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The acceptability and drivers' willingness to pay and departure time choice model for HOT lanes on I-495 in Maryland

Prepared for the

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1 Problem Statement

A number of new road pricing projects have emerged in the U.S. over the past decade. Currently, 35 of the 50 states have some sort of road pricing project in the planning or implementation stage. One promising approach in implementing road pricing is to convert existing under-utilized high occupancy vehicle (HOV) lanes to high occupancy toll (HOT) lanes. The development of HOT lanes can bring new revenue and pricing incentives to road users by essentially auctioning off space on existing HOV lanes. However, policy makers have always been hesitant to adopt HOT lanes due to insufficient political support. One of the reasons is because it is believed that the HOT lanes will mainly benefit travelers with high incomes due to their high valuation of travel time saving.

In summer 2008, the State of Virginia has approved the HOT Lanes Project and has started major infrastructure enhancements to the Beltway (I-495). The project includes four new lanes in each direction from the Springfield Interchange to just north of the Dulles Toll Road and the replacement of more than $260 million in aging infrastructure. HOT lanes will operate as tolled lanes alongside existing highway lanes to provide users with a faster and more reliable travel option. Buses, carpools (HOV-3), motorcycles and emergency vehicles will have free access to HOT lanes. Drivers with fewer than three occupants can choose to pay to access the lanes. Tolls for the HOT lanes will change according to traffic conditions to regulate demand for the lanes and keep them congestion free - even during peak hours. (www.virginiahotlanes.com)

Maryland's roadways are among the most congested in the country. Travel on Maryland's highways has increased by 20 percent since 1995 – despite only a four percent increase in miles of highway lanes over the same period. This imbalance has contributed to the increase in traffic congestion, making the Baltimore-Washington region one of the worst areas in the country in the amount of time it takes for people to commute to work. In light of the State's severe fiscal constraints, creative approaches must be found to reduce the "congestion tax." The Maryland Department of Transportation (MDOT) has made a promise to Maryland's residents and businesses to make tangible and near-term improvements to traffic flow throughout the State and, in so doing, achieve MDOT's vision of a More Mobile Maryland. The State's transportation agencies are committed to easing the near-crippling congestion that clogs our highways – and to do so as soon as possible.

MDOT and State Highway Administration (SHA), and Maryland Transportation Authority (MDTA) are considering providing drivers in Maryland an alternative of relatively congestion-free travel with some fee charged. The idea of building HOT lane therefore comes out. The HOT lane will give drivers the option of paying a fee to drive in a separate, relatively free-flowing highway lane on a given trip. The toll will be collected electronically via the use of electronic transponders. Toll rates could vary based on demand- either by time of day or based on mileage traveled. HOT lane program can be structured to encourage motorists to travel during off-peak traffic hours and simultaneously provide alternatives for motorists who do not have the flexibility of switching their travel time – i.e., the option to pay a fee to gain access to the express lanes. A parent who needs a reliable travel time to pick up a child at daycare, for instance, can choose to pay a fee to travel in the relatively free-flowing lanes. Similarly, a service technician can save valuable time by choosing to pay to travel in less congested lanes.

Moreover, pricing schemes are gaining attention as a travel demand management strategy by providing incentive to travelers with more flexible departure time to travel during off peak period, thereby shifting peak travel demand. Despite the widespread interest in the concept of departure time choice, there is very little empirical study on the impact of departure time choice in the presence of time-of-day toll pricing. Departure time choice is also an important ingredient in policy implementing and evaluation for some other emerging policy issues such as:

- Evaluation of vehicle emission as results of vehicle volume forecasts and speed by time of day due to achieve air quality analysis standard for federal and state clean air standard.

- Improvement of model accuracy to forecast travel speed, congestion, delay, and time of day travel to achieve travel demand model analytical standard due to the Intermodal Surface Transportation Efficiency Act (ISTEA) and State Congestion Management Program.

- Modeling the peak spreading behavior affected by departure time shift. Identification of highway system problems due to peak period congestion and accounting for route diversions caused by the congestion.

- To compliment Transportation Demand Management (TDM) by alleviating peak traffic congestion, reduce dependence on single occupant auto level, and other environment concerns associated to auto travel.

2 Purpose

With this project we propose to investigate the acceptability of HOT lanes and the willingness to pay for their use from the traveler perspective. In particular, we aim at formulating a model system that will be able to simulate individual behavior in response to HOT lanes on I-495 in Maryland. The project will utilize state-of-art and advanced methods to calculate the number of riders that will be willing to pay to use HOT lanes, the distribution of the willingness to pay and the main factors affecting their choices. Furthermore, our objective is to capture the ability of travelers to change their behavior in response to congestion pricing and their flexibility to accept more sustainable way to access work, shopping and leisure places.

This project will also propose an empirical study that integrates the joint effects of departure time and mode choice. Modeling departure time is essential for policy makers evaluating travel demand management alternatives, such as time-of-day toll pricing. Different toll prices by time of day induce traveler to perceive departure time choice similar to the mode choice selection. We will consider variables affecting departure time such as travel time, travel cost, travel time reliability and activity duration. The presence of time-of-day toll pricing will be taken into account in the model estimation process to develop a model that represents behavioral responses to pricing. Possible response of traveler to pricing in term of mode shift and departure time shift will be carefully examined. The extent to which the model could aid local agencies to achieve several objectives including toll revenue, system performance, and environmental impact will be examined. Finally the project team intends to establish a continuous dialog with local State agencies in order to adapt our modeling tool to their needs in terms of policy analysis.

3 Literature Review

Adopting HOT lanes is one of the measures when considering managed lanes in a freeway corridor. HOT lanes offer drivers the option of traveling on a HOV lane for a toll when they would not normally meet the occupancy requirements of the lane. With HOT lanes, though, such free-flow lanes can be made available to all motorists. For example, vehicles carrying sufficient numbers of passengers still could use the HOV lanes for free, but those same lanes would serve as HOT lanes when vehicles with a single occupant pay variable tolls to travel on them.

3.1 Research and applications of managed lanes

Ginger Goodin on the ITE journal (Goodin, 2005) explains reasons of considering managed lanes (such as HOT lanes): the inability to build enough lanes to address congestion during peak periods because of cost, environmental concerns or community issues, the desire to offer travel options in a congested corridor, the need to address funding issues and the potential for revenue generation, the desire to increase the effectiveness of HOV lanes as well as the need to separate large vehicles. Goodin highlights three primary management strategies for implementing the operational managed lane facilities: pricing, vehicle eligibility and access control. As of March of 2006, HOV lanes have been converted to HOT lanes in only five cases. However, numerous cities are in various stages of implementing a HOT lane. Some of HOT projects have been included into the FHWA Value Pricing Pilot Program, which offers funding and technical guidance for testing and evaluating pricing strategies to manage demand.

