by vehicle type, purpose, travel group size, level of income, and whether individual or employer pays tolls • recommends assessing effect of facility in changing departure time, group size, land use, mode (unlikely significant), origin-destination (OD) patterns, and increase in trips • suggests 10 percent of data be kept from calibration for validation • suggests modeling +/- 20 percent for all VoT segments, toll sensitivity, two to three growth sensitivity scenarios to determine elasticity of demand, and scenarios with alternative/competing projects • recommends that data collected include area of influence of facility (land use/economic data), socioeconomic info, zones, networks, vehicle operating cost (VOC) functions, travel times, sample sizes, speed data, OD surveys, SP/revealed preference (RP) surveys • VoT should be assessed based on willingness to pay (cars: income and who pays toll; trucks: cargo, contract type, dangerous goods requirements) and quality of time (road quality, quantity and extent of stoppages)

3.1.2 T&R Reports

This section collects information from T&R studies conducted for specific toll corridors, including facilities in Virginia, Arkansas, Florida, and New Jersey, within the last 3 years. These reports illustrate wide variations found in the values of time (between $3 and $39 per hour, depending on class), although the average appears to be around $15 per hour.

[6] Department for Transport, *DfT Transport Analysis Guidance Module 3.12.2: Modelling Road Pricing*, DfT TAG Unit 3.12.2, 2007. Accessed from <www.dft.gov.uk/webtag/documents/ expert/pdf/unit3.12.2c.pdf>.

[7] Willumsen, L. et al, *Modelación de demanda para carreteras de cuota* (*Toll road model manual*), SDG /Transconsult/ Mexico, 2006. Accessed from <uac.sct.gob.mx/fileadmin/espanol/manual _modelacion/modelacion.pdf>.

Chesapeake Expressway Traffic and Revenue Study[8]

Report	Chesapeake Expressway Investment Grade Traffic & Revenue Study Draft Report
Author	SDG
Location/Year	Virginia, 2010
Key Points	• describes route choice toll model for T&R study • models scenarios including economic downturn; high fuel prices; unexpected corridor growth; willingness to pay more; performance of competing route with diversion; 5,10, 25 percent increase/decrease; 25 percent +/- VoT • identifies recommended toll increases up to $5 for future cash rate with binary logit route choice model • recommends SP and RP surveys; travel time survey; seasonal, day type, and time of day counts; population, employment, and recreational forecasts and growth rates • VoTs combine SP and RP (including freeway bias) results; $7–$31 (discount users), $8–$39 (full toll users); VOC of 13 cents/mile • SP surveys compare slow untolled and faster tolled options and RP surveys; RP VoTs are higher than SP; validated against 2009 data

Bella Vista Bypass Traffic and Revenue Study[9]

Report	Bella Vista Bypass Traffic and Revenue Report
Author	Jacobs/Stantec
Location/Year	Arkansas, 2009
Key Points	• develops new estimates and reviews 2004 and 2006 projections on toll road • develops new estimates and reviews 2004 and 2006 projections • validates growth rates against historic patterns • models scenarios for lower/higher toll rates, lower/higher VoT, aggressive traffic growth rate, programmed toll rate increases • 2006 model data are supplemented by updated traffic counts and travel speed data • VoT $15/hour (recalculated from earlier 2006 report); pricing $1.50 for cars, $3.00 and $6.00 for trucks

First Coast Outer Beltway Traffic and Revenue Study[10]

Report	First Coast Outer Beltway Planning Level Traffic and Revenue Analysis Draft Report
Author	WSA
Location/Year	Florida, 2010
Key Points	• describes T&R model • models varying tolling assumptions from 5 to 30 cents per mile; low, medium/high, high socioeconomic forecasts; and 50 percent growth reduction scenario • surveys done of number of hours worked; data from northeast regional planning model; FKA and BEBR socioeconomic projections • VoTs 22 cents/minute ($13/hour); VOC 17.5 cents/mile; VoTs are segmented by purpose and income; pricing 15, 20, and 25 cents/mile (cars); 38, 50, and 63 cents/mile (commercial vehicles)

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[8] Steer Davies Gleave, *Chesapeake Expressway Investment Grade Traffic & Revenue Study Draft Report*, City of Chesapeake, 2010. Accessed from <www.chesapeake.va.us/services/depart/pub-wrks/chesapeake_expressway/pdf/2010-10-Chesapeake_Expressway_Report.pdf>.
[9] Jacobs, Stantec, *Bella Vista Bypass Traffic and Revenue Report*, Arkansas Highway Transportation Department, 2009. Accessed from <www.arkansashighways.com/BVB/Traffic_Revenue09.pdf>.
[10] Wilbur Smith Associates, *First Coast Outer Beltway Planning Level Traffic and Revenue Analysis Draft Report*, Florida DOT, 2010. Accessed from <www.fdotfirstcoastouterbeltway.com/forum_docs/T-RStudyUpdate.pdf>.

New Jersey Traffic and Revenue Study[11]

Report	New Jersey T&R Study Final Report
Author	SDG
Location/Year	New Jersey, 2008
Key Points	• reviews expected T&R range on series of existing roads • based on the state TP+ model, with spreadsheet-based revenue model projecting from 2006 base • models scenarios allowing for annual base growth, peak spreading, road capacity upgrades, tolling scenarios, and the level of suppression of excess traffic • data from existing TP+ state model and three sets of population, labor force, and employment projections, freight and freight facility trends, observed revenue and transaction data from existing tolled areas • VoTs $3 to $37/hour auto, $54 truck; VOC 1 cent/mile (auto), 2 cents/mile (truck)

3.1.3 Reviews

This source differs from the others in that it represents a panel review of a toll model, rather than the actual model. However, it describes a similar approach and methodology to the others, with a combination of a demand model and the revenue component.

I-405/SR 167 Panel Review[12]

Report	I-405/SR 167 Corridor Tolling Study Expert Review Panel Final Report
Author	G. Goodin (Panel Chair)
Location/Year	Washington State, 2010
Key Points	• evaluates WSA toll model for the SR 167 corridor • reviews approach and methodology used in corridor (model not described in detail) • four components: regional model, microsimulation, "willingness to pay" revenue model, microsimulation • data include speed and demand profile information from regional model input to revenue model

3.1.4 Surveys

These sources describe the findings of surveys conducted to investigate traveler preferences, without applying the survey results to develop a model but rather to identify influencing factors on VoT by market segment. They also describe means to conduct surveys, whether by using Global Positioning System (GPS) tracking or roadside interviews.

[11] Steer Davies Gleave, CRA, EDR, *New Jersey T&R Study Final Report*, New Jersey DOT, 2008. Accessed from <www.state.nj.us/treasury/pdf/njtrstudypart1.pdf>.

[12] Goodin, G. (Panel Chair), et al., *I-405/SR 167 Corridor Tolling Study Expert Review Panel Final Report*, Washington DOT, 2010. Accessed from <www.wsdot.wa.gov/Tolling/EastsideCorridor/Report.htm>.

University of Leeds M6 Toll Study[13]

Report	University of Leeds M6 Toll Study: Modelling of Passenger Choices Final Report
Author	Wardman et al., Institute for Transport Studies (United Kingdom)
Location/Year	United Kingdom, 2008
Key Points	• describes response to variations in journey cost (toll and fuel) and in time, extent to which SP design and presentation influences findings, heterogeneity of driver preferences and other modeling issues • SP analyses of route choice, route and departure time choice, and abstract choice (influence of lane width, etc); sensitivity hypotheses grouped in terms of cost (level of toll), time, route choice (SP), socioeconomic attributes, and other variables • mail-back SP surveys (3,235 responses); SP surveys on route choice, time choice, and other areas influencing choice of route; roadside interview sites and postal contact, with mail-back questionnaires • sensitivity greater to increases in £3.50 (approximately $5.70 at September 2011 exchange rate) existing toll than to decreases • VoTs £7.54 to £10.08 ($12.30 to $16.40 at September 2011 exchange rate) varying by journey length, type of time (free flow or congested), travelling alone or with others, width of lane, percentage of trucks on route, quality of surface; no indication of varying with the course of time

Puget Sound Value of Time Analysis[14]

Report	Value of Time for Travel Forecasting and Benefits Analysis
Author	Outwater and Kitchen (PSRC)
Location/Year	Puget Sound, 2008
Key Points	• calculates values of time to assess benefit by purpose and income level • uses results from GPS survey and literature review to calculate VoT by market segment and quantify the value of travel time saved to assess reaction to variable pricing • GPS data from 275-household survey for auto VoTs, with separate literature study done for truck VOTs • auto commute VoT $9–$33/hour based on income (~75 percent of wage rate), non-work $16/hour, trucks $40–$50/hour

[13] Wardman, M. et al, University of Leeds M6 Toll Study: Modelling of Passenger Choices Final Report: University of Leeds, 2008. Accessed from http://www.etcproceedings.org/paper/modelling-the-demand-for-toll-roads-in-the-uk.
[14] Outwater, M. and M. Kitchen, Value of time for Travel Forecasting and Benefits Analysis: Puget Sound Regional Council, 2008. Accessed from http://psrc.org/assets/1820/ValueofTimeMemo-updated.pdf.

Southern California Association of Governments Express Travel Choices Study[15]

Report	Various presentations (no report provided)
Author	Various
Location/Year	Southern California, 2010
Key Points	• multiyear study of congestion pricing alternatives aimed at reducing congestion and vehicle emissions and at enhancing revenue potential • comprehensive stated preference survey conducted of 3,590 residents of six-county Southern California Association of Governments (SCAG) region, examining eight different congestion pricing strategies: high-occupancy toll (HOT) (express) lanes; single, corridor or regional facility pricing; cordon or area pricing; parking pricing; and vehicle miles traveled (VMT) pricing • survey evaluated potential shifts to mode, route, and time of day, as well as trip suppression • results being used to enhance trip destination choice, mode choice, and time of day components of SCAG model

3.2 Econometric Modeling

This source describes the structure of econometric-network models and case studies where they have been applied.

Hybrid Econometric-Network Models[16]

Report	Freight and Passenger Modeling Using Hybrid Econometric-Network Models
Author	Pierre Vilain et al.
Location/Year	Florida, 2010
Key Points	• describes econometric toll road modeling • hybrid econometric-network model: logit toll model with corridor econometric model estimated in panel specification; examples include Alligator Alley (Florida) and Ambassador Bridge; includes fixed effects, tolls, fuel prices, employment, hurricanes, seasonal factors, and lagged transactions • validated with backcasts within mean absolute percent errors of 3 percent (two-axle vehicles) and 4 percent (three+ axle vehicles) at count locations • monthly transaction data used

3.3 Managed Lane Modeling

These sources describe the iterative procedures to follow for toll lane modeling, whether in general terms (the Federal Highway Administration [FHWA] guidelines) or through the use of CUBE-Voyager, as has been done in Florida. The managed lane travelers' study

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[15] See presentations by:

- Fowler, M., et al., *Discrete Choice Models and Behavioral Response to Congestion Pricing Strategies*, 13th Transportation Research Board National Transportation Planning Applications Conference, 2011. Accessed from <trb-appcon.org/program.html>.
- Oryani, K., et al., *Incorporation of Pricing in the Time-of-Day Model*, 13th Transportation Research Board National Transportation Planning Applications Conference, 2011. Accessed from <trb-appcon.org/program.html>.
- Regan, E., and K. Oryani, *SCAG Travel Model Improvement Program, Congestion Pricing Models*. Presented to SCAG 2008 Regional Travel Model Peer Review, June 27–28, 2011, Los Angeles.

[16] Vilain, P., et al., *Freight and Passenger Modeling Using Hybrid Econometric-Network Models*, TRR 2187, 2010. Accessed from <pubsindex.trb.org/view.aspx?id=910466>.

introduces the distinction between travel time saved through using a managed lane and the extra value attached to the perceived reliability of the lane.

FHWA HOT Lane Development Guidelines[17]

Report	FHWA: A Guide for HOT Lane Development
Author	FHWA
Location/Year	USA, 2003
Key Points	• provides recommendations for toll pricing: toll to be cost of congestion on alternative free road for upper 10 percent of income class • describes typical practices and examples of HOT lane modeling • recommends setting toll at cost of congestion on free road/lane for upper 10 percent income class to divert 10 percent to HOT lane • can vary by time-of-day or real time based on congestion in parallel roads • cites SR 14 study, demand decreases 22 percent with change in toll from 10–20 cents, demand decreases 10 percent with change in high-occupancy vehicle (HOV) definition from 2 to 3 • VoTs vary by level of income, but also depend on importance of arriving on time (can be greater for lower-income workers); SP surveys clarify conditions under which HOT lane would be used, including toll elasticities • recommends toll and HOV-definition variation testing

FDOT CUBE model (multiple sources)[18]

Report	FSUTMS-Cube Framework Phase III Draft Final Report
Author	Corradino Group
Location/Year	Florida, 2009
Key Points	• describes how to implement a HOT lanes model using CUBE • uses a loop-encompassing toll estimation and equilibrium assignment, incorporating toll value and time-saved diversion curve • includes study of how HOT lanes are modeled throughout the United States • as a framework, consists of suggestions rather than practices; model configuration and demand alternatives

FDOT CUBE model (multiple sources)[19]

Report	Toll Facilities Model: CUBE Voyager Version Documentation
Author	Fennessey/WSA/BCC
Location/Year	Florida, 2009
Key Points	• describes forecasting with toll facilities using CUBE/VOYAGER • an alternative report on the CUBE Framework, including details of coding; model is broken into five phases • set up/initialize, loop through links, loop through zones, calculate (and recalculate) link congested travel times, converge (set convergence criteria)

[17] Parsons Brinckerhoff, TTI, FHWA: *A Guide for HOT Lane Development*, U.S. Department of Transportation, 2003. Accessed from <ntl.bts.gov/lib/jpodocs/repts_te/13668_files/images/13668.pdf>.
[18] Corradino Group, *FSUTMS-Cube Framework Phase III Draft Final Report*, Florida DOT, 2010. Accessed from <www.fsutmsonline.net/images/uploads/reports/FSUTMS-Cube_Framework_Ph_III_Draft_Final_HOT_Lanes.pdf>.
[19] Fennessy, Wilbur Smith, BCC Engineering, *Toll Facilities Model: CUBE Voyager Version Documentation*, Florida DOT, 2009. Accessed from <www.fsutmsonline.net/images/uploads/reports/FDOT_Toll_Facilities_Model_Document.pdf>.

Managed Lane Travelers Study[20]

Report	Managed Lane Travelers – do they pay for travel as they claimed they would?
Author	Mark Burris et al. (TTI)
Location/Year	Texas, 2011
Key Points	• compares value of travel time saved (actual and predicted values) • develops separate mixed logit models from 2010 survey responses considering three different design strategies (Db efficient[21], random level generation and adaptive random) • VTTS varied across the models; only the Db-efficient design was able to estimate a value of reliability (VOR); a mixed logit model including all three designs was also developed • 2010 SP survey compared with 2008 survey; based on actual usage, the average VTTS was calculated as $51/hour; however, the $51/hour likely also includes the value of travel time reliability of the managed lanes; total (VTTS+VOR) amount from survey was $59/hour, close to the value estimated from the actual usage • implied mean VTTS was estimated as 65 percent ($22/hour) of the mean hourly wage rate, and the implied mean VOR was estimated as 108 percent ($37/hour) of the mean hourly wage rate

3.4 Summary

The studies and reports described in this chapter provide the material for analysis of modeling practices that follows in Chapter 4. They indicate the variety of data collection methods, parameters that influence VoT calculations, distinct road pricing demand market segments, and approaches to econometric and managed lane models.

[20] Burris, M., et al., *Managed Lane Travelers – do they pay for travel as they claimed they would?*, TTI, 2011. Accessed from <swutc.tamu.edu/publications/technicalreports/161002-1.pdf>.
[21] A term that refers to the particular method used to calculate the parameters so as to minimize the associated standard errors.

4. SUMMARY OF MODELING PRACTICES

4.1 Introduction

In this chapter, information acquired from the literature review sources identified in Chapter 3 is analyzed in more detail to develop a synthesis of model design and VoT assessment methodologies. These are broken into four sections: first, ideas for how to design a T&R model; second, how to incorporate econometric principles into traditional network models; third, how to deal specifically with managed lane modeling; and fourth, treatments of VoT.

4.2 T&R Models

Table 4-1 shows the steps to take into account when defining the structure of a T&R model.

Table 4-1: Model design method[22]

Model requirement	Details
Define responses to congestion and pricing	First-order or short-term (route choice, mode choice, time-of-day choice)
	Second-order or long-term (discretionary trip patterns, trip frequency and degree of chaining, joint travel arrangements, household mobility attributes, work and school location, residence location, land use development)
Define travel cost segments	Mode, route, time-of-day, frequency
Define willingness to pay segments	Population attributes (age/income/employment)
	Activity attributes (purpose/flexibility)
	Trip attributes (frequency/time of day/length)
Requirements for investment-grade calibration	Annualization calculations, long-term (40-50 year) forecasts, ramp-up analysis period, revenue loss factor consideration (bulk discounts, weather issues), toll rate escalation compared with income/VOT projections, sensitivity tests to optimize toll rate, risk analysis and mitigation measures

Here, *first-order* responses estimate how a traveler would be likely to react immediately or directly when confronted with a toll implementation, such as by switching to a non-tolled route, changing to a different mode, or traveling at a cheaper time of day. *Second-order* responses, by comparison, estimate additional long-term responses to pricing, such as changing trip patterns or even the location of trip ends, that may not occur on the day or month that the toll is introduced but rather as an eventual reaction to its presence.

The market segmentation of a T&R model is shown for two similar cases in Exhibit 4-1 and Exhibit 4-2. While the layout differs slightly between the Montreal and San Francisco examples, both illustrate the travel cost segments in terms of mode type and vehicle occupancy. In the Montreal case, the role of the SP survey in determining willingness to pay and how this fits into the overall model structure is shown.

[22] Parsons Brinckerhoff, David Evans, Stantec, Tolling White Paper 3 (2009).

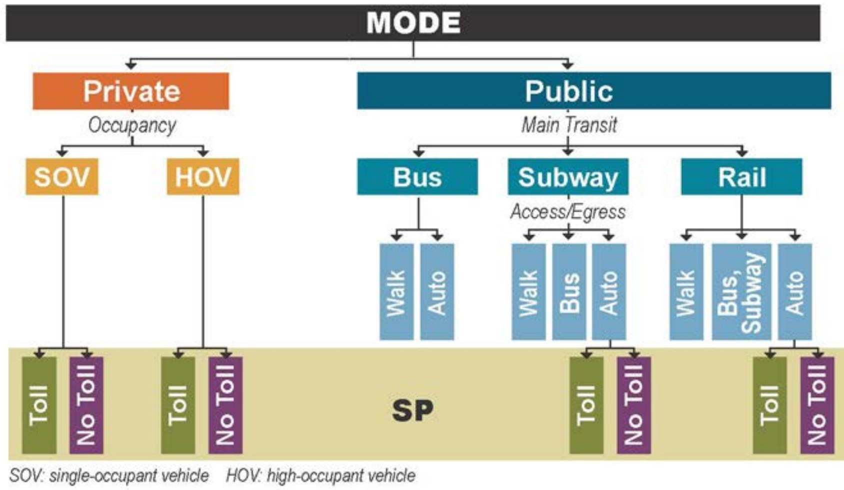

Exhibit 4-1: Toll model mode structure as used in Montreal[23]

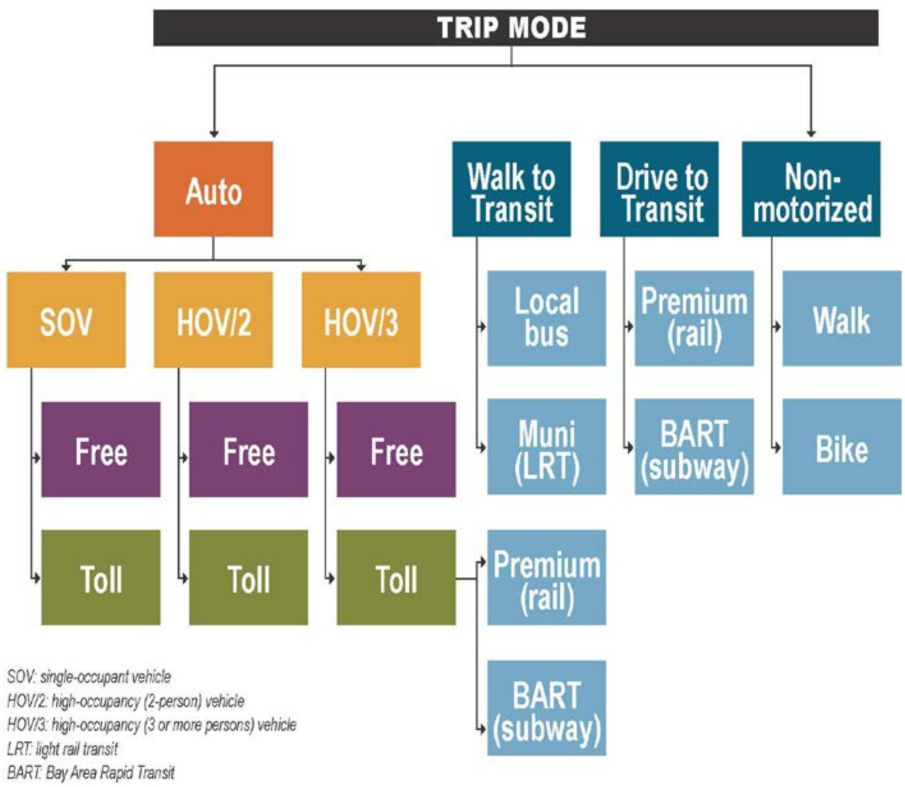

Exhibit 4-2: Toll model mode structure as used in San Francisco[24]

The Oregon DOT (ODOT) synthesis also lists a series of calculations and sensitivities that help to improve the dependability of a forecast, including calculation of annualization

[23] Parsons Brinckerhoff, David Evans, Stantec, Tolling White Paper 3 (2009), p.13.
[24] Parsons Brinckerhoff, David Evans, Stantec, Tolling White Paper 3 (2009), p.13

factors, cost escalation comparisons (how a toll increases in real terms over time), ramp-up analysis during the initial years of operation, and risk analysis.

