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16. Abstract

This report contains the proceedings of the Expert Forum on Road Pricing and Travel Demand Modeling, held November 14-15, 2005, in Alexandria Virginia. The Forum had two goals: to provide a venue for travel demand modelers to share experiences on how to incorporate road pricing into travel demand modeling; and to develop ideas for future research on this topic. The Forum was sponsored by the U.S. Department of Transportation, Office of Transportation Policy. It consisted of five paper presentations, remarks by expert panelists, and audience discussion. Attendees included staff from government agencies, state departments of transportation, metropolitan planning organizations, universities, and consulting firms.

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Preface

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The Forum was sponsored by the U.S. Department of Transportation, Office of Transportation Policy. It consisted of five paper presentations, remarks by expert panelists, and audience discussion. Attendees included staff from government agencies, state departments of transportation, metropolitan planning organizations, universities, and consulting firms.

These proceedings contain a *Summary Statement*, prepared by Professor Joseph Schofer of Northwestern University, that summarizes the Forum's presentations and discussions. It also presents ideas for improving the methodologies for incorporating road pricing into travel demand models, and for encouraging their use by transportation modeling agencies.

Following Professor Schofer's paper are summaries of introductory remarks by Mr. Tyler Duvall, Deputy Assistant Secretary for Transportation Policy, and Professor Frank Koppelman of Northwestern University, the Forum moderator. The remainder of these Proceedings contains the papers presented at the Forum, each of which is followed by a summary of the ensuing discussion.

Acknowledgements

The U.S. DOT thanks the authors of the papers presented at the Forum: David Kriger, iTRANS Consulting, Ltd.; Ram Pendyala, University of South Florida; Bruce Spear, Federal Highway Administration; Peter Vovsha, William Davidson, and Robert Donnelly, PB Consult, Parsons Brinckerhoff, Inc.; and Johanna Zmud, NuStats Partners, LP. Thanks also to Joseph Schofer of Northwestern University for his summary paper, Frank Koppelman of Northwestern University for moderating the discussion, and the panelists: Dan Brand, Ken Cervenka, Cherian George, Kara Kockelman, Keith Lawton, David Lewis, Chuck Purvis, Tom Rossi, and Dick Walker.

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Welcome: Tyler Duvall, Deputy Assistant Secretary for Transportation Policy[1]

Road pricing is becoming increasingly prominent as a measure for generating revenue, managing congestion, and improving travel time reliability. Prior to the recently-passed SAFETEA-LU, federal regulations prohibited states from introducing new tolls on interstate highways unless it was specifically authorized under the Value Pricing Pilot Program. Despite some reluctance from Congress, SAFETEA-LU expanded the opportunities for road pricing by allowing states to convert existing HOV lanes to HOT lanes.

Highways in the U.S. have been funded largely by gas taxes, both at the national and state levels. This has resulted in a disconnect between roadway operators (state and local transportation agencies) and roadway users. Roadway operators cannot glean information about travelers' preferences based on their willingness to pay. This often results in highway investments that do not meet users' needs. Furthermore, the lack of congestion pricing leads to inefficient land use. Subsidizing the cost of travel allows road users to travel farther and more often, making the cost of living far away from one's job artificially low and discouraging dense land use. Transit pricing faces the same opportunities and barriers as highway pricing. The fundamental question is how to price transit services so that supply equals demand.

Despite the compelling economic argument in favor of roadway pricing, it often lacks political support. Good politics, however, does not always lead to good policy. In fact, pricing can be a good way to take decisions on transportation investment out of the political realm and put it into the hands of the travelers, who "vote" with their willingness to pay. This applies to commercial vehicle travel as well as private travel. The trucking industry, which is generally against expanding tolling on interstate highways, can express their travel preferences through the price they are willing to pay for various travel options.

One way to create public and political support for road pricing is to educate people on the significant congestion reduction that can result from a small decrease in vehicle travel during peak travel times. This requires travel demand models that can accommodate various road pricing schemes.

There is a real concern for the effect of congestion pricing of roadways and transit services on low income people. However, one aspect that is frequently overlooked is that congestion itself is regressive. Congestion affects all travelers equally, regardless of income. Therefore, when the effects of congestion on individual travelers are converted into dollars, the amount represents a higher percentage of income for low income travelers than for high income travelers.

Given the momentum of road pricing, the U.S. DOT should invest in research on incorporating road pricing into travel demand modeling. There has been substantial academic research on this topic, leaving the state of the art far ahead of the state of the practice. An important next step is to determine how to encourage modeling agencies to reach beyond the current state of the practice to better incorporate road pricing into their models.

[1] This is a summary of Mr. Duvall's presentation. It is not a transcript.

Introduction; Frank Koppelman, Northwestern University[1]

This forum provides an opportunity for people from various disciplines and organizations to come together to discuss methods for incorporating road pricing into travel demand modeling and to generate ideas for future research on this topic. Travel demand modeling is complicated and risky. Adding road pricing into the mix introduces more complexity and more opportunities for errors. Modelers need to develop robust models to accurately forecast traffic and revenue under a wide variety of pricing schemes.

While there are valid engineering and economic reasons to consider tolling as a congestion management tool, policy makers tend to see road pricing as primarily a revenue generation opportunity. It allows capital expenditures to be funded by revenue bonds underwritten by private sector financial institutions. Tollway operators use toll money to cover this debt and to pay for highway operation and maintenance.

When road pricing is first introduced in an area, it always faces significant opposition from politicians and the public. Over time, however, its benefits become apparent, and support for pricing initiatives grow. For example, several years ago in Illinois, there was talk about eliminating tolls on the state's highways. Now, policy makers are talking about expanding it, primarily to generate revenue.

While travelers incur a cost when traveling on a tolled road, the overall benefits to society outweigh the costs to any individual user. For example, tolls can benefit society by:

- Reducing congestion and the externalities that accompany it;
- Decreasing energy usage; and
- Encouraging more efficient land use.

Any discussion of this topic has to include the risks in forecasting. This becomes particularly important when the infrastructure investment is financed by the private sector. The accuracy of revenue forecasts can be affected by:

- Inaccurate travel demand forecasting
- The wide range of modeling approaches with different levels of credibility
- Exogenous uncertainties such as macroeconomic conditions and regional growth patterns

[1] This section provides a summary of Professor Koppelman's presentation. It is not a transcript.

Summary Statement

US DOT Expert Forum on Road Pricing and Travel Demand Modeling

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Prepared for
Expert Forum on Road Pricing and Travel Demand Modeling
November 14 – 15, 2005
Alexandria, VA

Background and Purpose of the Forum

Road pricing has become increasingly attractive as a source of revenue to renew and expand highway infrastructure, as a revenue stream that can bring private money to public infrastructure investments, and as a mechanism for managing traffic congestion and its impacts. The growing gap between transportation infrastructure needs and available revenues is an important motivation. The availability of reliable vehicle identification technologies (*i.e*., RFID tags) is a key facilitator. The success of pricing schemes in a variety of cities around the world suggests that experience supports theory, and such favorable outcomes can build social and political support.

Forecasting traveler responses to pricing is a challenge because of the large errors in both demand and cost estimates associated with infrastructure projects in general, and transportation facilities in particular. Forecasting errors are at best embarrassing, and at worst may result in substantial financial losses. The market for accurate forecasting has expanded beyond government agencies now that private money is being invested in road systems. The private sector demands forecasting accuracy because of the risk of real money losses. At the same time, private investors seem better able than government to address and accommodate forecast uncertainty.

In parallel with the growing U.S. and worldwide interest in road pricing and private financing, the state of the art in travel behavior modeling has advanced considerably in the past two decades. New, behaviorally-based tools, more theoretically sound and more complex than traditional tools, have been the subject of much research, some development, and somewhat less implementation.

For all of these reasons, it was particularly timely to bring together experts in road pricing and demand forecasting to assess where we are and were we should go to enhance the ability to plan, predict, and make decisions about road pricing schemes. The specific intent of this conference was twofold:

- To provide a setting for travel demand modelers to share experiences representing road pricing in forecasting models, and
- To develop ideas for needed research in this field.

Overview of the Discussion Papers

The forum was focused around five discussion papers:

- “A Summary of the Current State of the Practice in Modeling Road Pricing,” by Bruce Spear, FHWA
- “Data Requirements to Support Road Pricing Analyses,” by Johanna Zmud, NuStats
- “Modeling Pricing in the Planning Process,” by Ram Pendyala, University of South Florida
- “Traffic and Revenue Forecasting for Roads and Highways: Concerns, Methods, and a Checklist for Practitioners,” David Kriger, iTrans Consulting

- “Making the State of the Art the State of the Practice: Advanced Modeling Techniques for Road Pricing,” Peter Vovsha, William Davidson, and Robert Donnelly, pbConsult

Spear points out that three firms dominate the market of providing investment grade forecasts in support of privately financed road pricing schemes. The approaches used tend to focus at the corridor level around a specific facility and predict route and sometimes mode shifting in response to road pricing. This can involve the use of traditional models or specialized diversion curves that are dependent on good estimates of the value of travel time. Spear’s research priorities include well-documented case studies, ways to assess the value of reliability (travel time consistency) as well as travel time, and improved ways to model user-system dynamics.

Zmud discusses data requirements for pricing analyses from the perspective of a broad history of road tolling and the motivations for it. She reminds us of the importance of understanding the audiences for pricing studies and their different needs. She focuses on data needs, recognizing that models and data evolve together, and each can be a constraint on the other. She distinguishes between the needs for policy analysis (emphasizing political and public acceptance and thus the need for attitudinal data), strategic decisions about the allocation of benefits and costs, and tactical financial planning for specific facilities. Zmud advocates conducting planned experiments, collecting before-after data, and developing locally accurate measures of the value of time and reliability. She identifies a need for data standardization to promote shared use and meta-analyses.

Pendyala’s paper focuses on specific modeling tools available to represent behavioral response to road pricing schemes, linking emerging models to specific pricing-driven behaviors. He posits that past forecasting errors may be attributable to flaws in underlying (four-step) models, as well as to overly optimistic assumptions about system performance and traveler response. He advocates tour-based demand models to accommodate trip reorganization within a tour; activity models to reflect the range of traveler adaptations to price structures that vary in time and space; dynamic traffic assignment to capture time varying route choice behaviors; and microsimulation for representing road conditions – including effects of toll collection methods – more accurately. He offers examples of such models as indicative of the potential to advance the state of the practice. Like Zmud, he supports formal experimentation, data collection, analyses, and model formulation – learning from experience and building the knowledge base.

Kriger points out that since private money has begun to flow into public roadways, financial feasibility analysis has become an increasingly important function for travel demand forecasting, and the financial community has become our new partner in the highway planning and investment field. He offers a brief critique of the four-step process in such applications and lists some of the more promising models and methods for forecasting toll road demand. He emphasizes the need to focus on the behavioral responses to pricing, to represent the effects of time of day more realistically, and to consider the impacts of pricing on commercial vehicles. Consistent with other papers prepared for this conference, Kriger underscores the importance of good estimates of value of time, which may vary with characteristics of the traveler, the trip, and time of day.

Kriger recognizes the importance of anticipating the nature and uncertainties associated with the toll facility startup period, advocates *stress tests* to explore worst case outcomes, and suggests the use of Monte Carlo techniques to take advantage of historical information on outcome uncertainties to guide decisions.

He offers a comprehensive checklist for practitioners engaged in toll facility revenue forecasting to support development and application of methods as well as interpretation of results. It includes questions on the decisions to be made, expected markets, available models and data, scenario assumptions, validity of value of time estimates, assumptions about the startup period, land use, the economy, and risk management techniques.

Kriger concludes with the suggestion for industry-wide guidelines on data and forecasting methods for use in toll financing studies; this parallels Zmud's proposal for data standards to promote consistency and shared learning.

Vovsha, Davidson, and Donnelly identify the most important planning needs associated with different pricing strategies and link these to the most promising models and methods. In line with the other papers, they advocate tour and activity based models, dynamic traffic assignment, and microsimulation as the tools of choice. They remind us of the behavioral importance of price levels and fee collection schemes, and of the impacts of subsequent demand changes on travel time and reliability. They offer a classification scheme for pricing forms, and assess the degree to which the four-step and more advanced approaches to modeling are responsive to expected behavioral outcomes.

This paper identifies important modeling challenges, specifically, accounting for reliability; considering the heterogeneity of users and their values of time; and dealing with time of day variations and peak spreading. They identify these basic approaches for modeling responses to pricing: use of generalized cost (time + money + reliability) in assignment models; use of binary choice models to describe traveler choice of toll facilities; and modeling use of tolled facilities as an additional option in the hierarchy of alternatives. They conclude that the best contemporary starting point for toll facility evaluation is a well-calibrated, advanced regional modeling system. This can be enhanced with additional local surveys, including stated preference data, to modify forecasts. However, representing the full spectrum of pricing outcomes will require a shift to the more advanced tools identified by all of the authors.

Presentation of each paper was followed by a discussion by a panel of experts including public agency modelers and planners, consultants in transportation modeling, academic researchers, and specialists in revenue forecasting and financial feasibility studies. An integrated interpretation of the papers, panels, and discussions is presented below.

Interpretation of the Forum

This conference revealed a lack of confidence in our current demand forecasting methods and their application in the context of a growing need for the information produced by those methods, and yet no indication of a commitment to invest in better forecasting tools. It was reported that, "Congress doesn't consider transportation planners to be experts..." Investors and their advisors give forecasts of revenues for proposed toll-financed facilities a 25% "haircut" to guard against excessive optimism that may have been common in past predictions. It was said that "we are using less data now," and we heard reports that budget cuts threaten key data sources such as the Commodity Flow Survey and the National Household Travel Survey. At the same time, we heard that in some applications the state of the practice in travel forecasting is well behind the state of the art. Together, these points suggest a need for investments in and improvements to methods for forecasting traveler responses to road pricing and the feasibility of tolled facilities.

Still, projects get done, investors are able to make choices, and private money comes to the table in increasing amounts, along with private scrutiny at a level seemingly higher than the skepticism applied to strictly public choices. There is an active market for risk analyses to manage the uncertainty in forecasting. This seems healthy; if the demand models don't get it right, we can prepare for them to get it wrong, anticipate the errors and, where necessary and appropriate, capitalize them in the marketplace.

Financiers appear to have confidence in the revenue forecasts of only a few consultants, who use proprietary techniques not subject to the scrutiny of peer review and publication. Thus, even if these consultants do get it right, the rest of the profession does not benefit from their special expertise. The tools used by these consultants are concerned not only with making forecasts more accurate, but also with finding ways to protect investors from the consequences of large forecasting errors.

This conference was made more useful by the presence of some *inside* forecasters, along with advisors to the investment community who have been anointed to go behind the curtain to examine the proprietary forecasting methods for their clients. While we did not come away with any proprietary tools, we have a general sense of approaches used to make and assess private forecasts, to treat forecasting uncertainties, to make use of the experiential knowledge base, and to manage financial risks. The use of subjective probabilities, meta-analysis of many outcomes in the knowledge base, and Monte Carlo techniques to utilize historical information on forecasting errors offer ways to use available knowledge to test and improve the accuracy of demand and revenue forecasts. Indeed, mainstream transportation planning and decision making would also benefit from the regular and systematic application of such methods of risk management.

Still, a fundamental message is that we need better – more responsive and more accurate – forecasting tools to support:

- Facility and policy design decisions – what should we do, for whom, when should we do it and at what level?

- Impact evaluation, including effects on congestion and throughput, equity, the incidence and importance of suppressed trips, development outcomes, and the implications for environmental quality and energy consumption;
- Financial feasibility analysis and forecasts of return on investment (ROI) required by risk sharing owners.

Better forecasts will not always be correct, but they should protect us against the most serious errors – financial loss for private investors, social loss to the public when the performance is deficient or the impacts too onerous, and political loss to decision makers associated with failure. The penalty functions for forecasting errors are asymmetrical: an ROI too low is worse than one that is too high; impacts too high are worse than impacts too low. This may tell us where to look for trouble, though the asymmetries may conflict for different outcomes and stakeholders.

Forecast quality is a function of several factors:

$$\text{Forecast Quality} = f(\text{data}, \text{models}, \text{modelers}, \varepsilon)$$

While models are key to forecasting, both models and data must advance together to improve the state of the art (see Figure 1). A solid underlying concept – a model – is important to guide data collection. The concept itself usually comes from data collected earlier.

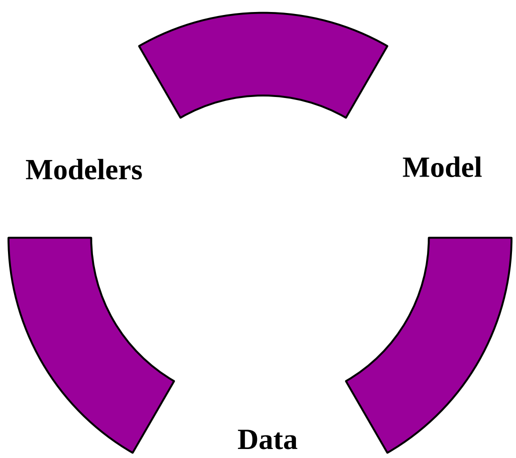

Figure 1: Modelers, Models and Data

<u>Data</u> to identify, quantify, and model the impacts of existing pricing schemes are essential to understanding behavioral relationships and building the next generation of models. The right data are clearly necessary to drive contemporary forecasting tools, whether traditional or innovative.

To be useful, data must be salient – describing a stimulus-response situation that is similar to the forecast case. In the context of this conference, stimulus-response means before-after data showing behavioral reactions to changes in pricing and/or some other factor, collected in a setting that is the same as, or similar to, the application setting. Useful data must also be timely (recent – the context has changed radically in the past decade) and detailed (*i.e.*, behavioral). Data must capture the complexity of travel choices; for example, in response to price changes, travelers may change modes, times of travel, routes, trip chains, destinations, activity patterns, and in the long run, auto ownership and location. And we should collect pricing information – price paid as well as attitudes and willingness to pay – in travel surveys.

While good data are important, it can be difficult to secure the resources to collect it. Sometimes decision makers are not interested in before-after data because they do not want to pay to measure their mistakes, but that is the kind of data we need to build the foundation for better forecasts. The Service and Methods Demonstration program of the Urban Mass Transportation Administration was a programmatic approach to data collection that is worth emulating.

Economies achieved by cutting back on thoughtful data collection can be viewed as deferred debt: the absence of good data will amplify future forecasting errors, which may be manifest as direct costs or discouraged investment. As a community, we should look for and highlight examples of the value of quality data in decision making to build the case for experimentation and data collection.

<u>Models</u> with realistic fidelity are essential to produce accurate forecasts. Traveler decision processes are complex, dynamic, and iterative, and thus it is not logical to expect models to be simple. In this context, it is increasingly difficult to defend continued use of the static four-step travel demand forecasting process. For example, individuals' value of time varies with personal and household situational factors. Time of day is a key variable in the response to time-varying road pricing schemes. These and other characteristics of the decision process are likely to lead us to activity- and tour-based models, dynamic traffic assignment, and microsimulation. In the long term, road pricing can be expected to produce land use impacts, which calls for advanced location modeling.

Some conference participants argued that it is easy to adopt and apply these new models, but change is difficult, and we are not all equally prepared for it. For some practitioners, and in some settings, converting to state of the art forecasting tools sensitive to the outcomes of road pricing and other policies will be a major challenge. The federal government does not mandate particular tools – a policy that probably encourages innovation and reduces the likelihood that an entire fleet of models and subsequent decisions may suddenly face recall. Still, some participants at this conference felt that more objective guidance about choice and application of models would help, though that might need to come from a TRB policy study or from recommendations by other professional organizations.

Demonstration projects where pricing is introduced and behavioral responses are measured and analyzed can serve as a test bed for evaluating existing methods, provide a foundation for developing better tools, and accelerate innovation in travel forecasting. To promote widespread adoption, new forecasting tools need to be proven in more pedestrian settings, not just in those MPOs at the cutting edge of methodology. These activities will require resources in an era when support for new tools is slim.

The modelers are also important contributors to forecast quality. Their experience and credibility bring wisdom and creativity to their work and influence the quality certification that goes along with the forecast. It has been argued that a good modeler has a greater impact on decisions than the model results alone, for the modeler brings experience, perspective, and judgment to bear on the numbers. The modeler adds the Bayesian twist that amplifies the value of the model. Thus, no matter how accurate the models become, there will always be room at the table for an experienced modeler, and as road pricing advances, experience in that application will become especially valued.

The error term listed in the conceptual quality equation reminds us that no forecast will be perfect, and we will always need ways to anticipate errors and manage the associated risk. Human behavior and its variations are too complex to expect perfection in travel forecasts.

Areas of Agreement

Although the forum did not define a formal consensus, there was good agreement on several key points:

- Road pricing is becoming more common for a variety of reasons.
- Accurate forecasting of behavioral responses to pricing schemes is important to plan, to ensure financial feasibility, and to draw private money into public infrastructure.
- Forecasting for pricing is complicated because tolls can influence many aspects of travel behavior.
- The four-step modeling system does not capture behavioral responses to pricing options because pricing has dynamic, interactive effects that cannot be accommodated in a linear, static modeling system.
- Specialist forecasters have developed a variety of tools for predicting traveler response to road pricing schemes. While the methods are proprietary, it appears that they rely on fairly traditional tools, adapted with special data collection efforts and experience with other projects, and challenged with a range of assumptions to identify likely risks.
- There are forecasting models available that should provide better results because they are differently sensitive to factors involved in road pricing. These are:
    - Activity-based travel models that consider intra-household activity choices and scheduling that may be affected by pricing;
    - Tour-based models that account for trip chaining that may result from road pricing schemes;
    - Microsimulation that captures pricing effects on level of service that result from demand changes and delays caused by the toll collection process;
    - Dynamic traffic assignment that considers the temporal dynamics that occur when road pricing is based on time of day and/or congestion levels.

- Those tools are at various stages of practical application. Some are available for immediate use; others require more work to advance them into practice. Some of this work is research. Some is testing, accumulation of experience, and education.
- All of this requires resources:
  - Additional money
  - Skilled (trained) modelers
  - Better data – more detailed, more timely, including attributes of travelers, values derived from behavior (time, reliability), stated preferences and attitudes toward tolling.

Transition Paths

The transition path to new and better forecasting tools that balance realistic complexity with ease of use should be considered explicitly. For example, we might consider this evolutionary sequence:

<u>1 - 3 years</u>: In the near term, as a profession, we should work toward extending the application of state of the art tools, *e.g.*, activity based modeling and dynamic traffic assignment. This can happen through professional organizations such as the Transportation Research Board, The American Planning Association, and the Association of Metropolitan Planning Organizations. The discussion needs to extend to organizations more closely tied to decision makers, such as AASHTO and the National Association of Regional Councils. This road pricing forum, and the TRB conference on Innovative Travel Modeling (May, 2006), are examples of settings for identifying opportunities to bring state of the art tools to the practice.

These organizations and activities should encourage the application and careful documentation of more advanced models in practical planning settings. Applications should not be limited to testing pricing schemes, because the objective is to move these models into routine practice so that they are more readily applied to road pricing and other options.

One limitation, of course, is that organizations and individuals further from the state of the art are less likely to participate in these events and applications. The training programs of the U.S. DOT Travel Model Improvement Program can be used to reach out to these practitioners, as can continuing education programs at universities around the country.

The perspective of financial analysts should be included in this effort by engaging those professionals in transportation activities and organizations. Experts from this field have made real progress in the use of existing tools with enhanced data, and, perhaps more importantly, they can teach us something about risk management that will make it feasible, if not easier, to make decisions in the face of uncertainty. Specifically, risk management is a way to cope with uncertainty in forecasting when it cannot be readily reduced with more sophisticated models.

To grow better theory and models, we need better data on traveler behavior, preferences, and valuation of time and reliability. Such data can be gathered in routine surveys collected by MPOs, and some of it can come from larger scale efforts such as the National Personal

Transportation Survey. Data describing behavioral dynamics in the context of price and service change will be most useful for model calibration and valuing time and reliability. Therefore, it will be important to establish a before-after data collection program around pricing experiments, thus building the knowledge base to improve the quality of forecasts.

Finally, we should promote discussion of ethical issues in forecasting through professional forums and more frequent peer reviews to drive out intentional or careless bias in predictions.

<u>3 – 10 years</u>: The intermediate term should see the growing use of truly dynamic, integrated models, TRANSIMS and its derivatives, that better reflect the complexity of traveler decisions. We need federal guidance and resources to promulgate such tools, just as we did to move the four-step modeling system into practice. That four-step process should enter phased retirement, saved for specialized uses and historical expositions. The Portland TRANSIMS application will provide a foundation for further advancement of this simulation model, and that effort should be completed and documented. Other applications are planned or underway, and they, too, should be documented to encourage wider use of such model systems.

<u>Beyond 10 years</u>: We need to begin investing now in the long term development of NEXTSIMS, a household-activity based modeling system that is lighter, smaller and faster than TRANSIMS, supporting rapid application in new places through the use of generic and parametric activity databases, stronger understanding of model and parameter transferability, and automated network coding. This new class of models should be built on behavioral theory grown from the expanding knowledge base of before-after studies. The intellectual resources are in place to accomplish this. It is now necessary to guide and support them. Just as in the case of TRANSIMS, this next generation of models will not grow of its own accord, although the seeds for it are in place in the work on activity models and dynamic traffic assignment now underway.

All of this will take additional, directed resources for data collection, model development, field testing, and documentation. We should view this not simply as a way to achieve significant improvements in travel forecasting, but as a pathway to innovative options, including road pricing and other policy initiatives, and as a way to support more informed transportation investment choices. This will take a concerted effort of public and private interests, modelers and practitioners, to achieve real advances in both the tools of forecasting and the ways in which we apply them.

A Summary of the Current State of the Practice In Modeling Road Pricing

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Abstract

"*Road pricing*" is a generic term for various strategies that charge tolls for vehicles to use a particular roadway facility. This paper presents a summary of the state-of-the-practice in modeling the impacts of road pricing on travel demand. It discusses how tolls are typically represented in current travel demand models and how toll revenues are estimated in investment studies. It also identifies the limitations of current modeling practice with respect to road pricing and recommends some directions for research and model improvements.

Introduction

Road pricing is a generic term used to describe various strategies that charge vehicles directly for using a particular roadway facility. Road pricing is not a new concept. Tolls on roads and bridges have existed in the United States since colonial times. However, road pricing has received renewed interest among State DOTs and MPOs as a supplementary source for local transportation funds, as an incentive for joint public-private partnerships to construct new road facilities, and as a demand management strategy in congested highway corridors.

Estimating the impact that tolls have on demand for the facility is an important consideration in implementing any road pricing strategy. Where toll revenues are used to repay the cost of construction and/or provide a return on investment to a private lender, the rate of return (and hence, attractiveness) of the investment is directly related to the number of users willing to pay the toll, multiplied by the amount charged per user. Where variable tolls are implemented to help manage traffic congestion, knowing the elasticity of demand with respect to price is critical in adjusting toll rates to maintain acceptable levels of service on the facility.

This paper presents a summary of the state-of-the-practice of the impacts of road pricing on travel demand modeling. It includes a discussion of how tolls are typically represented in current travel demand models and provides an overview of how toll revenues are estimated in investment studies. It also identifies the limitations of current modeling practice with respect to road pricing and recommends some directions for research and model improvement. The summary is based on material obtained from discussions with practitioners of travel demand modeling and road pricing and from other documents on modeling road pricing. Those documents are listed at the end of this paper.

Current Modeling Practices for Estimating the Impacts of Road Pricing

Travel demand models assume that travelers make economically rational choices in deciding where to go (destination choice), what means of transportation to use (mode choice), and what route to take (route choice). In other words, the models assume that for each travel decision (destination, mode, and route), travelers choose among a set of alternatives and select those alternatives that have the lowest generalized cost for their trip.

By *generalized cost* we mean a combination of factors, such as travel time, tolls or fares, reliability, comfort, etc., with each factor weighted by its relative importance to the traveler (e.g., some travelers may place a higher value on their time, and may be willing to pay more to reduce their overall travel time). Different travelers may see different generalized costs, given the same set of travel alternatives and might make different choices.

A toll can be represented as a factor that distinguishes one route from another in the *route choice* decision. A traveler can choose either to pay a toll to use a more direct or higher speed facility, or to pay no toll and use a slower or more indirect route. The route selected will depend on the traveler's value of time (VOT), the amount of the toll, and the amount of time saved by taking the toll road.

A toll may also be a factor in mode choice. For example, a high occupancy toll (HOT) lane allows carpools and transit buses to use the lane for free, while single occupant vehicles (SOV) may use the lane if they pay a toll. A traveler, therefore, might choose to take transit, join a carpool, or pay a toll to drive alone on the same facility. The mode selected will depend on the traveler's VOT, the out-of-pocket costs of driving alone versus transit fares, door-to-door travel times of each alternative and other mode choice considerations (e.g., riding with others, personal comfort, schedule flexibility, etc.)

Currently, there is no standard approach for representing toll roads in travel demand models. Each modeler that includes toll roads in their model uses a slightly different approach, depending on the underlying model structure and modeling software, availability of calibration and/or validation data, and intended applications. The approaches can be grouped into three general categories, depending on which step of the travel model process is used:

1. **Mode Choice**
   This is the easiest approach to implement using current travel modeling software and is most often used to evaluate the impacts of converting existing high occupancy vehicle (HOV) lanes to HOT lanes. Mode choice is typically modeled using a "nested logit" model, in which auto and transit modes are further divided into various submode choices (e.g., express versus local bus, drive alone vs. carpool). Toll lanes are treated as a submode of auto, competing directly with drive-alone and shared-ride and indirectly with transit at a higher level of nesting.

