MODELING PRICING IN THE PLANNING PROCESS

Ram M. Pendyala, Ph.D.
Professor, Transportation Systems
Department of Civil and Environmental Engineering
University of South Florida
4202 East Fowler Avenue, ENB118
Tampa, FL 33620-5350
Ph: +1-813-974-1084
Fax: +1-813-974-2957
Email: pendyala@eng.usf.edu

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. Public Transport Pricing Systems: 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. Parking Pricing: 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. Standard Tolls: 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. Pricing on Existing Roads: *New tolls on existing toll-free facilities (usually electronically-collected*)

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. Pricing on New Lanes: *Tolls on lanes added to existing highways (usually electronically collected*

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

- 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. <u>Pricing of Parking and Vehicle Use: *Pricing strategies that do not involve tolls*</u>

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

    - 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. <u>Trip Generation</u>: 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. <u>Trip Distribution</u>: 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.

REFERENCES

Acha-Daza, J.A. and H.S. Mahmassani (1999) User's Response to Pricing in a Traffic Network. University of Texas, Austin, Center for Transportation Research, Report No. SWUTC/99/465620-1, Southwest Region University Transportation Center, Texas Transportation Institute, Texas A&M University, College Station, TX.

Adler, J.L. and M. Cetin (2001) A Direct Redistribution Model of Congestion Pricing. *Transportation Research* **35B(5)**, pp. 447-460.

Adler, T., W. Ristau, and S. Falzarano (1999) Traveler Reactions to Congestion Pricing Concepts for New York's Tapan Zee Bridge. *Transportation Research Record* **1659**, Transportation Research Board, pp. 87-96.

Agnello, P. and G. Bandy (2002) Using Traditional Travel Demand Forecasting Model to Perform Variable Pricing Analysis. Proceedings of the Eighth TRB Conference on the Application of Transportation Planning Methods, Transportation Research Board, Washington, D.C., pp. 253-258.

Allen Jr., W.G. (1995) Model Improvements for Evaluating Pricing Strategies. *Transportation Research Record* **1498**, Transportation Research Board, pp. 75-81.

Arentze, T. and H. Timmermans (2005) *ALBATROSS Version 2.0. A Learning Based Transportation Oriented Simulation System*. EIRASS, European Institute of Retailing and Services Studies, Eindhoven University of technology, Eindhoven, The Netherlands.

Arentze, T., F. Hofman, and H. Timmermans (2004) Predicting Multi-Faceted Activity-Travel Adjustment Strategies in Response to Possible Congestion Pricing Scenarios Using an Internet-Based Stated Adaptation Experiment. *Transport Policy* **11(1)**, pp. 31-41.

Ash, N. (2004) De-Mystifying Traffic and Revenue Forecasting for Toll Roads. Presentation to the Municipal Analysts Group of New York, June 11. Jacobs Consultancy.

Axhausen K.W. and T. Gärling (1992) Activity-based Approaches to Travel Analysis: Conceptual Frameworks, Models, and Research Problems. *Transport Reviews* **12(4)**, pp. 323-341.

Barron, K. (2001) Roads Less Traveled. Forbes Magazine, September 3, 2001.

Berg, J.T. and F.B. Young (1999) Value Pricing Helps Reduce Congestion. *Public Roads* **62(5)**, pp. 47-52.

Bhat, C.R. and R.M. Pendyala (2005) Modeling Intra-household Interactions and Group Decision Making. *Transportation* **32(5)**, pp. 443-448.

Bhat, C.R. and S. Castelar (2002) A Unified Mixed Logit Framework for Modeling Revealed and Stated Preferences: Formulation and Application to Congestion Pricing Analysis in the San Francisco Bay Area. *Transportation Research* **36B(7)**, pp. 593-616.

Bhat, C.R., J.Y. Guo, S. Srinivasan, and A. Sivakumar (2004) Comprehensive Econometric Microsimulator for Daily Activity-Travel Patterns, *Transportation Research Record* **1894**, Transportation Research Board, pp. 57-66.