Risk analysis involves identifying and quantifying risk factors. General factors identified by the ODOT synthesis include:

- Start-up facilities (considered the most risky)
- Network context (accuracy is more likely where there are limited alternatives, such as a rural river crossing)
- Established corridors (where well-defined traffic flows exist, the forecasts are considered more reliable)
- Optimism bias (project sponsors tend to prepare more optimistic [higher] forecasts)
- Aggregation bias (where VoT are excessively aggregated across market segments instead of being calculated individually)
- Economic outlook (considering the likelihood and likely effect of economic downturns)
- demographic forecasts (considering possible variations in land use and demographic growth rates)
- Time savings (varying expectations of time saved)
- Competition (considering possible development over the length of the forecast of competing facilities)
- Off-peak traffic (considering off-peak and weekend traffic as low as 40–45 percent of peak flows)
- Truck market (separate assessment of trucking market risk factors, with risk increasing with the market proportion filled by small-scale haulers)

As part of the T&R modeling process, the likelihood of choosing a tolled route is typically evaluated through the comparison of utility functions. The Chesapeake Expressway Study established a formula for calculating the likelihood of choosing a tolled route (the Expressway) compared with a non-tolled alternative. The utility, β, of choosing a particular route (i) can be determined by applying the following equation:[25]

$$\beta = Toll_i + TT_i \times VOT + D_i \times VOC + f \times FB$$

Here, *Toll* is the toll charged on route (i), *TT* is the travel time in minutes, *VOT* is the value of time (in $ per minute), *D* is the route length (in miles), *VOC* is the vehicle operating cost (in $ per mile), *f* is a freeway indicator (1 for the Expressway, 0 for the parallel alternative) and FB is a freeway bias parameter. Therefore, for a particular VoT the utility is a function of the toll, travel time and trip distance, with an additional preference expected to be given to the expressway (45 percent of the toll value, in the Chesapeake case) to account for greater perceived reliability and greater ease of use for drivers unfamiliar with the area. Visitors or infrequent users of the area road network may be more comfortable with a tolled expressway, which offers less likelihood of their getting lost (and they may not even be aware of alternatives).

[25] SDG, Chesapeake Expressway (2010).

4.3 Economic Models

An economic forecasting model can be summarized by means of the following equation:[26]

$$Y_{ijt} = X_{ijt}B_j + fixed\ effects_{ij} + \epsilon_{ijt}$$

Here, the volume (Y_{ijt}) on a link (i) by vehicle class (j) at a specific time (t) is a function of independent variables (fuel cost, tolls, employment, leisure, and tourism spending), as expressed with the vector of coefficients ($X_{ijt}B_j$). Panel regression models are jointly estimated for a common set of coefficients over separate links. The economic effects are more likely to have a short-term impact on volumes, reflecting rapid economic cycles, while the traditional demographic growth forecasts have a more long-term effect. Location-specific fixed effects (such as point tolls) can be accounted for on individual segments and added into the overall equation. ϵ_{ijt} is an error term.

Exhibit 4-3 illustrates the structure of a hybrid econometric-network model, and how the two components come together to produce a forecast. [27]

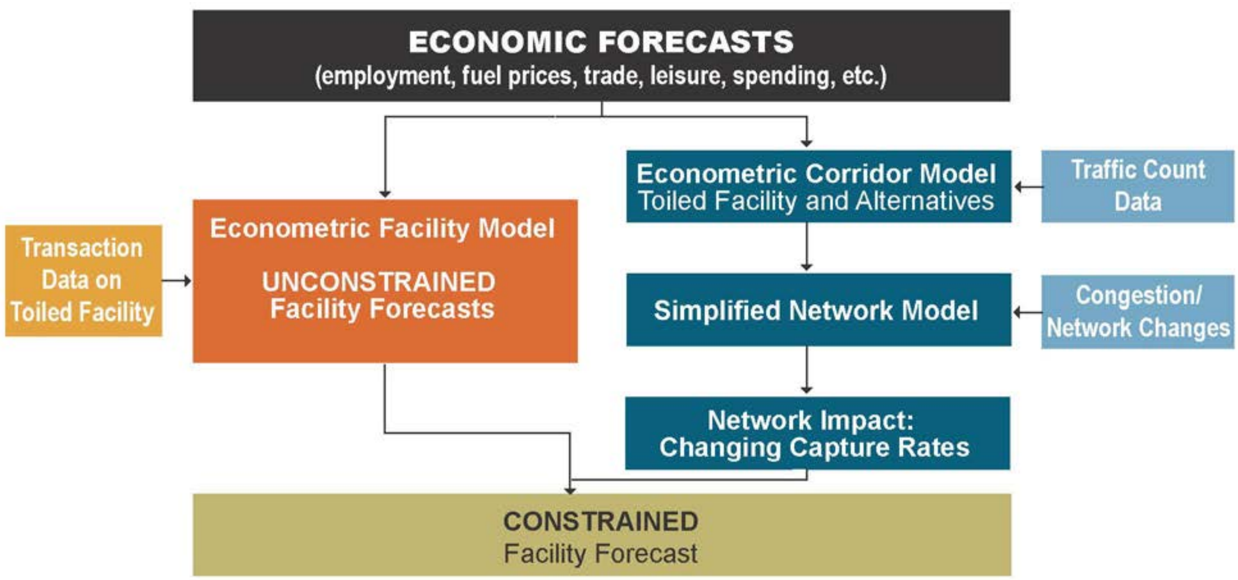

Exhibit 4-3: Hybrid econometric-network model structure

The hybrid approach combines the econometric side (modeling the effect of economic variables on traffic) and the network side (modeling network changes and traffic congestion on possible routes).

[26] Vilain, Muhammad, et al. (2010), Freight and Passenger Modeling using Hybrid Econometric-Network Models

[27] Ibid.

4.4 Managed Lane Models

The following schematic (Exhibit 4-4) shows the sketch plan methods recommended by the FHWA guide[28] for estimating revenue from managed lanes. While this source (from 2003) falls outside the 5-year window otherwise used for the literature review, it still provides a useful depiction of revenue estimation methods. As can be seen, there are two methodology paths—the simplified version sets the toll to the average cost of delay for non-HOT lane users, and then reassigns vehicles to the HOT lane until it is full. The more complex method uses a sequence of iterations whereby the top 10 percent (in terms of income or willingness to pay) of vehicles are shifted to the HOT lane, congestion delays are recalculated to account for that, and the process is repeated until the HOT lane is full.

The FSUTMS-CUBE Framework report, which summarizes managed lane modeling practices across the United States, describes two approaches to modeling HOT lanes—mode choice models and highway assignment models. The report recommends using the assignment model because the mode choice model may be less able to respond to dynamic pricing and congestion effects, as congestion is not determined until the assignment, meaning that a lengthy iterative feedback loop is needed. On the other hand, the assignment model also has disadvantages: the toll adjustment loop still must be outside of the assignment (requiring more processing time) and less household and purpose data are normally available at the assignment stage (although this can be overcome with multiclass assignments). In summary, mode choice and assignment model methods are preferred for diverse cases (in some situations, there are more likely to be viable alternative modes that travelers can opt for rather than paying the toll, while for other cases non-private vehicle modes are less likely to compete).

Table 4-2 describes the procedural steps for an iterative toll model managed lane assignment (assuming choice at the assignment level). Travel costs are determined for the different routes, trips are assigned using the corresponding splits (those willing to pay tolls may use any route, those unwilling to pay are restricted to toll-free routes), the toll is adjusted up or down to approach the optimal level of use on the managed lane, and the procedure iterates again for a specific number of iterations or until a designated convergence level is attained.

[28] Parsons Brinckerhoff, TTI, Guide for HOT Lane Development (2003).

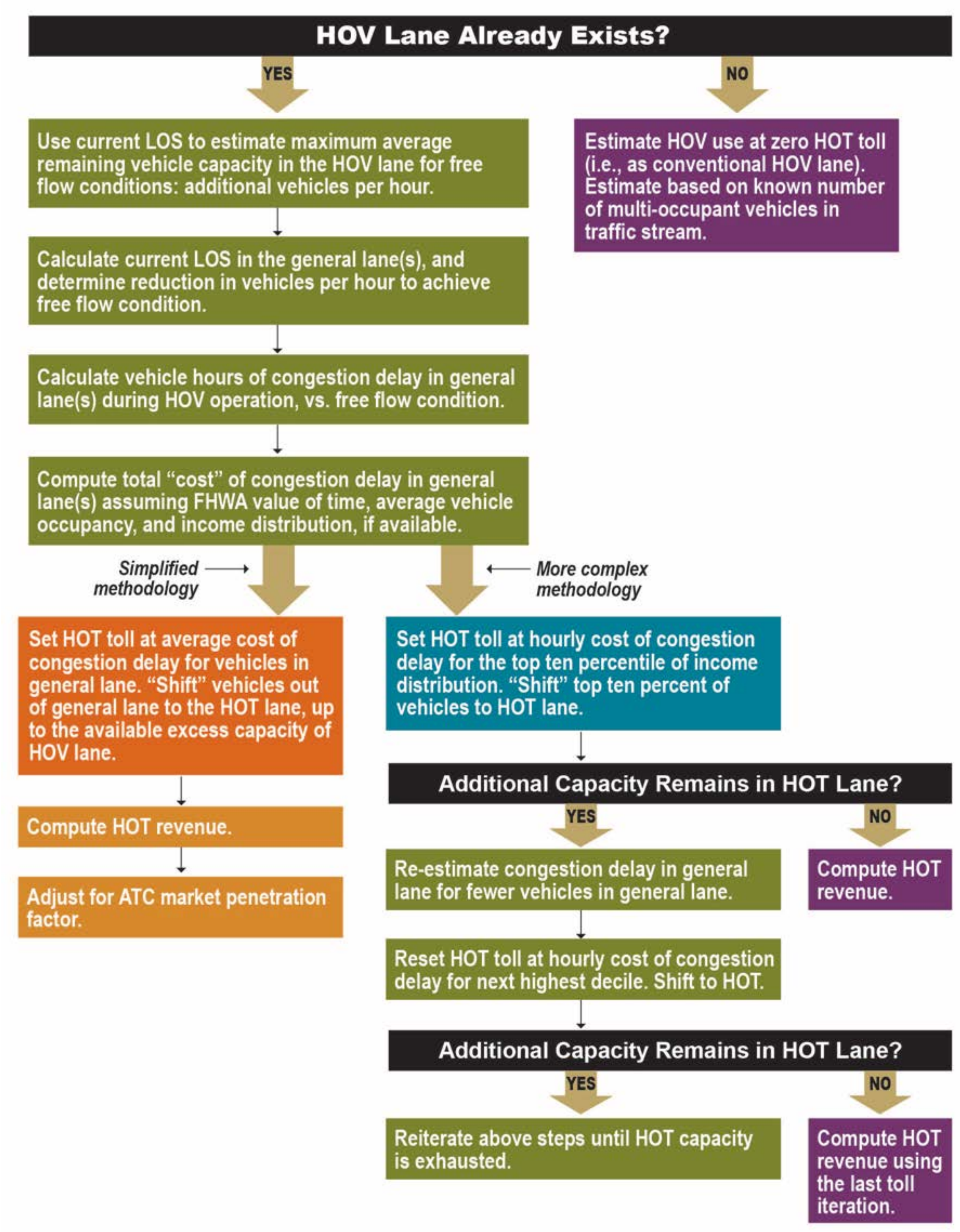

Exhibit 4-4: FHWA simplified and complex revenue estimation methods[29]

[29] Parsons Brinckerhoff, TTI, Guide for HOT Lane Development (2003).

Table 4-2: Steps for toll model assignment[30]

Step	Description
1	Skim multiple trip paths during highway assignment, applying split from function or look-up table, and then loading the path.
2	Make multiclass assignment for levels of auto occupancy and toll choice (pay versus free).
3	Adjust times using volume-delay function and adjust tolls to approach target v/c ratio in HOT lanes (toll/free split can be from a diversion curve or function).
4	People not willing to pay are prohibited from using the toll lanes, while those willing to pay are allowed to use the minimum impedance path.

4.5 Value of Time

4.5.1 Value of Time Models and Derivation

Users' VoT is of key importance in determining the demand for travel on tolled facilities. As was shown in the summaries of sources in Chapter 3, a wide range of VoTs have been used in recent studies, varying by income level, trip purpose, and several other parameters. This section presents a range of VoT models and methods. Appendix A presents a range of VoT values taken from metropolitan planning organizations (MPOs) and T&R studies across the United States.

An example of a detailed representation of a VoT calculation for a facility user is shown below.[31]

$$VoT = K\left[\frac{\beta_\tau}{\beta_c}\right]\left(\frac{Inc}{Inc_0}\right)^{N_{Inc}}\left(\frac{D}{D_0}\right)^{N_c}$$

Here, β_τ and β_c represent time and cost (distance) coefficients, Inc is the user's income, Inc_0 is the average income in the area, D is the trip distance, D_0 is the average trip distance, N is the elasticity of income or cost, and K is a calibration parameter. Thus, the VoT can be estimated for users in terms of their income, the distance of their trip, and other calibrated parameters. For the Department for Transport Study (United Kingdom), parameters were calculated for multiple trip purposes as shown in Table 4-3 below.

Alternatively, the variation in VoT can be described graphically as a function of route choice. The results found by the Puget Sound Regional Council and shown in Exhibit 4-5 below indicate that the VoT should increase almost in a linear fashion with income from a base value of $10/hour. Furthermore, for household income categories above $40,000, the VoT stabilizes at 70–80 percent of the wage rate.

30 Corradino Group, FSUTMS-Cube Framework Phase III Draft Final Report (2009), p. 1-11
31 Department for Transport, Modelling Road Pricing (2007), p. 23

Table 4-3: Value of time parameter example[32]

Parameter	Commuting	Other	Total Non-Work
β_T (time coefficient)	-0.10098	-0.082918	-0.086344
β_c (cost [distance] coefficient)	-0.024729	-0.022275	-0.021143
Inc_0	35 x K	35 x K	35 x K
D_0	7.58	7.58	7.58
η_{Inc} (income elasticity)	0.358773	0.156806	0.222585
η_c (cost [distance] elasticity	0.421305	0.314727	0.307487

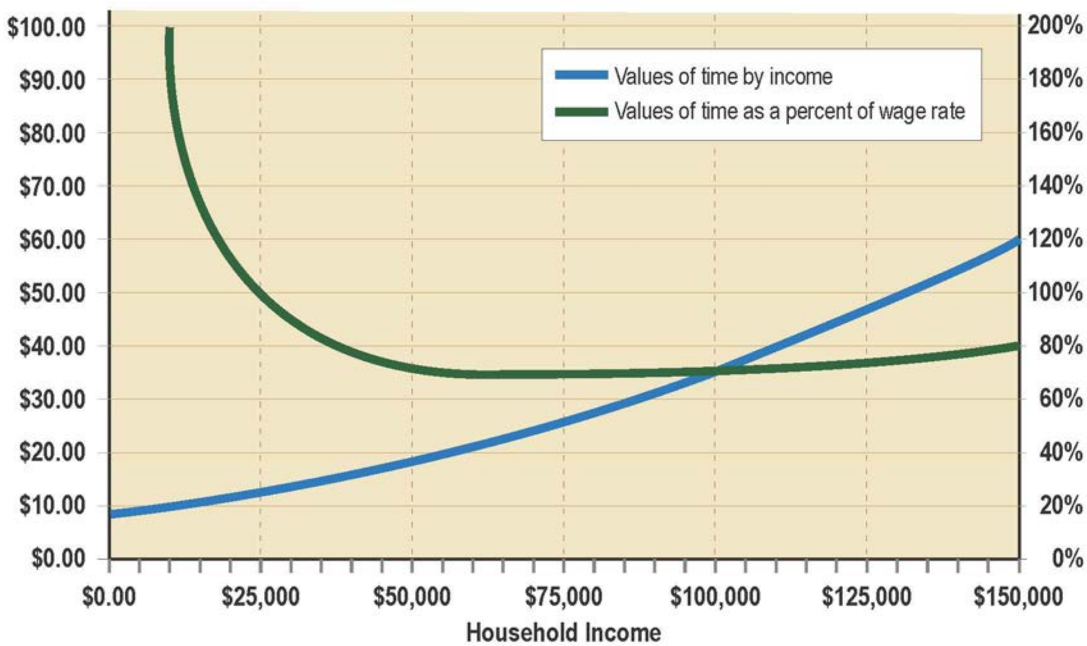

Exhibit 4-5: Observed home-to-work values of time (function of route choice)[33]

There are three categories of measures for which VoT can be assessed. Examples of each are shown in Table 4-4, summarized from measures surveyed and/or recommended measures by Wardman[34] and Willumsen.[35] Some measures fall into more than one category.

The first of these (cost-time equivalency) relates directly to the financial impact on the traveler. For private travelers, VoT will correlate to income, trip purpose (some trips being more time-sensitive), and employer contribution (if the employer pays the toll for a trip, the traveler's willingness to use a toll road is much greater). For commercial vehicles, the VoT

[32] Department for Transport, Modelling Road Pricing (2007), p. 23
[33] Outwater and Kitchen, Value of Time for Travel Forecasting (2008), p. 3
[34] Wardman, et al., M6 Toll Study (2008)
[35] Willumsen, et al., Toll road model manual (2006)

may depend on the type of contract and the nature of the carried goods, and how time-sensitive these are. For some oversized or hazardous loads, there may be no alternative routes and so the modeled VoT will be effectively infinite.

Table 4-4: Measures influencing the value of time

Cost-time equivalency	Quality of time	Reliability
• income level • trip purpose • employer contribution • time sensitivity of cargo • limitations of cargo (dangerous or excess loads) • type of cargo contract • availability of alternative routes	• size of group • width of lanes • truck percentage on road • road information (VMS) • quality of surface (noise and smoothness) • quality of lighting • speed enforcement • number of lanes	• journey duration • dangerous goods cargo (may have no alternative option) • level of congestion • predictability of congestion • length of time using route • availability of alternative routes

Another category is the quality of time spent using the facility as opposed to alternatives. A driver may opt to travel on a road with a well-maintained surface, wide or multiple lanes, good lighting, and/or a lower proportion of heavy vehicles even if the time saving would not, evaluated directly as in the first category, be enough to offset the toll. For example, Wardman's study[36] found that VoT increases by 0.7 percent for every 1 percent increase in the proportion of heavy vehicles on a route (i.e., suggesting that—all else being equal—auto drivers demonstrate some preference for roads with lower proportions of heavy vehicles).

The third category deals with measures of perceived reliability and level of congestion on the facility as compared with others, as well as familiarity with the route. Travelers are more likely to use a facility if the alternative route or routes are much more subject to congestion and stop-start travel; that is, time spent in stop-start or gridlocked traffic is considered to have a higher cost than time spent traveling under free-flow conditions (89 percent higher, according to Wardman's study). The issue of perceived reliability and familiarity was alternatively addressed by using a "freeway benefit" as described earlier in the Chesapeake Expressway Study and, in the case of managed lanes, by using a separate "value of reliability" as described in the TTI Managed Lane Study. Whether there is an influence of overall journey length—or the length of time that the facility has been in use—on VoT is less clear. Also in this category is the number of potential alternative routes, which affects the likelihood of being able to avoid a tolled facility and still find a reliable alternative.

Finally, recent work conducted by the Southern California Association of Governments (SCAG, which is the metropolitan planning organization for the six-county region centered about Los Angeles) provides a possible future direction for VoT analysis. SCAG is conducting the "Express Travel Choices" study, which is examining options for reducing congestion and vehicle emissions and for enhancing revenue potential.[37] An important part of this work includes the development of enhancements to the regional travel demand forecasting model to better model pricing alternatives.

[36] Wardman, et al., M6 Toll Study (2008), p.vi
[37] For more information, see <www.expresstravelchoices.org>

To this end, in 2010 SCAG conducted a comprehensive SP survey of 3,590 area residents.[38] The survey sought to examine the impacts on traveler behavior of eight potential congestion pricing strategies: pricing for individual facilities (HOT [“express”] lanes, single facility pricing, and corridor pricing), regional facility pricing, cordon and area pricing, “express” parking pricing, and VMT pricing. The survey evaluated a range of possible behavioral responses, namely: not making the trip (trip suppression), changing the destination, switching to transit, forming a carpool, changing the departure time, and changing the route. The alternatives for the SP experiments included the use of toll routes during and outside the peak and the use of toll routes in a carpool (HOV), alternate routes or destinations, or transit. Each respondent evaluated two different pricing strategies. Choice models were developed for four travel segments: the work commute and business-related travel (both at any time of day) and non-work (all other trip purposes) during the peak and off-peak. The VoTs were found to vary between $6.00 and $20.00 per hour, depending on the travel segment and annual household income. Several conclusions were drawn from the survey data and from resultant choice models:

- Facility pricing and regional facility pricing could “substantially” affect traveler behavior in three ways: time-of-day shifts, changes in mode, and use of express lanes.
- Cordon, area, and VMT pricing could affect trip destinations and could cause trip suppression, in addition to the preceding impacts.
- Collectively, these impacts could become “quite significant” as prices increase.

These results were used to develop selected enhancements to the regional travel demand forecasting model, namely:[39]

- A new trip destination choice model combines the trip distribution and mode share models, allowing for factors such as distance and price to account for these choices.
- Development of a new time-of-day model, which accounts for the temporal shifts in travel and which replaces the current use of factors to divide trips into four time periods (AM peak, PM peak, midday off-peak, and night). The time-of-day model choice model accounts for the characteristics of the origin and destination zones (e.g., its location and density), trip purpose, mode, household characteristics (size, income, workers, and vehicles), and the traveler’s age and employment industry type. Results have indicated a significantly more accurate calibration against observed volumes in the respective times of day, compared with the use of factors.
- The development of a new trip suppression model, prior to trip assignment.
- Incorporation of the enhanced pricing mechanisms into trip assignment. In particular, a new pricing field as added to the highway (road), distinguished by “avoidable” tolls (i.e., the driver still has a choice of routes) and “unavoidable” tolls (e.g., cordon pricing). Within trip assignment, three path-building methods were developed:

[38] Fowler, M., et al., *Discrete Choice Models and Behavioral Response to Congestion Pricing Strategies*, 13th Transportation Research Board National Transportation Planning Applications Conference, 2011. Accessed from <trb-appcon.org/program.html>.
[39] Regan, E., and K. Oryani, *SCAG Travel Model Improvement Program, Congestion Pricing Models*. Presented to SCAG 2008 Regional Travel Model Peer Review, June 27–28, 2011, Los Angeles.

1) Minimizes time + distance (independent of whether or not tolls exist)
2) Minimizes time + distance, but avoids all pricing/tolls
3) Minimizes time + distance, but for zones within a (specified) cordon, avoids optional pricing/tolls

For each origin-destination pair, the trip assignment routine accumulates time, distance, and link-based pricing. It then compares generalized costs using the Path 1 calculation and for Path 2 or 3, as appropriate, and uses a logit model to calculate the market shares of drivers willing to choose the priced and free alternatives. It then assigns each component to the corresponding route. The process then iterates within the assignment algorithm.

Initial tests of alternate pricing scenarios suggested that a higher and broader application of pricing results in "higher" impacts on AM and PM peak trip reduction. Targeted scenarios, such as cordon and parking pricing, resulted in trip reductions as well.

4.5.2 Value of Time Studies

The traditional economist's treatment of the subject was to assume VoT being equal to 50 percent of the average wage in the study area. These assumptions, while reasonable for many high-level studies, lack the differentiation by trip purpose, income, time of day, and trip type (passenger versus commercial). They are being replaced by VoTs that are derived from SP surveys.