   The primary benefit of treating toll roads as a mode choice decision is that current mode choice models use generalized cost functions to define alternative modes. This makes it relatively straightforward to include tolls as another factor in the generalized cost function. The primary drawback is that the relative differences in travel times between tolled lanes and free lanes do not directly reflect the volume/capacity relationships derived from traffic assignment models. In other words, as the non-tolled lanes become more congested, their travel times will increase and the HOT lanes will become more attractive. The only way to represent this in a mode choice model is to feed back the resulting travel times from trip assignment to adjust the travel times in the mode choice model and to continue iterating until a stable equilibrium is established (i.e., there is no significant difference between the highway travel times used as input to mode choice and those output from trip assignment).

2. **Trip Assignment**
   Trip assignment models are used to estimate and forecast the route choice decision. An all-or-nothing trip assignment model finds the shortest path (usually based on travel time) through a transportation network from each origin to each destination and then loads traffic traveling between each origin-destination (O-D) pair on the associated shortest path. A capacity-restrained assignment model computes the volume of traffic loaded on each link of the network, compares that volume to the capacity of that link, and adjusts the speeds downward using a volume/delay function. New shortest time paths are then computed based on these

adjusted speeds and the O-D traffic is reloaded on the network. This process is repeated until there is no significant difference in link volumes and speeds from one iteration to the next.

Toll roads can be represented in trip assignment models by using generalized cost rather than travel time as the basis for computing shortest paths. Toll roads (including HOT lanes) are represented as separate links from non-tolled lanes, with a generalized cost that reflects the equivalent time penalty of the toll (e.g., a 20¢/mile toll is equivalent to a time penalty of 1.0 minute/mile to someone having a VOT of $12/hour). Under free-flow conditions, the toll road would not be selected, but as traffic congestion increases on the non-toll facility, the toll facility eventually becomes the lower cost link.[1]

The primary benefit of addressing toll roads in trip assignment is the ability to evaluate directly the influence of traffic congestion on demand for the toll facility. Potential users of the toll facility may have different values for time, depending on their disposable income or trip purpose (e.g., someone picking up a child from daycare that charges a late fee of $1/minute has an effective VOT of at least $60/hr). To adequately reflect the range of users requires more complex, multi-class trip assignment models and stratification of O-D trip matrices into several sub-matrices based on VOT. Such models exist, but are not commonly used.

3. Diversion Models

Diversion models calculate the market share of travelers who would use a toll facility at varying levels of toll charges. They are used predominantly by transportation consulting firms who develop toll revenue forecasts for investment decisions.

Diversion models are typically applied to corridor studies to estimate the share of total vehicle trips traveling through the corridor that would use a proposed toll facility. A diversion model is applied either as a post-processor outside of the four-step travel demand model, or as a sub-route choice model within each iteration of the traffic assignment model.

Diversion models rely on development of at least two alternative paths for each trip – one using the toll facility and one using the best available (i.e., shortest time) non-toll route. The diversion model compares travel time, distance, toll cost and occasionally other factors, for the two routes and assigns a percentage of the market to each route. The diversion formulae used in the models are based on an accumulation of empirical data collected by the consulting firms from other toll revenue studies, results of site-specific surveys of potential users, and professional

[1] In the above example of a 20¢/mile toll and $12/hr value of time, a 10 mile highway segment with a free-flow speed of 60mph would have a 10 minute generalized cost on the non-toll facility and a 20 minute generalized cost on the toll facility. However, if the speed on the non-toll facility drops to 30 mph due to traffic congestion, its generalized cost increases to 20 minutes, and the two facilities become equally attractive. If speeds on the non-tolled facility drop below 30 mph, the toll road has the lower generalized cost.

judgment. The precise formulae used are considered to be proprietary to each firm.

The primary benefit of using diversion models to estimate the impacts of toll roads on travel demand is that they can be applied without modifying or recalibrating the existing four-step travel demand model structure. The principal drawback is that the formulae used to compute the market share are proprietary and based on an accumulation of empirical data that are not publicly available. Consequently, it would be difficult, if not impossible, for an MPO or State DOT to develop its own diversion models.

Forecasting Toll Road Revenues for Financial Investment Studies

Many existing toll facilities were built and are maintained by quasi-public agencies that use toll revenues to repay the construction debt (typically financed through low-interest revenue bonds) and to pay for ongoing maintenance and operations costs (e.g., road resurfacing, snow removal, police and emergency services, etc.) Interest rates on bonds issued for toll facilities are based on an assessment of the risk that toll revenues will be sufficient to cover the principal and interest on the construction loan.

Toll revenues are determined by the toll amount multiplied by the volume of traffic paying the toll. The volume of traffic using a toll facility is inversely related to the toll charge (i.e., as tolls increase, fewer drivers will use the facility). Therefore, an accurate forecast of future traffic and its sensitivity to alternative toll levels is a critical component of any financial risk analysis.

Virtually all traffic and revenue studies for toll facilities (roads, bridges, and tunnels) conducted in the United States are done by one of three transportation consulting firms – Wilbur Smith Associates, URS Corporation, or Volmer Associates. These firms have developed a long working relationship with bond underwriters, and their revenue forecasts are generally accepted as a basis for determining the investment risk of a particular project.

Based on discussions with a senior transportation analyst at one of these firms,[2] investment level traffic and revenue studies for toll facilities use existing, locally developed travel demand models, where available, and then supplement these with additional, independently collected data focused on the corridor where the proposed toll facility is to be built. Additional data collected may include:

- An independent analysis of population and employment growth and land development for the region.
- Supplemental origin-destination surveys, traffic and vehicle classification counts, and travel time runs within the study corridor.
- Stated Preference (SP) surveys of a sample of households in the study corridor. SP surveys are used to assess the VOT distribution of potential toll facility users

[2] Correspondence from Cissy Szeto of Wilbur Smith Associates, October 15, 2004.

and their sensitivity to various toll levels and other operational features (e.g., electronic toll collection).

Independent estimates of the growth and distribution of population and employment may be used to revise existing O-D trip tables for trips in and through the study corridor. Supplemental surveys and traffic count data may be used to update base year regional trip tables, particularly if the region has experienced substantial growth since the regional models were last calibrated.

Diversion models are typically used to forecast traffic volumes and revenues for the toll facility. As part of the analysis, diversion formulae may be adjusted based on SP survey findings. The diversion models are applied over a range of toll rates to identify the toll level that would provide the optimum combination of revenue and traffic volume.

While this approach may be acceptable for investment risk assessment, it has limited usefulness as a general procedure for analyzing the travel demand impacts of road pricing. The primary reason is that the diversion models used in these studies have been developed based on extensive empirical data collected by the consulting firms for similar studies. Both the data and the diversion model formulae are proprietary.

Barriers to Modeling the Travel Demand Impacts of Road Pricing

The primary barrier to successfully modeling the impacts of tolls on travel demand is the lack of sufficient empirical data on VOT and how it varies by socio-demographic characteristics and trip purpose. Practical methods already exist to represent toll facilities, including HOT lanes, in current four-step travel demand models, either under mode choice, trip assignment, or both. However, these options require a parameter that converts toll charges into equivalent units of time, or vice versa. This parameter, generally defined as "value of time," has been the subject of decades of substantial theoretical and empirical research. Research has concluded that VOT is sensitive to such variables as the income of the trip maker, the purpose of the trip, and the method of payment. Results of empirical studies (many from the United Kingdom and Europe) provide ranges for VOT parameters, which could be used as initial coefficients in travel models.

The problem with using VOT values based on past research is that the toll facilities examined in these earlier studies do not typically reflect the characteristics of currently proposed toll roads. For example, many earlier studies computed VOT for bridges across major rivers where few non-toll options were available. Demand for such facilities, where few alternatives exist, tends to be relatively inelastic (i.e., fewer travelers will shift as tolls are increased) and may result in a higher observed VOT. Also, most past VOT studies examined facilities where travelers had to stop at tollbooths to pay their toll. The combined inconvenience of slowing down, waiting in line and paying directly out-of-pocket could not be separated from the toll itself, resulting in a lower observed VOT than might be expected based on the toll charge alone (i.e., trip makers might take a slower, non-toll route to avoid the inconvenience of queuing at the tollbooth, rather than the cost of the toll itself.) With current advances in electronic toll collection, much of the inconvenience associated with tollbooths can be eliminated, suggesting that more travelers might be willing to use the toll facility than would be predicted based on earlier VOT parameters. Without additional empirical VOT studies of toll facilities using electronic toll collection, we cannot determine how much demand may be underestimated.

Virtually all of the road pricing models implemented to date have been used to analyze the travel demand and revenue impacts of *static tolls* (i.e., toll charges that remain constant over a fixed time period). Current four-step travel demand models cannot easily analyze the impacts of *variable tolls* (i.e., toll charges that are adjusted within a peak period to maintain acceptable levels of service), because they do not specifically consider the temporal build-up and dispersal of traffic during peak period.

Most current applications of travel demand models partition total daily traffic into a small number of discrete multi-hour time periods (e.g., peak vs. off-peak, or AM peak, mid-day, PM peak and off-peak). The share of total daily traffic assigned to each time period is typically based on a single, regionwide distribution of traffic by time-of-day. For each time period, traffic volumes are modeled as if they were uniformly distributed, and rarely is traffic shifted between time periods. Separate traffic assignments may be run for each time period or, alternatively, only for the most congested peak period. Variable tolls using this methodology can only be modeled to a level consistent with the number of defined time periods (e.g., peak period tolls vs. off-peak tolls).

In order to model variable tolls, the number of daily time periods must be increased (e.g., at least to hourly intervals in peak periods) and methods developed (e.g., a peak-spreading model) to shift trips between time periods, based on congestion levels.

In addition to average travel time savings, there is a growing body of empirical evidence that travelers value *reliability* as an important factor in their tripmaking decision.[3] Reliability is typically defined as the day-to-day variability in expected travel time due to non-recurrent congestion such as traffic incidents, weather, construction, etc. Reliability becomes especially important in variable priced HOT lane applications, where tolls are adjusted based on traffic volumes in order to maintain a specified level of service. HOT lane users may experience only a small reduction in their *average* travel time over non-toll lanes, but enjoy a substantial reduction in their travel time variability from day-to-day. This increased reliability can be critical for travelers with rigid schedule requirements (e.g., day-care pick-ups, workers on time-clocks, or airline passengers) and is not necessarily correlated with the traveler's general value of time.

Despite the potential importance of reliability in road pricing (especially as a congestion mitigation strategy), there are few, if any, examples of operational travel demand models that explicitly include reliability as a variable. One reason is that, like travel time, reliability requires a measure of how much travelers are willing to pay for better reliability. There have been a few studies conducted specifically to measure value of reliability (VOR), because

[3] See, for example, Small, K.A. & D. Brownstone, "Valuing Time and Reliability: Assessing the Evidence from Road Pricing Demonstration," presented at the Conference on Theory and Practice of Congestion Pricing, Imperial College, London, UK, August 2003.

there are even fewer examples of operational toll roads using variable pricing for congestion management from which empirical data can be drawn.

An even greater barrier to including reliability as a variable in road pricing models is that traditional four-step travel demand models are designed structurally to work with “average” or “mean” values (e.g., average daily or average peak period travel volume) and not the variation about those mean values. Recent progress in the development and deployment of simulation techniques in traffic modeling offer considerable promise for addressing variability in traffic congestion, but we also need a much better understanding of those factors that influence traffic variability.

Prior to the widespread deployment of continuous traffic recording equipment in conjunction with the establishment of traffic management centers in major urban areas, there was virtually no data available to measure day-to-day changes in traffic volumes. Only recently have efforts been made to archive this “operational” data, and research has just begun to identify and measure trends, periodic patterns (e.g., day-of-the-week, seasonality effects), and the effects of external factors such as weather.

Recommendations for Improving Current Practice in Modeling Road Pricing

Given the deficiencies noted above, there are several areas of research and information transfer that could help improve the current state-of-the-practice in modeling road pricing strategies. They include:

1. **Document case studies of transportation planning agencies that have incorporated road pricing in their travel models.** One of the included references provides brief descriptions of several case study examples of modeling road pricing.[4] Similar studies should be undertaken to provide additional details concerning changes in model structure, data requirements, value-of-time parameters, calibration and validation considerations, and specific application results from other modeling efforts. One such study is currently being conducted through the National Cooperative Highway Research Program (NCHRP) Synthesis of Highway Practice.[5]

2. **Compile and synthesize current and past empirical research on value of time and value of reliability.** Extensive research has been conducted on VOT, but it needs to be compiled into an application-oriented document that provides travel modelers with reasonable ranges for VOT, classified by income level, trip purpose or other relevant parameters, and includes practical guidance or rules of thumb on other VOT adjustments (e.g., use of electronic toll collection may decrease traveler sensitivity to toll rates, thereby increasing the effective VOT). Similarly, the more limited research on VOR should also be compiled to provide

[4] See *Estimating Demand for Value Pricing Projects: State-of-the-Practice*, prepared for the North Central Texas Council of Governments by Urban Analytics, Inc. & URS Corporation, March 2004.
[5] See “Estimating Toll Facility Demand and Revenue,” NCHRP Project 20-5, Synthesis of Highway Practice 36-11.

practical guidance, based on current knowledge and to identify priority areas for additional research and data collection.

3. **Encourage data collection on travel behavior on federally funded road pricing projects.** Programs like FHWA's Value Pricing Program, or the recently announced Special Experimental Project (SEP) 15 for Public Private Partnerships provide opportunities for demonstration experiments of innovative road pricing. Projects funded under these programs should include additional funding for data collection and documentation and a contractual agreement with the grantee that allows for an independent evaluation of the project. Depending on the specific project, the evaluation may collect additional empirical data to enhance our understanding of VOT/VOR, or provide an opportunity to compare observed changes in demand to model forecasts.

4. **Conduct basic and applied research to incorporate time-of-day and peak spreading models in current travel demand models.** The principal limitation in current travel demand models that prevents them from analyzing congestion management strategies (be they pricing or operational strategies) is the way in which they distribute daily trips by time-of-day. New methods or models need to be developed that will (1) allow finer resolution of daily trip distributions (e.g., by hour or even ½ hour intervals in peak periods); (2) perform efficient, multi-class assignments over multiple time periods; and (3) systematically shift trips between adjacent time periods to reflect peak spreading.

   Some preliminary work has already been sponsored on time-of-day modeling through FHWA's Travel Model Improvement Program (TMIP).[6] Further research and one or more case study deployments are needed.

5. **Conduct basic research to better understand and measure the influence of traffic congestion on travel time variability.** Efforts to model the effectiveness of road pricing strategies on traffic congestion will not be fully credible until we better understand the underlying factors that influence traffic congestion on a day-to-day basis, and the relationship between traffic congestion and travel time variability. Archived operational traffic data provides a rich and largely unexplored source for basic research in this area.

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[6] See "Forecasting Person Travel by Time of Day," FHWA Travel Model Improvement Program (TMIP), project description.

References

Estimating Demand for Value Pricing Projects: State-of-the-Practice, prepared for the North Central Texas Council of Governments by Urban Analytics, Inc. & URS Corporation, March 2004.

Small, K.A. & D. Brownstone, "Valuing Time and Reliability: Assessing the Evidence from Road Pricing Demonstration," presented at the Conference on Theory and Practice of Congestion Pricing, Imperial College, London, UK, August 2003.

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Audience Discussion

Revenue Forecasting Companies

An audience member observed that three firms dominate the field of toll revenue forecasting. One reason for this may be liability. Entry into the business of revenue forecasting might be hampered by fears that revenue forecasting companies could be held liable for damages to the toll road operator if actual revenues fall short of forecasts. Small firms may be more risk averse than the larger firms. Also, the firms that dominate the revenue forecasting field have developed reputations for revenue forecasting, and toll operators and bond-issuing firms may be reluctant to work with smaller, less established firms. Several audience members thought that encouraging more companies to do revenue forecasting could lead to innovative, less expensive, and ultimately more accurate revenue forecasts.

Federal Guidance

An audience member commented that there is insufficient federal guidance on how to do travel demand modeling generally, and more specifically, on incorporating road pricing into the model. This has led to wide variations in modeling techniques and quality. The response was that the FHWA has generally moved away from specific guidance on modeling techniques, in part because of the controversy surrounding it. There was also a sense that modeling agencies would be more receptive to guidance provided by other modeling professionals rather than the federal government.

In certification reviews, modeling has been largely ignored, with U.S. DOT reviewers focusing instead on the overall planning process. This has been due in large part to the fact that many FHWA and FTA field offices do not have staff who specialize in modeling. Only recently has the U.S. DOT begun to encourage field office staff to review travel demand models as part of the certification process. A participant suggested that the U.S. DOT establish a team of modeling specialists who can participate in compliance reviews throughout the country.

Data Requirements to Support Road Pricing Analyses

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Abstract

This paper discusses data requirements to support pricing analyses. It focuses on road pricing analyses as they relate to infrastructure financing and congestion management. Infrastructure financing can be defined as either revenue generation via toll roads or capacity enhancement via more efficient use of existing roadway lanes. Congestion management under the rubric of travel demand management (TDM) may include strategies to reduce peak-period vehicle traffic or shift travel to alternative modes or times of the day. The paper has four parts. In the first part, an overview of road pricing is presented, along with associated background information including pricing history, its impetus, and pricing options. This information is followed by areas of intersection between road pricing and travel demand modeling. Given the complexity of road pricing analyses, the paper then presents recommended data requirements at three levels: policy, strategic, and tactical. The paper concludes with ideas for future research, as well as recommended criteria for selecting data items.

INTRODUCTION

Government policy concerning roads existed long before the automobile was invented. Beginning in the 18th century, transportation, especially road transportation, was essential for economic development. Our 21st century economy is no different. Federal, state, and local governments are increasingly challenged to build sufficient roads to meet the demands of all road users for convenient and free-flow travel. Quality of life in the U.S. is strongly related to the ability to travel in a timely manner. This is being jeopardized by population growth and increased vehicle ownership. Throughout the U.S., demand for roadways is exceeding the supply, resulting in congestion, delays, deteriorating air quality, and loss of productivity. In the past 20 years, vehicle miles traveled (VMT) have increased by 80 percent while lane capacity has grown by only 2 percent; roadway congestion in the 75 most congested urban areas during 2003 caused 3.5 billion hours of delay (Standard & Poor's, 2005).

The provision of future mobility must be framed by realistic consideration of available financial resources, which are dwindling. The growing requirements for investment in roadway infrastructure and a concomitant shortage in funding sources has been documented by many industry observers, including the Federal Highway Administration (FHWA), the American Association of State Highway Transportation Officials (AASHTO), and the International Bridge, Tunnel, and Turnpike Association. Over the past decade, there has been an increased interest in alternatives to the standard approach to roadway infrastructure investment and operation. Highway infrastructure traditionally has been funded through general government budgets and dedicated taxes and fees. Fuel taxes (state and federal) have historically been the primary mechanism for highway financing. Inflation and increased fuel efficiency, combined with aging network of roads, bridges, and other surface transportation modes, have decreased these traditional funding sources leading to increasing interest in road pricing as an alternative way of meeting highway needs.

The economics of road pricing projects are complicated. They can vary widely depending on their function, physical characteristics, traffic profile, and ramp-up timeline. The predictability of market demand and / or the likely impacts of road pricing strategies are dependent on numerous factors – the type and magnitude of fees, where they are applied, what alternative routes and modes are available, technologies employed, and what is assumed to be the alternative or base case. These analyses rely on considerations that pertain to the context in which the road pricing will take place (e.g., political, land use, economic development, transportation network). In addition, external variables that are not easily anticipated or measured (i.e., gas prices, economic swings, demographic shifts) must be considered. Road pricing analyses are not only complex but also wide-ranging. Road pricing analysis could include travel demand and revenue forecasting as well as economic impact analysis, cost-benefit analysis, risk analysis, social equity analysis, among other types. The one element such analyses have in common is that they depend more on accurate and reliable data about traveler characteristics, their attitudes, and their behavior than conventional transportation policy and planning analyses.

This paper focuses on data requirements for road pricing analyses that are most pertinent to travel demand models. As such, it is concerned with forecasts related to infrastructure financing and congestion management. The paper addresses the need for improved and standardized data about travelers to accurately and reliably forecast traffic and revenue as well as to analyze effects of transportation pricing policies. Data requirements, and related issues, would be substantially expanded if addressing road pricing analysis in the broader sense.

ROAD PRICING STRATEGIES

Pricing and financing policies, and their complexities, are not new. As a result of social and economic necessity, direct user fees for road capacity and services to travelers have been in existence in the U.S. for over 200 years. Pricing has historically been used to facilitate mobility when needed. When not needed, pricing has been eclipsed by free roads.

Historical Considerations

The first major toll road (a private road) was built in the late 1790s in the United States. At that time, economic growth was associated with better transportation. Better transportation meant better highways, and state and local governments had limited budgets to respond. Private turnpikes, financed by private stock subscription and structured to pay dividends, were often financed by residents out of a spirit of community public-mindedness that valued investment for long-term community gain (Durrenberger, 1931). Under this strong sense of community spirit, private toll roads peaked in the mid-19th century. Competition from other modes of transportation (e.g., canals, railroads) impacted demand, and by 1920 the private toll roads had almost entirely faded. Most of the toll roads were taken over by state highway departments or by quasi-governmental authorities that issued toll revenue bonds to raise funds for construction and/or operation. There was also a growing public reluctance to support road pricing to finance infrastructure construction and operation as evidenced by the peak of toll roads in the mid-19th century to the low in the mid-20th century.

In the1950s the federal interstate highway program was established. It funded non-toll roads with federal dollars with a minimal state match, giving little incentive for states to expand toll road systems (Adams, et al, 2001). Instead roads were built with pay-as-you-go financing. States built roads as funding was received. At the same time, funding rules restricting the collection of tolls on new facilities, and in other situations and the expansion or rebuilding of a toll facility using Interstate Highway Program funding resulted in the removal of existing tolls. Throughout the 1960s, 70s, and 80s, the highway system was expanded using the pay-as-you-go system.

Current Road Pricing Manifestations

The 1990s brought a resurgent interest in road pricing, as economists advocated the concept as an efficient and equitable means to fund roadway costs and to encourage more efficient transportation (Small et al., 1989, Roth 1996). Debt financing (typically tolled highways) emerged as a tool to allow states or other quasi-governmental authorities to fund new infrastructure projects so they could be delivered faster than pay-as-you-go and less expensively. These projects avoided the higher construction costs that existed with long-term construction projects. Early practice in debt financing has morphed into a myriad of tools and programs under the banner of "innovative financing."

Road pricing has also become a strategy to reduce congestion (Adams, et al., 2001). Under congestion pricing, motorists pay directly for making a particular trip at a particular time on a particular route. They pay for greater convenience. The price varies based on the level of congestion. There could be multiple policy objectives for implementing congestion pricing: to discourage trip making, to shift trips to other times of day, to shift trips to other routes, or to shift to other travel modes, or to shift to greater efficiency in utilizing roadway capacity. The concept is to limit or manage demand by charging a fee. Currently there are several different types of road pricing.[1]

- Road Tolls, defined as a "fee-for-service," are used to fund new highways and bridges or improvements to existing structures. The toll revenue is dedicated to the project cost. Tolls are structured as fixed rates to maximize revenues and success is measured in terms of project cost recovery. Examples include Toronto's Route 407ETR, the Dulles Toll Road, and the Trans-Texas Corridor; all are public-private partnerships.
- Congestion Pricing, also called "value pricing", are direct time-of-travel charges for road use. The fees can vary by location, time of day, severity of congestion, vehicle occupancy, or type of facility. Examples include bridge projects in Lee County, Florida, operated by Lee County Department of Transportation, and the Tappan Zee Bridge in New York operated by the New York State Thruway Authority.
- Cordon (Area) Tolls are fees charged to enter a particular area, usually a city center to reduce congestion. London has an area charging system, while Singapore and Oslo have cordon tolls. With cordon tolls, motorists are charged each time they enter or exit the area. With area charges, motorists can enter and exit as many times as desired, for one daily charge.
- High Occupancy Toll (HOT) Lanes (or Managed Lanes) optimize capacity of High Occupancy Vehicle (HOV) Lanes by allowing solo drivers to pay a fee to use HOV lanes and avoid congestion. Tolls are structured to ensure free-flow conditions on the lanes while serving as many vehicles as possible. The tolls are intended to both maximize use of roadway capacity and raise revenues relative to HOV lanes. In many projects, the revenues are used to fund transportation improvements such as improved transit service or bikeways in the region. Example HOT lane projects in the U.S. include the I-15 "FasTrak" Express Lanes in San Diego, Houston's I-10W Katy Freeway QuickRide Program, and the I-394 MnPASS Lanes in Minneapolis.
- Distance-based or Insurance-based vehicle systems use global positioning system (GPS) technology, digitized maps, and odometer feeds to compute distance charges. Users pay for the amount of miles driven, usually by a monthly statement. Tolls are assessed that reflect the roadway costs imposed by each vehicle. Currently, demonstration projects are in Oregon and Minnesota. Austria, Switzerland, and Germany have launched automated weight-distance truck tolls (TRB, 2003).

[1] TDM Encyclopedia of the Victoria Transport Policy Institute, www.vtpi.org/tdm.

- Credit-based Congestion Pricing is a revenue neutral credit-based system to limit peak period vehicle trips. It is a variation of road pricing where the benefits are provided to the residents instead of road owners or governments. Road tolls are based on the negative externalities associated with driving during congested conditions. The tolls generated are returned to all licensed drivers uniformly, as a sort of driving allowance (Gulipalli and Kockelman, 2005). There are no known credit-based congestion pricing projects.

With each type of road pricing strategy, there may be different methods for collecting the user fees, such as passes, toll booths, electronic tolling, optical vehicle recognition, and GPS. In the U.S. tolling has evolved from simple systems such as flat rate fees imposed 24 hours per day, seven days per week with staffed toll booths, to complicated variable toll schemes based upon time of day and level of congestion using seamless electronic toll that do not slow traffic down. This latter approach is known as “open road tolling” (Rennacker, 2004).

Audiences for Road Pricing Analyses

In addition to the different types of road pricing, there are different audiences for road pricing analyses. Audiences include:

- Financial community who evaluate the bond capacity of a proposed toll project.
- Private consortia calculating a bid on a new toll road concession as a form of public-private partnership.
- FHWA fulfilling its Value Pricing Pilot Program’s project monitoring requirements; and
- State toll road authority contemplating the political and economic challenges of a toll facility.

These different audiences all have common need for data on which to base pricing decisions: What to price? When to price? Who to price? How to price? How much to price?

While many agencies are investigating the opportunities presented by road pricing, few have initiated projects that rely on pricing as an alternative to traditional funding sources. Transportation decision makers, the public and private sector road construction and operation industry, as well as transportation planners and modelers are only at the beginning of the “pricing” learning curve. The general public’s knowledge and awareness of pricing and financing strategies is even more limited. This situation places great burden on policy makers and planners to provide reliable and credible information on pricing options in terms of their policy implications, impacts, and performance expectations.

Data Quality Issues

That transportation decision-makers and planners require accurate and reliable data is not new. What is new is the increased pressure for politically acceptable, socially equitable, and economically successful road pricing projects. The costs and benefits of road pricing projects often run in the hundreds of millions of dollars, with risks correspondingly high. This situation places an even greater burden on the need for accurate demand forecasts as well as reliable assessments of whether road pricing projects are achieving goals related to effects on travel, traffic, and air quality. Despite the enormous sums of money spent on traffic and revenue forecasts, there is growing concern about the accuracy and reliability of these expensive forecasts (Fitch, 2003; Standard & Poor's, 2003). Revenue and traffic projections are critical inputs for credit evaluation. Forecasts are also critical inputs to evaluate the impact of road pricing projects on travel and congestion. Given the importance of accuracy in demand forecasts, there is surprisingly little empirical investigation of data quality issues and a lack of criteria or guidance for necessary data requirements. In one of the few statistically significant analyses of the factors associated with inaccurate demand forecasts in public works projects, Flyvbjerb et al. (2005) identified three main issues: (1) lack of sufficient "before" and "after" data, (2) a reliance on dated or incomplete information, and (3) manipulation of the estimates because optimistic forecasts are seen as a means to "getting projects started." It should be noted that factor three was cited in association with transit and rail projects and not road projects. The Federal Transit Administration (FTA) is addressing such issues with a new evaluation model with requirements for project sponsors to do better traffic and revenue forecasts, as well as better before and after evaluation, especially for New Starts (KT Analytics, 2005).

The credit ratings agencies, more than other stakeholders, have publicly aired their data concerns. Standard & Poor's (2003) has called for "more data, more information." But more than a need for further data, there is a need for better data. Forecasting is becoming more complicated as such components as electronic tolling, variable pricing, and public-private partnership become more common. The need to model a "real life" outcome is essential when funding is coming from the bond market or a private concession. Fitch Ratings (2003) has cited the need for "constructive discussion and debate driven at improving the quality of information." Stakeholders, planners, operators, and modelers are realizing the importance of survey research capability and guidance to ensure data quality. Quality is dependent on how the data are collected. Survey research introduces scientific methods of research design, sampling, and measurement that can have a critical affect on the precision and reliability of traffic and revenue forecasts. Well-designed traveler surveys, not just traffic counts or borrowed model coefficients, are needed to develop more precise forecasts or to better understand impacts.

Fitch has also recommended enhanced peer review of forecasts and increased competition within the community of demand forecasters. For a long time, there has been the perception that only forecasts from a very small group of firms are acceptable to achieve investment-grade ratings. This has led to higher costs, little incentive for methodological improvements, and the proverbial "black box" analyses. Many in the industry believe that a major problem is that there is too much secrecy amongst the leading toll road modelers about what data they actually use to development their models. Such a lack of analytical transparency is a key hindrance to consistent and standardized interpretation of results needed for accurate credit evaluation or measurement of long-term and dynamic effects of road pricing projects. A broader universe of firms will provide incentives to get analytical procedures and methods “out in the open”. In addition, competition will drive the development of new, innovative methods for increasing the precision of forecasts.

ROAD PRICING ANALYSES AND TRAVEL DEMAND MODELING

Enhanced modeling and analytic techniques are important steps in the pursuit of greater accuracy in road pricing analyses. This is opportune as travel demand modeling is advancing to “next generation” travel demand forecast models. These are models that go beyond the conventional models to understand travel behavior determinants and more realistically represent and forecast behavior.