3.1.1 State Route 91, Orange County

The State Route 91 Express Lanes in California are the first example in the United States of variable toll depending on the level of congestion; the project is operational since 1995. There are five free lanes and two toll lanes in each direction. Toll rates are set according to the level of congestion, making peak periods the most expensive time to travel. Carpools with three or more occupants (HOV3), motorcycles, zero-emission vehicles travel for free on HOV lanes. Vehicles with disabled person license plates are free at all times, with the exception of the evening peak period in the peak direction, when HOVs are charged 50 percent of the posted toll. Approximately 30,000 vehicles each weekday use the express lanes that replaced the median lanes of this congested urban freeway; toll charged is up to $ 5.00.

Knowing how travel time and its reliability are valued by travelers is of great importance in recent policy innovations regarding highway congestion. In particular, researchers are interested in evaluating the value of travel time (VOT) and the value of reliability (VOR). Lam and Small (2001) measured values of time and reliability on the State Route 91 in Orange County from the

‘98 data of commuter behavior. In Lam and Small’s paper, travelers face a choice between two parallel routes, one free but congested and the other with time-varying tolls (SR 91). The sample consists of 162 observations from a survey conducted in 1997 and 371 respondents recruited by observing license plates on SR 91 and by getting the owners’ address from the Department of Motor Vehicles. Decisions about route choice have been modeled; joint models of route choice and time of day, car occupancy and installation of an electronic transponder are also presented. The binary logit model which models route choice only, includes travel time, travel cost and a number of socio-economic variables; other characteristics considered include time of day and car occupancy. Household income and individual wage rate has been interacted with travel time variables in order to allow VOT and VOR to vary deterministically with these characteristics. It is often claimed that people are more concerned with travel time reliability than with travel time itself. This expectation is confirmed from the results obtained in this paper where the estimated VOR is 39%-46% higher than VOT. The authors also relax the assumption of exogenous time of day for the work trip and make use of nested logit model. The joint models of mode (carpooling) and route choice, which have six alternatives, consist of two possible routes for each of the three possible modes (SOV, HOV2, HOV3). In the nested logit structure mode choice is on the upper level while route is modeled on the lower level. The installation of an electronic transponder is also modeled; the joint model on transponder adoption and route choice is a hierarchical structure with the transponder choice on the upper-level. Finally, three choices are simultaneously considered: transponder, route, and mode. The model is conditional on time of day, and has nine alternatives --- three modes for each of the three joint transponder and route choice models. In total, five combinations among different choice categories are considered, route choice alone, route & time of day, route & mode, transponder & route, and transponder, mode, & route. The last combination which accounts explicitly for transponder, route, and mode choices is the most trustworthy of those presented. The resulting value of time is $22.87 per hour, while value of reliability is $15.12 per hour for men and $31.91 for women.

3.1.2 I-15, San Diego

Because of the success of the operation of HOT lane in Orange County, San Diego County converted an eight-mile reversible HOV roadway on I-15 to a HOT in 1996 as well. Originally, I-15 HOV express lanes were limited to vehicles with two or more occupants and transit vehicles and it had operated southbound in the morning and northbound in the afternoon and evening.

Because the lanes were not crowded after accommodating HOV users, the region tried to make those same lanes HOT to allow toll-paying, single-occupant vehicles (SOV) to use them. The whole project was implemented through several phases. During the first phase, solo drivers purchased monthly passes allowing unlimited use of the express lanes and carpoolers were allowed to travel for free in the express lanes, during the second phase, subscribers were issued transponders used for automatic vehicle identification. The second phase is referred to as FasTrak. Toll rates are displayed on variable message signs at each entry point and can change every six minutes based on traffic levels. Tolls range from $0.50 to $4.00 but can rise as high as $8.00 in severely congested conditions.

The adoption of congestion pricing depends fundamentally upon drivers' willingness to pay during the peak period. Brownstone et al. (2002) did some research on the commuter's willingness to pay to reduce travel time on San Diego I-15 congestion pricing project. They model travelers' choices: solo driving on the main lanes, solo driving using FasTrak, and driving with others in a car pool with a conditional logit model. The study is based on revealed preference data from a panel survey of travelers who use I-15 in the vicinity of the HOV lanes during the morning period, together with time-specific traffic flow data obtained from loop detectors embedded in the roadway and time-specific data on FasTrak tolls. Survey respondents are queried for detailed information about their most recent inbound trip along I-15, if that trip covered the portion of I-15 corresponding to the facility. By design, trip lengths must be at least eight miles long (the length of the facility). There are 684 I-15 respondents with full information on morning trips during the peak-period that were in the inbound (southbound) direction. The generic variables that vary across alternatives are: (1) toll price, (2) median time savings, (3) difference between actual and mean toll, and (4) reduction in variability of time savings from Express Lanes use. The toll variable is zero for the carpool and solo-free. Time savings and reduction in variability are the same for the FasTrak and carpool alternatives, and equal to zero for the solo-free alternative. Other variables (such as gender, age, and education) are interacted with the choice-specific constants. Solo-free is defined as the base alternative.

Using the logit models, Brownstone and al. estimated that willingness to pay to reduce commuter's time in the morning is about $30 per hour, which is higher the value obtained from stated preference data. The main difference between the I-15 and Route91 experiments is that the I-15 experiment uses congestion pricing instead of time of day pricing that was used in the Route

91 facility. The study by Brownstone et al. (2002) indicates that those drivers more likely to use I-15 toll facility include: (1) commuters as opposed to those traveling for personal appointments and pleasure, (2) individuals from higher income households (income of $100,000 or more), (3) women, (4) individuals between the ages of 35 and 45, (5) higher educated individuals, and (6) homeowners. Brownstone et al. (2002) study shows that drivers are much less sensitive to the toll level when the toll is unusually high since this is associated with increased congestion ahead.

3.1.3 Interstate 10, Houston

Before making the decision of turning HOV lanes to HOT lanes, the analysis and evaluation work play a significant role in the whole process. The I-10 HOV lane (Katy Freeway) in Houston has been open since 1984. The continuously increasing number of HOV lane travelers caused the lane to become congested during peak hours, so the peak hour occupancy requirement was raised to HOV3 since 1988. Both directions are one-lane reversible facilities separated from the main lanes with a concrete barrier. The facilities essentially operate as HOV lanes in off-peak periods and HOT lanes during peak periods right now, although SOVs are never allowed. However, this HOV3 restriction left unused capacity when HOVs with two persons (HOV2) are not allowed. To improve overall efficiency, the Metropolitan Transit Authority of Harris County of Texas implements tolling of HOV2s during the HOV3 restriction as a way to better utilize the available capacity of the HOV lane and the charge is $2.00 each way via transponder.