The VoTs used in investment-grade T&R studies commonly have been kept confidential, given their use in financing decisions and in raising investment bonds. However, some of these values are starting to become public. An increasing number of T&R feasibility and policy studies for the public sector has added to this knowledge. Two samples are provided below. They illustrate the range of applications from general policy studies to facility-specific, investment-grade T&R studies in different locations and contexts; therefore, they should be considered as illustrative as opposed to being directly applicable to the Phoenix area. Moreover, the recent SCAG study, which evaluated several types of traveler behavior in addition to the toll versus non-toll choice, demonstrates the complexity of the issue and the need for nuanced and qualified VoTs.

SR 520 Bridge Investment Grade Traffic and Revenue Study, August 29, 2011

Table 4-5 lists VoTs derived from SP surveys for the proposed replacement of the existing SR 520 bridge between Seattle and Medina, Washington—tolls would be introduced to fund the bridge replacement. The table is illustrative for several reasons:[40]

- It provides a recent, facility-specific example of VoTs in a western U.S. metropolitan area.

[40] Wilbur Smith Associates, *SR 520 Bridge Investment Grade Traffic and Revenue Study, Floating Bridge and Eastside Project*. Prepared for Washington DOT, August 29, 2011.

- VoTs are categorized in two ways that are meaningful in an urban environment: work and non-work, and peak and off-peak. The values appear to be reasonable, at least among the four categories.
- Notable for a T&R study, the table compares the results of SP surveys that were conducted for the current T&R forecasts in 2009 with an earlier (2003) set of surveys. It can be seen that the more recent VoTs have dropped, by up to –29 percent for the peak work trip, which, in turn, dominates the “aggregate” value, which has dropped by –24 percent. In turn, this difference illustrates the importance that changing economic conditions have on VoTs—the 2009 survey took place in a recession, which will affect the resultant T&R forecasts, including the forecast for the initial year of operation. This also illustrates the desirability of monitoring these values over time and relating them to current economic conditions and then assessing their impact on the forecasts.

Table 4-5: Comparison of 2003 and 2009 SP survey VoT – SR 520, Washington[41]

Type of trip	2003 SP VoT	2009 SP VoT	% difference
Peak work	$15.11	$10.72	–29%
Peak non-work	$7.94	$7.60	–4%
Off-peak work	$12.17	$10.62	–13%
Off-peak non-work	$13.98	$11.61	–17%
Aggregate	$13.71	$10.40	–24%

Southeast Florida Road and Transit User Cost Study, October 2008

Table 4-6 lists the derivation of VoTs for a variety of trip purposes for a study of user costs in southeast Florida (the Miami-centered region). The data were derived from (unspecified) surveys conducted in 2000. Of interest were:[42]

- The VoTs for four trip purposes—commute, local personal, visitor personal, and on-the-clock (commercial)—are transformed into VoTs according to the trip purposes used in the regional travel demand forecasting model.
- The transformation for each purpose was calculated as weighted proportions of the four trip purposes, derived “by consensus” among a group travel demand forecasters and planners “intimately familiar” with local conditions. In other words, some judgment and professional opinion were used to derive the VoTs from observed data for the purposes of this policy study.
- The surveys include a category for visitors, given the high visitation to the region. Their VoTs are incorporated into the home-based shopping and home-based social/recreational categories.

[41] Ibid., Table 3-2, page 3-10.
[42] Cambridge Systematics, *Southeast Florida Road and Transit User Cost Study (draft report).* Prepared for Florida Department of Transportation District Four, March 2009.

Table 4-6: Values of time by trip purpose – Southeast Florida (2004 dollars)[43]

Trip purpose	Commute $7.03	Local personal $5.86	Visitor personal $6.00	On-the-clock $12.08	Average (per hour)
Home-based work	100%	0%	0%	0%	$7.03
Home-based shopping	0%	95%	5%	0%	$5.86
Home-based school	0%	100%	0%	0%	$5.86
Home-based social/recreational	0%	95%	5%	0%	$5.86
Home-based other	0%	90%	0%	10%	$6.48
Home-based unknown	0%	95%	0%	5%	$6.17
Non-home based	0%	90%	0%	10%	$6.48

4.6 Summary

This chapter has presented a series of methodologies on T&R modeling and calculating VoTs. This gives an indication of where surveys should be focused and data collected, how VoT may be approximated knowing income and trip purpose (and refined with knowledge of other parameters), and how econometric and managed lane models combine with the standard T&R forecasting method to provide additional features such as dynamic HOT lane modeling and the incorporation of economic forecast data.

[43] Ibid., Table 2.4, page 2-5.

5. ANALYSIS OF RISK AND UNCERTAINTY

The consideration of uncertainty, or risk, in T&R studies has achieved an importance of its own. In so many words, this follows the direct involvement of the financial community in the decision-making and implementation process for a transportation project. In turn, the uneven performance of forecast versus actual T&R for many facilities is well known: One result is the financial community's increasingly common requirement for incorporating uncertainty into T&R forecasts.

Accordingly, this chapter provides an overview of current and best practices for incorporating uncertainty into T&R modeling and forecasting. It focuses on the application of risk analysis and the use of Monte Carlo simulation methods in the context of four-step travel demand modeling (and forecasting) in an urban environment. Alternative procedures and applications are presented as well.

The degree to which uncertainty must be incorporated into a T&R forecast depends on the type of study being conducted. For example, a sketch planning study might require only a qualitative consideration or sensitivity analysis of various inputs, whereas prospective lenders may require a formal risk analysis for an investment-grade T&R study. With this qualification in mind, the ensuing discussion focuses on approaches and methods for risk analysis.

5.1 Issues in T&R Forecasting

The relatively poor performance of T&R forecasts for toll road projects has been documented in a number of publications, in particular from rating agencies and the broader financial community. Most recently, Robert Bain, previously with Standard & Poor's, produced a summary of the research he undertook while working at the agency.[44] Comparisons of forecasts to actual traffic—for a global sample of 104 privately financed toll roads, bridges, and tunnels—revealed that actual traffic was measured between 86 percent below forecast to 51 percent above forecast. The comparisons also suggested that, on average, traffic forecasts were optimistic by 23 percent. These findings (large ranges of error and systematic "optimism bias") are broadly consistent with earlier results published by Standard & Poor's and other rating agencies. Several explanations have been proposed for these outcomes, including travel demand model imperfections, unexpected recessions or economic downturns, uses of complex tolling regimes, or over-estimation of the VoT.[45]

[44] Bain, R., *Error and Optimism Bias in Toll Road Traffic Forecasts*, Transportation, Springer Science+Business Media, 2009.

[45] Lemp and Kockelman (2009) provide a thorough review of the sources of uncertainty in traffic forecast identified in the literature. See Lemp, J. and K. M. Kockelman, *Understanding and Accommodating Risk and Uncertainty in Toll Road Projects: A Review of the Literature*, presented at the 88th Annual Meeting of the Transportation Research Board, Washington, D.C., January 2009.

Needless to say, decisions made on the basis of poor T&R forecast—and limited risk assessment—may have detrimental consequences on resource allocation, public perceptions, investors' confidence, and funding availability for decades to come. But while most investors and policymakers agree that incorporating uncertainty into T&R forecasting is important, only a few practitioners conduct any sort of risk assessment (Kriger et al. 2006).[46] For those who do, a number of procedures—varying in scope and complexity—are available.

5.2 Procedures for Incorporating Uncertainty into Forecasting

Four categories of procedures used in four-step modeling for T&R studies are described below: (1) sensitivity analysis, (2) scenario analysis or "stress tests," (3) extrapolation of errors, and (4) quantitative risk analysis (or probabilistic risk assessment).

5.2.1 Sensitivity Analysis

In a sensitivity analysis, forecasting assumptions are varied one at a time and the resulting changes in projected outcomes (e.g., traffic forecast) are reported accordingly.

A sensitivity analysis may serve multiple purposes, including:

- Help identify the variables and model parameters whose variations have the greatest impact on the forecast: the "critical" variables
- Evaluate the impact of changes in the critical variables of "reasonable" departures from their preferred, baseline values
- Assess the robustness of the forecast and, in particular, whether the general conclusions reached using the baseline assumptions are significantly altered through departures from those values

The term "sensitivity analysis" is also used, occasionally, to describe instances where multiple forecasting assumptions and model parameters are changed simultaneously. These are described as "scenario analysis" in this report (see below).

The limitations of sensitivity analysis have been documented in a number of publications. Lewis (1995), for example, argues that in a sensitivity analysis forecasting assumptions are often varied by arbitrary amounts instead of by reference to reasoned analysis of potential error. In addition, varying one assumption at a time does not provide an accurate view of the real world, where all factors affecting forecasts are likely to vary, simultaneously. On the other hand, this procedure can be useful for assessing the significance of individual assumptions in producing forecasts, and has been used extensively in T&R studies.[47]

[46] Kriger, D., S. Shiu, and S. Naylor, *Estimating Toll Road Demand and Revenue, Synthesis 364*, National Cooperative Highway Research Program, 2007.
[47] Lewis, D. L., *The Future of Forecasting: Risk Analysis as a Philosophy of Transportation Planning*, TR News 177, March–April 1995.

5.2.2 Scenario Analysis

In developing demand projections under this approach, many or all forecasting assumptions are modified in the same direction to produce an optimistic forecast and a pessimistic forecast.

This procedure has been among the most popular in T&R forecasting because it can be easily incorporated into four-step modeling techniques. It is also one of the easiest to implement because the scenarios are simply defined as a collection of high and low assumptions, without reference to the likelihood of these assumptions (taken individually or jointly). In addition, interpreting the outcomes of the analysis is generally straightforward and does not require any specific knowledge of probability theory: the concepts of "high" and "low" or "optimistic" and "pessimistic" are intuitive and generally well-understood.

In most cases, the baseline projections are presented as the "most likely" to occur, without any further assumptions or analysis. The scenarios can be formed on the basis of trend analysis, judgment, or projections of key input values developed exogenously.

However, the use of high and low scenarios can be problematic as practitioners may fail to recognize that the likelihood that all assumptions deviate from expectations in the same direction is extremely remote.[48] In addition, as with sensitivity analyses, the lack of probability assessment limits the use and applicability of outcomes.

The use of scenario analysis is relatively common in the financial community, where "stress tests" are applied and compared to "base case" conditions. The base case is generally more conservative than the base case developed by the project sponsor, eliminating any evident optimism bias. The stress case is developed to determine the project's ability to withstand rather severe (but not unreasonable) circumstances in which the ability to pay debt service is stressed.[49]

5.2.3 Extrapolation of Errors

This general approach consists of developing ranges of possible forecast values based on observed errors from historical forecasts.

An example of application in demography can be found in National Research Council (2000), where the distribution of past errors in forecasts by the United Nations over two decades is analyzed and used, by way of statistical simulations, to define predictive intervals for current and medium projections.[50]

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[48] Ibid.

[49] Lemp and Kockelman (2009), page 13.

[50] National Research Council, *Beyond Six Billion: Forecasting the World's Population*, Panel on Population Projections, John Bongaarts and Rodolfo Bulatao (eds.), Committee on Population, Commission on Behavioral and Social Sciences and Education, Washington, D.C., National Academy Press, 2000.

Flyvbjerg (2005) recommends the use of "reference class forecasting" to address optimism bias and general uncertainty in demand forecasting for public works. Reference class forecasting for a specific project involves the following steps:[51]

1) Identify a group of past, similar projects: the reference class.
2) Using data from projects within the reference class, establish a probability distribution for the variable of interest (e.g., traffic).
3) Compare the specific project with the reference class distribution, in order to establish the most likely outcome for the specific project.

Recent applications in the transportation sector include guidance on dealing with "optimism bias" in project cost estimates for the UK Department for Transport.[52]

Model validation studies also rely on observed errors to understand uncertainty. They examine how well traffic forecasts match observed data not used in model calibration.[53] They require data from two points in time: the older of the two data sets is used for model estimation and calibration; the newer is used for validation. Such comparison allows modelers to assess the accuracy of model output and inform decision-makers accordingly. They are relatively common in travel demand modeling.

5.2.4 Quantitative Risk Analysis

Quantitative risk analysis, or probabilistic risk assessment, is a comprehensive approach to assessing risks whereby the probability of a given outcome—e.g., a demand forecast—can be estimated. This is accomplished by attaching ranges (or probability distributions) to the forecasts of each explanatory variable and model coefficient used in the analysis. Through the use of "Monte Carlo" simulation methods, the approach allows all inputs to be varied simultaneously within their distributions, thus avoiding some of the problems inherent in conventional sensitivity analysis (where variables are modified one at a time). This is illustrated conceptually in Exhibit 5-1. The approach also recognizes correlations between variables and coefficients, and their associated probability distributions.

[51] Flyvbjerg, B., M. K. S. Holm, and S. L. Buhl, *How (In)accurate Are Demand Forecasts in Public Works Projects?: The Case of Transportation*, Journal of the American Planning Association, Vol. 71, No. 2, Spring 2005, 131–146.

[52] Flyvbjerg, B., *Procedures for Dealing with Optimism Bias in Transport Planning, Guidance Document*, prepared in association with COWI for the UK Department for Transport, June 2004.

[53] They are similar in concept to the practice known to econometricians as "back-casting."

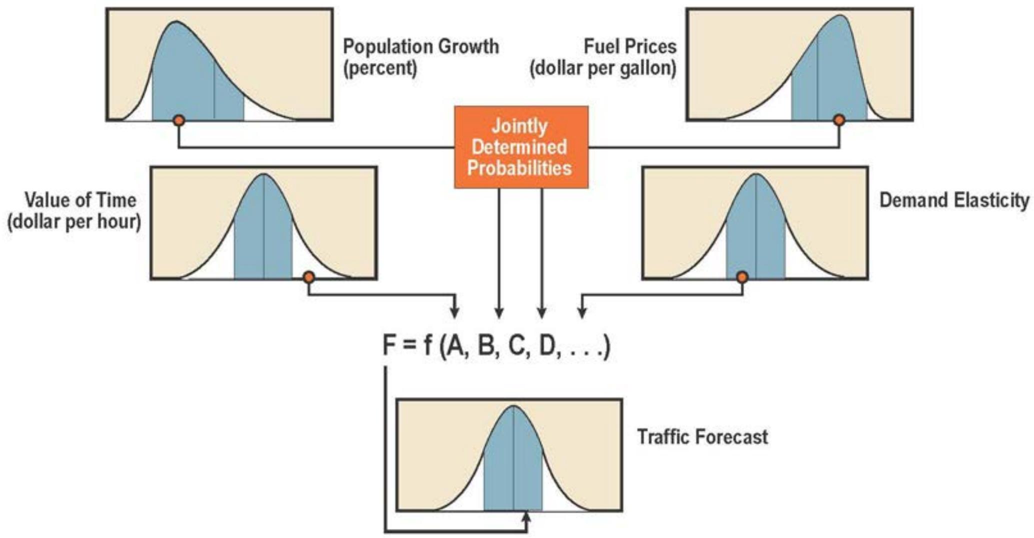

Exhibit 5-1: Use of Monte Carlo simulation methods to "combine" sources of uncertainty

Standard output from a quantitative risk analysis include probability distributions for the variable of interest (in the form of histograms and cumulative or decumulative probability distributions), as well as so-called "Tornado Diagrams," designed to help identify those input variables that contribute most to the dispersion of simulated output.

A decumulative probability distribution of annual revenue forecast (for a given year) is illustrated in Exhibit 5-2, with revenue estimates along the horizontal axis and probabilities along the vertical axis. Each point along the curve provides a probable revenue forecast, along with its probability of being exceeded.

Thus, in this illustration, there is a 90 percent probability that toll revenue will be at least $10.1 million and a 10 percent probability that it will exceed $27.7 million.
Stated differently, there is an 80 percent chance that actual, annual revenue will be found within an interval bounded by $10.1 million and $27.7 million.

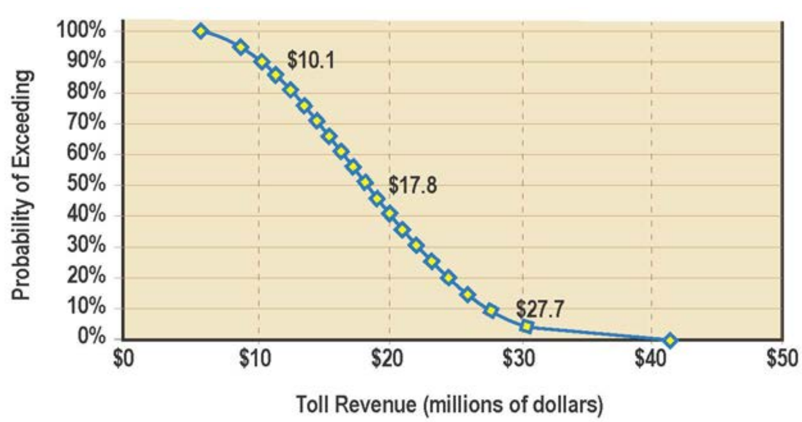

Exhibit 5-2: Decumulative probability distribution of annual toll revenue (illustrative)

Tornado charts may be derived in multiple ways. Some simply illustrate the mean expected impact of risk variables considered individually; others are based on the change in output for a given change in input (typically one standard deviation) estimated through statistical analysis. Exhibit 5-3 is an example of a tornado chart that ranks risk factors by their impact value (assuming a one-standard-deviation increase), in millions of dollars of 2030 toll revenue. The figure is for illustration only.

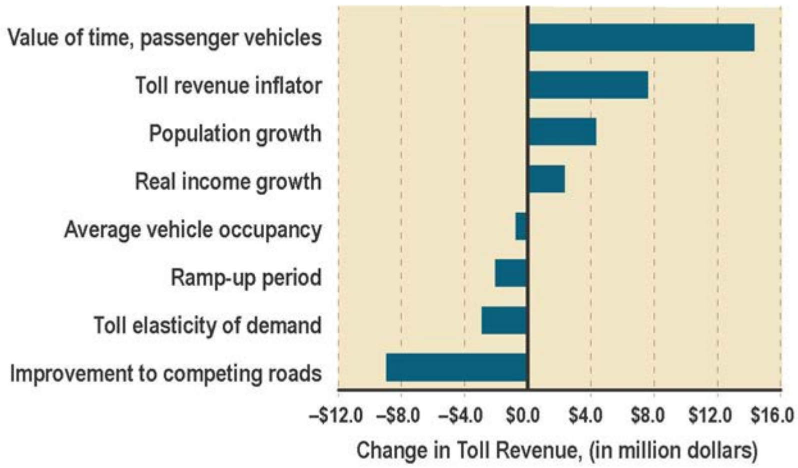

Exhibit 5-3: Example of a tornado chart

The use of Monte Carlo simulation methods within a four-step travel demand model would typically require programming an “add-in” to allow multiple iterations of the four modeling steps (generation, distribution, mode choice, and assignment), and storage and analysis of the resulting T&R forecasts. The add-in, and its interactions with the transportation model, are illustrated conceptually in Exhibit 5-4.

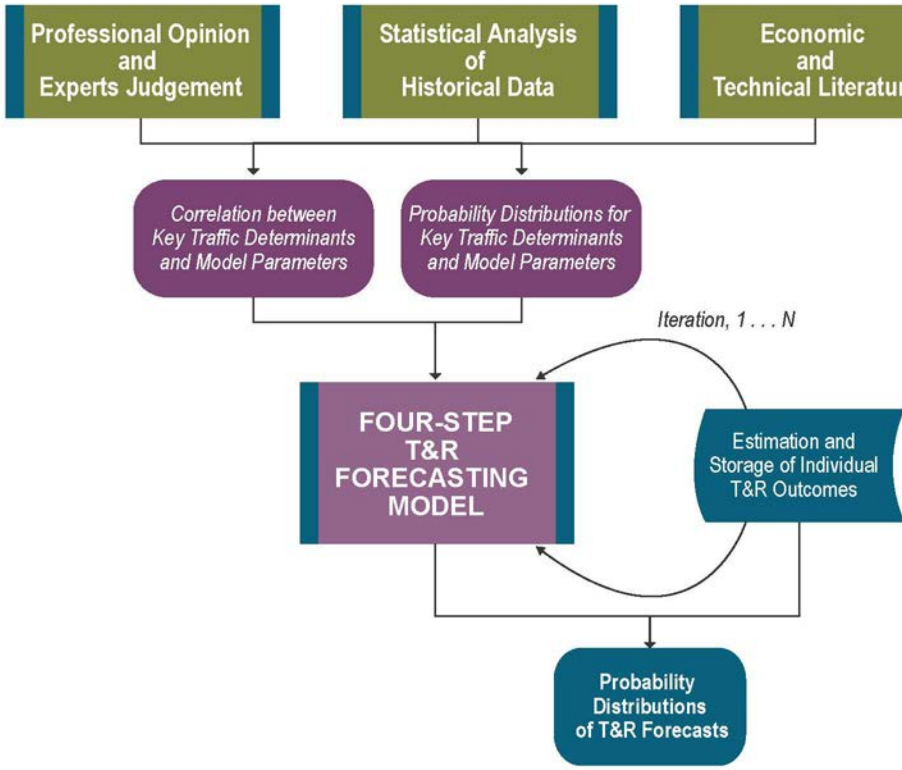

Exhibit 5-4: Integration of four-step travel demand model within risk analysis framework

Practitioners, however, may find the implementation of this conceptual framework difficult, for at least two reasons:

First, travel demand models are typically very complex and subject to various types of uncertainty. They have multiple moving parts and a general "grayness", which makes it difficult to tell where forecasting errors may come from. In this regard, a useful distinction has been made in the literature between three types of uncertainty

- **Input uncertainty**: uncertainty in the value of traffic determinants and other input variables (e.g., population growth and change in household income);
- **Model uncertainty**: uncertainty in the structure of the model (e.g., lack of sufficient understanding of determinants of travel demand) or technical uncertainty (e.g., hidden flaws in the technical equipment and typing errors in the source code); and
- **Parameter uncertainty**: uncertainty in the (calibrated) value of model parameters.

Most applications of risk analysis techniques to travel demand modeling have focused on quantifying the first type of uncertainty (Input); although a number of studies have also considered parameter uncertainty, through a variety of simulation methods. Examples include Zhao and Kockelman (2002), De Jong et al. (2005) and the general Risk Analysis Process outlined in Lewis (1995).

Running times and computation requirements represent a second source of difficulty, as the full four-step model must be recalibrated (and the full set of T&R forecast re-estimated) multiple times. Numerous approaches have been proposed in the literature to reduce computational requirements:

- Using a "streamlined" version of the four-step model, i.e., considering a subset of the roadway network and/or holding some assumptions in (and components of) the model constant to speed-up calculations. As noted in De Jong et al. (2005) or Lemp and Kockelman (2009), this approach is commonly used by practitioners and researchers; and most studies published to date have relied on relatively simple and aggregated travel demand models.
- Using advanced simulation techniques and sampling methods that essentially reduce the number of times the travel demand model needs to be re-run to produce meaningful output probability distributions. For example, Sevcikova et al. (2007) propose a Monte Carlo based method for assessing uncertainty in an urban simulation model (*UrbanSim*, developed by the University of Washington). The method (called "Bayesian Melding") is applied to analyze uncertainty in projections of household counts by traffic activity zone, and is compared to a more traditional, linear repeated runs method. Whereas traditional methods simply consist of applying the same model over and over again with different input values ("repeated runs"), Bayesian Melding combines all available information about model inputs and outputs and uses a statistical model (Bayes formula) to derive a (posterior) distribution for a measure of interest (e.g., number of households).[54] The use of this approach in travel demand modeling, however, remains very limited; and Bayesian Melding is not considered ready for public use.[55]
- Defining a set of "risk scenarios" whereby the combination of input values (demographic and socioeconomic variables, as well as model parameters) corresponding to a certain "level of risk" is determined outside the model. For example, one "pessimistic" risk scenario may consist of the 20th percentiles of the probability distributions of population growth, employment growth, VoT, etc. Another scenario ("optimistic") may be defined by the 80th percentiles of all T&R determinants. Under this option, the model would have to be re-run with these limited sets of values only, as opposed to with all possible combinations of individual realizations of traffic determinants.