Bowman, J.L., M. Bradley, Y. Shiftan, T.K. Lawton, and M. Ben-Akiva (1998) Demonstration of an Activity-Based Model for Portland. World Transport Research: Selected Proceedings of the 8th World Conference on Transport Research, Volume 3, Elsevier Science Ltd., Oxford, UK, pp. 171-184.

Brownstone, D., A. Ghosh, T.F. Golob, C. Kazimi, and D. Van Amelsfort (2003) Drivers' Willingness-to-Pay to Reduce Travel Time: Evidence from the San Diego I-15 Congestion Pricing Project. *Transportation Research* **37(4)**, pp. 373-387.

Burris, M.W. (2003) Application of Variable Tolls on Congested Toll Road. *ASCE Journal of Transportation Engineering* **129(4)**, pp. 354-361.

Burris, M.W. and R.M. Pendyala (2002) Discrete Choice Models of Traveler Participation in Differential Time of Day Pricing Programs. *Transport Policy* **9(3)**, pp. 241-251.

Burris, M.W., K.K. Konduru, and C.R. Swenson (2004) Long-Run Changes in Driver Behavior Due to Variable Tolls. *Transportation Research Record* **1864**, Transportation Research Board, pp. 78-85.

Cain, A., M.W. Burris, and R.M. Pendyala (2001) Impact of Variable Pricing on Temporal Distribution of Travel Demand. *Transportation Research Record* **1747**, Transportation Research Board, pp. 36-43.

Cambridge Systematics, Inc. (1997) Time-of-Day Modeling Procedures: State-of-the-Practice, State-of-the-Art. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. Available at: http://tmip.fhwa.dot.gov/clearinghouse/docs/Time-Day/

De Palma, A., M. Kilani, and R. Lindsey (2005) Congestion Pricing on a Road Network: A Study Using the Dynamic Equilibrium Simulator METROPOLIS. *Transportation Research* **39A(7-9)**, pp. 588-611.

DeCorla-Souza, P. (2001) FAIR Lanes: A New Approach to Manage Congested Freeway Lanes. In K. Turnbull (ed) *Proceedings of the 10th International Conference on High-Occupancy Vehicle Systems*. Report FHWA-OP-01-041, EDL Document No. 13482, Texas Transportation Institute, College Station, Texas. Federal Highway Administration, Operations Office of Travel Management, Washington, D.C., pp. 63-78.

DeCorla-Souza, P. (2002) Value Pricing Projects Around the United States. *Eighth TRB Conference on the Application of Transportation Planning Methods*, Transportation Research Board, pp. 45-55.

DeCorla-Souza, P. and R.E. Whitehead (2003) The Value of Pricing the Use of Roads. *Public Works Management and Policy* **7(4)**, pp. 267-276.

Dehghani, Y. and W. Olsen (1999) Potential Pitfalls in Forecasting Travel Demand for Toll Roads: Experience in the US and Overseas. Paper presented at the Annual Meeting of the Transportation Research Board, Washington, D.C.

Dehghani, Y., T. Adler, M.W. Doherty, and R. Fox (2003) Development of a New Toll Mode-Choice Modeling System for Florida's Turnpike Enterprise. *Transportation Research Record* **1858**, Transportation Research Board, pp. 9-17.

Dial, R.B. (1999) Minimal Revenue Congestion Pricing Part I: A Fast Algorithm for the Single-Origin Case. *Transportation Research* **33B(3)**, pp. 189-202.

Dial, R.B. (2000) Minimal Revenue Congestion Pricing Part II: An Efficient Algorithm for the General Case. *Transportation Research* **34B(8)**, pp. 645-665.

Flyvbjerg, B., M. Holm, and S. Buhl (2005) How (In)Accurate are Demand Forecasts in Public Works Projects: The Case of Transportation. *Journal of the American Planning Association* **71(2)**, pp. 131-146.

General Accounting Office (2003) Reducing Congestion: Congestion Pricing has Promise for Improving Use of Transportation Infrastructure. Testimony of Jayetta Z. Hecker, Director, Physical Infrastructure Issues before the Joint Economic Committee, U.S. Congress. General Accounting Office, Washington, D.C.