Current road pricing forecasts use regional travel demand models to estimate a “base case”, a four-step model with a land-use component for trip generation. Generally, it relies on data and model development support a local jurisdiction’s (usually MPO) long-range plan, despite the different intended purposes. Typical MPO models are concerned with trip production, trip attraction, trip distribution, modal split, trip time of day (TOD) factoring, and trip assignment (Baez, 2004). But to adequately forecast traffic and revenue or to analyze the effects of pricing policies, the model system must be sensitive to the effects of these policies on both travel behavior and land use, and it is here that the new generation models provide the most information for road pricing analyses. Goulias et al (2004) distinguished the new generation models from the conventional four-step model by three positive features:

- Tour-based structure where the tour (i.e., a closed chain of trips starting and ending at the base location) is used as the base unit of modeling travel instead of the elemental trip;
- Activity-based platform, which implies that travel is derived in a general framework of the daily activities undertaken by households and persons including in-home activities, intra-household interactions, time allocation to activities and many other aspects pertinent to activity analyses;
- Micro-simulation modeling techniques that are applied at the fully-disaggregate level of persons and households which convert activity and travel-related choices from fractional-probability model outcomes into a series of “crisp” decisions among the discrete choices. The application of the individual simulations at this detailed level helps to accurately capture numerous internal sensitivities of various population groups to changing travel conditions or land-use developments that are obscured in aggregate analyses.

Two specific elements of the new models have direct application for improved road pricing analyses: (1) disaggregate models, and (2) improved land-use forecasts. In a discussion of traffic forecasting challenges, Standard & Poor’s (2003) identified the need for highly detailed and disaggregate forecasts. This would allow individual contributors to a toll facility’s revenue stream to be pooled thus reflecting the project’s true probability of financial performance. Such disaggregate models would need to rely on more specific time of day categories as well as on other more rigorously defined market segments. This relates directly to the model improvements that are foreseen with the advancing state-of-the-practice in travel demand forecasting. S&P does suggest that disaggregate models provide greater explanatory power, but these models introduce further layers of assumptions (or uncertainty and error) into the prediction and modeling process.

One key benefit of the disaggregate models (as noted by both the modeling community and the road pricing community) is they estimate more accurately the values of time (VOT). VOT is the crux of most road pricing analyses. Fitch Ratings calls VOT the “X-factor of toll road forecasting.” Standard & Poor’s identifies miscalculation of users’ willingness to pay based on VOT as a “key error driver in forecast failures.” Both agencies suggest that VOT errors result from using a single average VOT rather than a distribution of values of time which can be derived from disaggregate models.

VOT is usually derived from surveys (i.e., stated preference surveys) and / or the mode choice coefficients estimated from household and transit surveys. Thus, survey research design principles, particularly related to sampling, are critical to capturing real-world VOT estimates. The data from which VOT estimates are derived must represent the population of inference (i.e., the population of users or potential users for the road pricing project). Sampling for this purpose often requires careful geo-demographic definition of the sampling frame because sample survey findings can only be taken as representative of the aggregation of elements that comprised the frame. In developing a sampling approach, stratified sampling should be considered in order to obtain a greater degree of representativeness and ensure that market segments of interest to the specific road pricing project are included in the survey sample. VOT estimates should not be borrowed from other regions or previous projects (as is often done) because the specific geographic, political, and environmental contexts in which users or potential users are being asked about their value of time savings do matter. It is becoming widely recognized that all persons do not have the same VOT. It can vary by attitudinal, demographic, or travel market segments, which are themselves influenced by region- or project-specific factors. Additionally, often to reduce data collection costs, choice (i.e., nonprobability) samples are relied upon, which severely impacts data quality. Data from choice samples present many problems, including the ability to calculate accurate response rates and derive bias estimates as well as the capability to reliably factor the samples to represent the population of interest.

Another key area in which the next generation models are evolving is in their focus on land-use assumptions. A long-term goal is to expand modeling capabilities to better reflect the traveler’s decision-making “chain” – particularly with the addition of a front-end land use modeling capability. Land-use and associated socio-economic growth are critical inputs for road forecasts. The use of more conservative (and often more accurate) land-use scenarios better reflects the characteristics of road pricing projects.

DATA REQUIREMENTS FOR ROAD PRICING ANALYSES

The traffic and revenue forecasting process has not been static; neither have travel demand modeling methods. To incorporate road pricing into travel demand modeling or to do the converse, incorporate travel demand modeling into road pricing, it is necessary to develop a data framework that can guide future analyses. The data required for road pricing analyses depend on if the purpose is forecasting traffic and revenue or if it is to evaluate the impacts of road pricing manifestations. While the data are not necessarily different, the models or methods used to conduct the analyses are. In addition, various road pricing strategies may require different analytical considerations.

There are three different types of pricing analyses: political, strategic and tactical. Each type has different data requirements making the organization of data a complex challenge. These types are distinguished by their time horizons. Policy has the longest and tactical the shortest. The level of data detail also distinguishes the three types. At the policy level, macroscopic or broad-brush data and methods suffice to assess policy implications. The strategic level represents a shift away from macroscopic (nationwide or regionwide) and focuses on investigating the impacts on specific toll facilities or roadway networks. At the tactical level, microscopic or extremely detailed and disaggregate models are required.

Policy Level

There is widespread interest at the federal, state, and local levels for using road pricing as a means to finance and manage demand. The idea of charging road users at the point of use is based on economic policies of system efficiency and the need to charge users the full cost of congestion and other externalities (Bonsall and Kelly, 2004). At the policy level, key questions deal with the ability of road pricing to meet its objectives of reducing congestion, efficiently using existing roadway capacity and financing needed infrastructure within the constraints of political feasibility, social equity, and project solvency. Road pricing policy is rarely implemented in a timely manner in the real world, so it is difficult to know the impacts or effects of policy in advance. Reliable models that can forecast the impacts of road pricing policy are needed now. The model for evaluating and developing a road pricing policy has two principal requirements. One is for the appropriate treatment of the demand side. The second and often overlooked is the appropriate treatment of the supply side. These analyses and their data are constructed on a macro level. While the data required are determined by the specific policies being considered, there are data elements common to most situations. Below are suggested data requirements:[2]

Demand Side

- Public sentiment and opinion
- Traveler characteristics including demographic and socio-economic data as well as assessment of equity and fairness issues

[2] These recommended data requirements have been culled from a number of sources including: TRB, 1992; National Research Council, 1994; Harvey, 1994; and Button and Verhoef, 1998.

- Traveler's activity levels including frequency of trip making, vehicle occupancy, modes
- Traffic flows including spatial distribution of origin-destination volumes by trip purpose, distance, and mode.

<u>Supply Side</u>

- Road network information
- Congestion effects

Strategic Level

Perhaps the most critical road pricing analyses are strategic. At the strategic level, pricing analyses focus on decisions regarding the implementation of road pricing strategies or on understanding the potential impacts of strategic decisions on the toll facility performance. While pricing strategies can provide new sources of revenue to fund transportation capacity expansion, they clearly will also impact travel demand and congestion. There are questions regarding who pays for improvements, who will use the facilities, and how these facilities will be operated to improve the overall transportation system performance. Unlike the policy level, the strategic level has specific real-world contexts in which the data collection can take place.

While road pricing is a common topic, in the U.S. there is a reluctance to implement actual projects. Many of the current congestion pricing projects (i.e., I-15 HOT Express Lanes and SR 91 in California, Katy Freeway HOT lane project in Texas, and MnPASS Lanes in Minnesota) have been supported by the FHWA through its Value Pricing Pilot Program. While these projects have a project monitoring or evaluation requirement, there are no evaluation standards as of yet. New, innovative financing projects (such as the Regional Mobility Authorities and Trans-Texas Corridor Project in Texas and the I-895 / Pocahontas Parkway in Virginia) are bellwether programs that are being watched closely by other states and other metropolitan regions. Required data will enable a thorough impact evaluation of the viability (financial and political) of these projects before they will "diffuse" to other parts of the U.S. The benefits of road pricing depend strongly on users varying preferences about time and money savings. Also, surveys of toll road users versus non-users are valuable to compare user characteristics to those of the full population. Analyses are dependent on discrete choice models estimated to calculate the probabilities that travelers will pay to use the toll facilities under different travel time savings and toll scenarios as well as on data about users and non-users current travel behavior, attitudes, and values. Supporting data includes:[3]

- Technical data on amount of travel (i.e., VMT, trips), traffic volumes and speed differences
- Revealed preference data on origin/ destination, time savings, toll paid, mode choice, travel time period (peak / non-peak), departure time, trip purpose

[3] These data requirements have been culled from TRB, 2003; WSDOT, 2002; Shefer and Reitvald, 1997; Sullivan 1998; and Golob et al, 2003.

- Stated preference data on mode choice, VOT savings
- Socioeconomic variables
- Demographic variables
- Attitudes and values
- Project revenues and expenditures
- Roadway performance related to safety (accidents) and customer satisfaction

Often overlooked are the constituent attitudes and values. Despite considerable interest in these variables, there has been limited applied use of them in policy and planning practice. As Pendyala and Bhat (2004) point out, this may be because such variables are not as easily forecast as demographic variables so are not considered useful. They cite research as far as the 1970s, as finding that attitudinal variables account for as much as 60 percent of the explained variation in traveler mode choice and often surpass traditional socio-economic and demographic variables in their explanatory power. Variables representing attitudes, values, and perceptions are not always easily quantifiable and may not be amenable to traditional quantitative statistical or econometric analyses. So in the transportation research arena, there is a growing interest in the application of qualitative approaches to travel behavior research – useful for informing quantitative model specifications and shaping transportation policies.

A second, often disregarded, element of strategic level analyses is the need for measuring longer term dynamics. Road pricing has the potential to alter travel behavior in significant and lasting ways. Road pricing may influence further decisions about trip-making, and potentially automobile ownership and location choice for residences, employers, and activities (TRB, 2003). While not a specific data requirements issue, the need for panel data sets with lags and leads in behavior are required to identify the necessary cause and effect relationships that determine policy impacts. True measures of exposure to pricing policies can only be determined with knowledge of day-to-day behavioral dynamics. At the strategic level, decision makers and planners should focus upon evaluating the impacts of pricing –on the behavioral and attitudinal responses of users and non-users alike, typically using before and after measurements. Specific "before" and "after" measures should include the following:

- Mode split to assess if pricing encourages or discourages use of certain modes
- Time of day, frequency of travel, length of toll trips, and route of travel
- Characteristics of road users
- Attitudes toward the pricing, including acceptance, equity, and perceptions of success in congestion management
- Perceptions of performance of the roadway in terms of reliability and safety

One consideration at the strategic level is the incorporation of pricing data into the standard data elements for household travel surveys either at the MPO, state, or national levels. As pricing strategies become mainstream alternatives in future MPO long-range transportation plans, MPO models must be ready to evaluate these alternatives. The current MPO models do not have the necessary data to support these types of evaluations. Such pricing data could take the form of either revealed preference or stated preference items relating to future pricing strategies or current pricing projects.

Tactical Level

At the tactical level, analyses are focused on project financing, the securing of a credit rating and obtaining revenue bond financing. Toll road forecasts are critical inputs into the credit evaluation process. While this may be the most focused use of the analytical results, it also has the greatest uncertainty and opportunity for errors. Data requirements include the specific information that feed comprehensive demand studies of traffic and revenue to support debt repayment. So what is needed are both short-term (base case) and long-term forecasts. It must be pointed out that it is not only the data items but also the methods used to collect them that are important. In this respect, the best possible scenario in terms of data sources is combined, rigorously collected revealed preference-stated preference data, with traffic counts for validation purposes, as well as a comprehensive socio-economic examination of the study area. This of course assumes that there would be sufficient funds to finance proper (rigorous) traffic and revenue studies. Specific data requirements for evaluating traffic and toll revenue include:[4]

- Land use and demographic assumptions of population and employment
- Alternative or competing routes or feeding projects
- Weekday versus weekend traffic
- Review of travel demand parameter assumptions
- Trip making characteristics (i.e., revealed preference)
- Value of time (probability of potential drivers paying to use the facility)
- Market segments
- Trip purpose
- Vehicle class
- Time of day
- Toll rates
- Demand forecast
- Economic and political risks.

In a best case scenario, these data would be used for the subsequent development of activity-based or tour-based models or for use in micro-simulation. Such advancing state-of-the-practice in travel demand forecast models has evolved to include a set of features that may provide a set of solutions to engender improved toll road forecasts. It has been widely discussed the current toll road forecasts need enhancements to incorporate the likelihood of multiple possible outcomes, given the potential for changing conditions (i.e., economic,

[4] Data requirements have been culled from Baez, 2004; Fitch, 2003; Muller, 2001.

demographic, political) between the base case forecast and the longer-term forecasts. In fact, there should be discussion of what is more important in serving the needs of the capital markets and bond holders – the base year or the long-term revenue forecasts. There is also the need to develop a standard way to define "accuracy" of the traffic and revenue forecasts. This will most likely entail the specification of an acceptable confidence interval and criteria for the interpretation of the possible outcomes within the confidence interval. The accuracy of toll road forecasts is many times undermined by underlying assumptions built into the models that travelers behave in a rational manner. The new generation of travel demand models attempts to accommodate the irrational or heuristic decision-making that more often influences travel behaviors. An emerging area of interest in the activity-based analysis is inter-agent interactions in activity-based travel decision-making, including those related to within household interactions (i.e., between individuals in a household) and across household interactions (i.e., across individuals in different households, such as carpooling arrangements and joint activity participation) (Goulias et al, 2004). For example, what is the effect of household composition on mode choice? On route choice? Another important element in the activity-based approach is the notion that people's activity and travel patterns are governed by numerous constraints (e.g., modal availability and accessibility, work and school schedules, household obligations, costs). What is the effect of VOT on choice in use of priced lanes and facilities? What is the impact of household obligations on time of travel? To model the conditions under which an *individual* is making the decision, it is important understand "why" and "how" these micro- (or disaggregate) level travel decisions are made. In addition, new modeling frameworks free up prior constraints on the numbers of explanatory variables that can be accommodated in the modeling process, which will lead to analyses that incorporate the compounded effects of different assumptions and changed conditions. It will also enable the adequate incorporation of external variables (i.e., gas pricing, economic environment, etc.) into the toll revenue forecast.

CONCLUSIONS AND RECOMMENDATIONS

This review of road pricing analyses data requirements has identified the need for the adoption of a data framework that is flexible enough to apply to policy, strategy, and tactical levels. There is overlap in the data requirements for these various levels. Specific data elements are not mutually exclusive, but the uses of the data differ. Given the complexity of road and financing analyses, there is a need for standards and consistency in the data regardless if the analyses are for political, strategic, or tactical objectives. Otherwise, how can one compare and contrast the results of one set of analyses with another or the impact of one road pricing project with another? In the long run, development of a continuing ability to assess project performance or to identify emerging issues will require constant monitoring and evaluation to analyze and adapt to changing conditions. Often, the analysis method, quality or outcomes differ depending on the consultant, client, agents, and budget. Thus, it is essential to have appropriate data design for a cost-effective result. The following criteria should be considered when designing the data system for road pricing analyses (Heggie and Vickers, 1998):

- Relevance in terms of having a direct influence on the required output
- Appropriateness both to the stage of planning and management process, and to the decision-maker's capability to undertake the required data collection
- Reliability in terms of accuracy, coverage, completeness and correctness, and
- Affordability in both financial and staff requirement terms

To be effective, the data framework needs to be developed in the context of explicit standards for pricing analysis. Since much of traffic and revenue forecasting is conducted in an analytical "black box" there is not a standard methodology for developing forecasts and interpreting their results. The practice then becomes as much of an "art" as a "science." Yet, as more innovative financing projects are taken to the bond market or proposed for federal support through the FHWA's Value Pricing Pilot or TFIA-Loan Programs, there is a growing and critical need for evaluation and monitoring standards. This practice will begin to build a knowledge base of information that will help ensure the success of future projects or quickly identify problematic start-up projects.

Another conclusion is the fact that few assessments of the accuracy and reliability of the road pricing analyses have been done by social scientists or transportation researchers. As noted previously, credit ratings agencies have primarily conducted such examination. This creates a further need for a TRB-sponsored or DOT-sponsored empirical meta-analysis of forecasting accuracy for both forecasting traffic and revenue as well as impacts of road pricing. Empirical investigation should focus on the factors or variables that impact different forecasting outcomes.

In addition, greater prominence and importance need to be given to the peer reviews that are part of traffic and revenue forecasts. The peer reviews are often an afterthought and rely on either data different from that used in forecasts or with incomplete data. The peer review data and analytical requirements o needs to be standardized. In addition, a systematic study of peer review versus original forecasts should be undertaken, both in term of factors associated with different outcomes, the processes involved in conducted each, and the implications of differences (i.e., what happens when there are differences).

Finally, the transportation needs in most states far exceed available funding, and increasing traffic congestion is adversely affecting the livability of our nation's metropolitan areas. Road pricing has been suggested as a solution for both these critical issues. Standard, valid, and reliable data and methods of analysis are needed for creating informed pricing options with regard to the policy implications, impacts, and performance expectations.

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Panelists’ Comments and Audience Discussion

Data Standardization

An audience member’s comment on the expense of data collection and the difficulty in getting money to pay for it prompted a discussion on data standardization. Data standardization would allow for data transferability, thus decreasing the cost of data. Additionally, if disparate models worked off standardized data sets, it would be easier to compare results from the different models to determine good modeling techniques. There was a consensus that modelers need to think creatively and carefully about opportunities to standardize and transfer data.

One potential problem with data standardization is that it is inherently non-competitive. Propriety information is crucial to continued private sector involvement in data collection and modeling methodologies. Furthermore, it might be too early to establish data standards because not enough research has been done to establish best practices.

Funding for Data Collection

Attendees agreed that there are significant data deficiencies associated with road pricing and modeling, and that decision makers are reluctant to invest in data collection. SAFETEA-LU provided little funding for data collection, despite the U.S. DOT’s efforts to convince Congress of its importance. Planners and modelers have to convince lawmakers and senior management that data collection is an important investment for good travel modeling.

A participant suggested that modeling agencies consider mining non-traditional data sources such as cell phone location records. In fact, the New Jersey DOT is planning to hire a firm for this task. However, this introduces privacy concerns that must be addressed. In addition, while collecting this data might be less expensive than traditional travel surveys, it would still be expensive. There might be a need for a national policy and standardized tools for the use of this type of data for transportation modeling.

An audience member noted that the private sector invests much more in data collection and analysis than does the public sector. This can be partially explained by the fact that good data reduces risks, which is important for profit-driven investments. Public sector agencies might be more inclined to fund data collection if they were more concerned with the risks inherent in revenue and traffic forecasts.

Value of Time

The panelists’ presentations began by addressing issues related to value of time (VOT). Data on VOT should be segmented by income at a minimum. However, this is probably not sufficient since many other factors—such as time of day, facility type, and vehicle occupancy—influence the way travelers value their time. Modelers must carefully consider the benefits of adding additional variables versus the complexity that will result. Several participants cautioned that the most complex approach is not necessarily the most accurate.

Studies from SR 91 in California generated a VOT of $28 per hour. Many modelers feel that this is much too high for the typical traveler, although it seems reasonable for at-work travel. A panelist said that his research indicates that average VOT is about 22 percent of the prevailing wage. However, it is common for modelers to use about 50 percent of the wage.

Some participants felt that stated preference surveys consistently under-estimate VOT. This might be because surveys capture *typical* VOTs, rather than the *actual* VOTs of users of the tolled lanes. The latter value is higher because travelers often use tolled lanes for atypical travel when time is more important than usual, such as when they are late for an appointment. An additional wrinkle in the VOT problem is that, over time, as people become more accustomed to toll roads and resigned to paying tolls, their willingness to pay—and therefore VOT—changes.

The industry needs to conduct careful studies comparing stated preference to revealed preference data. For new or modified tolled facilities, this can be done by comparing actual facility usage with forecast usage based on pre-implementation stated preference data. A probabilistic approach can be used to account for situational variation of VOT.

Time-of-day travel decisions are a corollary to VOT, and one of the key variables for incorporating road pricing into travel demand modeling. As one participant put it, "Once you address time of day, everything else falls into place." For this issue, tour- and activity-based models are far superior to four-step models.

Commercial Vehicle Travel

There was audience discussion about how commercial vehicles operators react to changes in road pricing policies. Given their high VOT, it is likely that truck operators will choose to pay a congestion-pricing toll that results in time savings and better travel time reliability. However, evidence from the Ohio Turnpike shows that truckers decreased their use of tolled roads when the toll increase was not a congestion management tool, and therefore was not likely to result in time savings or more reliable travel times.

MODELING PRICING IN THE PLANNING PROCESS

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ABSTRACT

Pricing-based policies are of much interest to transportation planners interested in managing travel demand and raising much needed revenue for transportation infrastructure improvements. Traffic and revenue forecasts of pricing-based policies are largely based on traditional four-step travel demand modeling paradigms or minor variations of such procedures. However, with the increasingly innovative and dynamic nature of pricing and tolling schemes, there is a need to understand the limitations associated with modeling pricing in the current planning process. In light of the limited capabilities of current modeling procedures to address emerging pricing policies, the profession is identifying new methods, paradigms, and enhancements that can and need to be adopted to reflect behavioral response and human decision-making processes in travel demand models. It is argued that tour-based and activity-based modeling paradigms offer a robust behavioral and causal framework for modeling dynamic pricing-based policies and that the profession should undertake research studies aimed at testing and validating these innovative modeling methods using real-world data derived from ongoing value pricing and variable toll-road projects.

INTRODUCTION

Ever since the passage of key legislative acts such as the Clean Air Act Amendments, 1990, the Intermodal Surface Transportation Efficiency Act (ISTEA), 1991, and the Transportation Equity Act for the 21st Century (TEA-21, 1998), there has been the need for, recognition of, and interest in modeling transportation systems under various pricing policy scenarios (DeCorla-Souza and Whitehead, 2003). TEA-21 created the Value-Pricing Pilot Program replacing the Congestion-Pricing Pilot Program that was established under ISTEA (DeCorla-Souza, 2001; Berg and Young, 1999). The most recent legislation passed in August 2005, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), continues to place emphasis on innovative financing of transportation infrastructure and management of travel demand through the use of pricing policies and toll mechanisms. Pricing constitutes one of the many key emerging policy issues that transportation planners must address using rigorous analytical tools and behavioral frameworks (Pendyala and Bhat, 2004).

There are two primary motivations for implementing pricing policies (Lauer, 1999). First, pricing schemes serve as potential travel demand management (TDM) strategies and transportation control measures. With increasing levels of congestion being experienced in urban areas around the country (TTI Urban Mobility Report) and the world (Ruster, 1997), pricing policies are seen as potential mechanisms for managing travel demand in a variety of ways (Levinson, 2005; Gifford and Stalebrink, 2001). Depending on the nature of the pricing policy, automobile travel may be shifted in space or time, or suppressed completely. In more effectively managing travel demand through the use of pricing policies, the need for building costly infrastructure may be potentially reduced as well. For example, parking pricing measures may reduce the need to build and provide large amounts of parking, particularly in congested central business district (CBD) areas where land acquisition costs are high. The same may hold true in the case of road capacity provision as well. Thus, pricing mechanisms show promise for improving the effective use of transportation infrastructure/capacity (General Accounting Office, 2003).

Second, pricing schemes and toll mechanisms are seen as potentially effective means to raise money required to finance projects which will benefit the road users (Urban Mobility Corporation, 2005). State and local governments do not have the financial resources to build much needed capacity in the face of increasing levels of congestion. Tax increases have generally not served as the solution to the infrastructure financing crisis in many areas, generally because of the reluctance of elected officials to impose taxes and the reluctance of the public to accept them (Stopher, 2004). With economic development at stake, infrastructure costs constantly rising, and the public demanding solutions, state and local governments have increasingly seen tolling and pricing schemes as potential sources of revenue for building the much needed transport infrastructure in urban areas choked with congestion (Levinson, 2002).

In a broader sense, both of these motivations for implementing pricing policies speak to the desire to enhance mobility and overall quality of life. By reducing congestion, improving travel times, enhancing safety, decreasing fuel use and vehicular emissions, and shifting automobile travel away from certain times and locations, the overall quality of life in an area may be made more attractive. Although this is true, one cannot ignore the potential conflict between the two primary motivations for the implementation of pricing schemes outlined above. The first motivation for pricing, i.e., travel demand management, is aimed at managing travel demand by *reducing* automobile use. The aim is to reduce automobile travel altogether or, at least, to reduce automobile travel on certain routes and at certain locations and times of the day. On the other hand, the second motivation, i.e., raising financial resources for expanding and maintaining the transport infrastructure, has transport agencies and planners hoping that automobile travel and use will be *high* so that revenues are high as well. Toll roads, parking garages, and other pricing-based infrastructure facilities are often built by issuing bonds to raise the financial resources needed to build the facilities. If the revenue stream from the collection of tolls or user charges is not commensurate with expectations to pay off the bonds, there is a serious danger of defaulting on bond payments and the bonds could potentially attain junk-bond status. In addition, agencies often rely on the user revenues to finance the construction of other transport facilities that are needed in an area.

The above discussion points to the need to exercise care in the planning and operation of pricing-based transport facilities. The potential conflict between the two primary motivations for the implementation of pricing measures can be avoided by clearly identifying the objectives of the pricing policy and the potential uses of the revenue raised. For example, pricing policies may facilitate the temporal or spatial shift in travel demand – a shift from a congested time or location to a more uncongested time, location, or tolled facility. This shift will serve the dual purpose of effectively managing travel demand where congestion and resultant externalities have become serious problems while simultaneously providing much-needed revenue as travel is shifted to the priced facilities. If, however, the two motivations driving the pricing policy are not complementary, then one of the two primary motivations must be primordial and the effectiveness of the pricing policy should be viewed in the context of only the primary motivation.

Regardless of the primary or dual-motivation of a pricing or toll policy, transportation planners have to be able to analyze and *model* the effects and impacts of the pricing policy on travel demand. Planners have to either rely on their own past experiences, peer city experiences, and/or travel demand models to predict travel demand, forecast patronage, and estimate the revenue stream – usually 20 or more years into the future. The assessment of pricing policy impacts from a travel demand perspective include modeling changes in travel time, vehicle hours of delay, traffic volumes, travel costs, vehicle miles of travel (VMT), vehicle hours of travel (VHT), and accessibility as a result of the pricing policy. From a revenue generation perspective, the ability to model patronage by time of day, market penetration by payment mechanism (type), and short-run and long-run demand elasticities is critical. From a social equity or environmental justice perspective, it is critically important to be able to model the impacts of the pricing policy on the mobility and accessibility of different market segments defined by income, race/ethnicity, gender, age, auto ownership, and residence/workplace location among others (Raje, 2003).

The planning and operation of pricing-based transport facilities calls for the application of travel demand models that can accurately predict the impacts of the pricing mechanism in time and space across socio-economic markets. Travel demand and revenue forecasting models serve as the risk management tools for the innovative financing of large infrastructure projects under a wide variety of possible public-private partnership arrangements. Travel demand models should capture behavioral relationships underlying human activity-travel patterns, reflect traveler attitudes, perceptions, and acceptance of pricing-based policies and collection technologies, and incorporate people's willingness-to-pay and value of time considerations to be able to accurately forecast patronage and revenue associated with pricing-based transport facilities. The models should be able to consider primary, secondary, tertiary, and interaction effects associated with the implementation of pricing-based strategies and facilities.

This paper aims to synthesize and identify new travel demand modeling methods, paradigms, and systems for modeling pricing in the planning process. The paper focuses on the capabilities of current travel demand models and the potential limitations associated with the use of traditional four-step travel demand forecasting models for assessing the impacts of pricing-based measures. The paper then explores how advances in the travel behavior modeling arena, primarily in the direction of tour-based and activity-based microsimulation model development, show considerable promise for enhancing the ability of transportation planners to accurately forecast demand and revenue. Although the paper does focus on advances in transport demand models to incorporate pricing effects, it does not cover advances in traffic network assignment and simulation algorithms under alternative pricing strategies. These advances, although critical to an understanding of pricing effects on traffic flow patterns, are beyond the scope of this paper and are mentioned only briefly for the sake of completeness. Likewise, the paper focuses heavily on roadway pricing and value pricing/charging schemes, although public transit pricing, parking pricing, vehicle registration and driver's license fees, and special taxation schemes are also very important and critical strategies that might be included in an overall transport pricing portfolio. In recognition of the growing realization that travel demand models are critical to analyzing and planning pricing-based strategies and facilities, this paper attempts to shed light on what model enhancements are needed, how best to accomplish the enhancements, and whether the enhancements are worth the effort. Despite the focus on road user charges, much of the discussion in the paper is applicable to a wide range of multimodal pricing strategies that might be considered.

SOME PRICING MECHANISMS IN TRANSPORTATION PLANNING

Pricing in transportation has been around for many decades in the form of federal, state, and local gas taxes that individuals pay at the pump. These and other special taxes passed by state or local governments or implemented through public referendums are generally geared towards providing the revenue and resources needed to provide and maintain essential transportation infrastructure services. However, in recent decades, there has been a reluctance to further increase taxes both on the part of elected officials and the public, potentially due to the political and public sensitivity to tax increases and their greater adverse impacts on certain sections of society. The search for revenue sources and the simultaneous growth in traffic congestion has led to the increasing interest in pricing-based demand management and revenue generation strategies (Shoup and Brown, 2003).

The use of pricing-based strategies to manage demand and raise revenue is not new. Utility companies including water, electricity, and telephone service providers have routinely varied pricing by time of day, day of week, and usage. Within the transportation arena, airlines routinely charge according to time of day, day of week, and demand patterns to both manage the demand and increase their revenue. Airlines and hotels also offer discounts, privileges, and other benefits to frequent or heavy users of their service with the intent of promoting loyalty and usage within its customer base. Many of these concepts and ideas translate directly into the surface transportation sector as well.