[54] Sevcikova et al. (2007) describe Bayesian Melding in these terms:

> "Bayesian Melding begins with prior probability distributions for the base year (y1) input parameters based on historical data, and also a subsequent year (y2) of data for comparison with model outputs. Monte Carlo simulation produces model outputs in y2 for numerous realizations of the y1 input parameters and random number seeds. Weights are assigned to each model run based on the likelihood of the outputs given the actual y2 data. For each parameter realization and random number seed, the model is then run until a third and future year, y3, is reached; and the weights are used to form a probability distribution for each output measure. The model is considered to be 'calibrated' if the actual data for y3 consistently fall within a confidence interval (e.g., 90%) of the output probability distribution."

[55] Kockelman et al. (2008), page 67.

The risk analysis elicitation framework introduced in Lewis (1995) illustrates how Monte Carlo simulation methods may be used in the context of T&R forecasting. Risk analysis elicitation is defined broadly, as a family of forecasting techniques and planning processes used to examine risk and uncertainty and achieve public consensus through expert and stakeholder engagement. The process, as defined by Lewis, involves four major steps:

1) Identification of the "structure and logic" of the forecasting problem.
2) Assignment of estimates and probability distributions to each variable and coefficient in the forecasting structure and logic.
3) Expert and stakeholder engagement in the assessment of model and assumption risks.
4) Issuance of forecast risk analysis.

Each step is described in detail below.

Step 1: Identification of the structure and logic of the forecasting problem
A "structure and logic model" depicts the variables and cause-and-effect relationships that underpin the forecasting problem at hand. Although the structure and logic model is written down mathematically to facilitate analysis, it is also depicted diagrammatically in order to permit stakeholder scrutiny and modification in Step 3 (described below). Structure and logic models reflect cause-and-effect relationships among economic, financial, demographic, policy, and political factors. Exhibit 5-5 is an example of a structure and logic model for estimating growth in annual average daily traffic (AADT).

Step 2: Assignment of estimates and probability distributions to each variable and coefficient in the forecasting structure and logic
Each variable is assigned a central estimate and a range or distribution to represent the associated degree of uncertainty. The central estimates and probability ranges typically come from two sources. The first is a historical analysis of statistical uncertainty in all variables and an error analysis of the forecasting coefficients. The second is based on experts' opinion or judgment, as gathered in Step 3.

Step 3: Expert and stakeholder engagement in the assessment of model and assumption risks
This step involves a panel of experts and the use of facilitation techniques to elicit, from the panel, risk and probability beliefs about:

1) Structure of the forecasting framework
2) Uncertainty associated with each variable and forecasting coefficient within the framework

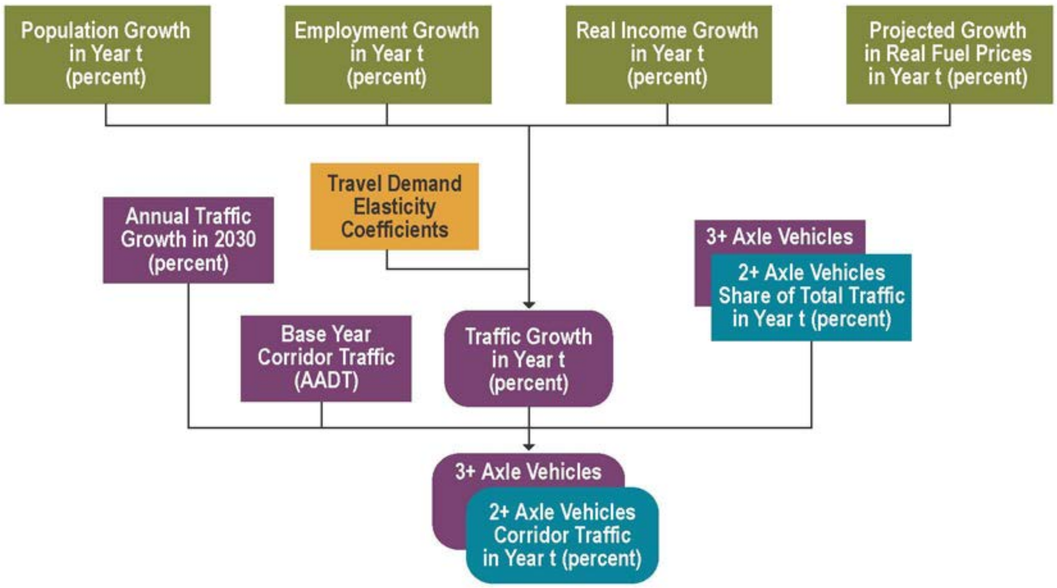

Exhibit 5-5: Example of a structure and logic diagram

In step 1, experts are invited to add variables and hypothesized causal relationships that may be material, yet missing from the model. In step 2, panelists are engaged in a discursive protocol during which the frequentist-based estimates and ranges, provided to panelists in advance of the session, are modified according to subjective expert beliefs. This process is aided with an interactive “groupware” computer tool that permits the visualization of probability ranges under alternative belief systems.

Step 4: Issuance of forecast risk analysis
The final probability distributions are formulated by the risk analyst and represent a combination of frequentist and subjective probability information drawn from Step 3. These are combined using Monte Carlo simulation techniques. The result is a forecast together with estimates of the probability of achieving alternative outcomes.

This framework has been used to provide decision support to credit analysts, bond insurers, lenders, and transportation agencies across the United States. It has typically been applied using highly streamlined roadway networks (centered on the tolled corridor) and simplified model specifications to enhance transparency, facilitate scrutiny, and speed up calculations.

Other applications of simulation methods for assessing uncertainty in traffic forecast have been described in the literature.

Zhao and Kockelman (2002) use Monte Carlo simulation methods to examine the propagation of uncertainty through a four-step travel demand model for a sub-network of the Dallas-Fort Worth region. They assigned density functions to 18 random model parameters (13 in trip generation, 1 in trip distribution, 2 in mode choice, and 2 in assignment) and 4 major model inputs for each of 25 zones (household counts along with basic, retail, and service job counts). Each of the uncertain parameters and inputs was assumed to follow a log-normal distribution; and the standard deviation of the coefficients in each of the four stages was set at 0.30 of the mean of the coefficients. After performing 100 simulation runs, two network links were examined in detail. On both links, traffic flows ranged from around 400 vehicles per hour to over 2,000. (reproduced from Zhao and Kockelman [2002], page 22) shows the propagation of uncertainty through the four-step travel demand model. Starting with a coefficient of variation (standard deviation/mean) of 0.30 at the input level, it is apparent that compounded uncertainty grows through the application of the first three steps (trip generation, trip distribution and mode choice). However, because the final step (trip assignment) is a user-equilibrium assignment -- with congestion feedbacks -- overall uncertainty is actually reduced in that stage.

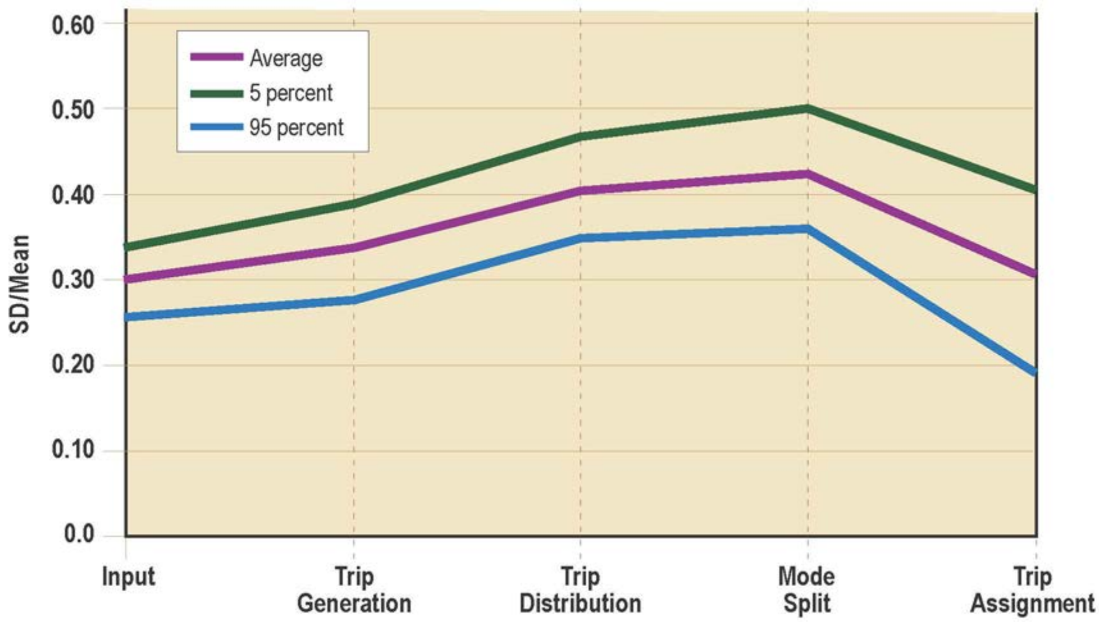

Exhibit 5-6: Uncertainty propagation through four-step models

Source: Zhao and Kockelman (2002), Figure 5, page 22

Overall, Zhao and Kockelman observed similar uncertainty levels in model inputs and model outputs, suggesting that opportunities for errors in one part of the model to offset errors in another can have a dampening effect on overall uncertainty.[56] This also suggests that simple statistical analysis (e.g., regression analysis) of link-flow outputs and inputs may have very high predictive power[57], and may be used to identify the main sources of forecast uncertainty.

De Jong et al. (2005) provides an analysis of uncertainty in traffic forecasts from the Dutch National Model System and the New Regional Model for Noord-Brabant, using simulation techniques. Statistical simulation methods were used to quantify uncertainty due to input variables (e.g., income, car ownership, car costs, population by age group, household size,

[56] Zhao, Y., and K. M. Kockelman, *The Propagation of Uncertainty through Travel Demand Models: an Exploratory Analysis,* Annals of Regional Science 36 (1), 2002, 145–163.

[57] Lemp and Kockelman (2009), page 16.

etc.) and to specification errors in the tour frequency and mode-destination choice modules. Overall, substantial, but not very large, uncertainty margins were found for total vehicle travel in the study area and for vehicle flows on selected links. The contribution of input uncertainty to these errors was generally much larger that that of model uncertainty (e.g., coefficient estimates[58]).

A comprehensive review of the literature on uncertainty in forecasting for public works and P3 projects is also provided in De Jong et al (2005).[59] Additional references can be found in De Jong et al. or in Chapter 9.

Of particular importance for projects where financial backing is dependent on toll revenue is the probability that toll revenue will cover debt service, and whether additional revenue will remain, over and above debt service.[60] Thus, in addition to providing information on the full spectrum of potential T&R forecasts, the outcomes of a quantitative risk analysis may be used in combination with estimates of project costs and a “dynamic” financial model to help determine the risk exposure of prospective investors. This is illustrated in Exhibit 5-7, where probability distributions for annual debt service coverage ratio (DSCR) are presented in a tabular format.[61]

[58] De Jong et al. (2005), page viii.

[59] De Jong, G., and A. Daly, *Uncertainty in Traffic Forecasts: Literature Review and New Results for the Netherlands*, RAND Europe Working Paper, 2005.

[60] Lemp, J., and K. M. Kockelman, *Understanding and Accommodating Risk and Uncertainty in Toll Road Projects: A Review of the Literature*, presented at the 88th Annual Meeting of the Transportation Research Board, Washington, D.C., January 2009.

[61] Each row is a decumulative probability distribution. Debt service coverage ratio is the ratio of cash available for servicing interest and principal payments of debt.

Fiscal Year	Probability of Exceeding: 99%	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%	45%	40%
2004	2.51	2.53	2.54	2.55	2.55	2.55	2.56	2.56	2.57	2.57	2.57	2.58	2.58
2005	1.71	1.74	1.75	1.77	1.77	1.78	1.78	1.79	1.79	1.80	1.80	1.80	1.81
2006	1.68	1.70	1.72	1.73	1.74	1.75	1.75	1.76	1.76	1.77	1.77	1.78	1.78
2007	1.63	1.65	1.66	1.67	1.68	1.69	1.70	[illegible]	[illegible]	[illegible]	1.72	1.72	1.73
2008	1.59	1.62	1.63	1.65	1.66	1.67	1.68	[illegible]	[illegible]	[illegible]	1.70	1.71	1.71
2009	1.48	1.52	1.53	1.55	1.56	1.57	1.68	[illegible]	[illegible]	[illegible]	1.61	1.62	1.62
2010	1.46	1.51	1.53	1.55	1.56	1.58	1.59	[illegible]	[illegible]	[illegible]	1.63	1.64	1.65
2011	1.25	1.29	1.32	1.34	1.35	1.36	1.37	[illegible]	[illegible]	[illegible]	1.41	1.41	1.42
2012	1.22	1.26	1.29	1.31	1.33	1.34	1.35	[illegible]	[illegible]	[illegible]	1.39	1.40	1.41
2013	1.20	1.25	1.28	1.30	1.31	1.32	1.35	[illegible]	[illegible]	[illegible]	1.38	1.39	1.40
2014	1.18	1.24	1.27	1.29	1.31	1.32	1.34	[illegible]	[illegible]	[illegible]	1.38	1.39	1.41
2015	1.17	1.23	1.27	1.29	1.31	1.33	1.34	1.36	1.37	1.38	1.40	1.41	1.42
2016	1.10	1.17	1.21	1.24	1.26	1.28	1.30	1.31	1.33	1.34	1.35	1.37	1.38
2017	1.09	1.17	1.21	1.24	1.26	1.28	1.30	1.31	1.33	1.34	1.35	1.37	1.38
2018	1.10	1.17	1.22	1.25	1.27	1.29	1.31	1.32	1.34	1.35	1.36	1.38	1.40
2019	1.10	1.18	1.22	1.25	1.27	1.30	1.31	1.33	1.35	1.36	1.38	1.39	1.41
2020	1.07	1.17	1.22	[illegible]	[illegible]	1.30	1.32	1.34	1.36	1.37	1.39	1.41	1.43
2021	1.00	1.15	1.21	[illegible]	[illegible]	1.28	1.30	1.32	1.34	1.35	1.37	1.39	1.41
2022	0.95	1.16	1.21	[illegible]	[illegible]	1.29	1.31	1.33	1.35	1.37	1.38	1.40	1.42
2023	0.91	1.15	1.21	[illegible]	[illegible]	1.29	1.31	1.33	1.35	1.37	1.39	1.41	1.42
2024	0.88	1.14	1.20	[illegible]	[illegible]	1.29	1.32	1.34	1.36	1.38	1.40	1.42	1.44

Probabiity of exceeding the DSCR values shown in the associated column

There is a 75% probabiity that DSCR in fiscal year 2015 will be 1.33

There is a 95% probabiity that DSCR in fiscal year 2020 will be 1.17 or greater

Exhibit 5-7: Risk analysis of annual debt service coverage ratio (illustration)

5.3 Conclusions

The procedures presented in this section are summarized in Table 5-1. The table includes a brief description of the procedure, provides a summary of its strengths and weaknesses, and assesses the extent to which the procedure is being used for T&R forecasting.

Simulation methods are increasingly considered a best practice for incorporating uncertainty into T&R forecasting and decision-making. For example, Lemp and Kockelman (2009) explain:[62]

> *"Monte Carlo simulation may be most appropriate to identify a (…) comprehensive set of possible futures. By drawing parameters and inputs from reasonable sets of distributions, the probability of particular outcomes can be understood (…) Thus, the recommended best practice for dealing with uncertainty in toll road projects is the use of Monte Carlo simulation"* (p. 14).

Similarly, the National Federation of Municipal Analysts (2005) recommends that a range of possible road project and policy outcomes should be explored based on different scenarios

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[62] Lemp, J., and K. M. Kockelman, *Understanding and Accommodating Risk and Uncertainty in Toll Road Projects: A Review of the Literature*, presented at the 88th Annual Meeting of the Transportation Research Board, Washington, D.C., January 2009.

(or assumptions), and that varying variables or parameters one at a time is insufficient. It also explains that:[63]

> "*By assigning probability distributions to each input, input variables can be changed simultaneously and investors can gain a perspective on the likelihood of each scenario*" (p. 18).

Table 5-1: Summary and assessment of current procedures

Procedures	Brief description	Specific questions being addressed	Strengths	Weaknesses	Use in T&R forecast
Sensitivity Analysis	Forecasting assumptions and model parameters are modified one at a time, in various degrees.	How robust are the forecasts? What are the critical variables or risk factors?	Ease of use and interpretation; flexibility; helps understand significance of individual assumptions	Assumptions varied one at a time, often by arbitrary amount; failure to consider synergies between risks	Sometimes used
Scenario Analysis, including Stress Tests	All assumptions are modified in the same direction to produce an optimistic and a pessimistic forecast.	How low (high) could demand fall (rise) if all turn for the worst (best)?	Ease of use and interpretation; flexibility; multiple risks considered at once; helps assess and plan for worst (best) possible outcome	Probability of low and high scenarios is unknown and can be extremely low	Frequently used, in particular within financial community
Extrapolation of Errors, including Model Validation Studies	Past, observed forecasting errors are analyzed and are used to adjust current forecasts.	How may future demand deviate from forecasted values given errors observed in similar settings?	Ease of use and interpretation; helps assess and communicate magnitude of uncertainty; based on observed errors	Data requirements; difficulties associated with defining relevant "reference class"	Sometimes used
Quantitative Risk Analysis and Risk Analysis Elicitation	Probability distributions are specified for all explanatory variables and model parameters and combined through simulation techniques. The process may involve consensus building through stakeholder engagement.	What is the likelihood of alternative demand forecasts given known uncertainties in forecasting assumptions?	Multiple sources of uncertainty considered simultaneously; probabilities assigned to different outcomes; allows explicit consideration of correlation across risks	Requires a large number of assumptions (e.g., input probability distributions, correlation factors); computational requirements and model run times	Generally not used

[63] National Federation of Municipal Analysts, *Recommended Best Practices in Disclosure for Toll Road Financings*, 2005. Accessed from <data.memberclicks.com/site/nfma/DG.BP.rbp_toll_road.doc.pdf>.

6. MAG MODEL ANALYSIS

The review of the structure of the existing model provided in this chapter is based on external model documentation provided by MAG. This section discusses the analysis of the model to determine what steps would need to be taken to incorporate road pricing and T&R study capabilities into the model.

6.1 Structure of Model

The model includes multiple trip purposes, including home-based work, home-based school, home-based shop, home-based other, home-based university, non-home-based work, non-home-based other, Arizona State University (ASU), and trips to and from Phoenix Sky Harbor International Airport (either home-based or non-home-based). This gives it the flexibility to define multiple classes of VoT by purpose.

Trips are generated by household (broken down by size and income quintile), and by number of workers per household, enabling the variation of VoT by income group. Airport trips (likely to involve a high VoT) are modeled as a separate purpose. Home-based airport trips are related to household properties, while others are based on office and non-residential trip rates. Truck trips (also likely to be important segments of a tolled facility's demand, with high VoTs), and trips starting and/or ending externally, are also modeled.

Skims are performed for transit, free-flow highways, and congested highways, to determine the relative impedances between origins and destinations. A utility expression calculator is then used to calculate spreadsheet-based utility equations for each trip purpose. A mode choice-based revenue model could be incorporated here.

6.2 Trip Values of Time and Operating Costs

A highway generalized cost matrix is used instead of a mode choice logsum method. The highway generalized cost is specified as follows:

*Highway Generalized Cost = Time (minutes) + DistanceFactor * Distance (miles)*

where *DistanceFactor* converts distance in miles to equivalent minutes based on an assumed cost per mile and a VoT defined by purpose as shown in Table 6-1, below. Highway time is based on peak travel times, but distance is based on off-peak travel skims. Vehicle operating cost does not vary by category (as the vehicle types are not different, only the definitions of the occupants).

Income groups are divided by quintile of household income.

The transit generalized cost is specified as follows:
Transit Generalized Cost = In-Vehicle Time + Initial Wait Time + Transfer Wait Time + Access Time + Egress Time + [*FareFactor * Fare]*

Table 6-1: Cost values in existing MAG model

Purpose	VoT ($/hour)	Operating cost (cents per mile)
HBW: Auto 0 Income Group All	6	16
HBW: Auto 1 Income Group 1	6	16
HBW: Auto 1 Income Group 2–5	12	16
HBW: Auto 2 Income Group 1	6	16
HBW: Auto 2 Income Group 2–5	12	16
HBU (home-based university)	12	16
Home Based School	6	16

Note: Auto 0 is households with no automobiles; Auto1 is households with one automobile; Auto2 is households with two or more automobiles.

Fares for transit modes are used in the mode choice component of the model, not in the assignment component, and vary from $0.75 to $1.32 based on type of transit, although these are held as base values (not increasing over time) and how they relate to operating cost and VoT figures is not completely clear.

*FareFacto*r converts the fare (in cents) to minutes based on a VoT of approximately $2/hour for transit fare. This conversion value appears to be very low.

6.3 Treatment of Tolls and Road Pricing

VoT by vehicle class is included in assignment parameters, but not used. No VoTs are defined for trucks. As VoTs are restricted to trip purposes, this suggests extra VoTs would need to be derived or surveyed for the additional assigned demand segments (such as truck and external trips) that do not fall into one of the main trip purpose categories, if an assignment-choice revenue model were to be implemented.

Cost values are constants, but have not been updated for a long time, and their origin and method of derivation are uncertain.

The model database contains a fixed link toll field, but it does not appear to be used or to vary by class (it would be expected that not all types of vehicle would pay the same toll, if one were to be implemented).

6.4 Vehicle Classes

Five classes are assigned: low-occupancy private vehicles (LOVs), high-occupancy private vehicles (HOVs); and heavy, medium, and light commercial vehicles. Once the mode choice model is completed, person trips are converted into HOV (2+ person) and LOV based on occupancy factors in the trip processing step. Truck trips are assumed to be single-occupancy. In standard assignments, outputs are HOV and LOV where LOV includes truck trips. In multiclass assignments, the LOV trip table is for drive-alone/single-occupancy

(SOV) trips but does not include truck trips. The separation of auto demand segments by occupancy categories, provided there are accurate survey data to back these up, is important to be able to model facilities such as HOT lanes.