The complexities and costs associated with adapting HOV lanes to HOT lanes necessitate detailed evaluations of such projects. Furthermore, each project is case specific, and the importance or relevance of the numerous factors that must be considered in adapting an HOV lane to a HOT lane, varying from one project to the next. Though detailed analysis of the factors is necessary before dedicating financial resources to such a significant transportation improvement, there is a need for a sketch-planning tool that can evaluate the multiple factors (quantitative and qualitative) involved in implementing an adaptation project. The Texas Department of Transportation (TxDOT) sponsored research to develop a decision support tool to aid in evaluating key issues related to adapting a HOV lane to a HOT lane (Eisele, et al. 2006). The tool has been used for the I-10 to confirm the decision made several years earlier to proceed with adapting the HOV lane to a HOT lane. The description and research results are provided in Eisele's paper. The tool includes three broad categories of factors to consider: facility considerations, performance considerations, and institutional considerations. Facility considerations, such as design, operations, and enforcement (e.g. facility cross section, access design, pricing strategy, incident management maintenance), can present insurmountable obstacles to the implementation of HOT lanes. Performance considerations and goals allow the user to estimate the likely levels of usage and person movement (e.g. HOV lane utilization, travel time saving, willingness to pay tolls, safety). Institutional considerations are also addressed, as factors of interagency cooperation and legal limitations (e.g. public and political acceptance, revenue use, interagency cooperation, media relations) that are historically important for HOV lane and HOT lane decisions. Finally, the research incorporates simple trade-off tools to allow TxDOT and local entities to assemble all relevant factors into an analysis to aid decision makers in evaluating the available options. The analysis tool was developed in Visual Basic.net. The program is called High-Occupancy Toll Strategic Analysis Rating Tool (HOT START).

HOT START program provides an analytical framework to assess the factors of interest when considering adapting an HOV lane to a HOT lane and illustrate how the tool can be applied to evaluate the facility and its performance.

Besides the evaluation software described above, some other modeling work was done as well. In order to investigate the impact of tolls on HOV lanes and on freeway travelers' travel behavior in Houston and Dallas, a survey was executed in the metropolitan areas of Texas (Burris, 2009). The survey was administered via internet from May to July 2006 and it generated 4280 responses. Then the crews collected additional 354 surveys mainly from low-income and minority neighborhoods. A nested logit model was developed to estimate the mode choice for travelers. Descriptive variables include trip purpose, travel time, trip length, pay to park at destination, number of people in the vehicle, travel companion, number of trips per week and some social-economic characteristics. It was found that the overall percentage of HOV2 and HOV3+ vehicles in the traffic stream decreased by only a small amount when a toll was required for them to use the HOV lane. However, that decrease did represent a significant portion of those modes (more than 9%) and resulted in more than a 10% increase in HOT lane revenue.

3.1.4 New jersey Turnpike Dual-Dual section, New Jersey

The New Jersey Turnpike (NJTPK) is a 148-mile toll road with traffic exceeding 700,000 vehicles per day (Ozbay, et al. 2006). The toll road extends from the Delaware Memorial Bridge in the south of New Jersey to the George Washington Bridge in New York City. Since 2000, the New Jersey Turnpike Authority (NJTA) has successfully implemented a time-of-day pricing program for NJTPK passenger cars with E-ZPass (a kind of electronic toll-collection system) to encourage peak period commuters to shift to off peaks to reduce congestion during peak hours. The program has been implemented in two stages. In September 2000, E-ZPass technology was introduced along with the first stage. As part of this program, different toll levels were charged to users depending on the time of day. Peak hour tolls are effective on weekdays from 7:00 to 9:00 a.m. and from 4:30 to 6:30 p.m. The second stage was implemented On January 1, 2003, when toll levels for each time period and vehicle were increased, 5% for E-ZPass off-peak, 10% for E-ZPass peak, and 17% for cash passenger cars. In 2006, for passenger cars with E-ZPass tags, peak tolls are 15% higher than off-peak tolls (10 to 60 cents). During peak hours and shoulders, more than 90% of vehicles are passenger cars with E-ZPass.

Ozbay et al. did some study about investigating the impact of the time-of-day pricing program on the travel trends at NJTPK. Responses are investigated both for the individual as well as for the complete set of origin–destination (O-D) pairs of NJTPK, considering seasonal variation. The database can be divided into two main parts: aggregate and disaggregate. The first part of the aggregate data includes traffic at typical workdays during peak and off-peak hours from October to June for years 1998, 1999, 2000, and 2001. The second part of the aggregate data includes total daily traffic observed at each day of May and June for 2000 and 2003. Disaggregate data provide detailed vehicle-by-vehicle information about O-D locations, tolls paid, and observed travel times of each E-ZPass vehicle, for each time of day and day of the week from October 2002 to March 2003 three months before and after the initiation of the second stage. The methodology used to investigate users' behavior, responses to time-of-day pricing and prevailing travel time. It includes four parts: investigate sources of time dependent variations by using aggregate data, investigate changes in total yearly, daily, and peak/off-peak period traffic by using average traffic volumes before and after the program, investigate the relationship between the changes in traffic and travel time for different periods, investigate traffic patterns of highly used pairs to get a better insight of individual and combined impacts of travel time and toll differentials on the NJTPK user behavior. The findings present a statistically insignificant shift to other modes and routes after the time-of-day pricing initiative. The aggregate analysis shows a slight shift to off-peak periods after the first stage and to peak periods after the second stage.

Disaggregate analysis then shows 53% of E-ZPass users prefer periods with lower travel times and higher tolls instead of peak shoulders with higher travel time but lower tolls. For most of the highly used O-D pairs, E-ZPass traffic at periods with the highest travel time has decreased after the second stage of the time-of- day pricing program. Given the small price differential between peak and off-peak periods, it is likely that NJTPK E-ZPass users are trying to avoid congestion rather than slightly higher tolls.

3.1.5 HOT lanes in Atlanta, Georgia

The Atlanta region is facing significant challenges in keeping its road network operating at acceptable levels of performance. The latest regional transportation plan, Mobility 2030, forecasts an additional 2.5 million people and 1.3 million jobs in 2030 compared to 2000. This tremendous growth is expected to result in a 41% increase in vehicle miles traveled (VMT), a 52% increase in vehicle hours traveled, and a decrease of 10% in regional average speed (with average speeds in congested corridors declining even further) (Atlanta Regional Commission, 2005). Congestion is expected to increase significantly for both major highways and arterial roads. Mobility 2030 represents investing $54 billion in the region’s transportation infrastructure and services which include managed HOV lanes. Even with more than $54 billion in investment in Mobility 2030, the Atlanta region is still facing a serious challenge in providing a reasonable level of performance of its road network. However, some research has shown that by assuming HOV lanes are built on all limited access facilities, unused capacity will be available in many of the region’s managed lanes. The available capacity in the HOV lanes is sufficient in some corridors to allow travelers to use these lanes to avoid congestion by paying a fee. With vehicles allowed to pay a fee to use this available capacity, highway users will be given an option to achieve a more reliable trip through a fee charged.