There are a variety of pricing mechanisms and policies that can be implemented in the context of the surface transportation system. They include, but are not necessarily limited to, the following:

1. <u>Public Transport Pricing Systems</u>: Public transit systems including rail and bus modes of transportation have routinely charged higher prices during peak periods and lower prices during off-peak periods. The higher prices during the peak period potentially manage travel demand, pushing discretionary and non-essential trips to the off-peak period, and provide additional revenue to help support the higher level of service offered in peak periods. In addition, public transport systems offer a variety of seasonal, monthly, daily, and discount passes (e.g., for elderly, students, etc.) to retain a loyal customer base and offer benefits and discounts to this base.

2. <u>Parking Pricing</u>: Parking pricing strategies are usually implemented to balance parking demand and supply, thus managing the demand for parking while raising revenue to maintain or potentially enhance parking supply over time (Shoup, 2005). Parking facilities at airports and other special facilities (e.g., stadiums, universities) and on- and off-street parking operators in downtown areas often charge patrons for parking in the facility. These charges often vary by time of day with higher rates during peak periods, are discounted for frequent or long duration patrons, and may be reimbursed by employers or businesses who benefit from the availability of parking in the vicinity. High parking rates and low parking supply have the potential to suppress auto trips and/or shift trip making from the automobile to alternative modes (public transit, non-motorized, taxi). However, parking pricing strategies also have the potential to shift travel patterns in space as individuals seek destinations where there is plenty of free parking supply. Thus, downtown pricing strategies have the potential ill-effect of leading to CBD decline and suburban gridlock. (Shoup)

3. <u>Standard Tolls</u>: Standard tolls are flat tolls that do not vary by time of day or day of week. By virtue of its nature, the constant flat toll is charged at all times of the day and is not intended to manage or shift travel demand. The standard flat toll is usually a reliable revenue generating mechanism to pay off the debt, maintain the facility, and obtain financial resources for transport infrastructure improvements.

4. Shadow Tolls: Shadow tolls are per vehicle amounts paid to a facility operator by a third party such as a sponsoring governmental entity and not by facility users (FHWA, 2005). Shadow toll amounts paid to a facility operator would be based on the type of vehicle and distance traveled. Shadow tolls can be an element of a highway finance approach whereby a public or private sector developer/operator accepts certain obligations and risks – such as construction, operations, and traffic volumes – and receives periodic shadow toll payments in place of, or in addition to, real or explicit tolls paid by users. Funds for shadow tolls can come from diverse government and/or private sector resources, including State Highway Funds, special assessments on nearby properties that benefit from the roadway, and regional dedicated tax streams. The concept of shadow tolls is particularly applicable to public-private partnerships where the private developer/operator bears some of the traffic risks.

5. Congestion Charging/Pricing: This pricing scheme may be viewed as a spatial-area based charging measure. This strategy is generally intended to serve as a means by which auto trips destined or located in an area of congestion are either suppressed, shifted to another mode, shifted to another less-congested location, shifted to another time of day, or made to pay for the costs of the externalities in the area of congestion. These pricing schemes may take different forms. For example, similar to that implemented in London and Singapore, all vehicles entering a certain area (such as a downtown or CBD area) could be required to pay a congestion charge. Usually, the congestion charge is levied only during the times of day when congestion prevails. Thus, any automobile entering the cordoned area during the time and day of congestion pricing would have to pay the charge. Alternatively, congestion charging could be imposed based on miles of travel. Using GPS technology to track location and distance traveled, automobiles traveling within a certain area during a certain time of day could be charged on a per mile basis. This pricing scheme may help suppress and shift auto trips to better manage travel demand and improve accessibility through reduced congestion levels.

6. Variable Tolls/Road Pricing/Value Pricing: Variable tolls or value pricing schemes are rather similar to congestion charging or pricing schemes discussed above. However, for purposes of this paper, variable tolls and value pricing schemes are considered to be more facility- or corridor-specific as opposed to area-specific. Thus, tolls or pricing schemes that vary by time of day and day of week are imposed on a facility (say, a bridge or tunnel) with a view to better manage travel demand, particularly in the peak periods. By charging variable tolls on the facility, it is envisioned that drivers who have the temporal flexibility may shift their trips to the off-peak periods or peak period shoulders, thus flattening the peak and spreading the travel demand more evenly through the day. Variable tolls and value pricing schemes may take the form of higher tolls in the peak periods or lower (discounted) tolls in the off-peak period. In either case, it is possible that there will be some temporal and route shifts that take place as a result of the pricing scheme.

7. HOT Lanes/FAIR Lanes: High-occupancy toll (HOT) lanes are generally erstwhile high-occupancy vehicle (HOV) lanes that generally did not see high levels of usage as pure HOV lanes. In order to enhance use of HOV lanes, better utilize available capacity, and raise revenue, several HOV lanes have been converted to HOT lanes where single-occupant vehicles are allowed to use the HOT lanes for a fee. Dynamic, variable, value, or time-of-day pricing can be implemented within the context of HOT lanes where single-occupant vehicles pay a toll for using the high-occupancy lane based on the time of day of travel. High-occupancy vehicles get to use the HOT lanes for free.

   The public has generally been slow to accept strategies where free lanes are converted to toll lanes. The objections could potentially be overcome using the concept of FAIR lanes, i.e., Fast and Intertwined Regular Lanes (DeCorla-Souza, 2000). This concept involves separating congested freeway lanes into two sections: Fast lanes and Regular lanes. The Fast lanes would be electronically tolled express lanes, where tolls are set in real time to limit traffic to the free-flowing maximum. The Regular lanes would continue to be free with constricted flow as at present, but drivers would be compensated with credits for giving up their right to free use of the Fast lanes.

   Another concept that aims to overcome public objections to toll lanes is that of Credit-Based Congestion Pricing (Kockelman and Kalmanje, 2005). This policy seeks to ration the use of road space based upon when and where people drive. Only those exceeding their allotted usage pay a congestion charge, while those who do not gain a credit. This is a potential solution to criticisms that congestion pricing policies discriminate against those who cannot afford the charge.

This section has highlighted some of the pricing mechanisms, strategies, and concepts that have been implemented or are being proposed in the literature for better managing travel demand in a socially equitable manner while raising much needed revenue. Given the variety of pricing strategies that exist and the myriad ways in which individual travel behavior may adapt in response to pricing mechanisms, it is imperative that travel demand models be sensitive to and capable of reflecting the diverse and complex inter-relationships and adaptation mechanisms underlying travel demand. The purpose of this paper is to identify the behavioral sensitivity and complex inter-relationships that need to be incorporated into travel demand models and generate debate on the emerging paradigms, methodologies, and microsimulation frameworks that show the greatest promise for modeling pricing in the planning process.

SOME EXAMPLES OF PRICING APPLICATIONS AND RESEARCH STUDIES

There is now a rather large body of literature on the analysis and modeling of pricing-based strategies for transportation planning. A complete review of the literature related to pricing-based analysis and research is beyond the scope of this paper. It is clear, however, that there is enormous interest in the field to analyze and model the impacts of pricing strategies, develop methods that help determine optimal pricing strategies, and simulate traffic networks under a variety of operational and behavioral assumptions.

As mentioned earlier, value pricing encompasses a variety of strategies to manage congestion on highways, including both tolling of highway facilities as well as other strategies not involving tolls. There are five types of pricing projects implemented or under consideration in the United States, including four types of pricing strategies (identified as A through D below) and one type of project (identified as E below) that can cover all four types of pricing strategies. The list of projects by project type is as follows:

A. <u>Pricing on Existing Roads: *New tolls on existing toll-free facilities (usually electronically-collected*)</u>

A-1. Conversion of HOV to HOT Lanes

- Operational Projects
  - California - HOT lanes on I-15 in San Diego
  - Texas - HOT Lanes on Two Radial Corridors in Houston (I-10) and US 290)
  - Minnesota - HOT Lanes on I-394 in Minneapolis
- Projects under Study
  - California – HOT Lanes on I-880 in Alameda County
  - California - I-680 SMART Carpool Lanes in Alameda County
  - Colorado - HOT lanes on I-25/US 36 in Denver
  - Florida - HOT lanes on I-95 in Miami-Dade County
  - Georgia - HOT Lanes on I-75 in Atlanta
  - Washington - HOT Lanes on State Route 167 in the Puget Sound Region

A-2. Cordon Tolls

- Projects under Study
  - Florida - Cordon pricing in Lee County

A-3. FAIR Lanes

- Projects under Study
  - California - FAIR Lanes with Dynamic Ridesharing in Alameda County

B. <u>Pricing on New Lanes: *Tolls on lanes added to existing highways (usually electronically collected*</u>

- Operational Projects
  - California - Express Lanes on State Route 91 in Orange County
- Projects under Study
  - California - Extension of I-15 HOT lanes in San Diego
  - California - Vehicle Enforcement System on I-15 Managed Lanes in San Diego
  - California - HOT lanes in Median of Route 1 in Santa Cruz County
  - Colorado - Express Toll Lanes on C-470 in Denver
  - Florida - Priced Queue Jump Lanes in Lee County
  - North Carolina - HOT Lanes on I-40 in Raleigh/Piedmont
  - Oregon - Express Toll Lanes on Highway 217 in Portland
  - Texas - Managed Lanes on the LBJ Freeway in Dallas

  - Texas - Managed Lanes on the Katy Freeway in Houston
  - Texas - Managed Lanes on I-30/Tom Landry Freeway in Houston
  - Texas - Managed Lanes on I-35 in San Antonio

C. Pricing on Toll Roads: *Variable tolls (usually electronically-collected) on existing and new toll roads, bridges, and tunnels*

- Operational Projects
  - California - Peak pricing on the San Joaquin Hills Toll Road in Orange County
  - Florida - Bridge pricing in Lee County
  - Florida - Variable tolls for Heavy Vehicles in Lee County
  - Illinois – Variable Tolls on the Illinois Tollway
  - New Jersey - Variable Tolls on the New Jersey Turnpike
  - New Jersey - Variable tolls on Port Authority Interstate Vehicle Crossings
- Projects under Study
  - Florida - Variable tolls with open road tolling in Broward County
  - Florida - Pricing options on Florida Turnpike in Miami-Dade County
  - New Jersey/New York - Express Bus/HOT Lane in the Lincoln Tunnel
  - Pennsylvania - Variable tolls on the Pennsylvania Turnpike in Philadelphia

D. Pricing of Parking and Vehicle Use: *Pricing strategies that do not involve tolls*

D-1. Usage-Based Vehicle Charges

- Operational Projects
  - California - Car Sharing in the City of San Francisco
- Projects Under Study:
  - Georgia - Simulation of Pricing on Atlanta's Interstate System
  - Minnesota - Variabilization of Fixed Auto Costs Statewide
  - Oregon - Mileage-based road user fee evaluation Statewide
  - Washington - Global Positioning System Based Pricing in the Puget Sound Region

D-2. "Cash-Out" Strategies

  - Washington - Parking cash-out and pricing in King County
  - Washington - Cash Out of Cars in King County

E. Region-wide Studies: *Region-wide pricing initiatives within metropolitan areas to attempt to identify candidates for implementation of pilot pricing projects*

  - Maryland - Feasibility of value pricing Statewide
  - Minnesota - Project Development, Outreach and Education
  - Texas - HOT Lane Network Evaluation in Houston
  - Virginia - Value Pricing for the Northern Virginia and Hampton Roads Regions

Details on these projects are available at the Federal Highway Administration Value Pricing website (http://www.fhwa.dot.gov/policy/otps/valuepricing.htm). In addition, there are specific references that describe individual projects and various studies undertaken in conjunction with a pricing project (e.g., Munnich and Barnes, 2003). These projects have provided the ability to actually measure the impacts of variable pricing and tolling schemes in the real world and conduct studies that investigate user responses, attitudes, and perceptions of various pricing policies.

The 9-mile long California State Route 91 (SR 91) express lanes opened for revenue service in December 1995. These toll lanes, located in the freeway median between Anaheim and Riverside County, provided the first practical implementation of congestion-based pricing in the United States. Sullivan (1997) has analyzed the impacts of these toll lanes on vehicle occupancy, traffic volumes, and income inequities. He found that commuters generally approve of the project features, low income commuters are not differentially impacted by the project, and traffic growth and vehicle occupancy patterns show that the SR 91 experiment is quite successful in meeting its travel demand management, route diversion, and revenue generating objectives. The San Diego I-15 congestion pricing project has offered key insights into the impacts of dynamic pricing schemes on traveler behavior, attitudes and perceptions towards pricing, and value of time. San Diego's HOT lanes currently generate $2 million per year in self-supported revenue with toll rates adjusting every six minutes depending on traffic volume (McGraw-Hill, 2003). Supernak, et al. (2003) present selected results of a study of the impact of the project on travel times and travel time reliability. They focus on the project's impact on travel times and their distribution on both the main lanes and the express lanes of I-15. Their analysis found that electronic toll subscribers on the express lanes can save up to 20 minutes avoiding delay on the I-15 main lanes. The findings agreed with the drivers' perception about their time savings when using the electronic toll subscription service on the express lanes. Brownstone, et al. (2003) used revealed preference data from the study to estimate drivers' willingness-to-pay to reduce travel time during the morning peak period. Their estimate found willingness-to-pay higher than that found in typical stated preference research, with drivers willing to pay approximately $30 to reduce commute time by one hour. They found that commuters, individuals from higher income groups, women, individuals 35-45 years of age, higher educated individuals, and homeowners are more likely to use the high occupancy/toll lanes than other socio-economic market segments. Golob (2001) developed joint models of attitudes and behavior to explain how both mode choice and attitudes about the San Diego I-15 congestion pricing project differ across the population. Surprisingly, he found that behavior and experiences arising from the behavior shaped attitudes of individuals as opposed to attitudes and perceptions shaping behavior.

Considerable work has been done on the Lee County (Florida) Variable Pricing project that was initiated in 1998 (Swenson, et al., 1999). In the Lee County project, tolls on two bridges heavily used by commuters were reduced during the shoulder and selected off-peak periods, while the tolls during the peak periods remained constant. Only electronic toll collection subscribers could avail of the 50% discount offered during the selected off-peak periods. Cain, et al. (2001) analyzed the impact of the variable pricing project on temporal distribution of travel demand. Due to the limited congestion experienced at the program locations, the effects of travel cost changes on the temporal distribution of travel demand could be isolated. Overall, the program implementation was found to have minimal impact on the aggregate distribution with demand for peak-period travel remaining relatively unaltered. At the disaggregate level, however, the impact of the program was more apparent, with significant temporal shifts in the proportion of demand within individual half-hour segments. Their study found a price elasticity relationship that was consistent with that in the literature and suggested that value pricing exhibited the potential to serve as a travel demand management tool. Burris (2003) estimated price elasticities of travel demand using both observational data and disaggregate survey data collected as part of the project. He then used the range of price elasticities to estimate the potential impact of variable pricing on a hypothetical congested toll road. He found that elasticities from 0.076 to 0.15 caused travel times to improve by 8.8% to 13.3%, respectively. Finally, Burris, et al. (2004) examined long-run changes in driver behavior to variable tolls using data from the Lee County project. By using empirical evidence, they found that, over time, the relative price elasticity of demand on one of the bridges decreased from -0.42 to -0.11 during the early morning discount period. Elasticities also decreased to a lesser extent during late morning and early afternoon discount periods. Their methodology offers the ability to determine changes in price elasticities over time.

Adler, et al. (1999) describe findings from a comprehensive evaluation of traveler reactions to congestion pricing concepts for the Tappan Zee Bridge in Westchester County, New York. The bridge is already tolled and the concept involves provide steep discounts during off-peak periods similar to the Lee County project. The focus groups conducted as part of the study indicated that travelers support congestion pricing concepts, provided they understand the congestion benefits and believe that the benefits will be realized. The surveys found that many travelers have flexibility in the timing of their trips and would exercise that flexibility in response to tolls that varied by time of day. They found that a slight majority favored the concept and that the level of support did not vary by income or gender.

There have been several noteworthy implementations of variable road pricing schemes in the international arena as well. The Symposium on International Perspectives on Road Pricing (TRB, 2005) held in November 2003 in Key Biscayne, Florida, offered valuable information on road pricing projects and experiences from around the world. The most well-known international examples include the Singapore and Central London electronic road pricing schemes. Unlike corridor-specific variable tolls or pricing schemes, these schemes are more area-specific congestion charging measures. Phang and Toh (2004) review the 28 years of experience with congestion pricing in Singapore (1975-2003) and the impact of the electronic collection methods introduced in 1998 which allowed tolls to be charged by vehicle size, route, and time of day. The Singapore road pricing scheme, when combined with other measures of taxation and car ownership restrictions, appears to have had success in limiting the growth of congestion and in shifting usage to other times of day or week. The authors note, however, that the unique characteristics of Singapore suggest its experience may not be easily translated to other parts of the world.

Santos and Shaffer (2004) present several interesting preliminary results of the London congestion charging scheme. Santos (2005) follows up with another study in which he compares the congestion pricing experiences of London and Singapore. The London congestion pricing scheme went into effect in February 2003. Congestion over the first year decreased by 30% as a result of the charge and overall traffic levels in the congestion charging zone fell by 16%. Speeds for car travel increased by more than 20%, and bus travel became more reliable. The average marginal congestion cost within the central zone is estimated at 1.65 British pounds per vehicle-km. The net revenues, amounting to about 68 million British pounds, are mainly being used to improve public transportation services. The overall results suggested that the scheme achieved the stated congestion reduction targets and that the five British pound charge is a reasonable approximation to marginal cost pricing. In comparing the London and Singapore experiences, Santos (2005) notes a result from Electronic Road Pricing in Singapore that a per-entry charge is more effective at reducing congestion than a per-day charge. He notes that any city contemplating the introduction of similar road pricing mechanisms should complement the measures with valid alternatives to the car. Providing such alternatives may be the key to widespread public acceptance and market adoption.

There are a number of other attempts in the international arena to implement electronic road pricing schemes as a means of dealing with congestion. Ison and Rye (2005) examine why some pricing schemes never get off the drawing board. They draw on the experiences of such road user charging schemes, namely Electronic Road Pricing in Hong Kong and Congestion Metering in Cambridge (UK), and seek to make comparisons with the way implementation of congestion charging has been undertaken in Central London. They find that certain issues have contributed to the two schemes not being implemented, such as the level of congestion not being severe enough, lack of clarity of objectives, concern over invasion of road user's privacy, and timing and presentation of the proposals. Thus, they note that there are several important factors that must come together for the successful implementation, adoption, and market penetration of a road pricing scheme.

There have been numerous research-oriented studies that have examined the potential impacts of road pricing schemes in a small experimental study context or through theoretical network simulations. Thorpe and Hills (2003) investigate drivers' responses to road user charges using GPS technology. The authors assessed the feasibility of using the technology to implement user charges on a point- and distance-based mechanism. They found the technology to be capable of running such a system, although adjustments in the algorithm to calculate charges and assess driver behavior are needed.

One of the key aspects underlying the implementation of road pricing is that people (travelers) value time and travel time reliability. Mayet and Hanson (2000) develop an economic model of congestion pricing in which the value of time has a continuous distribution as opposed to a constant value (of time). They analyze distribution effects among the population and find different optimal tolls depending on the definition of the social welfare function that is maximized. Ranges of Pareto efficient tolls under different assumptions concerning the distribution of toll revenue are identified. Small, et al. (2002) use recent econometric advances to study commuters' preferences for speedy and reliable highway travel with the goal of exploring the efficiency and distributional effects of road pricing that accounts for users' heterogeneity. The authors find that highway users show substantial heterogeneity in their values of travel time and travel time reliability. In addition, they show that road pricing policies catering to varying preferences can substantially increase efficiency while maintaining political feasibility.

A number of studies have explored toll design and road pricing using dynamic traffic simulation methodologies in the context of optimizing traffic networks (Marin, 2003). Yang and Zhang (2002) impose social and spatial equity constraints in solving the multiclass network toll design problem and show how the toll mechanism can be designed to minimize not only social inequities, but also spatial inequities. Dial (1999, 2000) has solved the minimal-revenue congestion pricing problem by designing an algorithm that finds tolls that induce a traffic pattern minimizing average time per trip at a minimal average toll per trip. This minimal-revenue congestion pricing problem involves the identification of the minimum tolls that induce system optimal performance. Adler and Cetin (2001) present a direct redistribution model of congestion pricing in which money collected from drivers on a more desirable route are directly transferred to users on a less desirable route. It is shown (using a small test network) that this model of toll collection and subsidization will reduce the travel cost for all travelers and totally eliminate waiting time in the queue. The direct redistribution model offers results identical to the social optimal assignment. De Palma, et al. (2005) use the dynamic network simulator, METROPOLIS, to analyze alternative road pricing schemes. The simulator treats endogenously departure-time decisions as well as mode and route choices of individual travelers. Six types of toll-collection mechanisms are analyzed and the findings suggest that time-varying step tolls are better than flat tolls in terms of welfare gains. They induce a smaller shift of trips from auto to transit and generate smaller revenues than do flat tolls, consequently having more favorable distributional impacts on travelers. Acha-Daza and Mahmassani (1999) use a dynamic traffic assignment algorithm in conjunction with estimates of user response to pricing in a traffic network to predict network level impacts on congestion and fuel consumption. The methodology is designed to identify candidate locations for congestion pricing in Texas and the associated energy savings at these locations.

As mentioned earlier, a comprehensive review of pricing studies is beyond the scope of this paper. A recent Special Issue of Transportation Research Part A devoted to the Theory and Practice of Congestion Charging contains a series of papers that illustrate the theoretical and empirical advances being made in designing suitable pricing mechanisms and modeling/ understanding their impacts on travelers (Wong, et al., 2005). However, the rather limited review presented in this section does indicate the following:

1. There are a growing number of real-world applications of a variety of road pricing schemes around the world. Road pricing schemes can be used to manage travel demand and encourage system optimality.
2. There is significant and growing interest in understanding and modeling the impacts of road user charges on travel demand and traffic network performance.
3. Most of the real-world applications to date have shown that value pricing schemes have an impact and generally yield benefits consistent with the objectives of the scheme.
4. The barriers to real-world implementation of road pricing schemes include political and public acceptance, concerns about invasion of privacy, and social equity considerations. In general, technology (for Electronic Road Pricing) cost and reliability do not appear to be constraints in implementing road pricing strategies.

5. There are a host of factors that play a role in determining the impact of a road pricing scheme. These include behavioral, attitudinal, perceptual, value of time, and willingness-to-pay considerations in addition to land use and network configurations.
6. Models of travel demand need to be sensitive and responsive to all of these factors to be able to accurately forecast usage and revenue.

EXPERIENCES WITH TOLL ROAD FORECASTING USING CURRENT METHODS

The state-of-the practice in travel demand forecasting has largely remained in the realm of the four-step transportation demand modeling arena. Much has been written about the limitations of the four-step travel demand modeling approach and the notion that the four-step travel demand modeling methodology was originally intended to serve transportation planning in the era of capacity expansion. Much has also been written about the inadequate capabilities of four-step transportation demand models to accurately predict impacts of travel demand management strategies and transportation control measures, including pricing policies such as congestion charging, road/value pricing, and variable tolls (Wallis, 2005). The discussion in this section will closely mirror much of what has already been documented in the literature, with a focus on modeling pricing in the planning process.

Generally, toll and road pricing analysis is done using a combination of traditional travel demand forecasting models along with specialized stated preference market research that helps identify the potential market response and adoption of alternatives in the event of pricing implementation. Agnello and Bandy (2002) discuss the methodology and techniques used by the Baltimore Metropolitan Council to perform variable pricing analysis for the Maryland Department of Transportation's Variable Pricing Study. The modeling analysis was performed using the Baltimore Region Travel Demand Model within the framework of the TP+/VIPER software. The variable pricing scenarios considered included both point and distance based tolls and high-occupancy toll lanes. The model was enhanced to model both types of tolls within the existing model framework. Methods were also developed to display results showing route shifts and traffic quality between different scenarios. The paper provided a discussion on the benefits and limitations of using a traditional travel demand model for such an application.

Allen (1995) reported on enhancements made to traditional travel demand models for analyzing pricing policies in conjunction with a study commissioned by the Environmental Protection Agency to study the effects of transport pricing on emissions. The study required a planning tool that could analyze many different pricing actions. The approach represented an incremental advancement in modeling practice by successfully combining features of the more advanced four-step models. Trip distribution used a composite definition of impedance that reflected time and cost of all modes. Mode choice was a logit model with some degree of nesting in the carpool mode; it was sensitive to peak and off-peak automobile operating cost, tolls, transit fare, and parking cost. A logit path choice procedure modeled the effect of tolls on drivers' selection of free and priced paths. All highway paths were based on a combined time and cost impedance.

Dehghani, et al. (2003) describe the development of a new toll mode-choice modeling system for Florida's Turnpike Enterprise. As the simple toll travel forecasting analysis methods were not adequate for reliably addressing contemporary toll study issues, they addressed trip makers' toll route decisions as a mode choice step sensitive to changes in service levels by time of day, trip purpose, and socio-economic attributes (Dehghani and Olsen, 1999). The toll mode choice model described in the paper includes a statistically estimated nested mode choice modeling system with a discrete choice for toll travel. The models were developed for a combination of four periods and four trip purposes. In addition, they implemented a pre-mode choice time-of-day process, a generalized cost assignment procedure that uses travel time and cost by time of day, and a feedback loop process that uses an iterative successive averaging procedure to estimate travel times.

The above examples illustrate the use of traditional travel demand forecasting models to analyze pricing scenarios. There are undoubtedly many more analyses of toll and pricing scenarios documented in feasibility reports that are not typically archived in the literature databases. There are, however, a few documented research studies in which toll road forecasts used to justify the construction and financing of the toll roads have been compared against actual toll road usage and revenue. Barron (2001) examined forecasts and actual usage for several toll road and bridge projects in Florida. The Garcon Point Bridge spanning Pensacola Bay was projected in 1992 to carry 6,500 cars paying $2.50 in tolls. Based on these projections, promoters floated $95 million in bonds to finance the project. In 2001, only 3,500 cars a day used the bridge. The bonds traded at 71 cents on the dollar, following multiple downgrades to junk status by the ratings agencies. On the Seminole Expressway, revenue in 2001 reached $16 million compared to an original projection of $20.9 million in 1992. For the Veterans Expressway in Tampa, actual revenue was $14.9 million in 2001 compared to a forecast revenue of $25.8 million in 1992. Similarly, actual revenues were found to be only about 50% of forecast revenues for the Polk Parkway. Initial projections in 1992 for the 15-mile San Joaquin Hills Toll Road in Orange County, California were 40% above actual traffic counts. By 1997, $1.1 million in bonds had to be replaced with lower-rate bonds or risk default.

The most notable studies examining errors and optimism in toll road forecasts are attributable to Flyvbjerg, et al. (2005) and Standard and Poor's (2004). Flyvbjerg, et al. (2005) do not focus exclusively on toll road forecasts, but rather examine forecast inaccuracies for road (highway) projects vis-à-vis forecast inaccuracies for transit projects. They examined 183 road projects and on average, traffic was 9.5% higher than forecast. They conclude that road forecasts are inaccurate with about half off by over 20%, but not seriously biased up or down. However, their analysis did not distinguish between toll and non-toll roads. With respect to rail forecasts, they note that "there is a massive problem with inflated rail passenger forecasts." Ninety percent are inflated and almost three-quarters over predict traffic by more than two-thirds. Actual rail passenger traffic in the sample of 27 new rail projects was 49% of forecast traffic. They note that there is a high level of statistical significance that rail passenger forecasts are less accurate and more inflated than road vehicle forecasts. While simple uncertainty regarding inputs to the models would account for the type of inaccuracy found with road traffic forecasts, with a fairly even distribution of high and low forecasts, simple uncertainty does not seem to account for the outcome of rail forecasts that are overestimated too consistently for an interpretation in terms of simple uncertainty to be statistically plausible.

While the study by Flyvbjerg, et al. (2005) focused on the errors found in rail forecasts, Standard and Poor's (2004) conducted a traffic forecast risk study to examine the bias associated with toll road project forecasts in comparison with toll-free road project forecasts. The empirical evidence suggests that toll road forecasts have, on average, overestimated traffic by 20-30%. In examining the traffic forecasting performance for 87 toll road projects, they find that the average ratio of traffic forecast to actual traffic is 0.76. The standard deviation of the spread (of this ratio) is about 0.26 and the range of the distribution stretches from projects whose traffic was only 15% of the original forecast to projects that exceeded their forecasts by more than 50%. In comparing forecast performance for toll road projects vs. toll-free road projects, they find that there is a systematic optimism bias of about 20% in toll road project forecasts.

There are certainly numerous factors that potentially contribute to these errors in forecasts (Ash, 2004). They include, but are not necessarily limited to, the following:

1. Errors in input assumptions regarding costs, parameters, coefficients, rates, distributions of values of travel time and reliability, etc. that drive the model forecast
2. Errors in socio-economic and land use forecasts that serve as critical inputs to the four-step travel demand modeling steps
3. Errors in coding networks and node/link attributes <u>by time of day</u> that play a critical role in defining paths, impedances, and route choice
4. Errors in truck travel forecasts
5. Underestimate of ramp-up period (reaching traffic stability following adaptation by traveling public)

All of these potential errors have the ability to significantly undermine the credibility and accuracy of toll road forecasts. Queiroz (2005), in reviewing traffic forecasts risks in an international context, finds that, on average, actual traffic is only 56% of forecast traffic in countries with no tolling experience, but 87% of forecast traffic in countries with tolling experience. Thus, having prior experience with traffic patterns that emerge from a tolling/pricing policy certainly helps in developing forecasts that are likely to more closely mirror actual usage.