There are five assigned time periods: AM, PM, 24-hour, midday, and night. The conversion process to peak hour appears to be presently non-functional.

Time-of-day factors are applied by trip purpose and time period. A 24-hour assignment is based on the 24-hour trip table. The ability to model different time periods would enable modeling of differential pricing by time of day.

6.5 Conclusions

The existing MAG model does not have any provision for modeling tolls (reasonably, as there are no existing tolled roads in its area of coverage). Additionally, some of the VoTs included in the model (such as the transit fare-time equivalence of $2) are difficult to reconcile with those values found in the literature review. However, the specific act of adding tolls is not complicated and the model does have a well-defined series of purpose and occupancy segments, as well as multiple modes and time periods, which facilitate the inclusion of tolls by vehicle type and VoTs by market segment and/or mode choice. A detailed review of the operating costs, VoTs, and fares used in the model, along with expanding VoT definitions to include additional demand segments, would be important next steps to modify the model to enable it to carry out T&R forecasting.

7. SUMMARY OF GAPS AND OPPORTUNITIES

7.1 Analytical Gaps and Opportunities

The review of current and best practices in Chapters 3 and 4, combined with the review of the current MAG four-step model in Chapter 6, identify several gaps as well as opportunities. In broad terms, these can be summarized as follows:

1) The MAG four-step model is sound structurally; however, it lacks the capabilities for addressing T&R initiatives at any level. Specifically, it lacks a toll choice modeling capability for any type of priced facilities, and it lacks current, comprehensive VoTs.
2) Insofar as toll choice (diversion) models are concerned, the primary choice is between treating tolls as a mode choice or as a route choice. The advantages of modeling toll diversion as a mode choice are: expansion of the alternate choices beyond route choice (including, ultimately, possible impact on trip distribution), especially if region-wide measures such as congestion pricing are introduced; consistency with how other choices are modeled; integration within the four-step demand modeling process; and an explicit modeling of vehicle occupancy. The key disadvantage is the practical complexity in modeling this choice reasonably, especially when pricing does not yet exist in the region and—practically speaking—the likelihood of switching to others modes *may* be small.[64] The advantages of modeling toll diversion as a route choice (assignment) are: a more practical treatment of the choices (i.e., it is assumed that neither mode choice nor trip distribution is affected directly, although the potential does exist to feed this back into the demand model), a simpler choice model (which is integrated into the trip assignment), and a more appropriate treatment when specific facilities are being considered for tolling (again, treating it as a route choice). The disadvantages are the inability to consider other mode choices (which may be sensitive, even if the numbers are small), increased complexity in the assignment process, and exclusion (absent a feedback mechanism, which is generally the case) from the demand model.
3) A primary requirement is the development of appropriate VoTs, commensurate with the trip purposes by time of day. This implies the conduct of SP surveys.
4) The information requirements for T&R studies differ from those of "typical" transportation planning applications. This means that:
    - Greater attention must be given to the calibration and validation of the model (see also the next section regarding "airtight" validation criteria).
    - The ability to expand model outputs to daily, weekly, seasonal, and annual values must be considered.
5) Econometric models have an important role to play in T&R studies, in two ways:

[64] The choice is complex and nuanced. For example, a recent study on the impact of converting HOV lanes to HOT lanes and charging all users a toll, including HOVs, caused only a small reduction in the HOV proportion of overall traffic (i.e., relatively small impact overall); however, this represented a 9 percent reduction in the HOV share and an increase of 10 percent in HOT revenues. See M. W. Burris, D. H. Ungemah, M. Mahlawat, and M. S. Pannu, *Investigating the Impact of Tolls on High-Occupancy-Vehicle Lanes Using Managed Lanes*, Journal of the Transportation Research Board, TRR 2099, 113–122.

- The development of reliable short-term forecasts, which are a far more accurate means of accounting for economic cycles than is the use of a four-step model (again, the importance here is that if the short-term T&R forecasts are "off," then the long-term forecasts likely will be "off" as well).
- The ability to account for economic determinants of travel demand, which the four-step model does not do well.

7.2 Procedural Gaps and Opportunities

In Chapter 2, we noted the importance of considering *procedural* requirements for T&R modeling and forecasting, in addition to the analytical requirements. This places the analytical requirement in the context of the decisions that are required to support a P3 initiative. This means the model is being used to inform decisions. However, the information requirements have changed: In 'traditional' public sector modeling, the model outputs are used to address long-range transportation plans, corridor studies, environmental impact statements, policies, etc. For P3, new decision-makers enter the picture, namely, the financial community. They bring with them, in turn, new requirements:[65]

1) New information – for example, the need to differentiate revenues by vehicle class (i.e., according to the toll structure), which may not correspond to the ways that trip purposes and modes are modeled currently. This means that some translation or extraction of vehicle trip tables by vehicle class—e.g., type of vehicle or occupancy by trip purpose—must be developed before the trip tables can be assigned.
2) New tabulations – notably, accounting for annual T&Rs, which means that reliable ways of expanding hourly or sub-daily model outputs must be developed. Also, weekend travel, seasonal variations, special event travel, and the varying characteristics of off-peak and nocturnal travel (especially for trucks) must be considered. The availability of models for multiple time periods provides an appropriate basis for developing daily forecasts, in that the forecasts for each time period reflect that period's specific mix of trip purposes, mode shares, travel times, etc.
3) New levels of precision – forecasts typically must be developed for each year of the concession, meaning that (a) annual forecasts must be interpolated between the typical forecast horizons (e.g., between 2011, 2021, and 2031); (b) sub-annual, even quarterly, T&R forecasts for the critical initial ramp-up period; and (c) accordingly, the base year validation must be "air tight." The sensitivity to getting the initial years "right" lies in the concern that, if these are off, then the long-term T&R forecasts also will be off.

   The "air tight" validation means two things: First, the model's inputs, networks, zone system, and forecasting process must be appropriate for the analysis in question, in terms of spatial and temporal detail as well as their ability to generate meaningful, understandable, and defensible results. For example, the forecasts cannot be presented as being more precise than the model allows, or that local data must be used rather than

[65] The ensuing paragraphs expand on a discussion that first appeared in HDR's workplan for this task order.

values imported from elsewhere. The application of the model to the specific problem must be reasonable.

Second, the model's validation must be conducted at a level that is more precise and is more detailed spatially than is the case commonly with regional four-step models. A fixed standard does not exist. However, Table 7-1 presents commonly used criteria that are specified by potential sponsors for the preparation of investment-grade T&R studies on their behalf for specific facilities.

Table 7-1: Airtight validation criteria

Item	Applicability	Criteria
Ratio of observed to simulated vehicle counts at screenline	Applied at the screenline and along the facility corridor	Simulated/Observed <4% variance (ideally GEH <4)
GEH Statistic[66]	Applied at selected screenline locations along the facility corridor, and miscellaneous locations	>60% of all counts at GEH <5 >95% of all counts at GEH <10 100% of all counts at GEH <12 The GEH criteria should be satisfied for total volumes and each user class separately, on an hourly and directional basis
RMSE		≤30%
R^2 Value		>0.90
Slope of Regression Line		>0.9, <1.1
Journey Time	Applied to selected routes relevant to the project	Within 95% confidence interval of the mean observed journey times

These criteria refer to the assignment results – that is, to the assigned traffic on the corridor or facility that is in question. Of particular note:

- The need to focus on the market area for the proposed facility. This may entail the development of a sub-area model (network and zone detailing). It also requires the inclusion of the facility as well as of all competing routes, which in turn defines the study area that will be subjected to the airtight validation.
- The creation of new screenlines that are specific to the analysis; that is, to supplement and be interspersed among existing screenlines.
- The broad use of the GEH statistic, which compares absolute and relative differences between observed and simulated traffic flows at screenlines, as the goodness-of-fit criterion (of assigned and observed traffic volumes).
- The increasingly tight GEH criteria, with tighter tolerances closer to the tolled facility.

[66] The GEH formula is $GEH = \sqrt{((2(M-C)^2)/(M+C))}$ where M is the hourly traffic volume estimate from the model and C is the actual traffic count.

- The need to apply the GEH criteria to individual vehicle classes—e.g., autos or even subsets of autos separately from trucks, as opposed to total vehicles—by direction and by the modeled time of day.
- Criteria that measure alternative ways of looking at the same information—that is, RMSE, R^2 values, and the slope of the regression line of comparisons of assigned and observed volumes.
- The inclusion of trip travel time (journey time) along the corridor and along parallel, competing routes. This is important, because of the sensitivity of the diversion to accurate representations of travel time, in addition to the VoT relationship. Moreover, the criterion is described in terms of confidence intervals, which in turn implies the need for multiple travel time surveys along the competing routes for all time periods of importance. The idea is to account for variations in trip time by time of day, varying congestion levels, start-and-stop traffic conditions, etc.
- The resultant need for project-specific data to support the analysis in question.

4) Understanding of the short-term – related to the previous point, the impact of short-term boom-or-bust economic cycles on the forecasts can be significant. However, in a "traditional" model, they fall between the forecasting horizons. Accordingly, the validation of the base year model will require accounting for short-term fluctuations in the economy (which, in turn, drive traffic growth), etc. (For example, recreational or discretionary travel may drop suddenly for 1–2 years before going back to normal levels, but this must be accounted for in the base year model and in the forecasts. Similarly, the timing of proposed developments on a P3 corridor becomes critical for short-term forecasting.) Econometric models, which are described in the previous chapters, are an industry-accepted means of addressing this issue, and are integrated fully with travel demand T&R models.
5) Appropriateness of validation – the financial community typically requires a tighter validation of the model, using criteria that are accepted by the financial community (e.g., GEH within specified tolerances at screenlines and individual stations; confidence intervals for travel times) in addition to the validations normally done for models.
6) Appropriateness of inputs – this means that (a) alternative population/employment scenarios may be required, as sensitivity analyses to policy growth scenarios, to account for potential exogenous "downside" events unforeseen by the model (e.g., impact of severe changes in gasoline prices on vehicle ownership); and (b) accounting for economic or monetary factors in the analysis, such as gross domestic product, personal disposable income, etc. The base year model inputs also must be up-to-date.
7) Risk analysis – more than sensitivity analyses, these require a rigorous statistical analysis of all elements of the modeling, including inputs and outputs, to identify potential points of sensitivity and their impacts on the outcomes. In the context of T&R forecasts, the analysis of risk corresponds to how the financial community and its insurers address financial risk: for example, in the use of stress tests to examine worst case scenarios of the endogenous and exogenous factors that drive T&R forecasts, taking into account the combined impact of several factors. (A common example: the impact of changes in gasoline prices, which are not typically modeled in four-step models, on vehicle purchase, trip rates, trip chains, and mode share.)

8. DIRECTIONS FOR MAG

This chapter discusses a series of recommended directions for implementing T&R capabilities in MAG's four-step model. The chapter draws together the findings of the preceding chapters. It also draws on selected input from a small group of MPOs and departments of transportation consulted regarding lessons learned in T&R modeling and data collection, and on input from a workshop on toll road modeling that was held at MAG's offices on October 24, 2011. The consultant's presentation slides from the workshop are provided in Appendix B.

8.1 Directions for Modeling and Data

This section lists recommended directions for MAG according to priority. The priorities allow MAG to address basic needs first to enable it to model T&R, at least at a sketch planning or conceptual level. Two points should be noted:

- Although the focus is on the four-step model, virtually all of the recommended directions should be applied to the activity-based model as well (or in the case of the toll choice models, the incorporation of pricing should be considered in the activity-based model as it is being developed).
- We have proposed that MAG introduce both a route choice and a mode choice model. The latter *might* not be required depending on the type of pricing initiative MAG wishes to model. These initiatives are not yet known. However, discussion at the October 2011 workshop suggested that tolled facilities and managed lanes would be the most likely initiatives and that diversion to other modes was not likely to be a significant outcome of these facilities. Moreover, mode diversion may be seen as being more appropriate for network-wide initiatives, such as congestion pricing. As other agencies such as SCAG and the Puget Sound Regional Council have moved toward being able to model a broader range of responses, MAG may want to embark on this more comprehensive path to go beyond a mode choice model and account for destination choice and time-of-day models. However, this decision may depend on the parallel progress of the activity-based model.

There are nine directions. In order of priority, they need to:

1) Develop VoT data that are specific to the Phoenix region. This requires conducting an SP survey that captures VoT relationships for travelers in the Phoenix region. The key attributes of a VoT SP survey, and the statistical and sampling attributes of an SP survey, are described, respectively, in Appendix C. It is important to note that these discussions are intentionally somewhat generic given that MAG's needs are not yet defined; they are intended to inform and guide MAG as it details its requirements.
2) Ensure the adequacy, sufficiency, and currency of complementary data, especially classification counts and travel time surveys.
3) Develop route choice toll diversion models (i.e., in trip assignment). This uses the aforementioned SP survey results to develop the necessary components for route choice capability under tolls. (It is understood that more specific model development for managed lanes may arise from MAG's concurrent HOT lane modeling study.) We also

propose that MAG review, at the same time, its volume-delay functions while the route choice diversion model is incorporated into assignment, so as to ensure that there are no unintended consequences. MAG also should ensure that travel times are simulated reasonably.

4) Ensure the adequacy of the model for toll choice modeling—that is, ensure that the model has been properly validated to provide outputs that are suitable and defensible for toll forecasts. This does not necessarily mean that the “airtight” validation criteria described previously must be applied rigorously if only a sketch plan or concept is being considered. Rather, it means that the assumptions and data sources must be clearly stated and disclosed and that the model validation must be appropriate for the purpose. Perhaps most importantly, the inclusion of pricing into the model via the route choice model means that different skims may be generated for feedback into trip distribution and mode choice, and their application to the demand model must be examined to ensure that no untoward impacts or distortions result that could “undo” distribution or mode share.
5) Add output/reporting capabilities to provide an appropriate basis for reporting revenues and other inputs that allow for benefit-cost analysis.
6) Add an econometric model to allow for more advanced consideration of the short-term economic cycles and for an improved basis for long-term forecasting.
7) Add risk analysis capability through incorporation of Monte Carlo simulation of inputs and selected model outputs.
8) Incorporate toll diversion into the mode model, should network-wide schemes such as congestion pricing or time-of-day or destination choice models be considered.
9) Support the mode choice model with a comprehensive SP survey, similar in concept to that conducted by SCAG (and described in Section 4.5.1), which captures a broader range of responses to tolling (such as time shift and mode shift) as well as other attributes such as reliability.

Directions 1 through 7 together represent short-term actions that could be implemented within the next 1½ to 2 years (allowing time for data collection). It is important that these pieces be integrated with the ongoing update to the four-step model’s individual components. In other words, Direction 3’s enhancement of the volume-delay functions and network review should occur while the network is being reviewed and certainly commensurate with any upgrades to trip assignment. The need to ensure that the model is properly validated for tolling (Direction 4) means that the incorporation of updated prices into the skim must be considered when the trip distribution and mode share models are being updated.

The same is true for the development of toll choice models for toll diversion (Directions 8 and 9). However, the need for these models depends on MAG’s needs, as outlined previously.

8.2 Lessons Learned

We contacted four MPOs and a department of transportation: Puget Sound Regional Council in Seattle; Metro in Portland, Oregon; North Central Texas in Dallas-Fort Worth; SCAG; and the Florida Department of Transportation. Each had incorporated pricing in its models in different ways, meaning that their work applied to specific greenfield tolled facilities as well as extensions to existing tolled roads and, to a lesser extent, to managed lane studies (the latter being primarily at the sketch planning level). The agencies moved in sequence from analytical techniques that were suitable for sketch planning to more detailed models and data according to their requirements (SCAG's new models being an example of the latter [Section 4.5.1]).

Practitioners offered these key lessons:

- Account for (understand) unintended impacts of incorporating pricing in models.
    - Understand how the incorporation of improved pricing data is reflected in trip distribution, including integrated land use-transportation models.
    - Account for "leakage"—that is, unexpected impacts on mode share (possibly related to changed trip distribution) that may result from the imposition of tolls.
    - Ensure consistency and reasonableness when incorporating pricing in the model: i.e., the introduction of a new value that is "absolutely" correct may conflict with a value or parameter that has been calibrated well in "relative" terms.
- Ensure that the toll model is supported.
    - Update volume-delay functions (more generally, ensure that the model networks are up-to-date, complete, and consistent).
    - Collect site-appropriate and specific data (VoTs, counts, travel times, etc.).
- Ensure transparency—manage expectations during what are often controversial discussions regarding pricing. Here, the message as to what the model can and cannot do is important to focus the discussion and the public/political debate on the issue of pricing, not on the technicalities of the model. Model outputs that respond to the issues at hand must be developed, and interpretations and explanations must be applied to any discourse.

To these lessons, the consultant notes others from its NCHRP 364 Synthesis on best practices in T&R models, notably:

- Conduct peer reviews of T&R models.
- Ensure that data supporting the model are current and relevant to the need at hand and to the area.
- Get the short-term forecasts right; in particular, capture short-term economic cycles correctly.
- Model trucks properly. These may be small in number but they represent a significant market because they are commonly tolled at higher rates than autos. Moreover, avoidance by truck drivers of a tolled facility in favor of a free option may have significant propagation impacts across the road network. Truck traffic characteristics and behavior must be understood.
- Assess and understand viable options to the tolled initiatives; notably mode shift, trip suppression, and time-of-day shift.
- Provide full disclosure of assumptions, sources, and modeling processes in the documentation; in particular, in the validation and applicability of the model to the T&R issue at hand.

Finally, as part of the October 2011 workshop, the consultant noted two key drivers motivating MPOs' need to enhance their T&R modeling capabilities: (1) the need for agencies such as MAG to understand how pricing (tolls) affect travel behavior, and (2) the growing role of financial decision-makers in determining investments and priorities. Both drivers implied new roles and information requirements from the models, especially from the monetary perspective. Of key importance was the need to improve the *credibility* and *reliability* of traffic forecasts. There are several ways in which models for T&R studies or for P3 initiatives differ from traditional public sector models, including the importance of incorporating pricing in the analysis, addressing ramp-up, ensuring that trucks are modeled appropriately (small proportion of traffic but large proportion of revenues), and addressing the need for airtight validation.

This being said, MAG must clarify the objectives of implementing tolled facilities: to maximize revenues (i.e., for funding infrastructure implementation, operations, or maintenance) or to manage congestion (i.e., to promote more efficient use of the multimodal transportation network). This distinction is important because the potential tolled solutions, tolling structures, tolling rates, set-up of a P3, etc., are not necessarily the same for the two objectives, nor are specific goals, such as maximizing travel time benefits or optimizing the level of service.

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Appendix A.
Values of Time from T&R Studies

Values of Time (single number or range)

Category		Source (refer to table at right for information)														
	Total Range*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	(All)	CO	GA	GA	GA	MN	NJ	NJ	OR	TX	WA	FL	FL	OR	WA	OR
Overall Value	$14.31	$14.31														
Peak	$7.35-$19.61			$7.35-$15.25										$19.61		$18.89
OffPeak	$7.18-$15.27			$7.18-$11.99										$15.27		$12.57
Work	$4.17-$36.97							$4.17-$36.97								
Non-work	$2.92-$25.88							$2.92-$25.88								
Home-based work	$4.00-$14.00			$7.64-$10.79		$12.28					$4.00-$14.00	$8.32-$10.65	$7.03			
Home-based non-work	$5.33-$15.71			$9.23-$15.71		$5.71					$6.20	$5.33-$8.41	$5.86-$6.48			
Home-based school	$8.40										$8.40		$5.86			
Non-home based	$5.53-$12.89			$8.29-$12.89							$6.50	$5.53-$10.91	$6.48			
Non-home-based work	$2.54					$2.54										
Non-home-based non-work	$5.71					$5.71										
Business	$11.39-$30.06								$30.06				$11.39-$12.08			
Non-business	$14.93								$14.93							
Private vehicle	$6.79-$16.31								$16.31	$10.00			$6.79			
SOV - specific	$9.52-$33.83														$9.52-$33.83	
Commercial vehicle	$12.00-$54.25						$54.25			$12.00						
Light truck	$9.95-$40.00			$9.95	$18.00				$20.35				$12.08		$40.00	
Heavy truck	$12.08-$50.00			$13.48-$27.73	$35.00				$29.50				$12.08		$45.00-$50.00	
Vanpool	$37.38-$102.49														$37.38-$102.49	
Private vehicle commute	$4.20-$36.90						$4.20-$36.90									
Private vehicle non-commute	$2.90-$25.90						$2.90-$25.90									
Peak Work	$14.83	$14.83														
Peak Nonwork	$13.13	$13.13														
Offpeak Work	$13.56	$13.56														
Offpeak Nonwork	$12.77	$12.77														
Peak SOV (HBW)	$7.25-$7.63		$7.25-$7.63													
Offpeak SOV (HBW)	$7.15-$8.01		$7.15-$8.01													
Peak HOV (HBW)	$4.20-$6.88		$4.20-$6.88													
Offpeak HOV (HBW)	$4.93-$13.69		$4.93-$13.69													
Peak SOV (HBNW)	$5.03-$5.59		$5.03-$5.59													
Offpeak SOV (HBNW)	$4.25-$4.87		$4.25-$4.87													
Peak HOV (HBNW)	$4.73-$7.28		$4.73-$7.28													
Offpeak HOV (HBNW)	$5.13-$8.29		$5.13-$8.29													
Peak SOV (NHB)	$7.24-$8.97		$7.24-$8.97													
Offpeak SOV (NHB)	$5.30-$8.25		$5.30-$8.25													
Peak HOV (NHB)	$7.06-$38.34		$7.06-$10.66												$23.00-$38.34	
Offpeak HOV (NHB)	$5.14-$21.35		$5.14-$9.94												$19.34-$21.35	

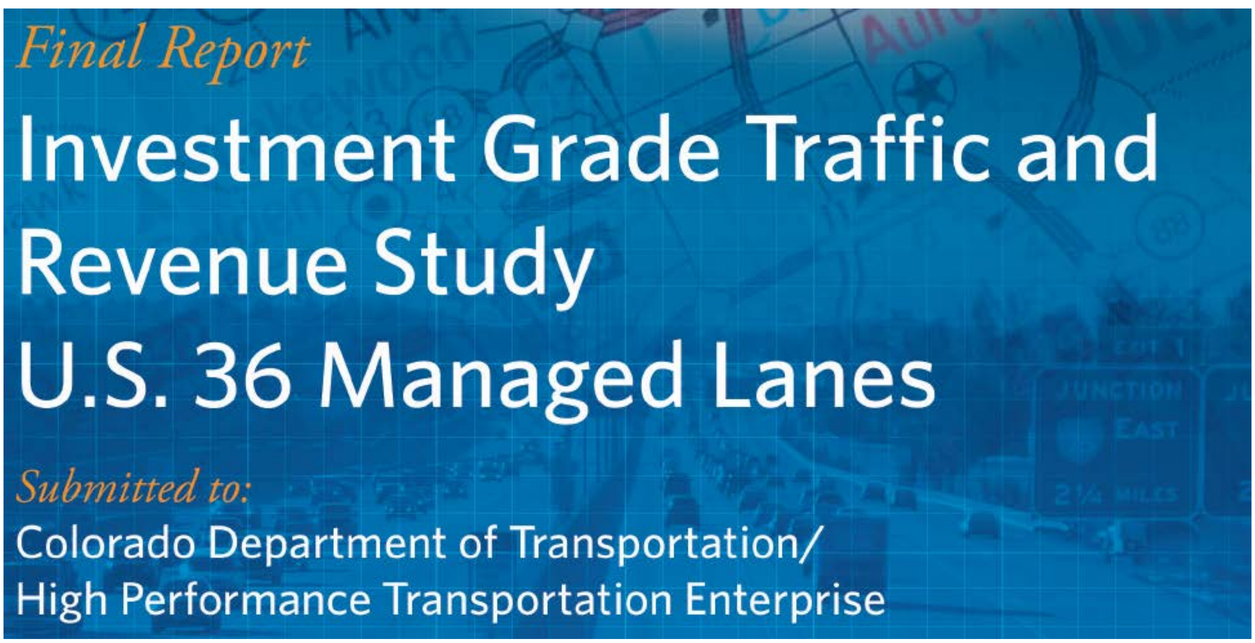
*Ranges may include values of time from different years