In order to further study the feasibility of the Atlanta HOT lane program and to figure out how the available capacity should be used to provide the maximum benefit to freeway network performance, a managed lane network has been coded in the regional demand model for all the limited-access facilities in the 10-county Atlanta Regional Commission (ARC) region (Meyer, et al. 2006). Performance measure such as vehicle and person trips, VMT, travel time savings, managed lane operational costs, and revenues are used to compare different network management strategies. Measures are developed at the system and corridor levels to assess potential managed lane benefits as well as the impact on freeway general purpose and managed lane operations. The target year for the analysis is 2030. Different managed lane strategies for 2030 are defined for vehicle eligibility and pricing. An intermediate-year (2015) has been selected to evaluate HOT network scenario and HOV eligibility policy, to determine which corridors show potential for short-term HOT application and to examine short-term implementation steps that could lead to a long-term managed lane network. A regional HOT network is based on a variety of strategies for pricing and vehicle eligibility. There are three HOT network scenarios analyzed for 2030: HOT 2+, HOT 3+, and HOT 4+ and two additional scenarios for comparison: HOV2+ without HOT lanes and HOV3+ without HOT lanes. The study consisted of two major analysis efforts: (a) market research based on focus groups to gauge the public's willingness to pay for HOT lane use as well as its viewpoints on other aspects of management lane design (e.g., types of barriers) and (b) network modeling that examine individual corridors as well as network-level performance.

Results show that the average willingness to pay for managed lane use is over $0.08 per mile; willingness to pay per work trip ranges between $0.50 and $2.00. Five performance measures are used to compare the analysis results among the different pricing and vehicle eligibility scenarios. These criteria are (a) VMT on HOVs and single-occupant vehicles in the freeway general purpose lanes and in the managed lanes, (b) illustrative trip time savings between specified origins and destinations for managed lane users, (c) impact on congestion in the freeway general purpose lanes, (d) vehicle trips in the managed lanes, and (e) person trips in the managed lanes. In addition, projected revenues and costs for building, operating, and maintaining the HOT managed lane system are estimated. The results are promising because at least one of the HOT scenarios (HOT 2+) shows the largest utilization (VMT), significant trip time savings, and the largest number of vehicle and person trips carried in managed lanes.

In greater Atlanta, some other research has been done to identify travelers' preference behavior, for example the stated preference (SP) survey designed by Stephane Hess et al. (Hess, 2008). The SP survey uses a computer-assisted self-interview approach. The survey instrument is customized by presenting questions and modifying wording on the basis of respondents' previous answers.

The questionnaire consists of four parts: (1) context questions asking for details about the respondent's trip, (2) a description of the proposed managed lanes, (3) SP questions that present a managed lane or carpool alternative to the current route, and (4) socio-demographic questions. A series of variations in the experimental design and methods for selecting the set of choice situations are tested. MNL models are used for comparing and estimating travelers' valuation of travel time savings and propensity to use managed lanes under a range of different conditions.

3.1.6 HOT lanes in Denver, Colorado

As managed lanes and HOT lanes gain popularity as a potential mobility measure, the question of how the public views these relatively new concepts is of great importance. The Colorado Department of Transportation (CDOT) was intended to convert the Downtown Express HOV lanes on I-25, north of downtown Denver, as a HOT facility. CDOT sponsored market research, public outreach and assessment for evaluating the level of controversy. The findings provide valuable information for communities that consider HOT lanes as a component to their mobility challenges. David Ungemah et al. (2005) outlines the effort conducted by CDOT's project team, including focus groups with commuters and business owners, stakeholder outreach to vested public officials and interest groups, conversations with the public in varying open houses, and a stated preference telephone survey. Their paper draws conclusions that (a) support for HOT lanes is greater than it was a few years earlier, (b) issues related to income and equity are not as pronounced as anticipated, (c) public opinion can be favorably affected when individuals are informed on means of avoiding tolls by carpooling or riding the bus, and (d) HOT lanes are viewed as an interim solution that is only a component of a regional multimodal transportation system. For practitioners hoping to extend support for HOT lanes to their facilities, the principal finding indicates that co-marketing the HOT lane option with a means of avoiding a toll (through carpooling or riding the bus) may favorably affect public acceptance.

3.2 Summary for managed lane research

Before continuing the discussion on HOT lanes for the Maryland side of the Beltway, we summarize the projects described above and we discuss possible extensions to our case study.

The State Route 91 Express Lanes in California study models route choice, route and time of day, route and mode, transponder and route, as well as transponder, mode and route. The main objective of this research work is the calculation of Value-Of-Time and Value-Of-Reliability. The sample size is composed by 533 traveler units. MNL, joint MNL, and NL were adopted. Variables include annual household income, education, occupation, age, language, sex, travel time, variability in travel time, cost, total trip distance, car occupancy and the interactive variables between these socio-economic characteristics and alternative-specific dummy. Each discrete choice model is intended to calculate VOT and VOR which are represented in the equations below for each individual n:

$$\begin{aligned} VOT_n &= (\partial V / t_n)/(\partial V / \partial c_n), \\ VOR_n &= (\partial V / v_n)/(\partial V / \partial c_n) \end{aligned} \tag{1}$$

where $t, v,$ and c are the measures of travel time, variability in travel time, and cost, respectively.

In order to study the willingness to pay for the congested I-15 in San Diego, revealed preference data were collected and conditional logit model was used to estimate travelers' preference. The total sample size is 684 units. Alternatives that travelers are facing consists of solo driving on the main lanes, solo driving using FasTrak, and driving with others in a car pool. The generic variables across alternatives include: (1) toll price, (2) median time savings, (3) difference between actual and mean toll, and (4) reduction in variability of time savings from Express Lanes use. The socio-economic variables are interacted with choice-specific constants. Discrete choice models are used to calculate users' willingness to pay (or value of time). Willingness to pay is the amount of extra tolls a respondent would need to pay for a 1 hour increase in time savings to keep the choice probability constant. The equation of WTP presented in the paper is:

$$\frac{\beta\_time\,saving}{\beta\_toll + (\beta\_toll \times reduction\_in\_variability)(reduction\_in\_variability\_for\_respondent)}$$

In order to investigate the impact of tolls on HOV lanes and on the travel behavior in Houston and Dallas, a survey was designed and executed on the I-10 in the metropolitan areas of Texas. The survey totally generated 4634 responses including low-income and minority neighborhoods. A nested logit model was developed to estimate mode choice for travelers; one nest groups alternatives including a toll option: SOV and HOV2 on managed lanes. The other nest includes non-toll-paying alternatives: the general purpose lanes (GPSs) and most of the HOV3+ on the managed lanes (MLs). Variables analyzed include trip purpose, travel time, trip length, pay to park at destination, number of people in the vehicle, travel companion, number of trips per week and some social-economic characteristics.