Gifford, J.L. and O.J. Stalebrink (2001) Transportation Demand Management. In K.J. Button and D.A. Hensher (eds) *Handbook of Transport Systems and Traffic Control*. Elsevier Science Ltd., Amsterdam, The Netherlands, pp. 199-208.

Gliebe, J.P. and F.S. Koppelman (2002) A Model of Joint Activity Participation. *Transportation* **29(1)**, pp. 49-72.

Golob, T.F. (2001) Joint Models of Attitudes and Behavior in Evaluation of the San Diego I-15 Congestion Pricing Project. *Transportation Research* **35(6)**, pp. 495-514.

Hensher, D.A. and P. Goodwin (2004) Using Values of Travel Time Savings for Toll Roads: Avoiding Some Common Errors. *Transport Policy* **11(3)**, pp. 171-181.

Hensher, D.A., F.W. Milthorpe, N.C. Smith, and P.O. Barnard (1990) Urban Tolled Roads and the Value of Travel Time Savings. *Economic Record* **66(193)**, pp. 146-156.

Ison, S. and T. Rye (2005) Implementing Road User Charging: The Lessons Learnt from Hong Kong, Cambridge, and Central London. *Transport Reviews* **25(4)**, pp. 451-465.

Johnston, D.K. and D. Patterson (1990) Toll Roads – A Method for Estimating Usage and Revenue. Proceedings of the 15th ARRB Conference, Part 4, pp. 191-209.

Kitamura, R. and S. Fujii (1998) Two Computational Process Models of Activity-Travel Choice. In Gärling, T., T. Laitila, and K. Westin (eds) *Theoretical Foundations of Travel Choice Modeling*, Pergamon, Elsevier Science Ltd., Oxford, UK, pp. 251-280.

Kitamura, R., C. Chen, R.M. Pendyala, and R. Narayanan (2000) Micro-Simulation of Activity-Travel Patterns for Travel Demand Forecasting. *Transportation* **27(1)**, pp. 25-51.

Kockelman, K.M. and S. Kalmanje (2005) Credit-Based Congestion Pricing: A Policy Proposal and the Public's Response. *Transportation Research* **39A(7-9)**, pp. 671-690.

Kuhnau, J. and K.G. Goulias (2003) CentreSIM: First-Generation Model Design, Pragmatic Implementation, and Scenarios. In K.G. Goulias (ed) *Transportation Systems Planning: Methods and Applications*, CRC Press, Boca Raton, FL, pp. 16-1 – 16-14.

Kuppam, A.R., R.M. Pendyala, and M.A.V. Gollakoti (1998) Stated Response Analysis of the Effectiveness of Parking Pricing Strategies for Transportation Control. *Transportation Research Record* **1649**, Transportation Research Board, pp. 39-46.

Kuppam, A.R., R.M. Pendyala, and M.A.V. Gollakoti (1998) Stated Response Analysis of the Effectiveness of Parking Pricing Strategies for Transportation Control. *Transportation Research Record* **1649**, Transportation Research Board, pp. 39-46.

Lauer, A. (1999) The Complexity of Urban Tolls. *Business Briefing: Global Mass Transit Systems*, World Markets Research Center, London, UK, pp. 136-139.

Levinson, D. (2002) *Financing Transportation Networks.* Transport Economics Management and Policy Series, Edward Elgar Publishers, New York.

Levinson, D. (2005) Micro-foundations of Congestion and Pricing: A Game Theory Perspective. *Transportation Research* **39A(7-9)**, pp. 691-704.

Mahmassani, H.S. (2000) Trip Timing. In D.A. Hensher and K.J. Button (eds) *Handbook of Transport Modelling*, Elsevier Science Ltd., Amsterdam, The Netherlands, pp. 393-407.

Marin, E. (2003) Demand Forecast, Congestion Charge, and Economic Benefit of an Automated Highway Network for the Paris Agglomeration. *Transport Policy* **10(2)**, pp. 107-120.