USING A TRADITIONAL FOUR-STEP TRAVEL DEMAND MODEL

It is certainly plausible to argue that the consistent optimism bias that has been documented in the studies cited in the previous section is likely a result of optimistic input assumptions driving the forecasts. However, it behooves the profession to examine whether the modeling frameworks and methodologies and behavioral paradigms underlying current travel forecasting procedures are adequate to represent the changes or impacts caused by tolling and pricing policies of different types (Dehghani and Olsen, 1999). In other words, even if the input assumptions and input variable forecasts were perfectly accurate, would current travel demand modeling paradigms and methodologies be able to accurately replicate behavior under a pricing scenario? The remainder of this section examines this question.

The five fundamental steps of the travel demand forecasting process are examined below with respect to their potential ability to respond to pricing policies.

1. Trip Generation: Traditional trip generation procedures rely on trip rate analysis, cross-classification methods, or regression equations to estimate productions and attractions in traffic analysis zones. Trip generation models are generally sensitive to a host of socio-economic and demographic characteristics. However, trip generation models are rarely, if ever, sensitive to spatio-temporal accessibility and travel times/costs. In the event of a pricing policy, it is possible that trips will be suppressed as a result of the increased impedance or induced as a result of the improvement in level-of-service offered by the toll road. In addition, trips may be combined to form chains or tours; when this happens, the number of trips generated changes even though the same activities are pursued by an individual. In the absence of any sensitivity to accessibility/impedance and trip chaining propensity/behavior, trip generation models fall woefully short of being able to respond to pricing scenarios. In at least one enhancement, non-work trip generation models have been modified to incorporate work trip characteristics as explanatory variables to reflect the potential trade-off between non-work and work travel (Purvis). Thus, potential changes in work travel characteristics brought about by the pricing scenario may impact non-work travel demand.

2. Trip Distribution: Traditional trip distribution models are gravity models that are sensitive to zonal productions and attractions and inter-zonal impedances to calculate travel demand between zones. Special adjustment factors may be used to account for additional socio-economic characteristics that affect trip interchanges between zones. Pricing policies are likely to have important implications for the spatial distribution of trips. As impedance increases, travelers may tend to make shorter trips (for example, in the event of a distance-based pricing policy). As impedance decreases, travelers may tend to maker longer trips (say, if a toll road offers a higher level of service and is free of congestion). As trip distribution models are sensitive to changes in impedance (through the use of generalized cost functions), it is plausible to expect trip distribution models to reflect the impacts of pricing policies. The impacts of area-based pricing policies (e.g., tolls for entering congested CBD areas) may also be reflected in traditional trip distribution models as trips destined to these areas under free conditions may now be diverted to other zones where no such pricing policy is in effect. Similarly, destination choice models that are beginning to replace traditional gravity models incorporate the ability to respond to changes in impedance. As most trip distribution models (whether gravity or discrete choice in nature) are calibrated by trip purpose, the differential impacts of pricing policies on various trip purposes are also potentially captured. However, the impacts of pricing policies on destination choice are likely to depend on a host of socio-economic characteristics such as household lifecycle, income, and car ownership, and on trip chaining patterns that

might emerge as a result of the pricing policy. In addition, in the event of variable pricing, it is absolutely essential to have time-of-day modeling as an integral component of the modeling process. Current trip distribution models generally fall short of providing these capabilities.

3. Modal Split: Traditional mode split models rely on multinomial or nested logit based methodologies to reflect mode choice behavior in travel demand forecasting procedures. Most mode split models incorporate a host of level of service variables including time and cost as explanatory factors. In addition, socio-economic variables, market segmentation, and alternative specific constants are used to reflect the differential effects of level of service attributes on different types of travelers and trips (purposes). In response to pricing policies that are aimed at managing automobile travel demand, mode shifts away from the automobile may occur. Mode choice models are generally able to reflect this mode shift behavior. On the other hand, due to the trip-based nature of the four-step modeling process, mode choice models are not able to capture and reflect the inter-dependency among trips that are linked in chains. Although the mode choice model may suggest a mode shift is likely to occur (say, because the imposition of a toll increased auto impedance), that may not be possible in light of the other trips to which the subject trip is chained. The inability to reflect modal constraints associated with trip chaining behavior is a shortcoming of the traditional trip-based approach to travel forecasting.

4. Network Assignment: Traditional static equilibrium traffic assignment algorithms are sensitive to link impedance. In response to pricing policies, travelers may shift to lower priced routes even if there is no change in destination and mode. On the other hand, the introduction of road pricing may result in an improvement of level of service on toll-free roads as well (as a result of the diversion of some traffic from the free road to the tolled road). Thus, network wide re-distribution of traffic may occur as a result of the introduction of pricing policies. While it is plausible to suggest that traffic assignment algorithms reflect route shifts in response to changes in impedance (time and cost), there are reasons to believe that traditional traffic assignment algorithms fall short of being able to accurately replicate route choice behavior in the event of pricing implementation. First, it is critically important to be able to code and represent network (node and link) attributes under a wide variety of pricing scenarios, including those that involve the use of electronic road pricing and toll collection technologies. Second, it is necessary to develop and use appropriate speed-flow relationships that reflect the characteristics of tolled roads as opposed to toll-free roads. Third, in the event of variable or dynamic pricing, there is simply no way that a static traffic assignment algorithm can reflect traffic patterns. Under such scenarios, it is necessary to adopt dynamic traffic assignment algorithms that reflect time-of-day variation in route attributes and cost functions and dynamically define paths between origins and destinations.

5. Time of Day Modeling: Traditional travel demand modeling procedures are beginning to be modified to incorporate time-of-day modeling capabilities largely, in part, due to the need to analyze travel demand by time of day in response to changes

> in supply/network characteristics by time of day. Time of day modeling can be introduced into the traditional four-step model at different stages, i.e., after trip generation, after trip distribution, after modal split, or after traffic assignment. Each of these methodologies has its own relative advantages and disadvantages (Cambridge Systematics, 1997) and effectively adds a "fifth step" to the four-step travel demand modeling process. As pricing schemes, and in particular, variable pricing schemes impact the temporal distribution of travel demand, it is imperative that robust time of day modeling procedures be incorporated into forecasting methodologies. Trips may be shifted from the peak period to off-peak periods or from off-peak periods to peak periods (to take advantage of the higher-priced higher level-of-service). However, even after splitting the "single-day" four-step travel demand modeling process into a time of day based procedure, there are limitations in the ability to capture the time-space relationships underlying travel demand. Spatio-temporal constraints and flexibility and inter-relationships among trips undertaken at various times of the day are key features that need to be addressed to analyze the impacts of pricing on travel behavior.

In addition to the classical steps of the traditional travel demand forecasting method, it is necessary to consider the implications of socio-economic and land use forecasting procedures on modeling pricing in the planning process. Pricing policies and toll road facilities have the potential to alter the landscape. Property values may rise or fall, new developments may be induced, businesses may be impacted either positively or negatively, and a redistribution of land use activity may occur. Land use and socio-economic forecasts must be sensitive and responsive to changes in accessibility, and the impacts of these changes on people's residential/work location choices and travel patterns, to better represent likely future scenarios that result from the introduction of pricing policies. Recent developments in integrated land use-activity-travel microsimulation and urban systems simulation show great promise in enhancing the ability to forecast land use at the disaggregate level while explicitly accounting for the impacts of transportation accessibility on land use dynamics (Miller, et al., 1998; Waddell, et al., 2003).

Thus, in summary, the traditional travel demand forecasting procedure incorporates some elements that are responsive to and capable of reflecting the impacts of pricing policies on travel demand. However, there are a host of elements that potentially lead traditional travel demand models to offer erroneous forecasts <u>even if all of the input assumptions, input variable forecasts, and network coding procedures driving the travel forecasts were to be perfectly accurate.</u>

It is to be noted that many of the shortcomings of the four-step travel demand modeling procedures are not necessarily unique to the analysis of pricing policies. Limitations associated with reflecting trip chaining behavior, induced travel demand, temporal constraints and flexibility, spatio-temporal shifts in trip making, dynamic route choice behavior, variations in value of time, secondary and tertiary impacts on activity-travel patterns, and so on are precisely the limitations that generally make the four-step modeling process inadequate to address current and emerging policy issues, mobility options, and modal technologies. However, these limitations get amplified in the context of pricing policies, and in particular, variable or dynamic pricing policies that are link, time-of-day, and area-specific. In light of the widespread recognition of the challenge associated with estimating toll facility demand and revenue using current methods, the NCHRP has commissioned a synthesis study (36-11) to document best practices and experiences on this topic. This study is particularly timely and valuable because there is a paucity of documented toll and pricing analysis study results in the archival literature.

MOVING TO INNOVATIVE TRAVEL DEMAND MODELING METHODS

In recognition of the limitations of traditional four-step travel demand forecasting models in addressing policy issues, mobility options, pricing mechanisms, and modal technologies of the future, there has been a growing interest in exploring modeling innovations and (behavioral) paradigms that facilitate the robust analysis of emerging policies. The most significant development in this regard is the advent of tour-based and activity-based microsimulation models of travel demand. It is envisaged that tour-based and activity-based models are based on behavioral paradigms that allow a rigorous analysis of the impacts of pricing policies on travel demand.

Although it is likely that tour-based and activity-based models offer a robust framework for analyzing the impacts of pricing policies, it is important to note that the profession needs a strong understanding of behavior, and model specifications that reflect that understanding of behavior. Even a very advanced behavioral paradigm will come to naught if the underlying model specifications and parameters do not appropriately reflect the nature of the relationships driving the phenomena under study. In this context, it is very important for the profession to undertake experiments and research studies that contribute to a better understanding and modeling of traveler response to a variety of pricing policies. Although there has been some research towards advancing the state-of-knowledge on cause-and-effect relationships underlying travel demand (Pendyala and Ye, 2005), there is much that is yet to be understood about true cause-and-effect relationships. A knowledge of the true cause-and-effect relationships is imperative to being able to accurately forecast the impacts of pricing policies. For example, consider trip timing (time of day choice) and mode choice for a non-work (flexible) trip. Which decision is made first in the behavioral decision making process? If trip timing is decided first, then a person may temporally shift the trip (to avoid the congestion pricing) without having to change mode at all. The potential benefits in terms of reduced vehicle miles of travel, fuel consumption, and vehicle emissions may be minimal. On the other hand, if mode choice is determined first, then an individual may shift out of the single-occupant vehicle mode and choose an alternative mode without changing the trip timing. If this is true, benefits in terms of reduced vehicle miles of travel, fuel consumption, and vehicle emissions may be realized. There are many similar examples with equally important implications. Although it is possible that individuals adopt different causal decision making processes under different situations and that many decisions may be simultaneous in nature, the need to understand and reflect cause-and-effect relationships in travel models can not be denied.

As there are now several pricing policies and variable toll road facilities in place, there are clear and present opportunities to gain a deeper understanding of traveler response to pricing policies, short- and long-run elasticities (Matas and Raymond, 2003), value of travel time savings (Hensher, et al., 1990), and traveler attributes that affect the nature of the response. For example, there has been some work examining temporal shifts in travel behavior in response to congestion charging and variable pricing (Mahmassani, 2000; Olszewski and Xie, 2005; Burris and Pendyala, 2002). Discrete choice models of traveler response to congestion charging and variable pricing have provided key insights into the attributes and relationships that govern trip timing behavior. In addition, it is critical that the model specifications account for self-selection and individual heterogeneity in people's value of time and travel time reliability, responsiveness to level-of-service factors, and willingness-to-pay (Hensher and Goodwin, 2004; Bhat and Castelar, 2002). Stated adaptation and stated preference based market research studies have much to offer in better understanding how individuals might react in the event of a pricing policy (Johnston and Patterson, 1990; Richardson, 2004). These experiments should focus, not only on the primary impact of the pricing policy, but also on secondary and tertiary impacts that may occur throughout the daily activity-travel patterns of different household members (Kuppam, et al., 1998; Arentze, et al., 2004). Such studies can also shed much needed light on the attitudes, values, and perceptions that affect acceptance of and behavioral response to pricing policies.

Many of the shortcomings identified in the previous section (associated with traditional four-step travel demand forecasting procedures) are addressed by tour-based and activity-based microsimulation model systems. Tour-based models focus on the formation of tours and the inter-relationships of trips that form tours. Tours may be of various types including primary or secondary tours and work-based or non-work based tours. Tour-based models have been developed and successfully implemented in several areas including Portland, Columbus, New York, and San Francisco among others that are or will be implementing a tour-based model in the near future (Vovsha, et al. 2005). These models incorporate time-of-day modeling capabilities with the day often defined by discrete time periods (as small as 30 minutes in duration). Tour based models incorporate activity-type choice models to model the activities that will be undertaken in a tour, integrated/nested destination choice models and mode choice models to reflect inter-dependencies among destinations and modes in a tour, and provide time of day modeling capabilities to reflect impacts of time varying supply attributes on behavior. Bowman, et al. (1998) constitutes one of the early demonstrations of the tour-based model for Portland and its application to the analysis of a congestion pricing policy. Preliminary application results demonstrated the model's ability to capture activity substitution, time of day shifts, and increased leisure travel demand in response to a congestion pricing policy.

Activity-based models advance the notion of tour-based models further by adding critical dimensions of behavior that are not fully reflected in tour-based models. In addition to incorporating all of the features of tour-based models, activity based models incorporate concepts of time-space geography more explicitly in the modeling of activity-travel patterns. Activity-based models explicitly recognize the central role played by time use perspectives in modeling human activity-travel patterns (Axhausen and Gärling, 1992; Pendyala, 2003; Wen and Koppelman, 2000). These models explicitly consider time-space constraints as represented by time-space prisms (Pendyala, et al., 2002), household interactions in time and space (Gliebe and Koppelman, 2002; Bhat and Pendyala, 2005), activity durations and time allocation, activity scheduling and re-scheduling behavior, and activity participation behavior to simulate complete daily activity-travel patterns along the continuous time axis. There are several activity-based microsimulation model systems that have been developed and are in various stages of refinement, testing, and demonstration (Kitamura, et al., 2000; Pendyala, et al., 2005; Bhat, et al., 2004; Kitamura and Fujii, 1998; Arentze and Timmermans, 2000; Kuhnau and Goulias, 2003). The potential applicability of full-fledged activity-based microsimulation model systems for modeling the impacts of peak period congestion pricing has been demonstrated (e.g., Pendyala, et al., 1997; Pendyala, et al., 1998). These applications showed how an activity-based microsimulation model system simulated the adaptation behavior of an individual in response to a pricing policy. Individual activity-travel patterns were modified or adjusted in response to the pricing policy and the traveler would settle into a new activity-travel routine that was determined using on a satisficing paradigm that utilized a time-use based utility measure of activity-travel engagement.

Both tour-based and activity-based models are often implemented via a microsimulation framework in which complete daily activity-travel patterns are simulated for each individual in the population. This is a powerful method for analyzing the impacts of policies on travel behavior. For each individual, it is possible to simulate the effects of a pricing policy on the entire daily activity-travel pattern while recognizing spatio-temporal flexibility and constraints, household interactions, history dependency in activity/trip making, and mode/destination inter-dependencies across trips in a chain or tour.

It must be recognized that pricing policies, and in particular, variable pricing policies, are by nature “dynamic”. Developments in activity-based modeling have largely occurred independent of the developments in dynamic traffic assignment and network simulation (references). Activity-based models that accurately reflect the spatio-temporal impacts of pricing policies on activity-travel patterns are of no use if the resulting travel patterns are loaded on the network using traditional static equilibrium assignment algorithms. Dynamic traffic assignment algorithms that reflect network dynamics with respect to paths, travel times and costs, speed-flow relationships, and so on must be integrated with activity-based model systems to simulate the impacts of dynamic pricing policies on traffic volumes.

CONCLUSIONS AND FUTURE DIRECTIONS

This paper provides perspectives on modeling pricing in the planning process with the recognition that such analysis is and will be very important as transportation planners increasingly consider pricing mechanisms to manage travel demand and raise revenue for transport infrastructure improvements. Although current travel demand models incorporate elements that are responsive to pricing policies, they fall short of offering a robust paradigm and methodology for modeling the impact of pricing on travel behavior. Emerging tour-based and activity-based models together with advances in dynamic traffic assignment and network simulation algorithms offer rigorous methodological and behavioral frameworks for modeling increasingly innovative and dynamic pricing schemes in the planning process.

These methods recognize the activity-travel inter-dependencies, agent-based interactions, time-space constraints and flexibility, induced/suppressed activity engagement, and activity scheduling and re-scheduling processes that form the basis of behavioral response to pricing policies.

As the profession moves towards the development, refinement, and implementation of advanced activity-based travel demand modeling procedures, it is critical to understand how they perform vis-à-vis traditional four-step travel demand models in modeling pricing in the planning process. Several questions remain unanswered and controlled studies/experiments need to be commissioned to understand how, where, when, and why advanced activity-based modeling procedures offer clear benefits over traditional modeling methods. These questions include:

1) What is the effect of input assumptions and input variable forecasts?
2) What is the effect of alternative modeling methodologies and specifications (such as functional form, estimation method, explanatory factors, market segmentation, model parameters, etc.)?
3) What is the effect of the fundamental behavioral paradigm that forms the foundation of the travel demand modeling system?

Controlled studies using real-world data derived from ongoing value pricing and variable toll-road projects should be undertaken to answer these questions. Comparisons of estimates and forecasts offered by different modeling methods and paradigms would offer an ideal basis for testing and validating new activity-based travel demand modeling systems in precisely the context that these models are supposed to offer more robust capabilities. The ongoing projects also offer the ability to conduct specialized experiments and surveys that can shed light on such aspects as willingness-to-pay and traveler attitudes, perceptions, and acceptance of pricing policies and associated technologies.

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Panelists' Comments and Audience Discussion

Advantages of Tour- and Activity-Based Models

Panelists and audience members cited several advantages of tour- and activity-based models over four-step models:

- Because they can handle dynamic traffic assignment, they are generally better at simulating the complex relationships that determine travelers' behavior.
- They allow for more choices in discrete travel characteristics.
- They are more intuitive to people who are not modelers.
- They have a faster run time because they do not need matrices.
- They can handle peak spreading more effectively.
- They can handle trip chaining more effectively.

Enhancing the Four-Step Model versus Developing New Tour-Based Models

There was a sense among audience members and panelists that the modeling field in general would be better off investing resources in developing tour- and activity-based models capable of incorporating pricing, rather than tweaking four-step models; the four-step models simply are not sophisticated enough to handle pricing effectively. The four-step model's primary limitation is that it is not good at dynamic traffic assignments, which is necessary to reflect changes in behavior due to changes in road price.

While four-step models do not handle pricing as well as tour- and activity-based models, they have some capability to incorporate pricing, usually in the route choice or mode choice phase. The North Central Texas Council of Governments—the MPO for the Dallas-Fort Worth area—incorporates pricing in route choice, and then validates the model against actual traffic counts.

Nonetheless, a few participants cautioned against jumping into tour- and activity-based modeling too quickly. Modelers must understand the costs and benefits of developing new models before making the decision about how to best invest in modeling improvements. To best understand the advantages and disadvantages of each type of model, there needs to be comparative studies of forecasts using different kinds of models. A further caution is that modelers must keep their expectations low so as not to promise more than the new models can deliver.

Research on Tour- and Activity-Based Models

There is very little pure research being done on developing tour- and activity-based models. The major barrier to conducting this research is funding—most modeling agencies simply do not have the money to research, develop, and implement a new travel demand model. When they do invest in new models, they generally concentrate on the few model components that affect their decision making, rather than model. It is up to the modeling industry to convince modeling agencies to fund more pure research on the topic. One way to encourage more research would be to create an MPO coalition for pooled-funds studies. Also, FHWA and FTA may be able to fund some research. TRB might also be able to direct NCHRP money towards new modeling techniques. Now is a good time to convince decision makers that this is an important topic because road pricing has momentum as a way to finance road construction and operation.

The Optimal Price

Several panelists and audience members noted that determining the optimal road price depends on what modelers are trying to maximize—revenue, throughput, or social welfare. On tolled roads, the traffic volume that maximizes revenue may be higher than the volume that maximizes throughput. Revenue maximization, then, can result in congestion in the tolled lane. It can also result in a loss of social welfare because the price is higher than the equilibrium price. There are other, more direct, losses that can result from road tolling. For example, retailers within London's cordon zone have reported a significant loss of recreational shoppers.

Transportation planners want to optimize throughput. For congestion management, traffic in tolled lanes must be free flowing. The key to this is to set the toll so that demand is cut off before the tolled lane exceeds its capacity. Determining the price for maximum throughput requires dynamic assignment and microsimulation so that link loading is stopped when throughput is maximized. Current four-step travel demand models are simply not sophisticated enough to handle this type of problem.

Forecasting Errors

There was audience discussion on revenue and traffic forecasting errors, and why they are consistently over optimistic. One possible answer is that projects with low forecasts are not built. Focusing only on projects that are built, instead of also considering projects that were proposed but not built, results in a sample bias towards optimistic forecasts. Another explanation is that there are political forces driving forecasts. Whether deliberately or unintentionally, modelers—and therefore their forecasts—sometimes incorporate the political context. Finally, a technical explanation for forecasting errors may be because models have more opportunities for flexibility than constraints.

A panelist suggested that the main source of error is in willingness to pay and VOT. Another person thought that poor land use forecasts may also play a significant role. External factors such as a recession or unexpected government action may also play a role. Inaccurate predictions of VOT and land use were the primary causes of the failure of the Dulles toll road. At the outset, forecasters thought that the toll road would primarily serve people who could not afford to live closer to the city. They expected the land around the toll road to be mainly residential. However, the result was exactly the opposite. High income people moved to the suburbs served by the toll road, and the land around the toll road became a major center for high tech businesses. Originally, the plan was to set the toll low to attract users, and raise the toll incrementally until revenues equaled costs. However, demand was never high enough to allow for a sufficiently high toll.

A panelist observed that Europeans generally have better, more independent, and more robust models and forecasts than the U. S. This is probably because Europeans have more experience with road pricing and have learned the importance of good forecasts. Therefore, they are willing to invest in good forecasts. Too often, Americans are not. One participant suggested that the abundance of inaccurate forecasts might be one reason why government agencies do not invest in better models. Agencies may see further investment as throwing good money after bad.

Encouraging Better Modeling in State and Local Governments

The biggest barrier to better travel demand modeling is that most modeling agencies do not have money to invest the resources necessary for a complete change in their modeling techniques. Besides the expenditure on new data collection and model development, there is also significant risk involved, since the application of tour- and activity-based models has not yet been proved. As more tour-based models are implemented, it will be important to disseminate success stories and lessons learned to encourage their wider spread implementation.

Traffic and Revenue Forecasting for Roads and Highways:
Concerns, Methods and a Checklist for Practitioners

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Abstract

Traditional public sector funding sources are less able to meet the growing demand for highway infrastructure in the United States. As a result, some state DOTs and MPOs are considering alternative methods – notably, tolling - to finance new highway projects; and a growing number of projects involve financing, implementation and/or operation by or with the private sector.

Financial feasibility of a facility has taken on a greater importance in project approval and financing decisions. The revenue projections that are used to assess financial feasibility are derived from travel demand forecasting models. This creates new roles and applications for the models. In light of significant differences between projected and actual revenues for several tolled facilities, the credibility and reliability of the models have been questioned. Some of the problems identified reflect model structure and methods, while others reflect model assumptions and inputs. Many of the traffic and revenue forecasts used existing MPO or state DOT models as the initial platform.

This paper proposes to provide guidance to MPOs and state DOTs as they consider tolling or embark on the use of their models for traffic and revenue forecasts. There are three parts to the paper: First, a brief description the practice of modeling, current concerns and the evolution of the state of the practice. Second, an explanation of the differences between 'traditional' model applications and the applications of these models for toll road traffic and revenue forecasts. Third, based upon these differences, a checklist of questions that state DOTs and MPOs could use to guide the development and interpretation of the traffic and revenue application.

1. Introduction

1.1 Context

In the United States traditional public sector funding sources for transportation projects are not able to meet the growing demand for new highway infrastructure, nor are they able to meet the demand of maintaining an aging infrastructure. Motor fuel taxes, the primary source of transportation finance, have not kept pace with the demand for travel and in turn, for capital investment, due to inflation, improved fuel efficiency and increased vehicle usage (1). State DOTs are turning to user-based fees or tolling as a means of financing road improvements and expansion, in addition to managing the growing traffic demand for both urban and inter-urban facilities. The Texas DOT, for example, has determined that any new highway project in the state must be evaluated as a toll road (2).

The use of tolled roads is not new. Over the past decade, persistent questions have arisen regarding the reliability and credibility of the travel demand (i.e., traffic) forecasts. These are the base for the revenue projections that are used for financing. The questions are the result of the ‘performance’ of some toll roads, how closely projected revenues matched actual revenues. For example, the privately held Dulles Greenway (Virginia) went into default in 1996, when toll revenues were less than projected (20% of projected in 1995, its first year of operation; and still only 35% of revenues in its fifth year). Another example, is seen in the revenues from the Southern Connector (South Carolina) which covered operating costs but only a portion of the debt service, because traffic projections were not met (just over half the projected demand in its third year). Similarly, traffic on the Pocahontas Parkway (Virginia) has been just under half the projected demand in its second year of operation. As a result the ratings for the bonds for both facilities were lowered (3). The Foothill Eastern toll road was refinanced in 1999 (4). Various inaccuracies in the traffic and revenue forecasts were cited as contributing factors to the financial problems of the Pocahontas Parkway and the Foothill Eastern toll roads and others. These included the unanticipated impacts of a recession, actual ramp-up volumes being less than projected and the expected extension of a connecting road not occurring (5).

The credibility and reliability problems of some toll forecasts have not gone unnoticed in the transportation and financing communities. In recent years, there have been a number of attempts both to improve the state of the practice and to explain and address the problems (see, as examples, (6) and (7) respectively).

The problems are by no means resolved. One opportunity to improve the state of the practice, and the focus of this Forum, is to provide guidelines to practitioners as they embark on traffic and revenue forecasts in particular, to MPOs and state DOTs.

1.2 Purpose

The purpose of this paper is to develop a checklist of questions for local, metropolitan and state transportation planning agencies (and others) to use to guide the development, application and interpretation of traffic and revenue forecasts. The focus on public agencies is important because many traffic and revenue forecasts for individual projects to date have been based upon existing MPO or state models and data. These may or may not be updated, recalibrated or otherwise enhanced for the specific purpose. If toll facilities become widespread, it is possible that enhancements for toll road modeling will ‘feed back’ and influence the general application of models in the development of long-range transportation plans and other ‘traditional’ public sector activities.

1.3 Organization

The remainder of this paper is organized as follows. Section 2 outlines the evolution of modeling practice, identifying some concerns with existing models, emerging modeling methods and specific methods for modeling toll road demand. This outline is not an exhaustive treatment: it provides context for the discussion on applications to toll road traffic and revenue forecasting. Section 3 reviews the differences between traditional applications of the models, and their use in toll road traffic and revenue forecasts. Section 4 presents the checklist of questions that MPOs and state DOTs could consider as they develop and apply their models to toll road applications. Finally, Section 5 concludes with an outline of possible next steps.

2. Evolution of Modeling Practice

2.1 Concerns with Existing Models

Concerns regarding the reliability, accuracy and credibility of travel demand forecasts are not new. A 1989 U.S. Department of Transportation study found that the projected ridership for each of ten heavy- and light-rail transit projects in nine American cities was significantly lower than forecasted (11). A 1995 Transportation Research Board study on air quality conformity analysis found that the “analytical methods in use are inadequate for addressing regulatory requirements… current regulatory requirements demand a level of analytical precision beyond the current state of the art in modeling” (12). Recently, a study of 183 tolled and non-tolled road projects around the world found that forecasting accuracy had not improved even as new techniques became available, despite the fact that the newer forecasts attempted to address some of the concerns (7).

Model structures and methods are evolving. The traditional four-step paradigm of trip generation, trip distribution, modal split and trip assignment was developed in the 1950s and 1960s. The models were applied primarily to major transportation facility planning (mainly highways) in accommodating the rapid post-war urban growth. The four-step process continues to be the most commonly-used model formulation (13). Concerns regarding the structural and methodological basis of the four-step process have arisen. Most notably (14):

- Inconsistencies in the four steps, with respect to their formulation, choice of parameters, and the values (costs, etc.) assumed. Some agencies have addressed these through focused data collection and improved parameter estimation.

- The four-step process treats travel choices as independent decisions. In reality they are not mutually exclusive. Some agencies have addressed these by combining steps (e.g., the trip generation, distribution and modal split (15)).

- Several different methods are used to develop the land use (demographic and socio-economic) inputs to the forecasting process. There is no consistency in the methods or assumptions that are used to develop these primary determinants of travel demand. Problems of inaccurate and questionable results are compounded by the depiction of these data as zonal averages in the four-step process (16).

It is also important to note that the models of some agencies lack steps. For example, they lack the three demand steps, or model demand exogenous to the model. Or they treat some steps simplistically, for example, the 'all-or-nothing' method continues to be used for trip assignment in some models. Other applications lack basic capabilities, although the methods are readily available and have been well-established in practice.

2.2 Emerging Modeling Methods

Methods are emerging to address these concerns. Of particular relevance:

- <u>Activity-based modeling</u> addresses behavioral inconsistencies such as simultaneous choices, lack of feedback, etc. The approach simulates an individual's travel choices as part of overall daily activities, which ensures that the travel choices are depicted in context (13). For example, "I will go into the office today, rather than work from home. I won't leave for work until my children have left for school. I will take transit today because my spouse needs the car." Its basis in micro-simulation techniques also circumvents the problems associated with zonal averaging.

- <u>Time of day choice modeling</u> adds to mode choice and route choice modeling. Time of day choice can be expressed in terms of the time 'slices' of a day or the days that are modeled (e.g., weekday versus weekend or holiday); peak spreading (the allocation of trips between the peak hour or half-hour and the peak 'shoulders,' as the expansion of the duration of the peak period over time); or, trip 'scheduling' (the explicit modeling of the time at which the traveler starts his/her trip in order to arrive at a destination within a desired 'envelope' [e.g., between 8:45 and 9:00 a.m. every morning]).