These three studies are summarized in Table 1.

TABLE 1 Typical travel behavior modeling on managed lanes

<table>
<tr><th></th><th>SR 91 (orange country)</th><th>I-15 (San Diego)</th><th>I-10 (Houston & Dallas)</th></tr>
<tr><td>SAMPLE</td><td>533</td><td>684</td><td>4634</td></tr>
<tr><td>CHOICE</td><td>Route choice:
toll route
not toll route.</td><td rowspan="4">driving on the main lanes,
solo driving using FasTrak,
driving with others in a car pool</td><td rowspan="2">Toll options: SOV ML, HOV2 ML
(ML=Managed Lane)</td></tr>
<tr><td></td><td>Route & time-of-day:
(arrival time at the workplace)</td></tr>
<tr><td></td><td>Route & mode choice (SOV, HOV2, HOV3):
Mode choice only
Joint models of carpooling and route choices (6 alternatives)
Two-level nest (mode upper, route lower)</td><td rowspan="2">Non-toll options: HOV3+ML, SOV GPL, HOV2 GPL, HOV3+ GPL
(GPL=General Purpose Lane)</td></tr>
<tr><td></td><td>Transponder:
Whether-or-not having Transponder, binary logit
Joint models of transponder and route choice:
no transponder,
transponder using free route,
transponder using toll route.
Two-level nest (transponder upper, route lower)
Joint models of transponder, route, and route (9 alternatives)</td></tr>
<tr><td>MODEL</td><td>MNL, Joint MNL, NL</td><td>Conditional logit</td><td>NL</td></tr>
<tr><td>VARIABLES</td><td>annual household income, education, occupation,</td><td>toll price, median time savings,</td><td>trip purpose, travel time, trip length, pay to park at</td></tr>
</table>

	age, language, sex; variability in travel time, cost, total trip distance, car occupancy, interactive variables between these socio-economic characteristics and alternative-specific dummy, flexibility of work arrival time	difference between actual and mean toll, reduction in variability of time savings from Express Lanes use. The socio-economic variables are interacted with the choice-specific constants	destination, number of people in the vehicle, travel companion, number of trips per week and some social-economic characteristics
APPLICATION	VOT, VOR	WTP	

3.3 Fundamental approaches in modeling departure time model

Literature on departure time choice models is mainly based on two approaches: discrete and continuous models. The majority of the departure time choice models for academic and real applications are developed under the discrete choice framework. Continuous departure time choice are formulated as a finite number of discrete time periods where the choice of these time periods is modeled using the random utility theory framework.

Discrete choice alternatives could be defined in different ways. Discrete departure time models generally refer to the method proposed by Small (1982) who used the multinomial logit (MNL) to model departure time. The problem with the MNL model is the property of independence from irrelevant alternatives (IIA) which in effect, results in adjacent departure time periods to be correlated. Various relaxations of this assumption have been proposed by researchers which are described in more detail in the next section.

Continuous departure time model generally refers to the method developed by Vickrey (1969). His method is based on a single bottleneck where demand-supply equilibrium at this bottleneck is determined. This method has been named by Van Vuren *et al.* (1999) as 'Equilibrium Scheduling Theory' (EST). Vickrey (1969) model presented the formulation of disutility V (t) with departure time t as following:

$$V(t) = \alpha T(t) + \beta \max\Big(0, \big(\mathrm{PAT} - t - T(t)\big)\Big) + \gamma \max\Big(0, \big(t + T(t) - \mathrm{PAT}\big)\Big)$$

Where, *T(t)* is the travel time associated with a departure at time *t*; PAT is the preferred arrival time at destination; α, β, and γ are parameters to be estimated.

The continuous departure time model represents the more realistic departure time setting which is continuous in nature by providing a fine resolution of time. However, it has several model limitations. Incorporating time varying variable in continuous model such as level of service is challenging and generally require specialized econometric software to be developed (Bhat *et al.*, 2003). Discrete time model, on the other hand, enable analyst to easily accommodate time-varying coefficients and covariates with commercially available software. Discrete time model is also more commonly used in practice and can be easily incorporated with travel demand frameworks of MPOs (Bhat *et al.*, 2003).

3.3.1 Choice Alternatives

Choice set generation process consists of defining acceptable range of departure time intervals considered by the decision maker and the corresponding choice alternatives. Ben-Akiva and Bierlaire (2003) suggest that departure time intervals should be based on the range of feasible arrival times for each individual n [$PAT_{n,min};PAT_{n,max}$], and let [$TT_{n,min};TT_{n,max}$] be the range of travel times. Then the interval of acceptable departure times is [$DT_{n,min};DT_{n,max}$]=[$PAT_{n,min}$-$TT_{n,max};PAT_{n,max}$- $TT_{n,min}$] . According to Ben-Akiva and Bierlaire (2003) the overestimation of acceptable departure time length will not cause the model error if the model is well specified. However, underestimating the interval length can cause significant error to the model.

3.3.2 Attributes

In discrete departure time model, the departure time choice approach is generally formulated in term of trade off between time-of-day travel times and cost and the traveler's inherent preference for undertaking certain activities at certain time of day. The most commonly used approach is based on the schedule delays (Vickery, 1969). These variables represent the loss in utility associated with shifting a departure earlier or later relative to the preferred arrival time (*PAT*) or preferred departure time (*PDT*) of the existing trip. Depending on the collected information, the schedule delays could be computed based on either preferred arrival time (*PAT*), or preferred departure time (*PDT*).

Ben-Akiva and Bierlaire (2003) specified schedule delay variable based on the preferred arrival time (*PAT*) given that a penalty free interval is defined as the feasible arrival time; [$PAT_{n,min};PAT_{n,max}$] of individual n. It is assumed that individual suffer no penalty if the arrival time lies within the penalty free interval. Schedule delay early (SDE_n), and schedule delay late (SDL_n) are defined as

$$SDE_n = \text{Max}[PAT_{n,min}-AT_n,0]$$

$$SDL_n = \text{Max}[AT_n-PAT_{n,max},0]$$

Where the actual arrival time AT_n is equal to $DT_n+TT(DT_n)$, given $TT(DT_n)$ is the travel time if the trips starts at time DT_n.

Schedule delay could also be specified based on preferred departure time (*PDT*). Börjesson (2008) specified the schedule delay as

$$SDE_{in} = \text{Max}[PDT_n -DT_{in},0]$$

$$SDL_{in} = \text{Max}[DT_{in}-PDT_n ,0]$$

Where DT_{in} is the departure time of alternative i and individual *n*. *PDT* in her study is defined as the departure time the driver would choose if there are no queues on the road network. And *PAT* is defined as *PDT* plus the travel time the driver would face if there are no queues on the road network.