Matas, A. and J-L. Raymond (2003) Demand Elasticity on Tolled Motorways. *Journal of Transportation and Statistics* **6(2/3)**, pp. 91-108.

Mayet, J. and M. Hansen (2000) Congestion Pricing with Continuously Distributed Values of Time. *Journal of Transport Economics and Policy* **34(3)**, pp. 359-369.

McGraw-Hill (2003) Variably Priced Express Lanes Gaining Interest Nationwide. McGraw-Hill Information Systems Company **250(10)**, New York, NY.

Miller, E.J., D.S. Kriger and J.D. Hunt (1998) *Integrated Urban Models for Simulation of Transit and Land-Use Policies*, Final Report, Transit Cooperative Research Project H-12, Toronto: University of Toronto Joint Program in Transportation.

Munnich, L. and G. Barnes (2003) Minnesota Value Pricing Project. Final Report MN/RC-2003-31, Minnesota Department of Transportation, Office of Research Services. University of Minnesota, Humphrey Institute of Public Affairs, Minneapolis, MN.

Olszewski, P. and L. Xie (2005) Modelling the Effects of Road Pricing on Traffic in Singapore. *Transportation Research* **39A(7-9)**, pp. 755-772.

Pendyala, R.M. (2003) Time Use and Travel Behavior in Space and Time. In K. G. Goulias (ed.) *Transportation Systems Planning: Methods and Applications*. CRC Press, Boca Raton, FL, pp. 2-1 – 2-37.

Pendyala, R.M. and C.R. Bhat (2004) Emerging Issues in Travel Behavior Research. *Web Proceedings of the Conference on Data for Understanding Our Nation's Travel: National Household Travel Survey*, Transportation Research Board, National Research Council, Washington, D.C. (http://www.trb.org/Conferences/NHTS)

Pendyala, R.M. and X. Ye (2005) Contributions to Understanding Joint Relationships Among Activity and Travel Variables. In H. Timmermans (ed.) *Progress in Activity-Based Analysis*. Pergamon, Elsevier Science Ltd., Oxford, UK, pp. 1-24.

Pendyala, R.M., R. Kitamura, A. Kikuchi, T. Yamamoto, and S. Fujii (2005) FAMOS: The Florida Activity Mobility Simulator. *Transportation Research Record*, Transportation Research Board (in press).

Pendyala, R.M., R. Kitamura, and D.V.G.P. Reddy (1998) Application of an Activity-Based Travel Demand Model Incorporating a Rule-Based Algorithm. *Environment and Planning B: Planning and Design* **25**, pp. 753-772.

Pendyala, R.M., R. Kitamura, C. Chen, and E.I. Pas (1997) An Activity-Based Micro-simulation Analysis of Transportation Control Measures. *Transport Policy* **4(3)**, pp. 183-192.

Pendyala, R.M., T. Yamamoto, and R. Kitamura (2002) On the Formulation of Time Space Prisms to Model Constraints on Personal Activity-Travel Engagement. *Transportation* **29(1)**, pp. 73-94.

Phang, S.Y. and R.S. Toh (2004) Road Congestion Pricing in Singapore: 1975-2003. *Transportation Journal* **43(2)**, pp. 16-25.

Queiroz, C. (2005) Assessing the Potential for Public-Private Partnerships (PPP) in Highways. Presentation to the Russian Federal Highway Agency, Moscow, February 28. World Bank.

Raje, F. (2003) The Impact of Transport on Social Exclusion Processes With Specific Emphasis on Road User Charging. *Transport Policy* **10(4)**, pp. 321-338.

Richardson, A.J. (2004) New Zealand Tolling Value of Travel Time (Stated Preference) Surveys, TUTI Report 27-2004, 37-2004, 36-2004, to Transit NZ. The Urban Transport Institute, Alexandra Vic, Australia.

Ruster, J. (1997) A Retrospective on the Mexican Toll Road Program (1989-1994). Public Policy for the Private Sector, Note No. 125, World Bank Group, Washington, D.C.

Santos, G. (2005) Urban Congestion Charging: A Comparison Between London and Singapore. *Transport Reviews* **25(5)**, pp. 511-534.