In addition, network micro-simulation models have come into use as tools to simulate the dynamics of traffic along corridors and networks. Whereas travel demand forecasting models simulate 'average' speeds for an hour's slice of traffic, these models represent traffic flows microscopically through a network as a series of individual vehicles and track each vehicle's progress at a finite resolution (e.g., one second or less). This allows for the analysis of such traffic phenomena as shockwaves, gap acceptance and weaving (17).

Network micro-simulation models are well established in transportation planning practice, notably including several recent managed lane applications. However, to date there is only a very small number of practical applications of activity-based models in the United States (18) and few applications of time-of-day choice modeling. The TRANSIMS initiative of the Travel Model Improvement Program also can be expected to impact transportation planning practice (12).

2.3 Methods for Modeling Toll Road Demand

There is no consensus as to the best methods for developing traffic and revenue forecasts. The choice of analytical methods varies, according to the method used to develop origin-destination trip tables for a given time, period, trip purpose and travel market segment (19).

A review of the practices for value pricing projects in several U.S. cities identified five categories of modeling procedures. Although the review focused on forecasting for managed lanes, the categorization is applicable more generally to toll road demand forecasts. The five categories are (18):

- <u>Activity-based model</u>, which allows pricing to be included explicitly into the decision hierarchy. To date only Portland, Oregon has applied this model to an analysis of value pricing.

- <u>Modal split model</u>, in which auto trips on a tolled or non-tolled road are considered as distinct modal choices within the existing four-step model, with separate modal split functions for work (or work-related) and non-work trip purposes. The functions also are differentiated according to values of time. Phoenix, Arizona and Sacramento, California have used this approach, as did the analysis for the "MnPASS" managed lane system in Minneapolis – St. Paul, Minnesota.

- <u>Trip assignment model</u> applies a diversion of trips within trip assignment. It assumes that trip distribution and modal share remain unchanged in the absence of feedback loops. There are two methods. One translates the monetary toll into a time-equivalent, through the value of time. Equivalent times then are incorporated into the model's volume-delay functions, which allocate trips among different paths according to travel time, capacity and congestion. The second method uses diversion curves. These commonly use the logit formula, which calculates the propensity to use a tolled facility as a function of the relative cost between the tolled and non-tolled route. The process develops tolled and non-tolled trip tables, which can be categorized by purpose, income group, auto occupancy, time period, etc., for assignment.

- Post-processor, which uses a separate procedure to divert the assigned traffic volumes from general purpose lanes to managed lanes, according to the excess capacity available in the latter. Washington, D.C. and San Diego, California applied this process as an add-on to their existing four-step models. The assigned volumes were input to the FHWA's *Surface Transportation Efficiency Analysis Model* (STEAM) in order to calculate costs and tolls as part of a pricing study in Minneapolis – St. Paul.

- Sketch planning methods, which are quick-response tools for project evaluation. Examples include the FHWA's *Spreadsheet Model for Induced Travel Estimation* (SMITE), SMITE-ML which is a variant for analyzing managed lanes, *Sketch Planning for Road Use Charge Evaluation* (SPRUCE); and the Texas Transportation Institute's *Toll Viability Screening Tool* (20).

3. What Makes Traffic and Revenue Forecasts Different?

It is useful to identify the features of traffic and revenue models and forecasts that differentiate them from 'traditional' public agency applications, such as long-range transportation plans or corridor plans. Some of the features are in common practice, while others represent emerging or desired treatments. The key features are:

- Focus on pricing. The models commonly focus on estimating the impacts of pricing, which can range from a high-level, network-wide analysis of the feasibility of pricing to a detailed, facility-specific estimation of expected toll revenues. This is then used as the basis for financing the project. The Texas Turnpike Authority considers four levels of analysis: conceptual, sketch, intermediate and investment grade. The last is used for proceeding to the bond market for project funding (21).

- Model 'performance'. Because of the magnitude of the monetary amounts involved over the lifetime of a facility, the 'performance' of the forecasts is subject to considerable scrutiny by the financial community. The bond rating community has assessed the performance of individual facilities, compared the actual and projected revenues, and attempted to categorize and explain the shortfalls. For example, one bond rater assessed the performance of 24 facilities over their first five years of operation. The facilities were grouped into four categories, according to location in an urban area, degree of integration with the existing road network, corridor income levels (i.e., of the drivers who would use the facility), time savings offered by the facility (i.e., the extent of congestion on competing non-tolled facilities), value of time, projected traffic growth (a function of the reliability of demographic and socio-economic forecasts) and the extent of development in the area served by the facility. The assessment found that the most 'accurate' forecasts were for facilities in built-up (suburban) areas of high congestion. In decreasing order of accuracy were facilities in outlying sections of metropolitan areas; developed corridors parallel to existing roads and/or facilities for which the underlying demographic and socio-economic forecasts were "faulty" or based upon overly optimistic projections of development; and, finally, facilities in least-developed areas where the facilities relied on one specific traffic generator as the project basis (such as an airport), the toll road was expected to stimulate development and there was insufficient congestion on the existing road network (4).

'Performance' has commonly been measured in terms of the *revenue* forecasts, as opposed to the *demand* forecasts upon which the revenues are based. Revenue forecasts may be adjusted separately from the demand forecasts, for example by assuming increases in toll rates applied to the same demand. Such post-modeling adjustments may mask inaccuracies in the demand forecasts, for example, in the breakdown of estimated traffic by vehicle type.

- <u>Time periods</u>. Traditional model applications focus on addressing peak network loading requirements, which in an urban area typically occurs during the morning or afternoon peak periods. Most MPO models are calibrated to one of these time periods. Traffic and revenue forecasts require annual rather than peak hourly estimates, which means that the base model traffic and revenue estimates must be extrapolated to daily and annual estimates. This in turn implies the need to consider how value of time varies by time of day and the associated differences in trip purposes, network congestion levels and trip distribution, as opposed to a simple extrapolation of peak-hour volumes according, for example, to traffic counts. Seasonal variations and different traffic compositions on weekends and holidays also may be significant. The use of simple extrapolations based on weekday peak hours may be inappropriate.

- <u>Land use inputs</u>. The appropriate demographic and socio-economic inputs are important, given that future travel demand is dependent upon the assumed magnitude, timing and distribution of development. This has several aspects. First, the basis of the input forecasts may reflect long-range official or policy forecasts from MPOs, with little or no consideration of actual, more 'conservative' market trends in development. Second, the base / current year estimates for the model may reflect very different conditions from the facility's actual base / first year – in particular, recessions in the opening year or a slower than expected recovery from an earlier recession. Third, even if overall region-wide forecasts prove accurate, localized development delays within the facility's corridor (i.e., in the expected market for the facility) may have a greater impact on demand. Fourth, the basis of the demographic and socio-economic inputs may not fully reflect the determinants of travel demand, such as expected increases in productivity or the retirement of the 'baby boom' generation. Finally, the demographic and socio-economic forecasts may not account for exogenous impacts, such as the post- September 11, 2001 reductions in air travel. (4) (5) (10)

- <u>Value of time inputs</u>. The 'value of time' equates monetary and travel time impacts of route choice - that is, the driver's decision to use the tolled facility rather than a non-tolled alternate route. The value of time commonly is modeled by trip purpose, mode, average income levels or time of day. Some researchers note differences according to gender, trip length and level of education (8). A traveler's 'willingness to pay' is a value of time that accounts for how much travelers value different attributes of the proposed facility (such as improved safety and reliability), as opposed to travel time differentials alone.

- Tolling history. Relatively few areas have a history of tolling. The introduction of a tolled facility often represents a concept where there is little local insight regarding appropriate time values and existing revealed preference (i.e., origin-destination) surveys do not capture this relationship. The stated preference survey technique is used to capture how travelers would behave in new situations, by quantifying how travelers value the benefits of alternative combinations of prices and travel benefits.

- Trucks and commercial vehicles. Commercial and freight activity is commonly considered to be an important market for tolled facilities, in addition to the private transportation of people. This is because of the typically higher tariffs that can be charged to them, given the direct impact of delays on operating and product costs. Their contribution to a facility's toll revenues thus can exceed significantly their portion of the vehicle mix. However, relatively few urban models simulate trucks or commercial traffic; and relatively few urban areas have detailed data or surveys on the characteristics of this traffic. The unique characteristics of truck and commercial traffic imply that this traffic cannot simply be extrapolated from the existing auto model – for example, peak truck activity in many cities typically occurs outside the (modeled) commuter peak hours. Moreover, the relationship between time and cost is different for truck and commercial drivers, meaning that their decision to use a tolled facility is not the same as that which is modeled for auto drivers.

- Ramp-up period. Both traditional and toll road forecasts must consider long-term horizons. The financing and debt servicing schedules of new toll facilities mean that considerable importance is placed on the short-term performance of the facility. The 'ramp-up period' refers to the time for traffic volumes to reach their full potential after the opening of a new toll facility, without the possible additional impacts of population or economic growth. An unanticipated opening-year recession can significantly impact the performance of ramp-up forecasts.

  The ramp-up period can last for several years. Its duration can be impacted by factors such as the existing level of congestion on the existing competing, non-tolled network; the magnitude of expected travel time savings; the income levels of corridor residents (i.e., of the expected users); and, the existence of a tolling history or how long it takes for drivers to accept the concept of having to pay for the use of a facility (9) (10).

- Risk analysis. The consideration of risk is common practice in financial analyses. 'Risk analysis' is not the same as sensitivity analysis, which is commonly used in traditional travel demand forecasting. Rather, it estimates the incidence and magnitude of an adverse effect on a given population (22). In the context of toll road traffic and revenue forecasts, it refers to the likelihood of particular values of various inputs (such as, the estimated value of time) or the assumed configuration of a base future network actually occurring, and when and where they occur. It can also refer to uncertainties in the modeling process and structure.

Emerging practices include the consideration of probability distributions of parameter values, through the use of Monte Carlo simulation (23). One treatment assigns a probability distribution to the input variables that are identified as being most influential to the forecasting process. The input variables, each with its own probability distribution, can be 'fluctuated' simultaneously. This combined treatment provides a more realistic depiction of outcomes, because variables do not generally change one at a time but concurrently, and with varying rates of change (23). The significance is that the value of time, for example, that is used in toll road traffic and revenue forecasts and which has been derived from stated preference surveys, may actually represent average values; can represent proxies for several attributes (such as comfort, safety, convenience, reliability, etc.); and, are assumed in the resultant models to reflect perfect knowledge on the part of the survey respondent at the time of his/her participation in the survey (24).

- Stress tests. The financial community commonly uses these to assess the financial stability of a project. The process revalues the project's financial performance according to a different set of assumptions in the face, for example, of unforeseen "shocks." [A hypothetical example for a toll road could comprise a sudden and severe energy shortage, with resultant sharp increases in fuel prices and a prolonged recession.] Most asset markets [including toll roads] lack a history of returns that provide sufficient information about the behavior of markets under extreme events. Stress tests complement traditional financial forecasting models by testing how the project's value changes in response to "exceptional but plausible" changes in the underlying risk factors. In addition to testing "market risk" [such as toll revenues being less than projected], the process also examines credit risk (losses from borrower defaults) and liquidity risks (illiquidity of assets and depositor runs). Several techniques have been developed in recent years. (25)

- Peer reviews. There are no formal requirements for peer reviews in toll road traffic and revenue forecasts. The bond rating community has called for more and improved reviews (5).

  In Europe the general practice is to conduct three sets of forecasts for: the grantors of the concession (governments); the facility sponsors (proponents); and, the financial backers (lenders, investors and/or auditors). The governments' forecasts are considered overly optimistic, because they are used to develop long-range policies and plans. The proponents' forecasts usually are the most extensive, although they do not always provide the best results because they are driven by the model and they have a strong technical focus. The financial forecasts (audits) usually are less intensive efforts that are intended to review the proponents' forecasts, although more substantive efforts may follow if the review identifies fundamental problems. The audit relies upon sensitivity tests, spreadsheet modeling and stress testing. At the end of the process, the auditors also must put their name to the forecast.

The proponents pay for their forecasts as well as those of the financial backers. As a result, the proponents try to control the latter's audit. Some proponents now bring the auditors into the process early, before the lenders are appointed. This puts some pressure on the auditors, but it provides an opportunity for the auditors to suggest improvements early in the process and – by the time proponents have put forward their case – allows issues generally to be understood. (24)

Peer review requirements vary in public sector modeling applications, although they do provide a reference point. The Federal Transit Administration has specific requirements and a standardized review procedure for its *New Starts* discretionary grant program (26). The Federal Highway Administration allocates funds on a formula basis, so that states and MPOs do not have to compete on a project-by-project basis for funding, meaning that the same degree of standardization as the *New Starts* program is not required. However, the FHWA provides technical assistance to ensure forecasts are credible and are based on proper planning practice. This assistance includes a checklist of questions, the use of peer review teams and the revision of specific individual forecasts for specific projects (27). The Travel Model Improvement Program recommended several improvements to current practice, such as: the incorporation of freight-based activities into travel demand modeling; the improvement of data quality through supplementary specialized surveys; the use of consistency checks throughout the modeling process; ensuring sufficient flexibility in the model design to support toll (and other) modeling; and, the inclusion of time of day variables in the models (28).

4. Checklist for Toll Road Forecasting: Questions to Ask

The following is a proposed checklist of questions that MPOs and state DOTs could use to ask their modeling staff, or consultants or other external organizations that calibrate and apply the agencies' travel demand models. The questions may vary according to the level of analysis (that is, whether it is being used for a first-cut, conceptual analysis or for a detailed investment-grade forecast) and whether a new model, or the enhancement or recalibration of an existing model, is being considered.

The list is derived from critiques of the performance of toll road forecasts prepared mainly by the financial community and from the peer review procedures. The questions might be asked of any model: the object is to pose them specifically for the issue at hand.

- For what type of analysis (or analyses) is the model being developed or applied, now and in the future? Who will be using the results of the model? Whose perspective do they represent (e.g., the government, a proponent, the financial community, an auditor)? What types of questions will they ask? What types of decisions must they make? What types of information is needed from the model to support these questions and decisions? Decisions made by the financial community will require different types of outputs, reliability and assurances than will those used, for example, in long-range transportation plans.

- Is the existing or proposed modeling tool appropriate for the level of analysis? For example, does a conceptual plan require a detailed travel demand forecasting model, or would a spreadsheet model suffice? Is the model too detailed and defined, or insufficiently detailed and defined, for the analysis?

- What, *a priori*, is the desired or expected ‘market’ for the new facility? For example, is the desired market local commuters, long-distance trucks, people accessing a major generator (such as an airport), or visitors to a national park? Many urban transportation planning models address the first market (commuters), but none of the others. If so, how will the model be modified or enhanced to depict a desired or expected market?

- How current is the base model? An out-of-date model may not capture critical changes in the travel ‘market,’ development patterns or the transportation network.

- What travel data are available to describe the desired or expected markets? What data will be collected to address any gaps in coverage or market, or any old data?

- Has the model been used in other applications? If so, what limitations were found in the application? Are these limitations well understood? If problems were identified, were these addressed? If so, how were they addressed?

- Was a peer review process used in the development of the model? What were its recommendations? How were these incorporated into the development of the model?

- What procedures and statistical tests were used to calibrate the model? What criteria were used to calibrate the model? How well did the calibration perform? How detailed was the calibration in the specific study area; and how well did it perform?

- Was the model validated? What procedures were used? How well did the validation perform? How many years were validated? What was the source of the data used for validation?

- What modeling approach is used to simulate demand? Does the model account for demand, or is it an assignment model only? If demand is not modeled, how would potential impacts of diversions in trip distribution and modal share be captured?

- Does the model have feedback loops? Do the impedances account for toll versus non-tolled routes? What is the impact of the toll route on trip distribution and modal split? Are these impacts significant and within expectations?

- What time periods are modeled? How can these be expanded to replicate conditions in other time slices of the day? What factors or procedures will be used, and on what will these be based? If the model is based upon 24-hour conditions, how are peak conditions derived (i.e., for trip assignment)?
- The importance is that the expansion must take into account the different travel conditions (e.g., congestion levels) and traffic characteristics (distribution, traffic mix) in determining how the driver's value of time varies at different times of the day. If weekend, holiday, seasonal traffic or special generator traffic is expected to be an important market for the facility, how will the (typically) weekday peak hour model be expanded to capture it, or will a completely separate model be developed?

- Are all relevant modes modeled (in particular, are trucks and commercial vehicles modeled and, if so, are they modeled to an appropriate level of detail and sensitivity to travel time and costs)?

- What modal split approach is used? What parameters are used as the basis for modal split?

- What approach is used to simulate trip assignment? Is the algorithm sensitive to travel time? What parameters are used as the basis for assignment?

- Can the model algorithms support the addition of a toll modeling function (using one of the five types identified in Section 2.3)?

- How detailed is the model in the study area corridor, in terms of the number of zones and the coding of the network? How consistent is the coding from one section or version of the network to another? A coarse treatment of the study corridor's zone and networks may miss critical details and connections regarding how the model assigns traffic to the proposed facility, independent of the impact of tolls. A simple sub-area detailing of the network coding and zone structure may require a model recalibration in order to ensure that the corridor is simulated correctly.

- What is the basis for the value(s) of time used in the tolling model? Are the values broken down by mode and purpose? Are the data and rates derived from local conditions, or are they borrowed from facilities elsewhere; the issue concerns the transferability of data from other facilities, given that each project has different characteristics. Regardless of the source, were the data based upon stated or revealed preference surveys? How were factors such as tolling 'history' taken into account? Is willingness to pay considered explicitly? What variables are taken into account? How are these quantified? How would the values of time vary if different toll collection methods were considered? How were values of time for trucks and commercial vehicles estimated given, for example, that someone other than the driver may be 'paying' for the toll? Do the values of time represent averages, or is variability taken into account? How? How is the impact of changes in toll rates over time taken into account in the forecasts? How do these rates compare with the opening-day rate?

How frequently are they expected to change and by how much? How are violation rates considered?

- What network scenarios are assumed for the first year of operation and for the future horizon years? Do these include only roads and other transportation improvements that are committed or are under construction, or do they account for facilities that would be built according to the local long-range transportation plan? Does the inclusion of specific facilities and connections add to or detract from the attractiveness of the planned toll facility? How does the configuration, staging or timing of the planned toll facility impact the demand?

- How is the assumed first year of operations simulated? Is this treated as a forecast in the model; in which case, what is the basis of the demographic and socio-economic inputs, given that the likely relatively short elapse of time between that year and the model's base year?

- What are the sources of the demographic and socio-economic inputs for the horizon years? Do these data replicate the significant determinants of travel demand generally, and of toll demand specifically (notably, income levels)? Do these data represent a policy or planning forecast? How closely do they reflect recent demographic and economic trends in the state, the region or the corridor? How would the demographic and socio-economic forecasts vary under recessionary conditions during, preceding or following the assumed first year of operation, or by duration (short or prolonged)? How is the non-linear growth in population and economic growth taken into account, given that growth may vary from year to year, independent of horizon year forecasts?

- How is ramp-up modeled? How is the duration of the ramp-up period determined? What are the impacts of significant changes in the demographic and socio-economic impacts (notably, recessionary conditions)?

- What sensitivity tests are planned? How dependent is the forecasted demand on projected future growth? How will it vary if this growth or other parameters (such as the toll rate and structure, or changes in the toll rate) varies or does not materialize, or if planned complementary / competing transportation infrastructure is not implemented? How would the forecasted demand for the facility vary if there were no tolls?

- How is risk analyzed? What variables are subjected to risk analysis, and in what combinations? What methods are used? What variables are subject to stress, and on what assumptions are these based?

- With what other data or studies can the forecasts be compared, as part of 'reality' check?

- How will the results be documented? Are assumptions, inputs and modeling procedures and their derivation described at a level of detail sufficient to allow the intended end user (who may not be a modeler) to understand them? How are the results presented? What caveats, limitations or conditions are provided as a context in the presentation? How are the results of the risk analysis and sensitivity tests presented?

5. Conclusions: What Next?

While some of the methods described in Section 3 are beginning to appear in traffic and revenue forecasts such as recessionary demographic and socio-economic scenarios and other variations, it is too soon to determine their impact. Their effectiveness will become apparent only after a facility is opened.

Understanding the differences between the traditional and tolling applications, and who is asking the questions and why, is critical. All participants in the traffic and revenue forecasting process must understand, and be able to speak credibly to, the reliability of the process and its outputs and to the sensitivities of these outputs to individual processes, inputs and assumptions. They must understand the determining factor(s) in a particular application: for example, is the assumed network configuration or the assumed value of time more important to the forecasts? This suggests the need for industry-adopted guidelines regarding modeling methods; types of input data and how to prepare them; interpretation, testing and validation of model outputs; etc. One example is the Texas Turnpike Authority, which has developed guidelines for the development of traffic and revenue forecasts (29).

Many of the references cited for this paper come from the financial community. The relevance is two-fold:

- First, the financial community is posing questions that have not commonly been considered in the transportation modeling community. As evidenced by the literature, the latter tends to be more focused on modeling method, as opposed to model credibility or reliability.

- Second, these questions are resulting in changes in practices. Risk analysis and the aforementioned testing recessionary scenarios are two examples of methods driven by the financial community that are being introduced to modeling practice. The use of stress tests, to examine the impacts of catastrophic, simultaneous occurrences could be another.

The questions, criteria and methods put forward by the ‘new’ partners, the financial community, in transportation planning decisions eventually will or should impact the overall process of long-range transportation planning. An improved modeling approach would anticipate these impacts by building the flexibility into the agency’s base model through better data and surveys, tighter calibration up front, etc., rather than trying to refit the model later for the specific tolling application. This approach recognizes clearly that the model will be used for purposes other than those for which it was originally intended.

The alternative – namely, the development of completely new purpose-built models – may be the ideal treatment for an individual traffic and revenue study. However, this is expensive, although the practice overseas is to devote the necessary resources to model development for such studies. It also requires reconciliation with the MPO's or state DOT's long-range transportation plans, and the land use and travel forecasts upon which the plans are based.

6. Acknowledgement

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Panelists' Comments and Audience Discussion

Liability

Panelists and audience members noted that the risk involved with revenue forecasting is one of the biggest challenges the industry faces. This led to a discussion of liability for inaccurate forecasts. No participant could recall a lawsuit that ensued from bad revenue forecasts. However, the possibility of a lawsuit may be a barrier to entry into the field for small companies.

There is currently no insurance available to cover damages due to bad forecasts. Generally, firms that do revenue or bond work assume more liability when they work for the public sector than the private sector because private sector firms, seeking to make a profit, are expected to have more in-house knowledge about revenue forecasting than does the public sector. For large clients, forecasting firms sometimes ask for indemnification.

If forecasters were required to be licensed, a market for malpractice insurance would probably emerge. It is also possible that, if there were any litigation based on poor forecasts, the liability would fall on the board of the toll operator rather than the revenue forecasting firm.

Risk Analysis

A panelist noted that revenue forecasting and bond-issuing companies can probably do better risk analyses than can the public sector. Private sector companies can review the proprietary information used in forecasting (methods and data), and have experts on staff to understand and evaluate it. The panelist also pointed out that, generally, revenue forecasters know the source of the risk (exogenous events and data), but do not necessarily know how to ameliorate it.

For risk tolerance, the amount of risk one is willing to assume is directly related to the precision of the revenue and traffic forecasts. For example, for a 90 percent probability that the actual value will be greater than x, x will be lower (and therefore less precise) than it would be if one were satisfied with an 80 percent probability.

Tolled Lanes versus HOT Lanes

There was a discussion about how the analysis of the effect of tolls changes when addressing an HOT lane as opposed to a pure tolled lane. Panelists felt that it is probably easier to forecast for HOT lane usage because tolled and non-tolled lanes are much better substitutes for each other than are roads on separate rights-of-way. In the case of HOT lanes, traffic volume will probably equilibrate between the free and HOT lanes because travelers can easily see which lane is the best choice for them and change lanes accordingly.

Making the State of the Art the State of the Practice:

Advanced Modeling Techniques for Road Pricing

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Abstract

A growing number of different road pricing forms and technologies represents a new challenge to travel modelers that requires a better understanding of the impact of pricing on various aspects of travel behavior and its incorporation in modeling procedures. A wide range of possible modeling techniques is currently applied for road pricing. For short-term revenue forecasts of an established toll facility, simplified sketch-planning tools are frequently used. Studies for construction of a new facility or large-scale road pricing schemes tend to use a comprehensive travel demand model either on a regional scale or at least corridor-based. In the current paper we primarily focus on general modeling techniques that are suitable for road pricing in the framework of a regional model since they represent the most comprehensive approach. The purpose of the paper is to identify the most important planning needs associated with different pricing forms and the most promising state-of-the-art techniques that could serve these needs.

The first important aspect is the nature of the road pricing project under study and its potential impacts on various dimensions of travel. In this regard, the paper provides a classification of road pricing forms with the linkages to possible modeling techniques. The paper identifies the limitations of conventional modeling tools and potential improvements. The most promising directions for principal improvement of road pricing models are associated with advanced network simulation tools (dynamic traffic assignment and micro-simulation) and advanced activity-based, tour-based demand models. These advanced tools have a much higher flexibility and behavioral realism in the incorporation of various impacts of road pricing on travel behavior as compared to conventional tools like static assignment and 4-step models. Specifically, these major breakthroughs provide for the incorporation of heterogeneity of road users with respect to their value of time and willingness to pay, accounting for reliability of travel time associated with toll roads, more comprehensive modeling of time-of-day choice based on the analysis of all constraints associated with changing daily schedules, and a proper incorporation of toll road choice in the general hierarchy of travel choices in the model system.

Introduction

The growing number of different road pricing forms and technologies represents a new challenge for travel modelers who want to understand the impact of pricing on various aspects of travel behavior and find efficient ways of incorporating it in modeling procedures. A wide range of possible modeling techniques (and underlying assumptions) is currently applied for road pricing. Choice of a modeling tool depends on numerous objective factors, such as the scale of the project and subjective factors such as the quality of the existing regional travel model and available information for model development, validation, and application.

For short-term revenue forecasts of an established toll facility, such as a bridge or tunnel where travel demand is stable and dependable historical data are available, as well as where only a minor improvement or change in the toll value is to be considered, simplified sketch-planning tools are frequently used. The forecasts are developed based on actual traffic and revenue performance which are adjusted for population growth and anticipated structural changes. The calculations are frequently implemented in spreadsheets based on predetermined demand elasticities with respect to toll value and time savings. A more advanced approach is based on sample enumeration of actual surveyed travelers, which allows for use of stated/situational variables (shifts of departure hour, switches of modes, desired departure time) and unlimited segmentation (including flexibility of working hours, etc.). It has the advantage of using observed rather than synthetic travel patterns; however, sketch-planning approaches are very limited with respect to the factors that can be taken into account in the forecast, specifically excluding the impact of road pricing on travel behavior, such as changing activity patterns and schedules as well as travel modes.

Studies for construction of a new facility or large-scale road pricing schemes tend to use a comprehensive travel demand model either on a regional scale or at least corridor-based. The regional model can have either a conventional 4-step structure or an advanced activity-based structure. A corridor-based network simulation model requires estimation of travel demand as an input. This input can be provided either by “windowing” on the regional model output, or by synthetic procedures based on observed traffic (counts, cordon surveys). Corridor-specific models can be specifically calibrated and adjusted for the project (as opposed to regional models) for existing facilities and short-term forecasts. Corridor-specific models can be based on actual congestion levels, operating speeds, frequency of incidents, etc., rather than on general modeled parameters. However, the corridor-level models have a limited spatial scale and simplified behavioral basis; they cannot effectively accommodate mode choice or fully address network equilibrium factors. Thus, a corridor-specific model can rarely be used effectively as an independent tool.

In the current paper, we primarily focus on general modeling techniques that are suitable for road pricing within the framework of regional travel demand models, since we believe they represent the most comprehensive and holistic approach, especially for large-scale projects and pricing policies. Many of the aspects discussed below are also relevant for the corridor-specific models and even sketch-planning tools; however, these applications are not discussed in detail. The paper does not represent an attempt to survey the existing models, or to identify possible research directions in a comprehensive way. Rather, it has the pragmatic aim of identifying the most important planning needs associated with the growing number of pricing forms, and to link them to promising state-of-the-art techniques that could serve these needs.

The paper is organized as follows. The next section provides a classification of road pricing forms with the linkage to relevant modeling aspects. It is followed by a classification of the modeling approaches and explanation of their relative advantages and disadvantages. Then several important issues are identified that correspond to potential breakthroughs from state-of-the-art to modeling practice of road pricing. They include reliability of service, heterogeneity of road users, advanced tour-based modeling of time-of-day (TOD) choice, and the placement of the related choices in the model system hierarchy. These issues are discussed in the subsequent sections in more detail. The final section contains conclusions and practical recommendations.

Classification of Road Pricing Forms

There is clearly a growing variety of road pricing forms, either already applied in practice or considered in literature. All applied or proposed forms relate to the principle of comprehensive marginal cost pricing that would reflect the full economic and social costs associated with individual vehicle movement. In practical terms, these schemes are also subject to policy considerations that may not follow the marginal cost exactly; for example, revenue maximization (especially if private investors are involved), as well as toll collection technology limitations that normally dictate some simplifications.