3.3.3 Model Structure and Specification

We group modeling approaches for departure time choice model into 3 categories: (1) Multinomial Logit Model (MNL), (2) Nested Logit Model (NL), and (3) Error Component Logit Model (Mixed Logit). We review the study corresponding to these modeling approach focusing on the model specification, data used, and model application.

3.3.3.1 Multinomial Logit Model (MNL)

A) MNL Model of Departure Time Choice

A number of research for departure time choice are based on MNL; we give below just a sample of the numerous papers appeared on the subject.

Bhat *et al.* (2003) estimate MNL model for departure time choice for home-based trip. Data used in the analysis is the 1996 activity survey data collected by the North Central Texas Council of

Governments (NCTCOG) in Dallas-Fort Worth area. Four models were estimated independently for each trip purpose: recreational, shopping, personal business, and community trip. The departure time choice alternatives are represented by six temporally contiguous discrete time periods throughout the entire day. Variable included in the models are socioeconomics, employment related attributes, and trip related characteristics. This departure time choice model treats mode choice as being exogenous to the departure time.

In her doctoral dissertation, Jin (2007) used RP data sets from the 2001-2002 NHTS and 2000-2001 California Statewide Household Travel Survey to investigate the traveler decision on departure time choice for long-distance travel.

The extracted data from the NHTS data consist of 3,322 long distance trip records by 2,439 individuals from 1,924 households. Multinomial logit (MNL) model of departure time choice is estimated from NHTS data. The model includes six discrete time periods throughout the entire day. The 6 time periods are early morning (0:00 am-6:29 am), a.m. peak (6:30am-8:59 am), a.m. off-peak (9:00 am-11:59 am), p.m. off-peak (12:00pm-15:59 pm), p.m. peak (16:00 pm-18:29 pm), and evening (18:30 pm-23:59 am). The departure time choice was constructed throughout the day because the thesis focus on long distance trip which are generally not limited to day time period. The mode choice was based on 3 alternatives (car, airplane, and others) that were treated as dummy variables in the model. Based on NHTS data, the analysis found that household size and household structure (life cycle) are significant in the model when they entered the model separately. Other significant variable includes number of non-household member in the trip, time spent at destination, age, sex, mode choice, weekend, worker, and purpose.

In the CA data, 4,527 distinct long distance trips made by 3,089 travelers from 2,795 households were used for the analysis. The MNL model is estimated with the same choice structure used for the NHTS model; results indicate that traveler’s work status, number of jobs, household income, and number of household worker are significant in departure time choice modeling.

In conclusion, Jin (2007) analysis indicates that trip characteristics including trip duration, activity duration, trip purpose, and whether trip take place on weekend has strong effect on long distance departure time choice. Traveler socioeconomic (sex, age, work status, and education level) and household characteristics (household income, household size, number of workers and number of vehicle) are found to present significant impact on departure time choice. It was also found that mode choice had not a significant impact toward departure time choice, and therefore nested logit model was not considered. To conclude, a small scale SP survey was suggested in this study to capture traveler trade-off between the departure time and the related constraints, such as peak hour congestion, mode captivity, and work schedule.

Saleh and Farrell (2005) estimated a MNL model for departure time choice by accounting for variable congestion pricing and trip scheduling flexibility. Travel survey data (both RP and SP information) on congestion charging collected in the city of Edinburgh was used for the analysis. RP data consist of work trip information (mode choice, travel time, usual departure time, etc.), work and non-work schedule. SP survey consist of three sets of congestion pricing scenarios related to mode choice, departure time choice, and combined mode and departure time choice. The choice considered in the model are (1) depart the same time as reported, (2) depart earlier than reported, and (3) depart later than reported. Variables introduced in the SP experiments are toll price, departure time change, and travel time saving. Variable included in the model are arrival time, travel time delay, departure time (in minute), travel distance (in miles), travel time, toll price, and the schedule delay. The arrival time is included as the categorical variable describing traveler's usual arrival time at work. The categorical value of arrival time represents 6 time intervals. Value of 1 to 5 represents 5 groups of 30minutes time interval from 7:00 to 9:30 am and 6 represents time after 9:30 am. The model calibrated supports the fact that work schedule flexibility affects departure time choice.

B). MNL Model with Latent Choice Set

Ben-Akiva and Boccara (1995) estimate discrete choice model with latent choice set using a choice set generation model. In their setting, it was assumed that the choice set considered by each decision maker could not be deterministically explained by observed data due to the existence of decision maker's perceptional and attitudinal effects. The data used for their study are travel survey conducted in city of Baltimore, Maryland 1977. Three mode choices are considered (1) Drive Alone, (2) Shared Ride, and (3) Transit. They propose probabilistic choice set generation model that represents the probability that each choice set is considered by the decision maker. The estimation method is based on the data from the alternative availability information obtained from the survey question and the observed choice made. Their choice set generation model is treated as a latent process of constraint elimination where explanatory variable contains both latent variable and observable characteristics. It is assumed that situational constraints and preferences across individuals in the choice set generation process are heterogeneous. In the analysis, two models are compared, the MNL and the probabilistic choice set (PCS) model; the comparison is performed on mode shift sensitivity due to change in LOS. Increase in vehicle travel time for auto and decrease in service frequency for transit were used in two tested scenarios respectively. The MNL model shows higher mode shift compared to the PCS model in auto and transit respectively. This is due to the fact that PCS model gives full consideration to alternative availability which restricts some portion of the mode shift to be impossible to occur due to unavailability of that new alternative. The study concludes that the PCS model generally outperforms a simple MNL model when substantial heterogeneity in the choice set affect decision maker choices.

3.3.3.2 Nested Logit Model (NL)

Departure time models based on MNL do not account for correlation among time periods. This limitation is usually relevant when the time interval for each period is comparatively small, thus the consecutive time periods become very similar. Nested logit model (NL) are able to handle this correlation issue. In nested logit models, a uniform amount of correlation within each nest is allowed while alternative in different nest are still uncorrelated. Apart from MNL, and NL model, some studies have focused on generalized extreme value (GEV) model. The special features of OGEV model is its capability to allow the estimation of a correlation parameter, for each pair of alternatives, which depend on the distance between the alternatives along the ordering scale, such as clock time in departure time choice. With this approach, the highest correlation is expected to be found for adjacent departure time alternatives, while departure time alternatives far away from one another will be independent as in the common MNL. Some other approach in identifying correlation parameter is the paired combinatorial logit (PCL) model. The PCL model allows for different correlation between each pair of alternatives; however, the correlation factor does not depend on the distance between the alternatives in the OGEV.