Santos, G. and B. Shaffer (2004) Preliminary Results of the London Congestion Charging Scheme. *Public Works Management and Policy* **9(2)**, pp. 164-181.

Shoup, D. (2005) The *High Cost of Free Parking*. American Planning Association, Chicago, IL.

Shoup, D. and J. Brown (2003) Pricing Our Way Out of Traffic Congestion: Cash Out and HOT Lanes. Report UCTC No. 509, University of California Transportation Center, University of California, Berkeley, CA.

Small, K.A., C. Winston, and J. Yan (2002) Uncovering the Distribution of Motorists' Preferences for Travel Time and Reliability: Implications for Road Pricing. UCTC No. 546, University of California Transportation Center, University of California, Berkeley, CA.

Standard and Poor's (2004) Traffic Forecasting Risk: Study Update 2004. Standard and Poor's, a Division of the McGraw-Hill Companies, Inc., New York, NY.

Stopher, P.R. (2004) Reducing Road Congestion: A Reality Check. *Transport Policy* **11(2)**, pp. 117-131.

Sullivan, E.C. (1997) Impacts of Implementing the California Route 91 Variable-Toll Express Lanes. Paper presented at the 67th Annual Meeting of the Institute of Transportation Engineers, Boston, MA. Institute of Transportation Engineers, Washington, D.C.

Supernak, J., C. Kaschade, and D. Steffey (2003) Dynamic Value Pricing on I-15 in San Diego: Impact on Travel Time and Its Reliability. *Transportation Research Record* **1839**, Transportation Research Board, pp. 45-54.

Swenson, C.R., S.M. Gilbertson, M. Byers, and M.W. Burris (1999) Variable Toll Reduction as a Practical Transportation Demand Strategy. Transportation Frontiers for the Next Millennium: 69th Annual Meeting of the Institute of Transportation Engineers, Publication No. CD-006, Institute of Transportation Engineers, Washington, D.C.

Thorpe, N. and P. Hills (2003) Investigating Drivers' Responses to Road-User Charges Using Global Positioning System (GPS) Technology. *IATSS Research* **27(1)**, pp. 75-84.

TRB (2005) *International Perspectives on Road Pricing*. Proceedings of the International Symposium on Road Pricing. Transportation Research Board, Washington, D.C.

Urban Mobility Corporation (2005) Toll Financing is Gaining Popularity. *Innovation Briefs* **16(1)**, Urban Mobility Corporation, Potomac, MD.

URS Greiner, Inc. (1999) The Selective Use of Shadow Tolls in the United States. In Association with Public Financial Management, Inc. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. Available at: http://www.fhwa.dot.gov/innovativefinance/shadtoll.htm

Vovsha, P., M. Bradley, J.L. Bowman (2005) Activity-Based Travel Forecasting Models in the United States: Progress since 1995 and Prospects for the Future. In H. Timmermans (ed) *Progress in Activity-Based Analysis*, Elsevier Science Ltd., Oxford, UK, pp. 389-414.

Waddell, P., A. Borning, M. Noth, N. Freier, M. Becke, and G. Ulfarsson (2003) Microsimulation of Urban Development and Location Choices: Design and Implementation of UrbanSim. *Networks and Spatial Economics* **3(1)**, pp. 43-67.

Wallis, I. (2005) Implications of Selected Urban Road Tolling Policies for New Zealand. Land Transport New Zealand Research Report No. 270, Booz Allen Hamilton, Wellington, New Zealand.

Wen, C.H. and F.S. Koppelman (2000) A Conceptual and Methodological Framework for the Generation of Activity-Travel Patterns. *Transportation* **27(1)**, pp. 5-23.

Wong, W.K.I., R.B. Noland, and M.G.H. Bell (2005) The Theory and Practice of Congestion Charging: Foreword. *Transportation Research* **39A(7-9)**, pp. 567-570.

Yang, H. and X. Zhang (2002) Multiclass Network Toll Design Problem with Social and Spatial Equity Constraints. *ASCE Journal of Transportation Engineering* **128(5)**, pp. 420-428.