AGGREGATIONS
Only applicable values or ranges have been filled in.
Note: where sources used more than one method, express range across two methods
Where different facilities used, also express range across the values
Where different years used, use latest (assume VOT is in $ for year of source unless stated otherwise)
Where peaks are separated (AM and PM), use range across both peaks
Where multiple off-peak periods are listed, use the midday value
Where trucks are defined by axle, define 3-6 as "heavy"
Where HOVs are separated (2+ and 3+), use range across HOV categories (except vanpools)
Show ranges for non-work non-school purposes, when multiple purposes are listed
Medium trucks classed as heavy

	Identification of Sources					
Code	**Location of study**	**Author, title and commissioner of study report**	**Source Year**	**VOT Year (assume source year if not stated otherwise)**	**Basis for calculating VOTs**	**Weblink (if available online)**
1	Colorado	WSA, *Investment Grade Traffic and Revenue Study US-36 Managed Lanes*: Colorado DOT	2011	2011	SP Survey	http://www.coloradodot.info/about/high-performance-transportation-enterprise-hpte/us-36-managed-lanes/us-36-managed-lanes-investment-grade-traffic-and.url
2	Georgia	HNTB, *Study of Potential Managed Lanes on I-75 South Corridor*: Georgia SRTA	2008	2008	SP Survey	www.georgiatolls.com/assets/docs/I75_VPPP_brochure.pdf
3	Georgia	HNTB, *Managed Lane System Plan Stated Preferences Survey*: Georgia DOT	2010	2010	SP Survey	http://www.dot.state.ga.us/informationcenter/programs/studies/managedlanes/Documents/Stated%20Preference%20Survey.pdf
4	Georgia	Parsons Brinckerhoff, *Truck Only Toll Facilities: Potential for Implementation in the Atlanta Region*: Atlanta	2005	2005	Review of SP surveys	http://www.georgiatolls.com/assets/docs/TOT_Final_Report.pdf
5	Minnesota	Cambridge Systematics, *MnPASS System Study--Technical Memorandum 3*: Minnesota DOT	2005	2004	Reviews of SP survey and RP data	http://www.mnpass.org/pdfs/techmemo3forecasting.pdf
6	New Jersey	SDG, *New Jersey T&R Study Atlantic City Expressway Asset Appraisal Final Report*: New Jersey Dept of Treasury	2008	2006	Census data and wage rate factors	http://www.njslom.org/njtrstudypart4.pdf
7	New Jersey	SDG, *New Jersey T&R Study Background Report Final Report*: New Jersey Dept of Treasury	2008	2006	Census data and wage rate factors	http://slic.njstatelib.org/slic_files/digidocs/f491/f4912008a.pdf
8	Oregon	Oregon DOT, *The Value of Travel-Time: Estimates of the Hourly Value of Time for Vehicles in Oregon 2005*	2006	2005	Literature review and wage rates	http://www.oregon.gov/ODOT/TD/TP/docs/publications/ValueTravelTime2005.pdf?ga=t
9	Texas	NCTCOG Travel Model Development Group: *Dallas-Fort Worth Regional Travel Model Model Description*	2009	1999	Demographic survey data	http://www.nctcog.org/trans/modeling/documentation/DFWRTMModelDescription.pdf.
10	Washington	Cambridge Systematics, *PSRC Travel Model Documentation (for Version 1.0) Final Report*: PSRC	2007	2007	SP Survey	http://psrc.org/assets/1511/model_doc_final_.pdf
11	Florida	RSG, *South Florida Stated Preference Travel Survey and Toll Mode Choice Models:* Florida's Turnpike Enterprise	2006	2006	SP Survey	
12	Florida	Cambridge Systematics, *Southeast Florida Road and Transit User Cost Study Draft Report*: Florida DOT	2009	2004	Census data and wage rate factors	
13	Oregon	Portland, *Addendum to the Metro Travel Forecasting March 2008 Trip-Based Demand Model Methodology Report - Transportation demand modeling as it relates to tolling in the Columbia River Crossing project*	2010	2010	SP Survey	
14	Washington	PSRC (Outwater and Kitchen), *Value of Time for Travel Forecasting and Benefits Analysis*: PSRC	2008	2008	RP data (auto), literature review (truck)	http://psrc.org/assets/1820/ValueofTimeMemo-updated.pdf
15	Oregon	Stantec (Nielsten and Abendschein), *Recommendation for the selection of the Value of Time to be used in the METRO modeling runs*: CRC Modeling Review Team	2009	2009	SP Survey	

Table 3-6
Value of Time

Travel Time Segment	Mean Income	Mean Distance (miles)	Value of Time ($/hr)
Peak Work	$ 118,658	24.1	$ 14.83
Peak Non-work	108,780	26.3	13.13
Off-peak Work	114,902	25.8	13.56
Off-peak Non-work	106,621	26.3	12.77
Aggregate	113,634	25.3	14.31



STUDY OF POTENTIAL
MANAGED LANES ON
I-75 SOUTH CORRIDOR

November 2008

FINAL

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Table 2-8: Imputed Value of Travel Time Savings ($/Hour)

Purpose	Home Based Work	Home Based Other	Non Home Based
Method A (Logit model)			
Peak period SOV	$ 7.63	$ 5.59	$ 8.97
Off-peak SOV	$ 8.01	$ 4.87	$ 8.25
Peak period HOV2	$ 6.88	$ 5.92	$ 9.30
Off-peak HOV2	$ 7.25	$ 5.19	$ 8.57
Peak period HOV3+	$ 4.93	$ 7.28	$ 10.66
Off-peak HOV3+	$ 5.30	$ 6.56	$ 9.94
Method B (Individual values)			
Peak period SOV	$ 7.25	$ 5.03	$ 7.24
Off-peak SOV	$ 7.15	$ 4.25	$ 5.30
Peak period HOV2	$ 7.82	$ 6.77	$ 8.30
Off-peak HOV2	$ 13.69	$ 5.13	$ 5.14
Peak period HOV3+	$ 4.20	$ 4.73	$ 7.06
Off-peak HOV3+	$ 8.40	$ 8.29	N/A

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January 2010

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Table 27: Mean Values of Time for Auto Segments

Segment	Value of Time ($/hour)				
	I-20E	I-20W	I-75	I-85	I-285
Home-based work	$ 7.89	$ 10.79	$ 7.64	$ 8.20	$ 7.86
Home-based other	$ 11.74	$ 15.71	$ 9.23	$ 10.69	$ 10.15
Not home-based	$ 9.04	$ 12.89	$ 8.29	$ 8.86	$ 9.06
AM Peak	$ 10.41	$ 15.25	$ 9.97	$ 9.39	$ 9.26
PM Peak	$ 7.71	$ 8.70	$ 7.84	$ 7.35	$ 8.20
Off-peak	$ 7.18	$ 10.40	$ 9.57	$ 11.99	$ 10.54
Average Income ($/year)	$ 69,629	$ 72,737	$ 86,262	$ 85,020	$ 78,632
Average Distance (miles)	26.8	27.5	26.7	26.9	26.4

Table 28: Mean Values of Time for Commercial Vehicles by Number of Axles

Segment	Value of Time ($/hour)
2-axle trucks	$ 9.95
3-axle trucks	$ 13.48
4-axle trucks	$ 17.80
5-axle trucks	$ 22.95
6-axle trucks	$ 27.73
Average Distance (miles)	63.7

Truck Only Toll Facilities:

Potential for Implementation in the Atlanta Region

HOT & TOT FEASIBILITY STUDIES FOR THE ATLANTA REGION

Atlanta TOT Facilities Study

Final Report

July 18, 2005

Prepared by:
Parsons, Brinckerhoff, Quade & Douglas, Inc.
A Member of the Parsons Brinckerhoff Team

Two recent surveys (Kawamura, 1999 and Smalkowski, 2003) suggest a range for (heavy) truck operators' value of time from $30 to $60 per hour. Both studies also tested various operator characteristics for significance in determining value if time. One important variable suggested by both in determining value of time is business type, that is, whether operators are for-hire or private. Survey results suggested that for-hire operators have a higher value of time than do private carriers (3,4). Because business type and other operator characteristics are not available from the travel demand model, a representative value of time for the entire heavy truck category was desired.

The study team presented the value of time research to the steering committee in order to gain feedback from industry representatives regarding the values used for the TOT analysis. The committee agreed that for the purposes of this study, a value of time of $35 per hour for heavy duty commercial vehicles and $18 per hour for light duty commercial vehicles (as defined by the ARC model) is sufficient. These values were used in the travel demand model and were adjusted (with average speed) to estimate initial toll rates. As discussed above, toll rates were then adjusted according to conditions on each TOT corridor.

technical memorandum

MnPASS System Study

Technical Memorandum #3

Travel Demand Forecasting Approach

February 3, 2005 (Revised)

Table 1. Implied Values-of-Travel Time for the Council Regional Travel Model

Trip Purpose	Implied Value-of-Time ($/hr)
Home-Based Work	$12.28
Home-Based Non-Work (Home-Based Work-related, shopping, and other trips)	$5.71
Home-Based School	NA – No Cost Coefficient
Non-Home Based Work	$2.54
Non-Home Based Other	$5.71

Source: PB Consult, Inc., *Twin Cities Regional Model: Development of the Twin Cities Year 2000 Mode Choice Model* (March 2004).

NEW JERSEY TRAFFIC AND REVENUE STUDY

Atlantic City Expressway Asset Appraisal

Final Report

January 2008

Value of Time (VOT) (2006 prices)	Based on Census 2000 Household income levels. Household income levels were converted into average wage rate by dividing by 2080 hours; commuter VOTs were calculated as 50% of the wage rate, and other VOTs as 35% of the wage rate ($ / hr): • Car Commute: 4.2 / 10.8 / 18.1 / 36.9 • Car Other: 2.9 / 7.6 / 12.7 / 25.9 Trucks: 54.25

Prepared for:

State of New Jersey
Department of Treasury
State House

Prepared by:

Steer Davies Gleave in association with CRA International and EDR Group

NEW JERSEY TRAFFIC AND REVENUE STUDY

Background Report

Final Report

January 2008

TABLE 2.3 VALUES OF TIME BY INCOME GROUP AND TRIP PURPOSE (2006 DOLLARS)

	Average Annual Household Income	Average Wage Rate ($/hr)	Work VOT ($/hr)	Other VOT ($/hr)
Income Group 1	$17,351.61	$8.34	$4.17	$2.92
Income Group 2	$45,036.42	$21.65	$10.83	$7.58
Income Group 3	$75,343.61	$36.22	$18.11	$12.68
Income Group 4	$153,774.81	$73.93	$36.97	$25.88

Source: CRA International, 2007

Prepared for:

State of New Jersey
Department of Treasury

Prepared by:

Steer Davies Gleave in association with CRA International and EDR Group

Oregon Department of Transportation
Economics & Policy Analysis Unit
April 2006

Table 3. Effect of Changing Underlying Assumptions of Value of Travel-Time Estimates

Category	Auto	Light Trucks	Heavy Trucks
2005 Estimates	**$16.31**	**$20.35**	**$29.50**
Occupancy Rate of 1.0	$14.82	$18.92	$27.37
Miles On-the-Job Doubled	$16.65	N/A	N/A
Miles On-the-Job Cut in Half	$14.63	N/A	N/A
Value of Benefits Excluded	$14.53	$12.55	$20.23
Decrease Wage 10%	$13.78	$17.58	$27.57
Increase Wage 10%	$16.84	$21.49	$33.28

Table 2. Details of Estimated Value of One Hour of Travel-Time by Vehicle Class, Oregon 2005

#	Category	Vehicle Class[8] Auto	Light Trucks	Heavy Trucks
1	2005 Oregon Average Wage	$17.38	$13.30	$16.56
2	2005 Value of Fringe Benefits	$7.34	$6.42	$8.00
3	Total Compensation	$24.72	$19.72	$24.56
	On-the-Job Trips			
4	Average Vehicle Occupancy	1.22	1.03	1.12
5	2005 Cost of Employees	$30.06	$20.35	$27.50
6	2005 Freight Inventory Value	$0.00	$0.00	$2.00
7	Total "On-the-Job" Value	$30.06	$20.35	$29.50
8	Miles "On-the-Job" %	9.1%	100.0%	100.0%
9	Weighted Value	$2.74	$20.35	$29.50
	Off-the-Job trips			
10	Average Vehicle Occupancy	1.58	N/A	N/A
11	Total "Off-the-Job" Value	$14.93	$0.00	$0.00
12	Miles "Off-the-Job" %	90.9%	0.0%	0.0%
13	Weighted Value	$13.57	$0.00	$0.00
14	**Total Weighted Average**	**$16.31**	**$20.35**	**$29.50**

Note: Table values are rounded to two decimal places, but calculated values are not. As a result, calculations made by the reader will differ slightly from some values in the table.

North Central Texas Council of Governments
Transportation Department
Travel Model Development Group

DALLAS-FORT WORTH REGIONAL TRAVEL MODEL (DFWRTM):

MODEL DESCRIPTION

CAMBRIDGE SYSTEMATICS

PSRC Travel Model Documentation (for Version 1.0)

Updated for Congestion Relief Analysis

Final Report

Table 8.1 Summary of Recommended Values of Time

Trip Purpose	Values of Time (Dollars Per Hour)
Home-Based Work	\$4-\$14 depending on income (average = \$8.40)
	Low income = \$4
	Low-medium income = \$7.23
	Medium-high income = \$10.84
	High income = \$14
Home-Based College	Average = \$8.40
Home-Based Non-Work	Average = \$6.20
Non-Home Based	Average = \$6.50

Documentation for

SOUTH FLORIDA STATED PREFERENCE TRAVEL SURVEY AND TOLL MODE CHOICE MODELS

Prepared by

Resource Systems Group Inc.

Prepared for

Florida's Turnpike Enterprise

July 2006

Table 6: Toll Mode Choice Models

	Coefficient	Units	HBW			HBO			NHB		
			Estimate	T-stat	VOT	Estimate	T-stat	VOT	Estimate	T-stat	VOT
Broward	Travel time	Minutes	-0.052	-18.0		-0.051	-25.1		-0.056	-12.3	
	Cost	Dollars	-0.372	-12.6	$ 8.32	-0.422	-18.5	$ 7.17	-0.341	-9.7	$ 9.82
	Time shift	Minutes	-0.020	-10.9		-0.016	-11.6		-0.019	-6.7	
	Toll free constant	(0,1)	0.697	8.9		0.706	11.2		0.477	3.7	
	Transit constant	(0,1)	-0.005	0.0		0.136	1.5		-0.098	-0.5	
Miami-Dade	Travel time	Minutes	-0.025	-11.1		-0.031	-15.5		-0.043	-9	
	Cost	Dollars	-0.141	-5.4	$ 10.65	-0.353	-14.2	$ 5.33	-0.467	-8.7	$ 5.53
	Time shift	Minutes	-0.019	-7.8		-0.022	-11.8		-0.035	-8.1	
	Toll free constant	(0,1)	0.500	4.9		0.227	2.8		0.068	0.4	
	Transit constant	(0,1)	0.180	1.4		-0.705	-5.9		-0.526	-2.2	
Palm Beach	Travel time	Minutes	-0.03898	-11.2		-0.04189	-19.2		-0.02952	-6.7	
	Cost	Dollars	-0.2503	-8.9	$ 9.34	-0.2989	-15.9	$ 8.41	-0.1624	-4.8	$ 10.91
	Time shift	Minutes	-0.01444	-5.4		-0.01569	-9		-0.01759	-3.8	
	Toll free constant	(0,1)	0.2303	1.8		0.5193	5.9		0.4708	2.2	
	Transit constant	(0,1)	0.1207	0.7		-0.4977	-4		-0.2117	-0.8	

draft report

Southeast Florida Road and Transit User Cost Study

prepared by

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2457 Care Drive, Suite 101
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date

March 2009

Table 2.2 Travel Time Value for Commuter and Personal Travel
2004 Dollars

	National Median	Southeast Florida	Percent of Wage Rate	Source
Wage-All Industries (2000 Dollars)	$22,508/year	$21,975/year		
Equivalent Year (2004 Dollars)[a]	$24,961/year	$24,370/year		
Commuter	$7.20/hour	$7.02/hour	60%	SE FL wage
Personal (Local)	$6.00/hour	$5.86/hour	50%	SE FL wage
Personal (Visitor)	$6.00/hour	$5.86/hour	50%	U.S. wage

Table 2.3 Per-Person Travel Time Value for On-the-Clock Travel

2004 Dollars

On the Clock TTV Component	Florida Median	Southeast Florida
Wages	$22,980	$24,370
Total Compensation	**$23,704**	**$25,139**
Total (2000 Dollars)	**$10.28 per hour**	**$10.90 per hour**
Total (2004 Dollars)	**$11.39 per hour**	**$12.08 per hour**

Note: For workers in the transportation and service sectors.

Table 2.4 Travel Time Value by Trip Purpose of Demand Forecast Models

2004 Dollars

	Commute	Local Personal	Visitor Personal	On-the-Clock	Average (Per hour)
	$7.03	**$5.86**	**$6.00**	**$12.08**	
Home-Based Work	100%	0%	0%	0%	**$7.03**
Home-Based Shopping	0%	95%	5%	0%	**$5.86**
Home-Based School	0%	100%	0%	0%	**$5.86**
Home-Based Social/ Recreational	0%	95%	5%	0%	**$5.86**
Home-Based Other	0%	90%	0%	10%	**$6.48**
Home-Based Unknown	0%	95%	0%	5%	**$6.17**
Non-Home-Based	0%	90%	0%	10%	**$6.48**

Table 2.5 Travel Time Value by Time Period
2004 Dollars

	6:30 a.m.-9:00 a.m.	9:00 a.m.-11:30 a.m.	11:30 a.m.-1:30 p.m.	1:30 p.m.-4:30 p.m.	4:30 p.m.-6:30 p.m.	Other	Value/Hour by Trip Purpose
Home-Based Work	40%	16%	11%	20%	32%	25%	$7.03
Home-Based Shopping	3%	16%	14%	11%	11%	13%	$5.86
Home-Based School	16%	3%	3%	10%	5%	3%	$5.86
Home-Based Social/ Recreational	3%	7%	5%	6%	8%	16%	$5.86
Home-Based Other	20%	25%	20%	21%	21%	25%	$6.48
Home-Based Unknown	0%	1%	1%	1%	1%	1%	$6.17
Non-Home-Based	16%	32%	46%	32%	22%	16%	$6.48
Average	**$6.56**	**$6.40**	**$6.40**	**$6.42**	**$6.50**	**$6.42**	

Table 2.6 Travel Time Value by Travel Purpose and Vehicle Type

2004 Dollars

	Personal Vehicles	Buses	Single Unit Trucks	Combination Unit Trucks
Commute	25%	15%		
Local/Personal	55%	70%		
Visitor/Personal	10%	10%		
On-the-Clock	10%	5%	100%	100%
TTV Per-Person Per Hour	**$6.79**	**$6.36**	**$12.08**	**$12.08**
Average Occupancy	**1.57**	**10.15**	**1.2**	**1.2**
Inventory Cost			**$0.14**	**$0.22**
TTV Per Vehicle Per Hour	**$10.65**	**$64.53**	**$14.64**	**$14.72**

Table 2.7 Travel Time Value by Roadway Functional Classification and Vehicle Type

2004 Dollars

	Personal Vehicles	Buses	Single-Unit Trucks	Combinati on-Unit Trucks	Per-Vehicle TTVs
Rural Principal Arterial – Interstate	80.1%	0.6%	2.8%	16.6%	$11.77
Rural Principal Arterial – Other	89.7%	0.4%	2.9%	7.0%	$11.27
Rural Minor Arterial	93.2%	0.2%	2.9%	3.6%	$11.01
Rural Major Collector	88.9%	0.3%	3.7%	7.1%	$11.25
Principal Arterial – Interstate	92.2%	0.6%	2.4%	4.8%	$11.26
Urban Principal Arterial – Other Freeways/Expressways	94.7%	0.5%	2.2%	2.7%	$11.13
Urban Other Principal Arterial	97.1%	0.2%	1.7%	1.0%	$10.87
Urban Minor Arterial	97.8%	0.2%	1.2%	0.8%	$10.84
Urban Collector	95.9%	0.4%	1.6%	2.1%	$11.01
Occupancy	**1.57**	**10.15**	**1.2**	**1.2**	

Addendum to the Metro Travel Forecasting March 2008 Trip-Based Demand Model Methodology Report (updated September 2010)

Transportation demand modeling as it relates to tolling in the Columbia River Crossing project

Demand model – destination and mode choice

Within the destination and mode choice models, tolls are input as additional operating costs for the SOV and HOV modes. The O-D weighted toll time matrices calculated in the skim building assignment procedure are passed into the model, where they are converted into monetary values using a values of time of $19.61/hr (2010$) for peak period and $15.27/hr (2010$) for off-peak periods. The resulting matrices represent the O-D weighted toll costs for trips between zones that use the I-5 Bridge. Zone pairs in which 100% of all trips use the I-5 bridge would see 100% of the toll cost, zone pairs with 50% I-5 Bridge use for trips would see 50% of the toll cost, etc.