A). Nested Logit Model (NL) of Mode Choice and Departure Time

Ozbay and Yanmaz-Tuzel (2008) estimate NL model based on stated preference survey data to evaluate New Jersey Turnpike time of day pricing program. They estimate the departure time choice as a result of time of day pricing. The NL structure was chosen for their model to account for the fact that traveler using E-ZPass tag is subjected to off peak period toll discount. In their NL model, the upper nest of the model is transponder ownership choice model (E-ZPass tag or cash) and the lower nest is the choice of travel period conditional on the transponder ownership choice. Their departure choice is categorized into 3 alternatives, pre-peak period, peak period, and post-peak period. Variable included in the upper nest is socioeconomic variables include income, age, sex, education, employment, and E-Z Pass possession. Variables in the lower nest are LOS variables including travel time, toll price, early arrival (minute), late arrival (minute), difference from departure time to preferred departure time, and travel distance.

Bhat (1998) estimate the NL model of mode choice and departure time choice for urban shopping trips. Data for the analysis is based on the 1990 San Francisco Bay area travel survey. The dataset comprises 4,516 home based person shopping trips which are obtained from the overall single-day travel diary sample. Three mode choices are considered: drive alone, shared ride, and transit. The departure time choice for shopping trips is represented by several temporally contiguous discrete time periods which are AM peak (6AM-9AM), AM mid-day (9AM-12Noon), PM mid-day (12Noon-3PM), PM peak (3PM-6PM), and other (6PM-6AM). The reason to aggregate travel time intervals relies on the fact that respondents are believed to choose among broad time periods rather than choosing to shop at a precise continuous point in time. His study also focuses on the effect of traveler from time of day pricing and peak spreading.

The study proposed three models for mode-departure time choice: the multinomial logit (MNL) model, the nested logit (NL), and the MNL-OGEV (ordered generalized extreme value) model. The NL and MNL-OGEV model consist of mode choice at the upper level and the departure time choice at the lower level. In MNL-OGEV model, the upper level is the MNL model where the lower level is the OGEV model. Socioeconomics are included in the mode choice model, while the trip destination attributes are included in both the mode choice and departure time choice. Trip destination attribute are the categorization of whether the destination is in SF downtown area or a Central Business District (CBD). LOS variables used in the analysis are: travel cost, travel time, and out of vehicle travel time over trip distance. The statistical test (Likelihood Ratio test) in his study showed that both MNL and NL are rejected due to misspecification compared to the MNL-OGEV model. MNL and NL were found to be biased in term of level of service estimates which is inappropriate for transportation policy evaluations.

B). Continuous Cross Nested Logit Model (CCNL)

Lemp *et al*. (2010) estimated a continuous cross-nested logit (CCNL) model for departure time choice. The analysis is based on the 2000 San Francisco Bay Area Travel Survey (BATS) data focusing on the work-tour departure time of the 48-hour weekday sampling frame. The advantage of the CCNL model is its ability to provide continuous choice setting while allowing for correlation across similar choice alternatives (for instance those intervals that are close on a continuous time spectrum). The choice set is represented by departure time choices for trips from home to work over a continuous time period from 0 to 24 hours. Since the data is RP type, travel time by time of day is estimated from speed regression equation. The nested structure model consists of allocation parameter and inclusion parameter. The allocation parameters define the degree to which an alternative is a member of the nest. In their setting, only departure time within 1 hour from the hour nest could have positive allocation parameter. The inclusive parameter represents correlation between pair of departure times depending on their time difference. The empirical result concludes that CCNL perform better than continuous logit model in out-of-sample prediction where CCNL offers more flexible choice behavior as well as welfare estimation.

C). Paired Combinatorial Logit Model (PCL)

PCL model relaxes the NL restriction of identical correlation among all the alternatives in the common nest by allowing for different correlation for each pair of alternatives. This allows PCL to account for flexible error correlation structure compared to MNL, and NL while still exhibiting the computational advantage deriving from the closed form for choice probabilities. In the paper by Koppleman and Wen (2000), the PCL model performance is assessed in comparison to the MNL, and the NL models. The analysis is based on the intercity mode choice data from the Toronto-Montreal corridor in 1989 which contain 3 intercity modes of interest (air, train, and car). The corresponding PCL structures for these 3 modes are 2 pairs of alternatives, train-car, and air-car. The PCL models have 3 specifications based on common similarity structure, train-car, air-car, and train-car with air-car. These PCL models are compared with NL with 2 different structures (train-car nested, and air-car nested) and the MNL model. Their result indicates that PCL with two pairs structure (train-car with air-car) which could not be incorporated in the NL model provide the best model fit based on log-likelihood and statistically rejects all other models. PCL models also show significant differences of direct and cross elasticities compared to NL and MNL model. The PCL enable the direct and cross elasticities result to provide a better prediction compared to NL where elasticities obtained from two nesting structure either under or over estimate the elasticities. Their results show that by allowing for pair wise correlation structure in the PCL model, the result obtained from PCL is substantially different from MNL and NL, which highly affects forecasted passenger demand.

3.3.3.3 Error Component Logit Model (ECL)

Another line of research focuses on the mixed logit (ML). Amongst all its features, ML models allow the estimation of a complete variance-covariance matrix and handle asymmetric disturbances. The model that approximates all other known discrete choice random utility model (i.e. Multinomial Probit, OGEV, and PCL), can be used for data set with repeated observations from the same individual.

A). Error Component Logit (ECL) of Joint Departure Time and Mode Choice

De Jong *et al*. (2003) estimated an error component logit model for the joint choice of time of day and mode choice based on stated preference data for car and train travelers in the Netherland. The analysis was based on data derived from a SP survey where respondents were persons traveling in the extended peak periods (6:00-11:00 and 15:00-19:00) as car drivers or train passengers within the Netherlands. The interview was done with the computer assisted personal interviews (CAPI) by WinMint software. The alternatives provided to respondents are: (1) depart the same time as reported (with the same mode as observed), (2) depart earlier (with the same mode as observed), (3) depart later (with the same mode as observed), (4) another mode of transportation (car for transit users and transit for car users) with the observed departure time. The stated preference data are tour based; in each of the scenario proposed to the respondent attributes for both the outward trip and the return trip were presented. The attributes incorporated in the SP scenarios are departure time from home, arrival time at destination, departure time at destination, arrival time at home, tour travel time, duration of stay at destination, travel cost, peak charges, probability of a seat on the train, and train service frequency. The model includes 3 departure time alternatives of observed mode choice and 1 mode choice alternative that is different from those observed. The variable included in the model are travel time, travel cost, schedule delay late (SDL), schedule delay early (SDE), time difference between the presented time of day and the observed time of day as well as socioeconomic variable. Three utility functions were estimated independently from three sample segments: (1) home based (HB) tours by car drivers, (2) non-home-based (NHB) business trips by car drivers, and (3) home based (HB) tours by train travelers. The main difference from HB and NHB model is that HB model is specified as tour based with trip attributes including both outward and returning legs while the NHB was specified as trip based. The analysis concluded that error component logit generally outperform MNL, and NL. Simulation results on the substitution pattern (by departure time of same mode, and mode versus time of day alternatives) and demand shift corresponding to increased travel impedance (i.e. travel time) were also presented.