The great variety of pricing schemes can be formally reduced and described in structural combinations of the four major pricing characteristics associated with the corresponding question for each -- Where, Who/What, For What Purpose, and How? (See Sorensen & Taylor, 2005 and Ukkusuri et al., 2005 for more details.):

1. *Where?* Road facility, area within a certain cordon, or certain lanes where the price is charged. The following types can be mentioned:
    a. Individual access-controlled facility (bridge, tunnel, highway segment) or some lanes on this facility
    b. Certain area within a cordon
    c. Sub-network of links (for example, inter-city roads)
    d. Entire regional network

2. *Who/What?* Vehicle/traveler types with the corresponding differentiation of pricing. The following types can be mentioned:
    a. Flat price for all types of vehicles and occupancy
    b. Vehicle type differentiation (auto, truck, bus, etc.)
    c. Auto occupancy
    d. Passenger car equivalent (PCE) differentiation (or number of axles/weight) for trucks
    e. Emission/fuel class
    f. Residence of the vehicle owner
    g. Adjustment for chains/studded tires

3. *For what?* Unit of travel for which the charge is imposed with the corresponding differentiation. The following types can be mentioned:
    a. Flat charge for each trip through the "gate"
    b. Predetermined time-of-day differentiation
    c. Area differentiation (for example based on air quality)
    d. Entry-exit matrix for closed schemes
    e. Distance-traveled-based
    f. Time-traveled-based
    g. Real time congestion-level/speed based
    h. Daily charge regardless of the number of trips
    i. Bulk discounting passes
4. *How collected?* Toll-collection technology and associated multi-trip discounts. The following types can be mentioned:
    a. Manual toll
    b. Pass/ticket
    c. Vehicle equipped with a device (transporder)
    d. Automatic vehicle plate identification

Most of the applied pricing schemes can be described as combinations of the attributes listed above. For example, so-called FAIR (fast and intertwined regular) lanes that correspond to the general concept of value pricing represent a simple combination of 1a-2a/b-3a/b-4a/b with differentiation on the same facility where only some lanes are subject to toll. So-called HOT (high-occupancy and toll) lanes correspond to the 1a-2c-3a/b-4a/b combinations. Area pricing generally falls to the 1b-2a/b/f-3a/b/g-4c/d categories. Incorporation of pricing in travel models represents a non-trivial technical problem since only a simple combination like 1a-2a-3a-4a is readily available by means of a link-based toll attribute. A proper scaling for non-link and non-trip pricing schemes (like daily area pricing) still represents an unresolved issue.

In general, three aspects should be properly addressed in the modeling procedure:
1. Road <u>price</u> imposed on the traveler/vehicle and its behavioral perception.
2. Associated improvement of <u>level of service</u> in terms of travel time savings, reliability, driving conditions, available information, etc.
3. Additional <u>delays</u> associated with toll collection.

A classification of the limitations of modeling techniques with respect to different pricing schemes is provided in Tables 1, 2, and 3 below. For each of the pricing attributes we consider the modeling techniques pertinent to the four major types of tools:
1. Static user equilibrium assignment,
2. Dynamic traffic assignment (meso-scale or micro-simulation of individual vehicles),
3. Conventional 4-step trip-based models,
4. Advanced activity-based/tour-based models.

The first two tools (static and dynamic assignments) serve the purpose of modeling route choice with predetermined trip tables. The last two tools (4-step and activity-based models) relate to a broader task of modeling such dimensions of travel as trip generation, trip distribution, mode choice, and time-of-day choice. Any of the demand models can be combined with any of the assignment procedures in the framework of a regional travel model system. The most frequently applied combination so far has been a 4-step model with the static assignment. The most advanced design is an activity-based model combined with dynamic traffic assignment. So far there has been only one example of an operational model system of this type (TRANSIMS application in Portland that represents an ongoing research project).

Table 1 relates to the modeling of the impact of price itself. Table 2 relates to modeling the corresponding level-of-service improvements. Table 3 relates to modeling additional delays associated with the toll collection.

Table 1: Modeling technique for incorporation of road pricing

Pricing characteristic	**Route choice**		**Mode, destination, and TOD choice**	
	Static equilibrium assignment	**Dynamic traffic assignment**	**4-step trip-based model**	**Activity-based tour-based model**
Features common to all forms	Link cost	Link or route cost	OD cost skim	Cost for individual trip, tour, and day
Additional features specific to facility type				
1.a – individual				
1.b – area/cordon	All entries	All entries		
1.c – sub-network	Relevant links	Relevant links		
1.d – entire network	All links	All links		
Additional features specific to vehicle/traveler type				
2.a – flat charge				
2.b – vehicle type	Multi-class	Multi-class or individual vehicle type	Trip tables by vehicle type	Individual vehicle type
2.c – occupancy	Multi-class	Multi-class or individual vehicle type	Trip tables by auto occupancy	Auto occupancy as joint travel and car allocation
2.d – PCE/weight	Multi-class	Multi-class or individual vehicle type	Trip tables by PCE	Trip tables by PCE
2.e – emission/fuel	Multi-class	Multi-class or individual vehicle type	Trip tables by emission/fuel	Individual vehicle type choice
2.f – resident vehicle	N/A	Individual vehicle	N/A	Individual vehicle
2.g – chains	Multi-class	Multi-class or individual vehicle type	Trip tables by tire type	Individual vehicle type choice
Additional features specific to unit of travel charged				
3.a – flat charge per trip through				
3.b – TOD-specific	TOD-specific assignments	TOD-specific slices	TOD-specific trip tables	
3.c – area-specific				
3.d – exit-entrance matrix	N/A	Route-based cost		
3.e – distance-based	Link toll per mile	Link toll per mile		
3.f – time-based	Link VDF	Dynamic route toll		
3.g – real-time congestion-based	Link VDF component	Dynamic route toll		
3.h – daily charge & bulk discounts	N/A	N/A	N/A	Impact on activity pattern
Additional features specific to toll collection				
4.a – manual				
4.b – pass	Multi-class	Multi-class or individual vehicle type	Trip tables by payment type	Pass as individual choice attribute
4.c – vehicle equipment	Multi-class	Multi-class or individual vehicle type	Trip tables by equipment (transponder)	Transponder as individual/vehicle choice attribute
4.d – automatic identification				

Table 2: Modeling technique for incorporation of level-of-service improvements

Pricing characteristic	**Route choice**		**Mode, destination, and TOD choice**	
	Static equilibrium assignment	**Dynamic traffic assignment**	**4-step trip-based model**	**Activity-based tour-based model**
Features common to all forms	Link & turn VDF	Link & turn VDF, intersection delay, queue, time variability	OD time/variability	Time/variability for individual trip, tour, and day schedule
Additional features specific to facility type				
1.a – individual facility				
1.b – area/cordon				
1.c – sub-network				
1.d – entire network				
Additional features specific to vehicle/traveler type				
2.a – flat charge				
2.b – vehicle type	Multi-class	Multi-class or individual vehicle type	OD time/variability by vehicle type	Time/variability by individual vehicle type
2.c – occupancy	Multi-class	Multi-class or individual vehicle type	OD time/variability by vehicle occupancy	Time/variability by auto occupancy at joint travel and car allocation stage
2.d – PCE/weight	Multi-class	Multi-class or individual vehicle type	OD time/variability by PCE	OD time/variability by PCE
2.e – emission/fuel	Multi-class	Multi-class or individual vehicle type	OD time/variability by vehicle type	Time/variability by individual vehicle type in car ownership & allocation
2.f – resident vehicle	N/A	Individual vehicle type	N/A	Time/variability by individual vehicle tag
2.g – chains	Multi-class assignment	Multi-class or individual vehicle type	OD time/variability by vehicle equipment	Time/variability by individual vehicle type (equipment & allocation)
Additional features specific to unit of travel charged				
3.a – flat charge for trip through				
3.b – TOD-specific	TOD-specific assignments	TOD-specific slices	TOD-specific OD skims	Linked schedule decisions
3.c – area-specific				
3.d – exit-entrance matrix	N/A			
3.e – distance-based				
3.f – time-based				
3.g – real-time congestion-based		Dynamic route choice		
3.h – daily charge & bulk discounts	N/A	N/A	N/A	Impact on activity pattern and number of trips
Additional features specific to toll collection				
4.a – manual				
4.b – pass	Multi-class	Multi-class or individual vehicle type	OD time/reliability by payment type	Time/reliability by payment type as individual choice
4.c – vehicle equipment	Multi-class	Multi-class or individual vehicle type	OD time/reliability by equipment (transporder)	Time/reliability by equipment as individual/vehicle choice
4.d – automatic identification				

Table 3: Modeling technique for incorporation of toll collection delays

Pricing characteristic	**Route choice**		**Mode, destination, and TOD choice**	
	Static equilibrium assignment	**Dynamic traffic assignment**	**4-step trip-based model**	**Activity-based tour-based model**
Features common to all forms	Toll plaza, lane, and booth as special links with delays	Toll plaza, lane, and booth as special links with delays/queue/time variability	Payment-type-specific trip tables with mode biases	Individual choice of payment type for trip, tour, and day
Additional features specific to facility type				
1.a – individual facility				
1.b – area/cordon				
1.c – sub-network				
1.d – entire network				
Additional features specific to vehicle/traveler type				
2.a – flat charge				
2.b – vehicle type	Toll collection delay by vehicle type	Toll collection delay by vehicle type	Payment-type-specific trip tables by vehicle type	Individual choice of payment type by vehicle type
2.c – occupancy	Toll collection delay by vehicle occupancy	Toll collection delay by vehicle occupancy	Payment-type-specific trip tables by vehicle occupancy	Individual choice of payment type by vehicle occupancy
2.d – PCE/weight	Toll collection delay by PCE	Toll collection delay by PCE	Payment-type-specific trip tables by PCE	Payment-type-specific trip tables by PCE
2.e – emission/fuel				
2.f – resident vehicle	N/A		N/A	
2.g – chains	Toll collection delay by vehicle equipment	Toll collection delay by vehicle equipment	Payment-type-specific trip tables by vehicle equipment	Individual choice of payment type by vehicle equipment
Additional features specific to unit of travel charged				
3.a – flat charge for trip through				
3.b – TOD-specific	TOD-specific toll-collection delays	TOD-specific toll-collection delays		
3.c – area-specific				
3.d – exit-entrance matrix	N/A			
3.e – distance-based				
3.f – time-based				
3.g – real-time congestion-based				
3.h – daily charge & bulk discounts	N/A	N/A	N/A	
Additional features specific to toll collection				
4.a – manual	Toll plaza & booth delay	Toll plaza & booth delay with lane change & queue		
4.b – pass	Toll plaza & booth delay	Toll plaza & booth delay with lane change & queue		
4.c – vehicle equipment				
4.d – automatic identification				

The major advantages, disadvantages, and principal limitations of the different approaches shown in Tables 1-3 can be summarized as follows:

- <u>Static user equilibrium assignment</u> incorporates the toll as a link attribute that is strictly additive along the route. Any differentiation of tolls by vehicle type, occupancy, or time of day requires a multi-class assignment with a full segmentation of origin-destination (OD) tables. This frequently leads to an infeasible number of tables to be generated and handled, especially with the user segmentation by value of time (VOT). Certain modifications of the link volume-delay functions (VDF) can be applied to account for distance-based, time-based, or even real-time-congestion-based pricing forms; however, the last is subject to a very detailed time-of-day segmentation. This technique cannot properly handle such non-link-additive pricing forms as daily charge, exit-entrance matrix, or any discount/exemption based on the place of residence. Static assignment is also very limited in its representation of toll collection delays, since it does not have any mechanism for queuing. Another principal limitation of the static assignment is that it can only produce average travel time estimates, while variability of travel time cannot be modeled.

- <u>Dynamic traffic assignment (on the meso-scale or with micro-simulation of individual vehicles)</u> is a more complicated tool than the static assignment; however, it can produce much more detailed output for analysis of road pricing. The main advantages of dynamic assignment versus static assignment relate to its ability to handle entire-route characteristics, queues, as well as a variety of vehicle types and traveler characteristics, and of course more realistic representation of congestion and linkage across different time-of-day demand slices. However, it should be noted that dynamic traffic assignment and micro-simulation cannot be yet applied on the regional scale (the TRANSIMS software that requires a unique multiple-processing environment has so far been the only example). Also, it still leaves open the question of daily pricing that is not implemented on the trip basis.

- <u>Conventional 4-step models</u> can be used to estimate sensitivity of such travel choices as mode, trip distribution, and time-of-day choice to road pricing. The corresponding sensitivity is ensured by using an OD skim of tolls as the additional variable. Also, any level-of-service improvements, as well as delays associated with toll collection are incorporated through travel time variables. If travel time variability estimates are provided by the network assignment procedures they also can be incorporated. However, 4-step models have several principal limitations that reduce their value as a modeling tool for road pricing. First, 4-step models can incorporate only a limited number of segments in terms of time-of-day periods, vehicle types, value-of-time, payment type, etc. which makes it difficult to realistically model all road pricing markets. Second, by ignoring the linkage across different trips included into the same tour made by the same person, as well as by ignoring daily schedule constraints on individual travel, 4-step models fail to properly model time-of-day and mode choice sensitivity, which is of crucial importance for road pricing. Also, similar to the assignment procedures, a trip-based 4-step model cannot adequately address daily pricing.

- Activity-based/tour-based models show promise in addressing road pricing in a much more integrated way, although they are characterized by a significantly higher degree of complexity compared to 4-step models. In addition to the standard technique of using trip travel time and toll skims as variables throughout the modeling procedure, activity-based models offer a wide range of additional options relevant to road pricing. First, the tour-based structure of mode and time-of-day choice ensures much more realistic sensitivities of those choices to road pricing. Second, activity-based models implemented in a micro-simulation fashion are characterized by virtually unlimited segmentation by travel segments and person types which better suits road pricing markets. Third, activity-based models can incorporate such additional choice dimensions as possession of a pass or transponder by each individual traveler, as well as address non-trip pricing forms through their impact on daily activity patterns. Theoretically, activity-based models can incorporate even various situational variables (like time pressure on a person who is late for some important activity) that are recognized as important determinants of willingness to pay. This is especially appealing if the activity-based model is integrated with the dynamic assignment/traffic microsimulation.

Modeling Travel Choices Relevant to Road Pricing

Road pricing affects many dimensions of travel behavior. The primary impacts of road pricing most frequently in the focus of travel modelers relate to route choice and time-of-day choice (peak spreading). These aspects are of primary importance for inter-city toll roads, as well as bridges and tunnels in metropolitan areas where transit does not play a significant role. However, this represents a very limited view of the general case. For example, in over-congested urban areas where transit plays a significant role and represents a viable alternative, mode choice becomes the central modeling aspect of road pricing. Moreover, for global area pricing forms that affect all aspects of travel behavior in the pricing area, the entire daily activity pattern of individuals can be changed with important implications for the number and chaining of trips over the entire course of the day.

Table 4 below summarizes the major travel dimensions and shows which of them can be effectively modeled by regional models (with additional subdivision into 4-step and activity-based models), and by models limited to the corridor or project level (with additional subdivision into traffic simulation and sample enumeration tools). In this summary, it is assumed that a regional model includes an assignment procedure.

The following general conclusions can be made. The major advantage of regional models over corridor/project specific models is that they can include several upper-level choice dimensions that relate to trip generation and distribution, while corridor/project specific models treat these dimensions as externally given. Pure traffic simulation tools also do not include mode choice and vehicle occupancy choice, assuming that the demand is externally segmented by vehicle type and occupancy. Sample enumeration tools are normally difficult to combine with network assignments, since they operate with a predetermined (enumerated) set of travel options (modes, routes, and time-of-day periods) for the travel market segments surveyed.

When comparing 4-step models to activity-based models, several limitations of 4-step models are evident. They include very crude and simplified modeling of vehicle occupancy and time-of-day choice, as well as the payment type (in presence of several toll-collection technologies). For these travel dimensions that are important for proper modeling of road pricing, activity-based models offer significant structural advantages, although associated with a higher level of complexity.

Table 4: Hierarchy of choices associated with road pricing

Choice dimension	Regional model		Corridor/project model	
	4-step trip-based model	**Activity-based tour-based model**	**Traffic simulation**	**Sample enumeration**
LU development	Not considered	Not considered	Not considered	Not considered
Residential & business location	Given	Given	Not considered	Given
Activity-travel pattern/trip generation	Trip production & attraction	Daily activity-travel pattern	Given or expanded	Given or expanded
Destination choice/trip distribution	Trip distribution	Primary destination/stop location choice	Given or expanded	Given or expanded
Time-of-day choice	Peak/off-peak factors	Departure time choice	Departure time choice (for DTA) or given	Switches
Mode	Mode choice	Tour and trip mode	Given	Switches
Vehicle occupancy	Part of mode choice	Part of DAP for joint trips; part of mode choice for individual trips	Given	Switches
Peak spreading	Auto trip shift	Part of departure time choice	Part of departure time choice (for DTA) or given	Part of departure time choice
Willingness to pay (toll/non-toll)	Part of mode choice, additional binary choice, and/or part of assignment	Part of mode choice and/or assignment	Additional binary choice, and/or part of simulation	Part of mode choice or additional binary choice
Payment method (ETC account/transponder, cash/manual booth)	Missing or externally segmented or part of mode choice	Person-based choice model	Externally segmented	Part of mode choice or additional binary choice
Toll facility/lane	Part of assignment	Part of assignment	Part of simulation	Part of mode choice or additional binary choice
Network route	Part of assignment	Part of assignment	Part of simulation	Not considered

Outline of Challenging Modeling Issues

The framework of a regional model, especially if it is implemented in an advanced activity-based, tour-based micro-simulation form, opens the way for consistent modeling of all interrelated travel dimensions associated with road pricing. To take real advantage of the modeling framework, however, all choice models that correspond to particular dimensions should be properly specified, and the most important choice dimensions should be identified and sequenced in a behaviorally realistic way. This is not a trivial task since each of the travel dimensions – route choice, mode choice, time-of-day choice, etc. – in itself represents a complex choice structure.

Road pricing adds significant complexity to all related choice dimensions since it requires a detailed consideration of the travelers' willingness to pay for the better level of service provided by toll roads in addition to consideration of travel time improvements and other factors included in the travel models. In particular, we will focus on the following modeling aspects that have been recognized as being of primary importance for road pricing models:

- Reliability of service and more general view on willingness to pay,
- Heterogeneity of road users in the context of choice models,
- Heterogeneity of road users in the context of network simulation,
- Advanced tour-based, time-of-day choice models,
- Placement of choices related to road pricing in the model system hierarchy.

We believe that a significant breakthrough in road pricing models could be achieved if the state-of-the-art methods that relate to these issues were incorporated in applied regional models. These particular modeling aspects have been chosen because efficient technical solutions have already been found and reported for all of them, including model estimation based on the available data and application experience in real-size regional networks.

Accounting for Reliability

There is a growing body of research and compelling statistical evidence, as well as model estimation results, that indicate that travelers' perception of toll roads and willingness to pay is not a simple consideration of average time and cost compared to the individual VOT. VOT corresponds to the monetary value given by travelers to travel time. Conceptually, VOT has two components – "lost" participation in activities, and the undesirability of travel *per se*. In general, willingness to pay for toll roads relates to many aspects and is not bound to VOT only.

Many additional attributes account for willingness to pay, such as improved safety (for example because of fewer trucks on the road), and reliability/predictability of travel time (especially for time-sensitive activities with fixed schedule and high perceived disutility associated with late arrival). In particular, improved reliability associated with a toll road has been recognized as a factor that may be as important as the average time savings. Variability of travel time (non-recurrent congestion because of incidents, weather, accidents, and road works) in certain actual situations may be of greater concern to travelers than the recurrent congestion. Other important "convenience" factors include safety and clear information, which may be especially useful for travelers unfamiliar with the area. Also, information on delays (for example, in the context of real-time congestion pricing) plays an important role as a "signaling" variable for traveler choice.

Willingness to pay for reductions in the day-to-day variability of travel time is referred to as value of reliability (VOR). Small et al. (2005) presented an interesting and operational approach for actual estimation of VOR in a consistent way with VOT by splitting their impacts on traveler choice. The adopted quantitative measure of variability was the upper tail of the distribution of travel times, such as the difference between the 90th and 50th percentile travel times. The authors argue that this measure is better than symmetric standard deviation, since in most situations being "late" is more crucial than being "earlier." Reliability as defined above proved to be valued by travelers as highly as the median travel time.

Table 5 below illustrates the VOR measure introduced for two hypothetical routes and observed travel times for trips (say, commuting days) for each of the routes. Though the second route is characterized by a significantly shorter average time, the first route is preferred by travelers because of the improved reliability.

Table 5: Measure of travel time reliability

Day	Road 1 time, min	Road 2 time, min
1	41	28
2	42	29
3	43	30
4	44	35
5	45	40
6	45	40
7	46	45
8	47	50
9	48	51
10	49	52
50th percentile: average (median) time, min	45	40
90th percentile: second longest time, min	48	51
Measure of reliability	3	11
Choice by average		X
Choice by average + reliability	X	

Making this approach operational within the framework of regional travel models requires explicit modeling of travel time distributions, as well as making assumptions on how the travelers acquire information about the random draw they are about to experience. Dynamic traffic assignment and micro-simulation tools are crucial for the assessment of travel time variability, since static assignment can only predict average travel times.

Other approaches to measuring variability of travel time can also be mentioned. They are similar to the approach described above in conceptual terms, but use a different technique at both the estimation and application stages. For example, in the travel model developed by PB Consult for the toll traffic and revenue study in Montreal, 2002, probability of delays longer than 15 and 30 minutes was introduced in the stated preference (SP) questionnaires for truck operation. The subsequent estimation of the choice model revealed very high significance of this variable comparable with the total trip time (in line with the VOR estimation of Small et al., 2005). Application of this model required special probability-of-delay skims that were calculated based on the observed statistics of delays as a function of the modeled volume-over-capacity ratio. Although this technique requires a multi-day survey of travel times and speeds, it can be applied in combination with the static assignment method.

Reliability and comfort are closely intertwined with VOT. If a reliability measure is not introduced, and VOR is not explicitly accounted for, then frequently a bias constant (toll road prime bonus) is applied that gives a crude estimate of these excluded factors, which has a similar role as mode-specific constants in the mode choice context. Similar to the mode choice technique, it has also been recognized that reliability-related bias could be better modeled as a function of distance rather than as a fixed value. For example, such variables as commuter-rail distance-based bias in mode choice have long been applied to account for the reliability of rail compared to bus.

Heterogeneity of Users in Choice Context

Heterogeneity of road users with respect to their willingness to pay for travel time savings (expressed as VOT) and higher reliability (VOR) has been the focus of research and practice of travel modelers for a long time now. The essence of the problem was well illustrated by Hensher and Goodwin (2005) in the following graphs showing very different numbers of toll road users under different assumptions about the actual distribution of VOT, while keeping the average VOT, toll, and travel time saving constant - see Figure 1 below.

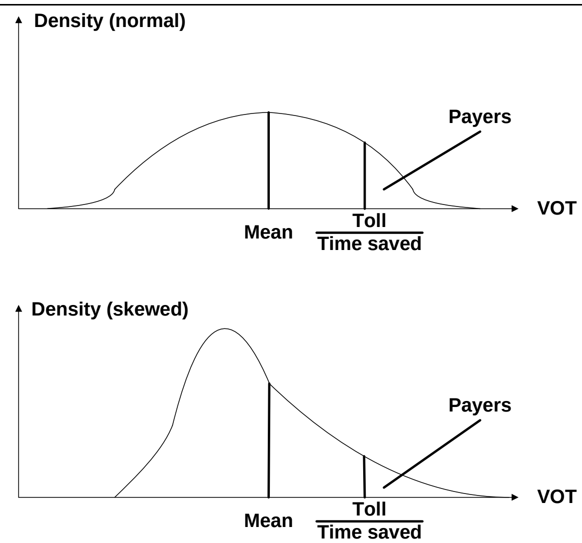

Figure 1: Distribution of VOT

The upper distribution of road users by VOT is assumed normal (symmetric), while the lower distribution is assumed left-skewed. The left-skewed distribution is realistic since there can be a disproportionately large number of individuals with relatively low VOTs that are not that different from the mean, and in contrast to that, a smaller number of individuals with VOTs that are significantly higher than the mean. With the same mean and toll value relative to the time saving, we predict significantly different numbers of users (who are willing to pay because their individual VOT is higher than the toll divided by time saving), depending on the shape of the distribution.

This shows that predicting toll road choice with the average VOT and ignoring the actual distribution of users by VOT, can lead to crude mistakes in predicting the number of toll road users.

There are two constructive ways to address the heterogeneity of road users:

1. An explicit segmentation of the corresponding assignment, mode choice, and time-of-day choice models while assuming a single average VOT within each segment.
2. The application of probabilistic distribution of VOT instead of deterministic values, with a corresponding adjustment of the structure of the assignment, mode choice, and time-of-day choice models.

Explicit segmentation by VOT has been applied in many travel models, including mode choice and toll road choice. It has also been incorporated in trip distribution (destination choice) models through mode choice log-sums used as the impedance measure. There is less experience reported with segmentation of trip tables for multi-class assignment, since this would lead to the need to produce and handle a significant number of tables, especially if they are already stratified by vehicle types.

The following dimensions for the segmentation of VOT have been proposed and statistically proven as significant in different sources:

- Income, where a higher income is normally associated with higher VOT,
- Travel purpose, where the work- and business-related purposes are normally associated with a higher VOT compared to non-work purposes,
- Gender, where all else being equal, female drivers are associated with the higher VOT compared to male drivers,
- Work status, where workers (even if travel for non-work purposes) normally exhibit a higher VOT compared to non-workers,
- Time-of-day, where peak periods (AM, PM) are normally associated with a higher VOT compared to off-peak periods (midday, night),
- Vehicle occupancy, where a higher occupancy is normally associated with higher VOT though not necessarily directly proportional to the number of persons.

Different choice contexts and time frames for route, mode, and time-of-day choice make it problematic when the same VOT is transferred from choice to choice. Different models use different dimensions for segmentation. For example, in the New York model based on the household travel survey of 1998, the base VOT values for drive-along were differentiated by six travel purposes:

- Work – $15.80/hour
- School – $6.50/hour
- University – $11.70/hour
- Maintenance – $12.40/hour
- Discretionary – $10.70/hour
- At work - $40.00/hour

VOT for shared ride was assumed to be proportional to the number of persons.

In the Montreal model, since toll revenue forecast was in the focus of the study, VOT values were specifically estimated for toll road users for three relevant travel purposes, with additional segmentation by gender, income group, and time of day – see Table 6 below.

All else being equal, a more detailed segmentation normally tends to dampen the price sensitivity (or stated otherwise, aggregation across different segments tends to overestimate sensitivity), since a typical sigmoid response curve, like the logit model, has the steepest (most elastic) part in the middle, while the ends are quite flat.

Table 6: Summary of VOT estimates for toll road users in Montreal model

Gender	Income	Time of day	VOT by purpose		
			Work	Maintenance	Discretionary
Male	Low	Off-peak	$7.30	$4.00	$3.00
		Peak	$10.30	$4.00	$3.00
	High	Off-peak	$10.20	$4.00	$3.00
		Peak	$10.20	$4.00	$3.00
Female	Low	Off-peak	$7.30	$6.40	$6.00
		Peak	$10.30	$6.40	$6.00
	High	Off-peak	$10.60	$7.30	$7.60
		Peak	$10.60	$7.30	$7.60

Explicit segmentation can be an effective way to improve the model while keeping it in a simple analytical form. However, there are several strong arguments in favor of a probabilistic treatment of VOT, instead of or in addition to explicit segmentation.

First, the number of segments quickly becomes infeasible if segmentation is applied across all dimensions simultaneously. This is especially apparent with the conventional modeling technique of the static assignment as part of a 4-step model, since it requires multiplication of full OD tables for each dimension involved. Additionally some dimensions like income require an arbitrary categorization with some open-ended categories with a high internal variation. Detailed travel segmentation can be more effectively incorporated in the activity-based micro-simulation framework that is almost insensitive to the number of segments that could be used in the model application. Even the activity-based model structure; however, has certain limitations on the estimation side.

Second, and more importantly, even with the maximum possible segmentation implemented, a travel model cannot include all possible situational variables that create significant additional variation of VOT within each (seemingly homogeneous) segment. For example, when driving to an important business meeting with a short time left, a worker can exhibit a much high willingness to pay than the average for the same person. The same can be said about a mother driving home to attend to a sick child. Also, a not insignificant (but generally unknown) percentage of commuters may have full or partial reimbursement of their travel cost by their employer, that is, another source of VOT variation.

This makes the probabilistic approach to VOT more realistic. Recent advances in random coefficient (mixed) logit model estimation (already available in commercial software like ALOGIT or LIMDEP) make it a practical tool for choices related to road pricing. The random coefficient logit form directly corresponds to the situation where VOT and underlying utility coefficients for travel time and cost are assumed randomly distributed, rather than deterministic.

Since mixed logit requires numeric integration (computationally intensive) for calculation of the choice probabilities, this is a technical problem for conventional 4-step models that operate with fractional probabilities. For activity-based micro-simulation models, however, there is no need to calculate choice probabilities. Random utilities can be directly simulated from their distributions and then the alternative with the maximum utility can be chosen. This technique eliminates the disadvantages of non-closed form choice models (like probit or mixed logit) and makes them as convenient as logit models in application.