Puget Sound Regional Council
PSRC

March 25, 2008
Updated October 2008

To: Regional Pricing Coordination Team

From: Maren Outwater and Matthew Kitchen, PSRC

Subject: **Value of Time for Travel Forecasting and Benefits Analysis**

Table 1a: Values of Time by Market Segment used in the PSRC Regional Travel Forecasting Model (Version 1.0b)

Market Segment	
Home-based Work Single Occupant Vehicles	
Low Income	$9.52
Low-Medium Income	$17.65
Medium-High Income	$26.09
High Income	$33.33
Non-Work Single Occupant Vehicles	
All Income Groups	$15.68
Carpool and Vanpool	
All Income Groups	See Table 1b
Trucks	
Light Trucks	$40.00
Medium Trucks	$45.00
Heavy Trucks	$50.00

Table 1b: Values of Time for High Occupancy Vehicles by Time of Day

	HOV2	HOV3+	Vanpool
AM Peak	$30.33	$38.34	$102.49
Midday	$19.34	$21.35	$37.38
PM Peak	$23.00	$27.01	$59.08
Evening	$20.56	$21.35	$37.38
Night	$26.66	$34.57	$88.02

Columbia River CROSSING

Memorandum

September 8, 2009

TO: CRC Modeling Review Team

FROM: Gerry Nielsten, Steve Abendschein, STANTEC

SUBJECT: Recommendation for the selection of the Value of Time to be used in the METRO Modeling runs

Summary

Based upon the Stated Preference Survey data and other considerations, we recommend using the following values of time for the METRO modeling:

Peak Periods:	$18.89 (2009 $)	$13.33 (1994 $)
Off Peak Periods	$12.57 (2009 $)	$10.38 (1994 $)

Recommendation for the Value of Time to be used in the METRO Model

Combining the above discussion, we recommend using the following value of times by period for the METRO modeling runs:

Peak Periods: $14.68 (SPS) * 1.20 (occupancy) * 1.1 (reliability, non-local, frequency) = $19.38 (2009 $) = $13.33 (1994 $)

Off Peak Periods: $11.43 (SPS) * 1.20 (occupancy) * 1.1 (reliability, non-local, frequency) = $15.09 (2009 $) = $10.38 (1994 $)

Appendix B. Presentation Slides (October 2011 Workshop on Toll Road Models)

Toll Road Modeling and Its Applications

What it is and why it is important to MAG

Toll Road Modeling Support

David Kriger, P.Eng., MCIP – *David Kriger Consultants Inc.*
Michael Gorton, AICP – *HDR*
Rhys Wolff, P.Eng. - *HDR*

MARICOPA ASSOCIATION of GOVERNMENTS

Maricopa Association of Governments
Phoenix, AZ
24 October 2011

HDR

Purpose

- MAG needs to consider the implications of tolls in its transportation plans:
  - What toll modeling capabilities does MAG need?
  - What supporting data are needed?
- Mandate
  1. Review best practices (literature, interviews)
  2. Review existing MAG model
  3. Identify gaps and opportunities
  4. Recommend next steps for modeling, data

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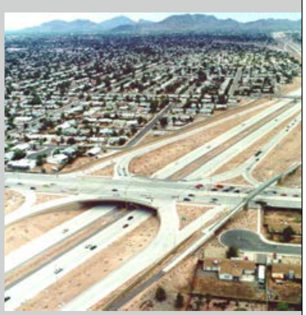
Today's presentation

1. Explain importance of toll modeling, its uses and its benefits to MAG
2. Describe key findings of a recent study
3. Recommended next steps for MAG



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By way of introduction…

- HDR Corporation:
  - 7,800 staff in 165 offices in US, plus international
  - Extensive experience with toll roads, express lanes:
    - Planning, engineering, construction management
    - Alternative Delivery / P3
  - In Phoenix since 1959 – model studies include:
    - North-South Corridor Study (ADOT)
    - Sky Harbor Airport Passenger Model (MAG)
    - Statewide Travel Demand Model (ADOT)
  - Traffic and revenue models:
    - Investment-grade and due diligence in US, Canada
    - Risk analysis
    - Best practice research and guides

4 HDR

Project team

- HDR:
  - Brent Cain, PE: Principal-in-Charge, Phoenix
  - Michael Gorton, AICP: Project Manager, Phoenix
  - David Kriger: David Kriger Consultants Inc. (formerly Director Traffic and Revenue Studies, HDR)
  - Rhys Wolff, P.Eng.: Researcher
  - May Raad: Statistician
  - Pierre Vilain, PhD: Economist
  - Stephane Gros, PhD: Risk Analysis
- Academic advisors:
  - Eric Miller, PhD – University of Toronto
  - Mark Burris, PhD – Texas A&M / TTI

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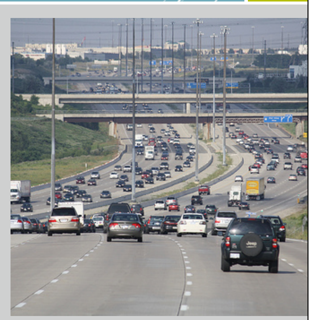
Tolls and toll road modeling

- Facilities for which a user fee is paid:
  - Toll highway, bridge, tunnel
  - Managed lane
  - Cordon pricing, …
- Fees used for:
  - Financing
  - Congestion management
- Alternate procurement models
- Direct or indirect toll
- Toll models used to assess impact of *pricing* on travelers' behavior



Highway 407 ETR, Toronto - Source: Danielle Scott

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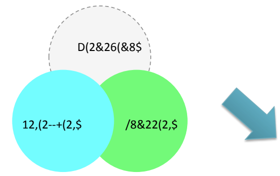
Why is toll modeling important to MAG?

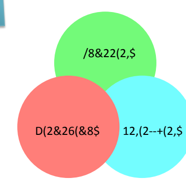
- Account for toll impact in current planning studies:
  - Corridor studies for greenfield (e.g., new toll road) or brownfield facilities (e.g., HOT lane on existing road)
  - Long-range transportation plans
- Examine policy implications of tolling:
  - Alternate source of revenues
  - Congestion management (TDM tool)
- Understand implications of initiatives by others:
  - MAG position / response
- Establish substantive basis for tolling proposals:
  - Setting up P3 bid
  - Public consultation

7

Financial decisions more prominent



Financial decision-makers are now key actors, and they pose different questions



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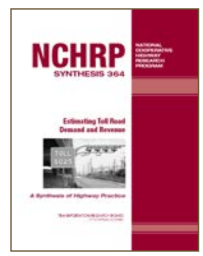
Different levels of analysis

- Several examples – e.g., TTA (Tx DOT):
  1. Conceptual (high-level feasibility)
  2. Sketch (project-specific estimates of costs, traffic, revenues, …)
  3. Intermediate (more detailed project-specific estimates)
  4. Investment-grade ("extensive and detailed" analysis to determine "value" as basis for funding)

9

Accuracy in forecasts is critical

- Financial community requires *credibility* and *reliability* in forecasts of revenue stream
- This determines model components and approach
- NCHRP Synthesis 364:
  - Several points require attention to promote credibility and reliability



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10 key differences

Traditional forecasts	T&R / P3 forecasts
1. Governments, politicians make decisions and set priorities	1. Financial community also key decision maker
2. Meant for planning programs: no guarantee it will ever be funded	2. Key input to financing, sponsor bid; real money at stake – transfer of risk
3. Focus on long term (10-20+ years: no finite bounds)	3. Short term *crucial* (business cycle, ramp-up, up-front debt loading)
4. Calibration is technical focus	4. Calibration, validation both important
5. Forecasts are taken as-is	5. Forecasts: how credible and reliable?
6. Risk: simple high/low – unrealistic!	6. Risk: worst case, combinations, externalities
7. Usually forecasts of hour / period	7. Monthly, quarterly or annual forecasts
8. Pricing: simplistic or too general	8. Pricing is everything, incl. perceptions
9. Travel time / speed calibration is secondary	9. Travel time / speed calibration is fundamental
10. Behavior: fcn of what's already observed (OD surveys)	10. Toll choice: fcn of stated preference surveys to quantify value of time ($/h)

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Key relationship: Value of time

- Value of time (VoT - $/hr) quantifies traveler tradeoff between time saving and payment for that saving
- Simple form: 50% of average salary
- VoT can be segmented in several ways:
  - Trip purpose (work, non-work, NHB, …) – also activity
  - Occupation
  - Income categories
  - Time of day (peak v. off-peak)
  - Vehicle class (auto v. commercial)
- Also important:
  - Reliability (level and predictability of congestion)
  - Quality of trip (e.g., safety, state of repair)

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Source of VoT

- If tolls are new to a region, how can we determine VoT?

1. Borrow VoT from elsewhere
   - Good for reality check but can miss local nuances
2. Stated Preference (SP) surveys:
   - Quantify how consumers value something
   - Widely used in marketing
   - Accepted (required) by financiers
   - Series of objective experiments

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What would an SP look like for MAG?

- Region-wide v. corridor specific
- Need segmentation, but sample size also increases → need balance:
  - Purpose, income, occupation, time of day, vehicle class, …
  - Experiment must be realistic: relate to respondent's "last" trip

Travel Time (min)
0-10
10-20
20-30
30-40
40-50
50-60
60-75
77-90
90+

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Sample Experiment: Travel Time Reliability

Please select either choice A or choice B.

A	B
Average Travel Time	Average Travel Time
9 minutes	**9 minutes**
You have an equal chance of arriving at any of the following times	You have an equal chance of arriving at any of the following times
7 minutes early	**7 minutes early**
4 minutes early	**3 minutes early**
1 minute early	**2 minutes early**
5 minutes late	**2 minutes early**
9 minutes late	**On time**
Your cost: **$1.25**	Your cost: **$7.50**

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Analytical core: toll choice

- Two common approaches:
  1. Mode choice (toll is a mode):
     - Toll may be an explicit out-of-pocket cost
     - Consistent, especially if HOV/SOV are explicit choices
     - Allows for diversion to other modes; time periods?
     - May be suited best for policy, cordon pricing, …
  2. Route choice (assignment):
     - Cost is converted to time penalty via VoT
     - May reflect the 'real' choice (no mode shift)
     - Computational subtleties (vehicle class, iterations, …)
     - May be suited best for facility-specific projects
- Must feed back prices through the demand model (including skims for trip distribution)

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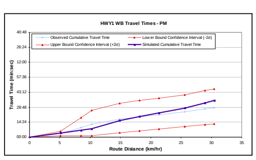
Model validation

- Ensure model is appropriate for the application
- Financial community demands "airtight" validation of corridor:
  - More screenlines / stations with tighter V/C ratios (GEH, RMSE, R^2)
  - Journey times on facility and alternate routes – mean within 95% confidence interval



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Econometric models

- Short-term economic boom / recession cycles not captured in travel demand models:
  - Long-term population / employment forecasts assume fluctuations have been ironed out
- Impact on actual traffic, revenue can be huge:
  - If short-term is wrong, then may never catch up
- Econometric models address this:
  - Regression: traffic = f(tolls, fuel, GDP, trade)
  - Used also for brownfield forecasts
- Complements (not replace) travel demand model
  - Validates model calibration (error ≥ ramp-up!)

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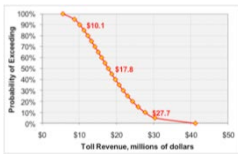
Risk analysis

- More than sensitivity analysis
- Translate model uncertainty into financial risk
  - Financial community requirement: assuming risk
  - Object is to lower cost of borrowing → more infrastructure dollars
  - Monte Carlo simulations commonly used
  - EG: probability of achieving 'X' revenues



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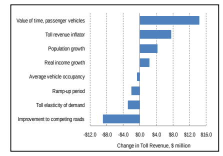
Risk analysis

- Use results to understand the relative impact of different variables on the results (revenues):
  - EG, impact of one standard deviation increase
  - Identify which are the weakest variables (which ones matter):
  - Look at ways of firming up these variables, e.g.:
    - Sensitivity to toll rate
    - Other improvements



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Lessons learned

- Interviewed selected MPOs, DOTs –key points:
  - Used for specific facilities, extensions
  - Mix of levels: sketch/assumptions to start (especially ML); move to detailed models/data
  - Account for (understand) unintended impacts of incorporating pricing in models:
    - Trip distribution, including land allocation models
    - Leakage (bridge changes transit share)
    - Relative v absolute values (consistency)
  - Ensure back-up:
    - Update volume-delay functions
    - Collect site-appropriate data (SPs, VoT, …)
  - Ensure transparency – manage expectations:
    - Messaging important – develop model outputs

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Lessons learned (NCHRP 364, etc.)

- Do peer reviews of toll model
- Get the right data: current, relevant
- Get the short term right
- Model trucks properly (small in numbers, but potentially big market)
- Assess and understand the viable options to tolling (mode shift, trip suppression, time of day shift, …)
- Full disclosure / transparency
- "It's just a model:" must interpret results

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Using the model to help define the P3

- *Each project is unique*
- Clarify objectives: build facility or manage congestion?
- Screen and prioritize potential projects
- Verify the use of P3:
  - Is project appropriate for P3?
  - Will it be attractive to bidders?
  - Will it yield competitive bids?
- Establish information requirements – determined by:
  - Who takes on risk? → partnerships and roles
  - What P3 structure best fits the need? (D,B,F,O, and/or M)
- Set bid evaluation criteria (e.g., "best value hard bid")
  - Establish disclosure requirements
- *Do homework: flexibility, patience, early start required*

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Applications of model to actual project

- Ensure compatibility with mandates (LRTP, EIA, etc.)
- Ensure engineering design objectives *and* financial objectives can be met
- Gain public input, support for P3 (often controversial)
- Establish equity (who gains?)
- Replicate (understand and verify) bid forecasts

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Recommendations for toll modeling

1. Get VoT:
   a. SP survey (basic VoT)
   b. Comprehensive SP (reliability, time shift, … [SCAG])
2. Enhance route choice in trip assignment
   a. Update volume-delay functions
3. Ensure adequacy of validation / unintended effects
4. Add output / reporting requirements
5. Ensure data adequacy (counts, travel time, …)
6. Enhance mode choice
7. Add econometric model (short-term)
8. Add risk analysis capability

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Key messages

- Tolling is coming:
  – Not sure how yet … be flexible
  – Need to analyze *pricing* impacts on travel behavior
- Financial decisions, issues are becoming more prominent:
  – Shapes model requirements
- Modeling and data needs:
  – Value of time
  – Toll choice
  – Tighter validation
  – Reporting requirements
  – Risk analysis
  – Econometric model

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Thank you!

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Toll Road Modeling: Technical Details

How to do it: Options for modeling and data collection

Toll Road Modeling Support

David Kriger, P.Eng., MCIP – *David Kriger Consultants Inc.*
Michael Gorton, AICP – *HDR*
Rhys Wolff, P.Eng. - *HDR*

Maricopa Association of Governments
Phoenix, AZ
24 October 2011

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Discussion topics

- Technical drill down on key topics:
  1. Value of time
  2. SP surveys
  3. Toll choice models
  4. Econometric models
  5. Risk analysis

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Value of Time

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Factors that influence VoT

Cost-time equivalency (financial impact on traveler)	Quality of time	Reliability
• Income level • Trip purpose • Employer contribution • Time-sensitivity of trip purpose / cargo • Limitations of cargo (dangerous or excess loads) • Type of cargo contract • Availability of alternative routes	• Size of group • Width of lanes • Truck percentage on road • Road information (VMS) • Quality of surface (noise and smoothness) • Quality of lighting • Speed enforcement • Number of lanes	• Journey duration • Dangerous goods cargo (may have no alternative option) • Level of congestion • Predictability of congestion • Length of time using route • Availability of alternative routes

- *Sources: Wardman, 2008; Willumsen et al., 2006*

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Value of time calculation (UK DfT)

$$VoT = K\left[\frac{\beta_\tau}{\beta_c}\right]\left(\frac{Inc}{Inc_0}\right)^{N_{Inc}}\left(\frac{D}{D_0}\right)^{N_c}$$

- VoT = f (income, trip distance)
- where:
  - β_T = time coefficient
  - β_c = cost (distance) coefficient
  - Inc = user's income
  - Inc_0 = average income in the area
  - D = trip distance
  - D_0 = average trip distance
  - N = elasticity of income or cost
  - K = calibration parameter

Source: UK Department for Transport, Modelling Road Pricing, 2007

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Value of time calculation (UK DfT)

- Values used in VoT equation:

Parameter	Commuting	Other	Total Non-Work
β_τ (time coefficient)	-0.10098	-0.082918	-0.086344
β_c (cost (distance) coefficient)	-0.024729	-0.022275	-0.021143
Inc_0	35 x K	35 x K	35 x K
D_0	7.58	7.58	7.58
η_{Inc} (income elasticity)	0.358773	0.156806	0.222585
η_c (cost (distance) elasticity)	0.421305	0.314727	0.307487

Source: UK Department for Transport, Modelling Road Pricing, 2007

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Comparison of representations of VoT

- As function of wage rate (left axis) and of income (right axis)

- *Source: Outwater and Kitchen, Value of Time for Travel Forecasting, Puget Sound Regional Council, 2008*

7

Use of SP Surveys to Derive VoT

Derivation of VoT

- Transformation of VoTs by SP trip purpose to model trip purpose
- Apportionment weights calculated by expert consensus

Trip purpose	Commute $7.03	Local personal $5.86	Visitor personal $6.00	On-the-clock $12.08	Average (per hour)
Home-based work	100%	0%	0%	0%	$7.03
Home-based shopping	0%	95%	5%	0%	$5.86
Home-based school	0%	100%	0%	0%	$5.86
Home-based social/recreational	0%	95%	5%	0%	$5.86
Home-based other	0%	90%	0%	10%	$6.48
Home-based unknown	0%	95%	0%	5%	$6.17
Non-home based	0%	90%	0%	10%	$6.48

- *Source: SE Florida Road and Transit User Cost Study, FDOT, 2008 (2004 data)*

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SCAG Express Travel Choices Study

- 2010 SP survey examined travel behavior impacts of eight pricing strategies:
  - Individual facility pricing (HOT lanes, single facility, corridor)
  - Regional facility pricing
  - Cordon and area pricing
  - "Express" parking pricing
  - VMT pricing
- SP evaluated several behavioral responses:
  - Trip suppression
  - Changed destination
  - Switch to transit
  - Carpool
  - Changed departure time
  - Changed route

10

SCAG Express Travel Choices Study

- Findings:
  - Choice models developed for four segments:
    - Work (any time of day)
    - Business-related (any time of day)
    - Non-work (all other trip purposes – peak)
    - Non-work (all other trip purposes – off-peak)
  - VoTs varied between $6.00 and $20.00, depending on segment and annual household income

11

SCAG Express Travel Choices Study

- Conclusions:
  - Facility pricing and regional facility pricing could "substantially" alter behavior through time-of-day shifts, mode changes and use of HOT lanes
  - Cordon, area and VMT pricing would add trip suppression
  - Collectively, impacts "quite significant" as prices rise
- Results used to enhance regional model:
  - New trip destination choice (combining trip distribution and mode choice) – brings in price, distance
  - New time of day model – accounts for temporal shifts; replaces use of factors
  - New trip suppression model (precedes assignment)
  - Enhanced pricing mechanisms in trip assignment

12

Toll Choice

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Determinants of model structure

Responses to congestion and pricing	Functions
First order: immediate responses	• Route choice • Mode choice • Time-of-day choice
Second order: cumulative over time (medium, long term)	• Trip destination • Trip suppression • Trip frequency • Residential / workplace / school location; development impacts

Source: Parsons Brinckerhoff, David Evans, Stantec. Tolling White Paper 3, prepared for Oregon DOT, 2009.

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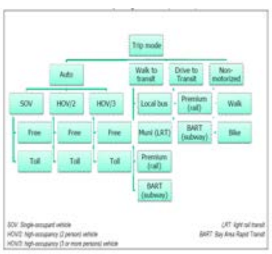
Toll mode choice structure – San Francisco



Source: Parsons Brinckerhoff, David Evans, Stantec. Tolling White Paper 3, prepared for Oregon DOT, 2009.

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Toll choice model (Chesapeake Expwy, VA)

$$\beta = Toll_i + TT_i \times VOT + D_i \times VOC + f \times FB$$

- β = utility of choosing toll or non-tolled route$_i$
- where:
  - $Toll_i$ = toll charged on route$_i$
  - TT = travel time (minutes)
  - VOT = value of time ($/min)
  - D = route length (miles)
  - VOC = vehicle operating cost ($/mile)
  - f = freeway indicator (1 for Expressway, 0 for parallel alternative)
  - FB = freeway bias parameter
- β = f (toll, travel time, trip distance, plus ‘expressway preference’ reflecting reliability, ease of use for visitors)

Source: SDG, Chesapeake Expressway Investment Grade Traffic and Revenue Study, City of Chesapeake, 2010

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Managed lane models

- Toll assessment methods:
  - Simple (use average cost of delay for non-HOT lane users)
  - Iterative (shift 10% of users to HOT lane at a time, recalculate delay and re-estimate toll)
- Types of model:
  - Mode choice (may not capture dynamic pricing)
  - Assignment (may not capture transfer to other modes to avoid toll)

I-15 Express Lane, Salt Lake City – Source: C Lemon

17 HDR

Econometric Model

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Economic forecasting model

$$Y_{ijt} = X_{ijt}B_j + fixed\ effects_{ij} + \epsilon_{ijt}$$

- Y_{ijt} = volume on link *i* by vehicle class *j* at time *t*
- where:
  - $X_{ijt}B_j$ = vector of coefficients (fuel cost, tolls, employment, leisure, tourism spending)
  - Fixed effects_{ij} = location-specific impacts (e.g., point tolls)
  - ϵ_{ijt} = error term
- Y_{ijt} = f (independent economic variables)

Source: Vilain et al., Freight and Passenger Modeling using Hybrid Econometric-Network Models, 2010

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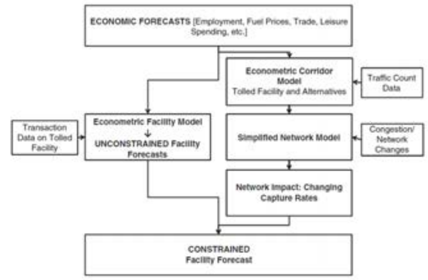
Hybrid econometric-network models



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Risk Analysis

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Risk analysis of four-step models

- Use of Monte Carlo simulations requires:
  - 'Add-on' to allow for multiple iterations of *each* step
  - Store each step's results
  - Analyze wrt overall forecasts
- Computationally difficult and time-consuming
- Some concern wrt propagation of uncertainty, magnitude of cumulated impact (eg, 1000%)

22 HDR

Risk analysis of four-step models: approaches

- "Streamlined" version of model (speed up calculations):
  - Use subset
  - Hold other parts constant
- Advanced simulation and sampling methods:
  - Reduce iterations required to produce meaningful probability distributions
- Defined "risk scenarios:"
  - "Level of risk" for some variables, parameters pre-defined outside model – e.g.:
    - 20th percentile = pessimistic
    - 80th percentile = optimistic

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Risk analysis: factors to consider

- Start-up facilities (the most risky)
- Network context (fewer alternatives: lower risk)
- Established corridors (well-defined flows: lower risk)
- Optimism bias (promoters' bias)
- Aggregation bias (VoT aggregated across market)
- Economic outlook (likelihood of downturns)
- Demographic forecasts (reliance on new growth)
- Time savings (varying expectations of savings)
- Competition (other routes, other modes over time)
- Off-peak / weekend traffic (how well modeled?)
- Truck market (composition; very different market)

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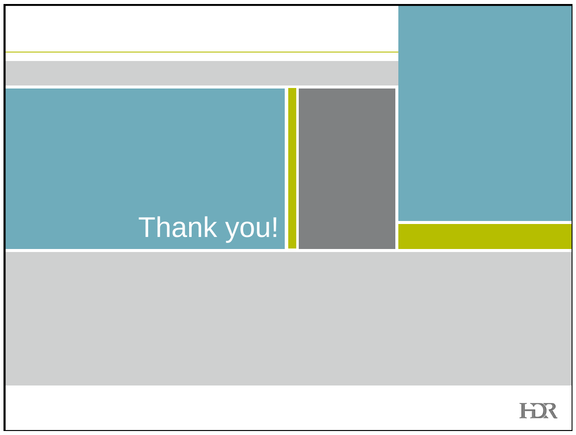
Thank you!
HDR

Appendix C.
Concept Definitions
for Stated Preference Surveys

MEMORANDUM

To: David Kriger, David Kriger Consultants, Inc.
Rhys Wolff, HDR Inc.

From: Mark Burris

Date: October 10, 2011

Re: Data for MAG's Modeling Efforts

The most common way of incorporating a toll facility (focusing here on a toll road/bridge and not a managed lane (ML)) into the four step planning process involves converting the toll charged on the facility to an equivalent travel time. This travel time is then added to the actual travel time on the facility in modeling the shortest path for trip assignment. To convert the toll to an equivalent travel time a value of time is needed.

Similarly, when performing a traffic and revenue (T&R) study it is necessary to determine travelers' value of time. In this case the value of time is used to estimate the percentage of travelers choosing the toll route versus the alternatives. This is often called the toll diversion rate for a group of travelers.

My research frequently attempts to understand travelers' willingness or propensity to use MLs. The MLs I examine are usually High Occupancy/Toll (HOT) lanes. HOT lanes allow high occupancy vehicles (HOVs) to use the lanes toll free while single occupant vehicles (SOVs) may choose to use the lanes for a toll. This complicates the analysis since the toll varies by mode – but again one of the key variables in the travelers' choice to use MLs is their value of time. In addition to travelers' value of time, the value they place on the travel time reliability of the lanes plays a key role in choosing MLs[1]. This is likely due to the fact MLs are situated within the same right of way as the general purpose lanes (GPLs) and thus travelers can choose the GPLs or MLs at almost any time. Plus ML travelers can observe any traffic congestion on the GPLs and remember that, at least on that day, their decision to pay for the MLs paid off.

[1] I suspect that the value of travel time reliability (VTTR) is also an issue for travelers selecting between a traditional toll road versus a non-toll route. I would also suspect the issue grows in relation to how close (physically) the tolled and untolled alternatives are. Thus, for MLs I think VTTR is more critical. However, since all of my work has focused on MLs I cannot say this for a fact. I can say for sure: (1) it is an issue on MLs and (2) there is considerable evidence that VTTR is important for all travel. There are dozens of studies estimating the VTTR and the consensus has it being approximately equal to travelers' VOT. However, I do not have a single traffic and revenue estimation report that uses VTTR.

The key factor in all of these analyses was the travelers' value of time. This value varies considerably over the traveling public and can also vary greatly from one trip to the next for an individual traveler. To help account for the variability over the driving population, the population is frequently segmented as follows:

- By trip purpose. Frequently this includes home-based work (HBW), home-based other (HBO) and non-home based (NHB).
- By vehicle class. At a minimum this includes auto versus commercial truck.

And to some extent:

- By income. Either as categories (such as low, medium and high) or as part of a route choice equation: $U_{TOLL} = \beta_{TOLL} + \beta_{TIME} \times Time + \beta_{COST} \times Toll/f(Income)$

Where U_{TOLL} is the utility of the toll facility option to the traveler
β_{TOLL} is the alternative specific coefficient for the toll facility
β_{TIME} is the coefficient associated with travel time
Time is the travel time on the toll facility
β_{COST} is the coefficient associated with travel cost, frequently just the toll rate in traffic and revenue estimates for toll facilities
Toll is the toll charged
f(Income) is some function of the traveler's income. For example, the natural log of the income or income divided by 2000 (to equate to roughly their hourly wage rate).

- By time of day (peak versus off-peak).

Additionally, not all travelers will save the same amount of time on a given toll facility since their origin and destination (O & D), and therefore distance traveled on the facility, varies. Therefore, O & D information must be collected as well. For a specific T&R study of a particular toll route it may be possible to develop values of time for specific O & Ds; that is, for specific activities such as going to the airport or to address distinctions in user characteristics (such as origin [home] zone income levels)[2]. However, for an area-wide planning model I suspect that would not be practical.

Estimating this value of time for the different groups of travelers is generally accomplished using stated preference (SP) questions in a survey of travelers. In their most basic form, the SP questions will ask the respondent to choose between:

[2] Commonly, O-D pair information is used to estimate travel distance on the facility and then calculate travel time savings for use in the model. To develop specific VOT for O-D pairs you likely need to have a reason beyond just attempting to estimate the traveler's travel distance. For example, you had a zone with particularly low incomes or a zone that included an airport. Then the model might benefit from having its own VOT for those O-D pairs.

(a) A toll facility that charges a specific toll (say $1) and requires a specific time to travel that facility (say 10 minutes), and
(b) A toll-free facility with a longer travel time (say 15 minutes).

In this example, if the traveler chooses the toll facility that indicates (for this trip) they value their time at a rate of at least $12 per hour ($1 for 5 minutes of time savings). The survey also collects data on this respondent's trip purpose, trip time of day (peak/off-peak), trip frequency, income, gender, etc. With enough respondents, reasonable average values of time for each category of respondents can be obtained. Therefore, the survey needs to contain SP questions and questions that appropriately categorize the travelers (noted below).

Taking this one step further, the SP question can also include the reliability of the travel time for that trip. For example, the trip on the toll facility might take between 9 to 11 minutes while the trip on the toll-free facility is much more unpredictable, taking between 12 and 18 minutes. Again, with enough responses the value of travel time reliability can be reasonably estimated.

Implicit in the above is having data on the travel time savings that the facility is expected to offer. Therefore, traffic counts and travel times on current facilities are required. Therefore, the minimum data required for the 4-step model include:

- Trip purpose. At a minimum this would be HBW, HBO, NHB. But it generally includes many more options when asking the travelers their trip purpose. These include commute, shopping, school, recreation, etc. However, even more categories of trips may be used in the future to improve on value of time estimates (see Note A at end of memo).
- Vehicle classification. At a minimum this includes private vehicle versus commercial truck.
- Origin and destination.
- Income.
- Time of day of travel.
- Travel times on roadways.
- Traffic volumes on roadways.
- SP questions to determine values of time. And possibly:
- SP questions to determine values of travel time reliability.

Other data frequently included in surveys:

- Frequency of travel on the route used. This can be useful in segmenting a mode/route choice model. Frequent travelers can have very different reactions to tolling options than infrequent travelers.
- Number of vehicle occupants. Modelers often assign higher VOTs to vehicles with multiple occupants. So, this information can be used to help assign more accurate VOTs to vehicles. However, in my work the use of these data is to gauge the amount of free vehicles one would see on a HOT lane.

- Alternative modes available/used. This information can be very helpful when developing the mode choice model

Some socio-economic data are also frequently collected (see Note B). These can be used to segment travelers to obtain values of time for more segments. However, the characteristics below are more often used to ensure an appropriate cross section of the population responded to the survey:

- Household size and composition
- Vehicle ownership (number of working vehicles)
- Age
- Gender
- Ethnicity
- Employment status
- Education level.

Plus, there is a need for background information such as population projections to help predict future travel demand. But these are outside of the travel survey.

Finally, if the analysis is for a potential HOT lane it is also important to get details of the traveler's current carpool partners and frequency of carpooling. Fampools (carpools made up of family members) are less likely to break up if the option of paying to use the HOT lane as an SOV becomes available. I suspect the toll choice model would be done (at least for HOVs) at the mode choice level since the two modes now have very different costs (one travels toll-free on the HOT lane). The best way would be to do this at the mode choice step.

Note A:

In a recent study of Katy Freeway Managed Lane travelers we examined how they valued their travel time savings for an ordinary (usual) trip versus how they valued their time for a trip in several unusual situations. It was clear that the situation had more influence than any other variable (see table below). However, this was the first study that we know of to look at this issue in this way. Therefore, exactly what categories of trips/scenarios to ask about and how often people find themselves in such situations, still needs considerable research. I think someday it will become part of modeling efforts, but for now I would suggest the traditional trip purposes for MAG.

Implied Mean VTTS for Ordinary and Urgent Situations

Situation	Mean VTTS ($/hr) for Categories of Household Income ($/year)		
	Low- < 50,000	Medium 50,000 -100,000	High- >100,000
Ordinary	7.9	7.4	8.6
Headed to an important appointment/meeting/event	18.7	15.9	22.8
Running late for an appointment or meeting	35.2	27.9	47.5
Worried about arriving on time	25.0	21.5	30.0
Expecting potential traffic problems due to bad weather	13.9	12.2	16.0
Left late knowing you could take advantage of the toll lanes	17.0	15.0	19.6
Need to make extra stops on the trip but still need to arrive on schedule	9.0	8.3	9.8

Note B.

This section assumes that MAG collects data similar to how many MPOs do – a travel diary type survey blanketing their travel shed in conjunction with intercept surveys at external stations. In this manner they get information on all trips – but the travel survey diary is much more in-depth than the roadside interview at the external station. The roadside interview can get at some basics (such as O&D, vehicle classification, trip purpose, number vehicle occupants). Recently TxDOT suspended the use of roadside interviews and TTI was asked to develop a way to estimate through trips (internal→external, external→internal, and external→external) without roadside interviews. My student was heavily involved in this project and we developed a pair of logit models that use standard available data (such as AADTs, travel distances…) to estimate through trip volumes. https://ceprofs.civil.tamu.edu/mburris/Papers/Through%20Trip%20Model%20-%20TRB%202011%20-%20Feb%20rev.pdf .

MEMORANDUM

Date: October 21, 2011

To: David Kriger

From: May Raad (HDR)

Copy: Don Cleghorn

Subject: Stated Preference Considerations for Sub-task 3 on Data Collection for Toll Road Modeling

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Description of Experiments

The objective of a stated preference survey drives the design of the survey which includes but is not limited to segmentation, minimum sample size requirements, set of choice alternatives per experiment, number of experiments and the questionnaire design. Based on MAG's statement of work, a general, region wide stated preference survey is required in order to estimate travellers' value of time by type of vehicle (private versus commercial) and possibly other factors based on HDR's review of modelling best practices. In addition to highlighting design considerations for general, regional stated preference surveys, this memo provides other considerations when a specific road segment(s) is (are) targeted for P3 development.

Segmentation and Sample Size

If only one VoT is required to represent all travellers in the Phoenix area, then the survey sample can any randomly select eligible travellers to answer the questionnaire. However, because groups of vehicle travellers have different needs and schedules, an average VoT across all travellers is meaningless. Incorporating one VoT to cover the myriad of scenarios captured in the MAG's existing traffic demand model would introduce significant bias in demand forecasts for key segments of the travelling population.

To improve accuracy in VoT estimates, segmentation of the target population is critical. The most common types of VoT estimates are segmented by the following factors: trip purpose, trip time of day, income levels, occupation and vehicle type. Each factor has different levels. For example, trip purpose includes home to work, home to school, business trip and personal trip (shopping, medical appointments, etc). A sufficient number of respondents whose personal and trip characteristics match each of the segments is required in order to have statistical reliability in the VoT estimates.

A conservative estimate in minimum sample size requirements for stated preference surveys is to follow minimum sample size used in many marketing and research surveys. Since the SP surveys are also used to estimate population demographics and opinions, it is important that those estimates have a reasonable level of reliability at either a 90 or 95 percent confidence level. For example, if we wanted to know the percentage of respondents who drive hybrid cars (provided we asked the type of car in the questionnaire) to have a reliability of ± 5 percent at a 95 percent confidence level for those travellers who took a home to work trip in the last week, then we would need to sample approximately 400 persons who have travelled from home to work some time during the last week. See the appendix of this memo for an explanation of deriving minimum sample sizes.

If many segments are planned, the total sample size can balloon. This is where trade-offs are made to keep costs manageable. The researcher may need to prioritize segments or relax reliability requirements. An inherent quality of a stated preference survey is that several observations are generated from each respondent in the process of answering the different experiments. If budget calls for a small sample, the reliability of the stated preference coefficients from which the VoT estimates are derived can still be maintained. For example, if a researcher can only afford to sample 50 people from a specific segment but those people provided answers to 10 choice questions, the final sample size is 500.

The approaches to segmentation and sample size determination are the same whether MAG plans to conduct a regional level stated preference survey or one targeting a proposed toll or managed lane (ML) option on a known road segment in Phoenix. Of note is the fact that the users of a specific road segment targeted for road pricing initiatives form a sub-set of the entire population of travellers in the Phoenix area. A regional survey can be conducted by randomly sampling from households throughout the municipality. This could include some oversampling of segments with low incidences in the population. However, sampling to select travellers who use a certain corridor may require different collection methods. One method is to survey license plates over several days and then contact the residents or businesses that own those license plates. Another alternative for this sub-population is to conduct an intercept survey and collect responses in a face-to-face manner at public locations near the corridor such as schools or shopping centers.

Road Pricing Experiments

At this point, it is not known the exact nature of the road pricing. It could be a toll facility or a managed lane such as a HOT lane. VoT estimates may be required to capture time savings, reliability or congestion. As such, introducing the concept of road pricing scenarios to travellers is a challenge since they must speculate on their choices for hypothesized pricing on an unspecified section of road. To aid the respondent in producing thoughtful choices, the experiments must come as closely as possible to the respondent's own experiences. This can be done by asking either average trip distances, average trip time or O-D of the respondent's last trip and assigning experiments with alternatives that approximately match the respondent's experiences. For example, if a respondent typically travels 10 miles each way to work, then the costs, trips times and reliability levels presented in the experiments should reflect conditions of travellers who travel that distance in the municipality.

MAG will need to do preliminary analysis of trip patterns in the Phoenix area to develop distributions of average trip distances or times. The trip distances or times can be binned into manageable groups. The number of groups is dictated by the level of effort that can be expended in the design development. If trip distances are segmented into six contiguous groups, then six groups of alternatives will have to be developed. If ten groups are defined, then ten groups of alternatives will be developed. Note that within each group, multiple experiments that capture realistic ranges in costs and time savings must be created. For example, if 12 different experiments are designed per set and there are ten sets, then 120 unique experiments will have to be generated.

If MAG chooses to conduct the survey online or with computer assisted telephone interviewing (CATI), the matching of a distance or time segment to a respondent's unique experiences can be done with logic programming using inputs provided by the respondent at the beginning of the survey. If a paper survey is required, then MAG will need to send out waves of questionnaires to respondents. The first mailout asks for demographic and trip characteristics. After the respondent mails in the questionnaire, then MAG selects the appropriate set of experiments for that respondent and mails the questionnaire to the respondent.

The design of the experiments can be simplified if a specific segment of road is being targeted for road pricing. If that is the case, then ranges of choice alternatives replicate the travel conditions known for that segment.

The generation of the experiments is a function of the number of alternatives and the differing characteristics of interest (also called variables) per alternative. For example, if we present either a free road or a toll road choice and we ask the respondent to trade off between the two modes based on cost, travel time and reliability and there are up to three different possible costs, reliability measures and travel times, then there are 3^3 or 27 possible sets of experiments (combinations of the levels). The researcher selects the minimum number that captures combinations where choices are possible. Combinations of alternatives are avoided where the choices are obvious.

The decision to have two, three or four or more levels per variable rests on the spread of values (variance). If travel times within a distance band have low variability, three different levels should suffice. If it is highly variable, then four may be required. Note that as more levels are selected, the complexity of the design increases. Prior to selecting the levels per variable, MAG will need to study the distributions of each variable at the regional level or at the road segment level depending on the type of SP survey.

In the ideal world, we would like to ask the respondent to choose on option over a multitude of experiments. This would provide rich data from which to model. However, respondent fatigue is a real issue. Most stated preference surveys limit the number of choices to less than 12. If after studying the patterns in trip travel times, costs, reliability and congestion among other factors, the variability in all observations is so large that many experiments (say M) have to be designed, the unique sets of experiments can be randomly assigned over the respondents set so that some respondents only answer one set of n experiments where $n < M$ and other set answer the remainder.

Below is a hypothetical example of how such a regional level survey could be implemented. It segments trips based on travel times since many people will have a better idea of how long their trip took rather than the distance in miles covered. Existing SP studies have shown that vehicle drivers can make trade-offs between free roads and toll roads based on average total door to door travel time, reliability and cost. The key will be presenting times that are believable for the respondent. A respondent will be asked to think of his or her last work, school, business or personal commuting trip. He or she will be asked to recall the mode used and how much time this trip took, door to door and either the address or nearest intersection of the destination. The location of the destination will be categorized into a finite set of geographical areas. The location of the destination may have an impact on value of time and can be tested as a possible explanatory variable in the SP logit model.

Once the person's last trip information is shared, the person will be matched to a time band segment and a hypothetical trip purpose scenario. Table 1 below provides an example of the proposed travel time segments. Each time band segment will have a set (typically less than 12) of experiments with trip characteristics that fall within the distribution of travel times and costs appropriate for that travel time band. The patterns in choices by varying travel times and costs are used to derive VoT for time savings.

Table 1: Example Travel Time Segmentation

Travel Time (min)
0-10
10-20
20-30
30-40
40-50
50-60
60-75
77-90
90+

The value of time placed on reliability can be a challenging attribute to capture. Technically, the standard deviation of average door-to-door travel time captures the reliability of a mode. However, presenting a standard deviation for a mode's travel time may be too abstract for many respondents. For example, an experiment can be presented to a respondent whose last commuting trip took 7 minutes. This person would fall into a 10 minute or less segment band. One experiment that could be asked is as follows:

Table 2: Example Question to Study Travel Time Reliability

Please select either choice A or choice B.

A	B
Average Travel Time	Average Travel Time
9 minutes	**9 minutes**
You have an equal chance of arriving at any of the following times	You have an equal chance of arriving at any of the following times
7 minutes early	**7 minutes early**
4 minutes early	**3 minutes early**
1 minute early	**2 minutes early**
5 minutes late	**2 minutes early**
9 minutes late	**On time**
Your cost: **$1.25**	Your cost: **$7.50**

The selection of differing reliability representations for a hypothetical trip does require extensive preliminary work to identify the travel time distributions per travel time band. The data may already exist within MAG's current trip demand model. If not, a preliminary study will need to be done to collect ranges of trip times per time travel band for the region. During the SP modelling exercise, these travel and arrival times would be translated back into standard deviations. The example in the above table is for illustration purposes, there are other ways to capture reliability. HDR strongly recommends that MAG conduct a pilot study of possible experiments in order to test if people understand how reliability is represented. Differing expressions of reliability should be presented to respondents to test which one generates the best comprehension and logical choices. Another example of reliability is to state the chance of being late instead of showing the range of minutes either being early or late.

If MAG is interested in estimating the value of fewer minutes in congestion, a possible experiment would present the respondents with options that gauge trade-offs between free-flow travel time, congested travel time and cost. For example, would a respondent choose B with the faster travel time even though it costs significantly more?

Table 3: Example Question to Study Congestion Pricing

Please select either choice A or choice B:

A	B
Average travel time 11 minutes	Average travel time 8 minutes
Percent of total time in stop and go traffic: 36%	Percent of total time in stop and go traffic: 38%
Your cost $1.25	Your cost $7.50

Information Requirements

MAG has access to a rich database of current trip characteristics, as well as to the findings of HDR's review of modelling practices. The following information should be collected prior to designing the SP survey and questionnaire:

1. For each proposed travel distance or time band in Table 1, collect the range of average times or distances travelled based on typical speeds for home based to work/school/other trips, separately for each alternative (free road, toll facility, ML, other);
2. Average and standard deviations of door-to-door travel times within each travel distance or time band for trips by each alternative;
3. Average and standard deviations of auto operating costs for distances travelled in the time or distance travel bands;
4. Average and standard deviations of toll costs for typical distances travelled per time or distance travel band; and,
5. Average and standard deviations of congestion for typical distances travelled per time or distance travel band;

If data at this level of detail are not available, then MAG does have the option of using engineering judgement to find realistic attribute levels per variable per travel time or distance band. The data needs can be simplified if the SP survey is conducted to address VoT estimates for users of a specific corridor of roads since trip characteristics are specific to trips taken on that road segment(s).

Appendix: Determination of Minimum Sample Size

Researchers can control the level of precision associated with sample survey estimates (represented by *p*) by means of setting the minimum sample size. An example of a survey estimate is the percentage of businesses that plan to hire foreign workers.

The first step is to decide how much error can be tolerated in a sample incidence. An estimate can either be smaller or larger than the true population value (represented by *P*). The population value is the number that would be produced if every person in the <u>population</u> provided input. Since a sample is being taken to try to estimate what the true population value it, there will be an error associated with the survey estimate.

The most common level of error most researchers are willing to take is ± 5 percent around the survey estimate. Let us represent this margin of error by the letter *d.*

The next step is to decide how much risk one is willing to take. Because nearly every time researchers take a random sample from a population, each resulting random sample is slightly different. There is a risk that the true population value is actually much different from the sample estimate. Most people are familiar with a risk level of 5 percent or one in twenty. In other words, one is assuming that the chance the observed difference between the sample estimate and the true population value is larger than anticipated is 5 percent. Let us call this level of risk α. Alternatively, one can say that the true population value lies within the error band around the survey estimate at a risk of 1- α. Often survey estimates are released with the statement that the true population value lies within ± 5 percentage points 19 times out of twenty (19/20=95 percent).

We can rephrase the desired level of precision, statistically as

$$\Pr(|p - P| \geq d) = \alpha$$

Provided the sample is randomly selected, the standard deviation of the survey estimate *p* is

$$\sigma_p = \sqrt{\frac{N-n}{N-1}}\sqrt{\frac{PQ}{n}}$$

The formula that connects n with the desired degree of precision is

$$d = t\sqrt{\frac{N-n}{N-1}}\sqrt{\frac{PQ}{n}}$$

Where *t* is the value from the Student's t distribution that cuts off an area of α at the tails. At the 5 percent risk level, the value of *t*=1.96. *N* represents the population number and *n* represents the sample size.

P represents the known population value and *Q = (1-P).* In most cases, one does not know the true population value prior to sampling. The value of .5 is recommended for *P* since it produces the most conservative estimate of the minimum sample size. In other words, if you hit the minimum numbers produced by the formula, you can be guaranteed that your sample estimates will have the desired level of precision.

Solving for n produces the following formula

$$n = \frac{\frac{t^2PQ}{d^2}}{1 + \frac{1}{N}\left(\frac{t^2PQ}{d^2} - 1\right)}$$

As a demonstration, if one has a sample of 485 businesses and one wants to produce an overall survey estimate with a level of precision of ± 5 percent at a 95 percent confidence level (at that level of confidence, *t*=1.96), then the minimum sample size is as follows

$$215 = \frac{\frac{1.96^2 * .5 * .5}{.05^2}}{1 + \frac{1}{485}\left(\frac{1.96^2 * .5 * .5}{.05^2} - 1\right)}$$

Cochran, William. 1977. Sampling Techniques. John Wiley & Sons, Inc. New York, p. 75.