Small et al. (2005) provides an interesting example of estimation of a binary model of choice between a toll and a non-toll route that accounts for the heterogeneity of travelers with respect to VOT (as well as VOR). In this formulation, the non-toll route served as the reference alternative with zero utility while the toll route utility included a constant term, various transformations of cost and time differences between the routes, as well as a measure of travel time unreliability. The constant term was specified as a random parameter dependent on such variables as gender, age, and household size. The cost and time coefficients were specified as random parameters interacting with income and trip distance. In this way the model was able to capture a significant observed heterogeneity (through variables that differentiate the distribution of the constant term and time/cost coefficients), as well as residual unobserved heterogeneity through the specification of the random component of the constant and time/cost coefficients. The utility structure of a model of this type can be written in the following general way:

$$U_{sn} = \alpha_{sn} + \sum_k \beta_{snk} x_{nk} + \varepsilon_n \,, \qquad \textbf{Equation 1}$$

where:

s	=	segments by income, travel purpose, person type, etc.
n	=	observations (instances of choice)
k	=	independent variables like travel time and cost
x_{nk}	=	values of the independent variables for each observation
α_s	=	constant that is assumed to be random
β_{sk}	=	coefficients for time and cost that are assumed to be random
ε_n	=	random disturbance term

The random constants are specified in the following way:

$$\alpha_{sn} = \overline{\alpha} + \sum_l \varphi_{sl} y_{nl} + \xi_n \,, \qquad \textbf{Equation 2}$$

where:

l = variables for capturing observed heterogeneity (like gender and age)

y_{nl} = values of the variables for each observation

$\overline{\alpha}$ = fixed component (generic alternative-specific bias)

φ_{sl} = coefficients capturing observed heterogeneity

ξ_n = random term capturing unobserved heterogeneity

The random coefficients are specified in the following way:

$$\beta_{skn} = \overline{\beta}_k + \sum_m \gamma_{skm} z_{nm} + \zeta_n, \qquad \textbf{Equation 3}$$

where:

m = variables for capturing observed heterogeneity (like income and distance)

z_{nm} = values of the variables for each observation

$\overline{\beta}_k$ = fixed components (generic coefficients)

γ_{skm} = coefficients capturing observed heterogeneity

ζ_n = random term capturing unobserved heterogeneity

The model was estimated based on the combined revealed preference (RP) and SP data sets for California State Route 91. The authors reported significant observed and unobserved heterogeneity amongst travelers that affects the forecast; a proper accounting for this heterogeneity could enhance the political viability of pricing. In modeling terms it means that a combination of an explicit segmentation (to account for the observed heterogeneity) with probabilistic VOT distribution (to account for unobserved heterogeneity) is essential.

The random disturbance term ε_n is specified according to the expected correlation structure (similarities) amongst alternatives. An assumption on independently extreme-value distributed disturbances leads to a standard mixed logit model. More complicated structures with differential correlation amongst utilities lead to more complicated mixed generalized extreme value models. This is probably the most promising avenue for integrative modeling of mode and toll road choices.

Heterogeneity of Users in Traffic Simulation

Accounting for heterogeneity of road users at the network simulation (route choice) stage is in a certain sense similar to accounting for heterogeneity of users in the general choice context. In both cases we have to account for differential VOT among various users, either through explicit segmentation, or by applying probabilistic distributions in order to eliminate significant aggregation biases associated with using the average VOT. However, the network simulation framework adds a certain technical complexity to the issue, because of the large number of routes in real-size networks that are difficult to enumerate explicitly in a computationally effective way.

One possible solution is to apply a simple static equilibrium assignment with multiple vehicle classes associated with VOT categories. This is, however, a limited approach since it quickly leads to an infeasible number of trip tables to produce and handle, especially if user VOT classes are crossed with vehicle types and detailed time-of-day periods.

Recent advances in the algorithms for finding bi-criterion paths in large scale networks open a way to effectively account for heterogeneity of road users in both static and dynamic assignment frameworks. This is based on the fact that for each OD pair there is always only a limited subset of so-called "extreme efficient" paths in the bi-criterion space "time × cost" for the entire range of VOT. A path is considered "extreme efficient" if it is Pareto-optimal and also lies on the boundary of the convex hull of points corresponding to the time and cost skims for the Pareto-optimal paths. With a reasonable assumption regarding the VOT distribution of users, approximate route choice probabilities can be calculated in a computationally effective way even for large dynamic traffic assignment applications – see Mahmassani et al., 2005. The concept of extreme efficient paths is illustrated in Figure 2 below. For simplicity, we assume three extreme efficient paths and two other Pareto-optimal paths.

If we assume a probabilistic distribution of VOT for users, then the probability of choosing one of the three extreme efficient paths can be associated with the fraction of users that belong to one of the following VOT intervals:

1. Users with $0 \leq VOT < \omega_1$ will use route 1
2. Users with $\omega_1 \leq VOT < \omega_2$ will use route 2
3. Users with $\omega_2 \leq VOT$ will use route 3

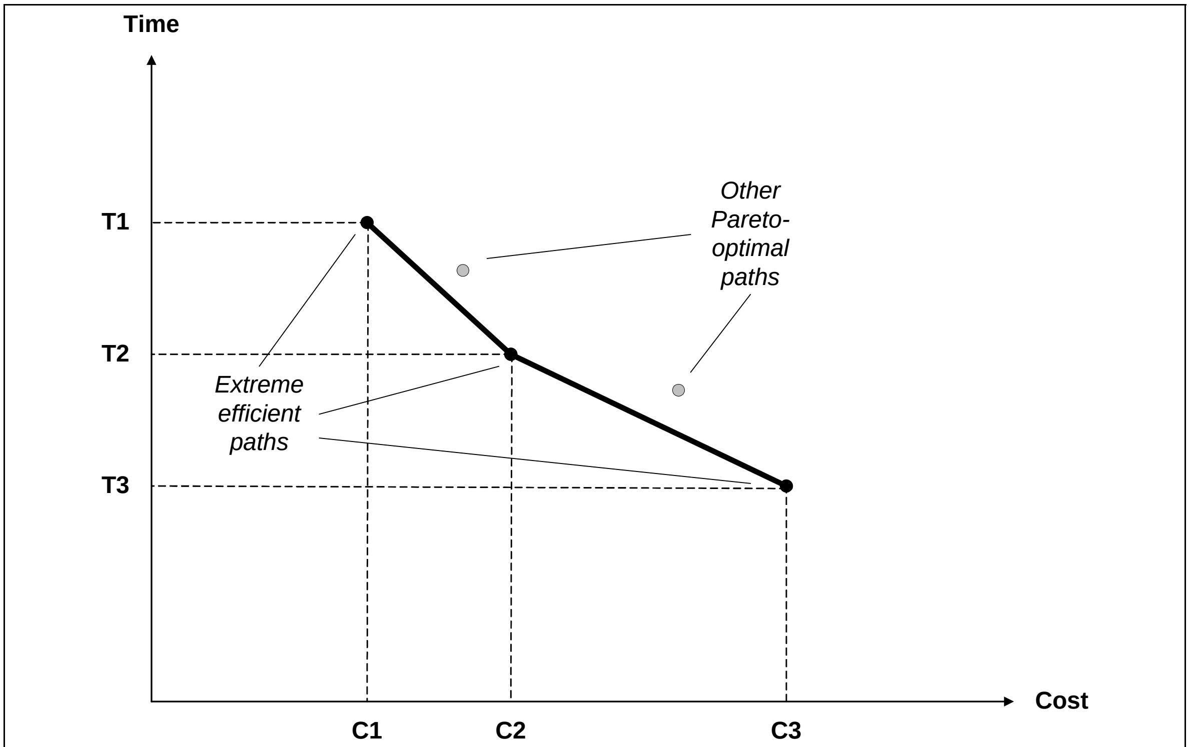

Figure 2: Extreme efficient paths

The breakpoints ω_1, ω_2 can be calculated for the set of extreme efficient paths in such a way that the following condition is held:

$$\frac{C_1}{T_1} < \omega_1 < \frac{C_2}{T_2} < \omega_2 < \frac{C_3}{T_3}.$$ **Equation 4**

Effective approximation algorithms for finding bi-criterion time-dependent efficient paths in large-scale networks represent a promising avenue for better simulation of route choice between toll and non-toll facilities.

Advanced Time-of-Day Choice/Peak-Spreading Technique

Modeling traveler responses to different toll strategies and congestion pricing schemes is an important advantageous feature of activity-based models. This aspect has always been the "Achilles' heel" of 4-step models. Four-step models are limited to predicting local shifts of departure/arrival times in the framework of each particular time-of-day period and cannot predict consistent daily schedule changes. Actually, the placement of a time-of-day choice model and its interaction with the other models has never been fully established for 4-step models. Additionally, a 4-step model operates with 3-4 broad time-of-day periods while congestion pricing is intended to spread traffic more evenly across specific hours of the peak and adjacent off-peak periods.

For this reason, many modelers decided to single out the congestion pricing (or peak-spreading) model and apply it to specific studies "on the top" of the auto trip tables produced by the 4-step model rather than include it as an integral part of the model chain. As a result, the inherent linkages between trip distribution, mode, and time-of-day was broken and the model system exhibited illogical elasticities in response to combined policies (for example, transit service improvement accompanied by congestion pricing).

The important factor to account for is the <u>entire-work-tour and entire-day-schedule</u> framework. When travelers make decisions about changing outbound commuting time in response to AM congestion pricing, they consider numerous consequences for the subsequent schedule of their day. In general, work schedule considerations (and the corresponding components of the time-of-day choice utility function) can be broken into the following three groups:

- Departure time from home, including flexibility of the work schedule, avoidance of congestion (longer travel times and/or higher tolls), household errands associated with the outbound commute (giving a ride to a child to school, or just having breakfast together), etc.;
- Arrival time back home, including flexibility of the work schedule, avoidance of congestion, household and personal errands associated with the inbound evening commute or post-work maintenance and/or discretionary activity, etc.;
- Necessary duration of the work activity, including normative workplace regulations (8-hour workday for most full-time workers), as well as some particular work arrangements

required on the given day (for example, working extra time to finish an urgent project), etc.

A decision to shift the departure time to a later or earlier hour cannot only violate some of the arrangements in the morning commute, but can also trigger a chain of related changes in the evening commute/post-work activity, as well as conflict with the necessary work duration. It is known that when responding to a stated-preference questionnaire that includes only morning commute time scenarios, commuters tend to overestimate their willingness to change departure time from home. In reality, they exhibit a much more conservative behavior because of the numerous entire-work-tour and entire day-schedule constraints.

Four-step models operate with trips, not tours, thus their time-of-day choice sub-models (or stand-alone peak-spreading models) cannot incorporate entire-tour effects. Conventional peak-spreading models are focused on one period (frequently AM peak) or have two separate models for the AM and PM peaks. In both cases, the AM peak spreading analysis and modeling is isolated from the other periods. This frequently leads to overestimation of the demand sensitivity to congestion pricing and expected congestion relief, while underestimating the revenue.

Ignoring entire-tour and entire-day schedule considerations may eventually hamper the effectiveness of the pricing policy. For example, an AM peak spreading policy intended to move traffic from the peak hour to the late shoulder or midday period may result in worsening congestion in the PM period. This can happen because of the shifting of such travel segments as part-time workers' commute and non-work travel to a generally later start which would result in traveling back home in the PM peak period.

In general, by shifting individual daily schedules to a later hour, one should expect more intensive activity and travel agenda in the evening post-work period with the potential for worse congestion in the PM period. Consider a typical work commuter who leaves home at 7:30 AM and arrives back home at 6:00 PM. Most of the commuters with this schedule do not have significant additional travel-related activities before 7:30 AM. They undertake almost all non-work travel in a relatively narrow residual time window between 6:00 PM and 11:00 PM. By shifting the work schedule to an hour later (from 8:30 AM to 7:00 PM) one cannot expect significant redistribution of non-work activities from the post-work to pre-work period. Thus, almost the same amount of activities and travel would just be compressed in a narrower residual window (from 7:00 PM to 11:00 PM). Moving the late threshold for non-work activities (from 11:00 PM to 12:00 PM) perhaps should follow the work schedule shift is actually problematic because of the intra-household interactions (children still go to school with the same early schedule as well as the second worker may not be affected by the policy).

Activity-based models will show a consistent response of commuters to variable time-of-day tolling strategies, including the impact of AM period tolls on the PM period (reverse commuting) and vice versa. They also capture inter-linkages between work and non-work activities and associated constraints. Activity-based tour-based models normally show a reasonably low sensitivity (compared to 4-step models) to congestion pricing when applied in a single period (AM); however, they explicitly capture the impact of AM peak-spreading policies on the PM peak and other periods, which a 4-step model would ignore. An example of an advance time-of-day choice model, as well as the estimations and application, results in the framework of the Columbus, Ohio Mid-Ohio Regional Planning Commission regional travel model, reported by Vovsha & Bradley, 2004.

Review of Approaches to Represent Road Pricing in Travel Choices

Placement of the road-pricing-related choices in the model system hierarchy should be based on the proper association of road pricing with the relevant travel dimensions. Below are some examples of the reported approaches and associated choice structures.

Choice models reported by Yan et al. (2002) were based on surveys in 1999 on California State Route 91. Several dimensions of traveler responses to value pricing were modeled. First is the decision of which route to take. This decision is represented as whether to travel in the SR 91 Express (91X) Lanes, the SR 91 free lanes (91F), or the Eastern Toll Road (ETR). Other traveler responses include changing time of day and changing car occupancy. Five time periods are distinguished based on the toll schedule. Three car occupancy categories are distinguished: driving alone (SOV), two people (HOV2), and three or more people (HOV3+). In addition, as part of the route decision but still distinct from it, the traveler decides whether or not to acquire a transponder in order to pay tolls electronically. Two bi-level nested logit models have been estimated – see Figure 3. They both have the same lower level of joint choice of route and transponder. However, the first model has three mode/car occupancy alternatives as an upper-level choice while the second model has five time-of-day alternatives as an upper-level choice.

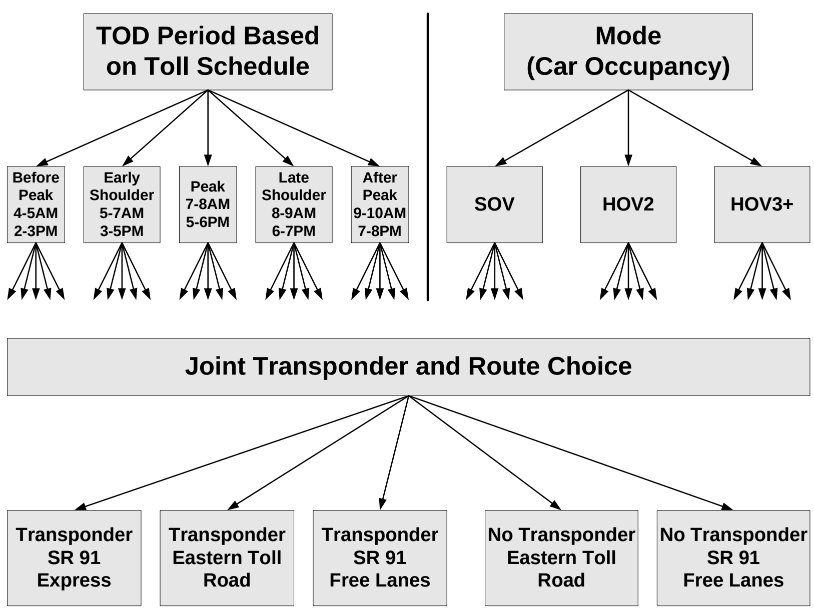

Figure 3: Choice models for SR-91 (Yan et al., 2002)

The research reported by Mastako et al. (2002) also used data on SR-91 to estimate individual choice sets for commuters in this value-priced corridor. In the short term, traveler response to value pricing in the SR-91 corridor occurs along several choice dimensions including route, vehicle occupancy, and time-of-day. A binary representation was selected for each choice decision in order to keep the number of alternative combinations to a minimum. For route choice, the decision is whether to pay a toll (Paid) or not pay a toll (Free). The two alternatives for vehicle occupancy mode are travel solo (SOV) or share a ride with at least one other person (HOV). Mode choice is equated with vehicle occupancy because the share of bus and rail in this corridor is very small. The two alternatives for time-of-day choice are travel in the middle of the peak (Peak) or travel outside the peak (Off-Peak). The three responses can be represented simultaneously as 2×2×2=8 commute alternatives. More alternatives are generated whenever greater detail is added to any of the choice dimensions. For example, if the route choice decision is represented as a choice between the 91 Free, 91 Express and Eastern Toll Road and the mode choice decision is represented as a choice between SOV, HOV2 and HOV3+, then there are 3×3=9 combinations for each time slice.

The study described by Li (2001) examines the determinants of HOT lane use, also with the data on SR 91. A multivariate logistic model was adopted that is essentially analogous to a binary choice model since the dependent variable was a dichotomous variable indicating whether or not the respondent used the SR91 HOT lanes. Contrary to the conventional wisdom, work-to-home return trips are found more likely to use HOT lanes than home-to-work and other trips. These findings have several modeling and policy implications. In particular, explicit modeling of joint household trips from the generation stage that is possible in the activity-based model framework may better fit the HOT lane choice model compared to the conventional treatment of HOV as a part of mode choice.

The San Diego I-15 Congestion Pricing Project is another demonstration of the policy of selling excessive capacity of HOV lanes to solo drivers by means of HOT lanes described by Ghosh (2001). In this research, the morning and afternoon commutes are modeled as a joint decision process. The multinomial logit choice model was developed for occupancy choice combination for both commuting legs joined with the pass (transponder) binary choice. This led to seven choice alternatives: 1) No pass-solo-solo, 2) No pass-carpool-carpool, 3) Pass-solo-solo, 4) Pass-solo-FasTrak (HOT), 5) Pass-FasTrak-Solo, 6) Pass-FasTrak-FasTrak, and 7) Pass-Carpool-Carpool. The trip price is adjusted depending on the traffic conditions on the HOT lanes in order to maintain a satisfactory level of services for HOV and can range from $0.50 to $8.00. HOVs use the lanes at no cost. A time-variability variable has been introduced, and it was found that morning commuters dislike variability, while commuters are more tolerant to variability in the afternoon.

The latest regional transportation model of the San Diego Association of Governments in combination with the toll-diversion assignment was used as the base for traffic and revenue analysis for the proposed SR125 South Tollway, as reported by Wilbur Smith Associates (2001). The model consisted of eight steps: trip generation, trip distribution, person-to-vehicle trip factoring, external trips integration, preliminary highway assignment, trip distribution (using congested network), mode choice, and final highway traffic assignment. The last step in the trip table processing was to assume some percentage of electronic toll collection (ETC) traffic for the various assignment years. The trip table was then divided into two categories: ETC traffic and cash traffic, before assignment. This allowed for simultaneous assignment of both categories with tolls corresponding to each type of payment. Traffic and revenue on a toll facility is dependent on motorists' willingness to pay a toll for benefits received in using the toll facility. These benefits can include mileage savings, improved quality of travel, safety, and reduced congestion. The motorists' VOT, vehicle operating cost and toll charges are the three key elements in determining the cost of making a particular trip and, therefore, the selection of a specific path to travel from the origin to destination of the trip. VOT was derived from median household income by zone.

The Northwest Parkway traffic model used a traditional 4-step procedure as reported by Vollmer Associates (2001). A fifth step, toll diversion, was added to account for the effects of tolls on motorists' choices of routes. The model estimated for the project is a binary logit model. The model assumes that the driver's decision to choose the toll road over an alternative route is a function of the utility of the toll road for that driver. The utility included attributes of the toll road (cost and travel time) and the driver's personal preference (willingness to pay the toll, value of their time, etc.). Based on results from August and October 1991 SP surveys conducted in the Denver Area, a set of toll diversion models was developed to estimate the market share for the project. SP models were developed for work trips; airport passenger trips; and other trips, such as a trip to a shopping mall or a trip to a client's office from a driver's work location. An RP model was developed for shopping and recreational trips. The latter model was developed from a telephone survey of Parker-area residents and a roadside survey of Parker-area drivers using the newly open first segment of E-470 road and the parallel alternative routes. When the full three segments of E-470 had opened, it was discovered that drivers were more likely to pay tolls than they had expressed in the SP surveys. The toll curves were modified by shifting them upward, but keeping their original shape, to better reflect the RP survey. The revised utility expressions for each of the four purposes included three components: 1) bias constant; 2) natural logarithm of travel time difference (in minutes), and 3) squared toll charge (in dollars).

An overview of analytical methods used to develop traffic and revenue forecast for toll roads is presented by Dehghani & Olsen (2000). The most common method for conducting toll diversion analysis is through capacity-restrained equilibrium assignment of vehicle trips onto a highway network. It requires the effective time to be calculated for the links where tolls are collected. Effective time is obtained by combining link travel time, delay time due to queuing and service time at toll plazas, and a time penalty equivalent to the toll payment. The last component is based on the VOT estimation. Diversion curves represent another method used to prepare toll forecasts. The use of logit functions, which provide S-shaped diversion curves, has become a popular choice. Recent attempts have been made to include toll facility diversion within the mode choice model. This approach provides forecasts of toll facility demand for each category of auto occupancy. The paper also presents a useful assessment of potential pitfalls that must be recognized and coped with by the toll road analyst in order to provide accurate forecasts. The ramp up (public acceptance lag) phenomenon, which can last for several years, can be identified by a significantly higher traffic growth rate than that of other roadways within the corridor. There appear to be significant cultural factors that affect the acceptance and usage of toll facilities. Communities that have never had toll facilities and communities that previously phased out their existing toll facilities take longer to accept them. Another potential pitfall in the forecasting of toll revenues is the model assumption that all vehicles passing through toll plazas will pay tolls. In practice, there is a significant degree of toll evasion at toll plaza facilities.

To summarize the generalized modeling constructs that are used for toll-road traffic and revenue forecasting, the following three basic approaches stand out:

- Application of traffic assignment model with generalized impedance functions that incorporate tolls by means of VOT estimations, as well as additional delays associated with toll collection. This is the simplest approach that does not require the development, estimation, and application of choice models. Only VOT estimation is necessary. However, there are several strong limitations of this approach, such as ignoring tolled-off (diverted) travelers who may change mode, destination, time of day, car occupancy, etc., as a result of imposing a toll.
- Application of a binary choice model that considers a choice of toll road versus non-toll options in combination with network equilibrium assignment that uses correspondent networks (with and without toll facility) to ensure travel time saving for those who chose to pay a toll. Two versions of this approach can be identified: 1) treatment of the tolled-off travelers as non-toll road users, and 2) treatment of the tolled-off travelers as diverted from the highway mode in this time-of-day period. In the last case, a binary choice model essentially works as a diversion curve.
- Modeling toll-road options as an additional component in the travel demand hierarchy of choices fully accounting for travel behavior across all relevant dimensions. The relevant dimensions that are closely intertwined with toll-road choice include mode, car occupancy, and time-of-day. There can be a potential impact on destination and trip-frequency choice as well; however these dimensions are considered less obvious and of second-order importance in practical terms. Figure 4 below illustrates an incorporation of the binary toll/non-toll choice as the lower level in the mode choice nested structure applied by PB Consult for the Montreal Toll Traffic and Revenue Study.

Conclusion: How to Choose the Right Tool in a Planning Context?

It is difficult and probably impossible to unambiguously state what single model structure is the universally best for road pricing. For several objective and subjective reasons, the application of different tools in practice including advanced and simplified ones will be required. The first important aspect to consider is the nature of the road pricing project under study and its potential impact on various dimensions of travel. For example, for intercity toll roads where peak spreading and route choice are the major factors, a certain simplification of the approach (not considering mode choice) can be justified. Contrary to that, for dense urban areas where area pricing is applied, modal shifts can be a central question and consequently a reasonable mode choice model is essential.

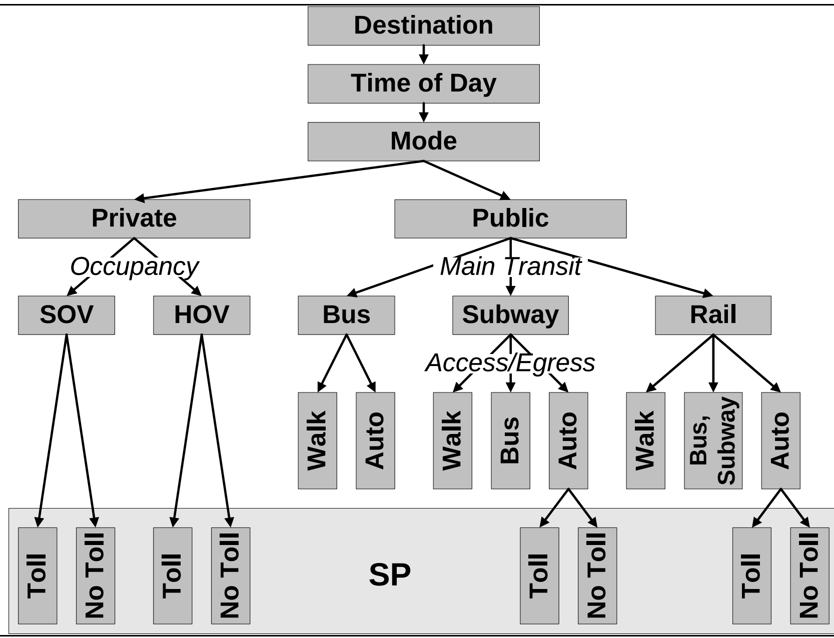

Figure 4: Nested structure for combined mode and toll road choice

The second important aspect is the comprehensiveness and quality of the existing regional or statewide travel model (if any), as well as the availability of relevant information for model development and/or improvement and calibration. In general, the best starting point for the modeling of road pricing is a well-calibrated regional model, "on the top" of which certain additional features could be added, such as an additional nesting level for toll/non-toll choice in the mode choice structure. This would require only a focused additional SP survey that would be designed to estimate the willingness to pay for better service on a toll road. If the forecasts are to be done in a situation where a regional model is not available, and/or there is a very limited time and budget allocated for the project, the application of a simplified sketch planning technique would probably be justified (with the corresponding recognition of the implications for the accuracy of the produced forecasts).

The third approach is to make use of advanced (and more complicated) modeling tools, rather than conventional (and generally simpler) tools. Undoubtedly, the most promising directions for principal improvement of road pricing models are associated with advanced network simulation tools (dynamic traffic assignment and micro-simulation) and advanced activity-based demand models. These advanced tools have a much higher flexibility in incorporation of various impacts of road pricing on travel behavior compared to conventional tools like static assignment and the 4-step model. More specifically, the major current breakthroughs relate to the incorporation of heterogeneity of road users with respect to their VOT and their willingness to pay, accounting for reliability of travel time associated with toll roads, more comprehensive modeling of time-of-day choice based on constraints associated with changing daily schedules, and a proper incorporation of the toll road choice in the general hierarchy of travel choices in the model system.

The last important aspect we would mention relates to the integrity of all the stages in the modeling of travel demand and associated toll revenue for a road pricing project – network simulation, demand modeling, and the subsequent evaluation of multiple scenarios and choice of the optimal pricing scheme. We believe that it is impossible to make significant progress by advancing only one of these stages. For example, any progress in dynamic traffic assignment algorithms will not pay real dividends in practice until after the demand has been estimated in a proper way. By the same token, behaviorally realistic activity-based models require accurate estimates of travel time and reliability for all periods of a day. Finally, the evaluation of different pricing schemes with respect to their social welfare and/or maximum revenue criteria should be derived from the model output in a consistent way, rather than estimated independently. This calls for further coordinated research in all related modeling fields.

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Audience Discussion

Travel Time Reliability

It is becoming increasingly apparent that travelers place a high value on travel time reliability. Evidence shows that travelers want travel time to meet their expectations from 50-80 percent of the time. Measuring the improvement in travel time reliability and its value to travelers—personal travelers and freight carriers—is critical to evaluating the behavioral response to pricing strategies. The value of travel time reliability can be taken into account indirectly by introducing alternative mode specific bias constants in four-step models.

Appendix A. Program

Day 1 (Monday November 14, 2005)

8:30 Registration/Continental Breakfast

9:00 Welcome, Tyler Duvall, *Deputy Assistant Secretary for Transportation Policy*, U.S. Department of Transportation

9:15 Introduction and Overview Frank Koppelman, *Professor* Department of Civil and Environmental Engineering, Northwestern University

9:30 Overview of the State of the Art of Travel Models and Pricing Bruce Spear, *Travel Model and GIS Specialist*, FHWA

10:00 Group Discussion

10:30 Break

10:45 Data Requirements to Support Pricing Analyses Johanna Zmud, *Partner*, NuStats

11:15 Panel Discussion

Charles Purvis, Metropolitan Transportation Commission
Thomas Rossi, Cambridge Systematics
Richard Walker, Portland Metro

12:00 Lunch

1:00 Group Discussion

2:00 Modeling Pricing in the Planning Process Ram Pendyala, *Professor* Civil and Environmental Engineering, University of South Florida

2:30 Break

2:45 Panel Discussion

Kenneth Cervenka, North Central Texas Council of Governments
Keith Lawton, Keith Lawton Consulting
Kara Kockelman, University of Texas at Austin

3:30 Group Discussion

4:30 Adjourn

Day 2 (Tuesday November 15, 2005)

8:00 Continental Breakfast

8:30 Review of Day One, Overview of Day Two, Frank Koppelman

8:45 Revenue Forecasting, David Kriger, *Vice President*, iTrans Consulting

9:15 Panel Discussion

Cherian George, Fitch Rating
Daniel Brand, CRA International
David Lewis, HDR | HLB Decision Economics Inc.

10:00 Break

10:15 Group Discussion

11:15 Making the State of the Art the State of the Practice, Peter Vovsha, *Principal Consultants*, PB Consult

11:45 Summary and Research Priorities, Joseph Schofer, *Professor*, Department of Civil and Environmental Engineering Northwestern University

12:30 Concluding Remarks, Frank Koppelman

12:45 Adjourn

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Appendix C. Abbreviations

AASHTO – American Association of State Highway and Transportation Officials
CBD – Central business district
DOT – Department of transportation
ECT – Electronic toll collection
FAIR lane– Fast and intertwined regular lane
FHWA – Federal Highway Administration
FTA – Federal Transit Administration
GPS – Global positioning system
HOT – High occupancy and toll
HOV – High occupancy vehicle
ISTEA – Intermodal Surface Transportation Efficiency Act
MPO – Metropolitan planning organization
NCHRP - National Cooperative Highway Research Program
O-D – Origination-destination
PCE – Passenger car equivalent
RFID – Radio frequency identification
ROI – Return on investment
RP – Revealed preference
SAFETEA-LU – Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SOV – Single occupant vehicle
SP – Stated preference
SR – State route
TDM – Travel demand management
TEA-21 – Transportation Equity Act for the 21st Century
TIFIA – Transportation Infrastructure Finance and Innovation Act of 1998
TMIP – Travel Model Improvement Program
TOD – Time of day
TRB – Transportation Research Board
TTI – Texas Transportation Institute
U.S. DOT – United States Department of Transportation
VDF – Volume-delay function
VHT – Vehicle hours of travel
VMT – Vehicles miles traveled
VOR – Value of reliability
VOT – Value of time