Börjesson (2008) estimates a departure time choice model incorporating travel time variability. Her analysis is based on joint RP and SP data relative to the congestion charging trial in Stockholm 2006. In this survey, the respondents were randomly chosen among the car drivers traveling toward the city center during the extended morning period (06:00-10:00).

The RP survey consist of driver's trip information in term of observed trip (departure, arrival time, trip duration, preferred departure time, travel time) as well as socioeconomic information. Respondent were also asked what time they would have departed, and travel time the trip would have taken if there were no queues in the roadway. This information was used to derive indications on travelers' preferred departure time. The SP survey was mailed to the selected drivers on the next day. In SP survey, respondents were asked to choose among 2 car alternatives with different departure time as well as switching to public transport (with reported departure time), bike and walk, or cancelling the trip. Variable included in the SP survey includes departure time, travel time, travel time uncertainty, and travel cost.

The joint departure time model consists of 21 choices from RP and SP alternatives. Three choices are SP alternatives, two car alternatives with different departure times, and one public transportation alternative. Another 18 choices are RP alternatives, assuming that individual choose to depart within the extended morning peak (5.15-9.45 a.m.) this time frame is divided into 18 groups of 15-minute departure time intervals. Variable included in the models are travel time, travel cost, travel time variability, schedule delay early (SDE), schedule delay late (SDL), and the respondent's possession of season ticket for the transit. The departure time shift was accounted in both the RP and SP choices by the schedule delay variable.

The review summary of departure time choice models is outlined in Table 2.

TABLE 2 Review Summary of Departure Time Choice Model Structure

Author	Choice	Data Used	Variable	Application
1. Multinomial Logit (MNL) Model				
1. 1 MNL Model of Departure Time choice				
Jin (2007)	Departure time choice of 6 periods	2001-2002 NHTS and 2000-2001 California Statewide HTS	Trip characteristics, socioeconomics	Long distance trip
Saleh and Farrell (2005)	Departure time choice of 3 alternatives (depart early, late, or as actual)	congestion charging in Edinburgh (RP, SP)	Arrival time, travel time delay, departure time, travel distance, travel time, toll price, and the schedule delay	Variable congestion pricing, schedule work flexibility
Bhat et *al*. (2003)	Departure time choice of 6 periods	1996 activity survey data (NCTCOG)	Socioeconomics, employment related attributes, and trip related characteristics	
1.2 MNL Model with Latent Choice Set				
Ben-Akiva and Boccara (1995)	Combination of Choice Set from 1) Drive Alone, 2) Shared Ride, 3) Transit	1977 Baltimore Travel Survey	Household characteristics for choice set generation, and LOS for choice model	Sensitivity to mode shift due to change in LOS
2. Nested Logit (NL) Model				
2.1 NL Model of Mode Choice and Departure Time				
Ozbay and Yanmaz-Tuzel (2008)	Transponder Ownership (upper level), and 3 departure time choices (lower level)	New Jersey Turnpike (NJTPK) Travel Survey Data	Travel time, toll price, early arrival, late arrival , schedule delay, travel distance, socioeconomics, and E-Z Pass possession	New Jersey Turnpike time of day pricing program
Bhat (1998)	Joint model of mode (3 choices) and departure time choice (5 choices)	1990 San Francisco Bay area travel survey	Socioeconomics, trip destination attributes, and LOS variables	Departure time choice for urban shopping trips
2.2 Continuous Cross Nested Logit (CCNL) Model				
Lemp et al. (2010)	Continuous Departure Time Model	2000 San Francisco Bay Area Travel Survey (BATS) data	LOS variables, socioeconomics interaction variables	Welfare estimation from toll policy
2.3 Paired Combinatorial Logit (PCL) Model				
Koppleman and Wen (2000)	Mode choice for Intercity trip (air, train, and car)	Toronto-Montreal Corridor Travel Survey	LOS variables including service frequency (train), in vehicle travel time, out of vehicle travel time, and	Ridership forecast for intercity train service

travel cost

Author	Choice	Data Used	Variable	Application
3. Error Component Logit (ECL) Model				
3.1 ECL Model of Joint Departure Time and Mode Choice				
De Jong et al. (2003)	Joint model of departure time and mode choice (4 choices for each market segment)	RP/SP Data from car and transit users in the Netherland	Travel time, travel cost, schedule delay, time difference from scenario to observed, socioeconomics	Peak spreading, toll pricing
Börjesson (2008)	Joint RP/SP Model of 3 SP and 18 RP choices	Survey on congestion charging in Stockholm 2006 (RP,SP)	Travel time, travel cost, travel time variability, schedule delay, and transit season ticket possession	Time of day pricing

4 Survey design, data collection and HOT lane demand model structure

Based on our findings, the existing data is only partially available for the HOT lane choice and departure time choice modeling on the I-495. To supplement the existing data, we have designed a dedicated survey. The survey aims to investigate traveler's willingness to use HOT lanes and departure time response to toll on I-495. The data collection will provide all the necessary information needed for a proper model specification under different time-of-day traffic conditions and variable congestion pricing strategies.

4.1 Survey design

The survey questionnaire is designed as a web-based survey interview (http://travelsurveys.org/). The front page of the website is shown in Figure 1. The target population is the travelers on the I-495 during peak and out-of-peak periods on weekday. The survey recruitment will be conducted by flyer distribution at several locations of I-495 off ramps. Information on the flyer contains the website address and the questionnaire instructions to guide respondents in answering the questionnaire. The questionnaire consists of revealed preference (RP) and stated preference (SP) survey. RP part gathers respondent's socioeconomic and recent trip information. SP part gathers respondents behavior on toll lane usage and departure time choice. Description of each part of the questionnaire is given in the next section.

FIGURE 1. Front page of the survey website

4.1.1 Revealed Preference (RP) Questionnaire

The RP questionnaire consists of two sections, respondents' socioeconomics and recent trip information.

A. Socioeconomics

The socioeconomics section gathers data about respondent's characteristics. The purpose of this section is to investigate socioeconomic characteristics of the potential HOT lane users in I-495. The respondent is asked to describe his/her socioeconomic situation via the following constructs:

- Gender
- Age
- Household income range
- Education
- Occupation
- Number of worker per household
- Number of vehicle in the household
- Vehicle type most used by the respondent
- Number of years the vehicle has been used
- ZIP code of work place

B. Most recent trip information on the I-495

The recent trip information gathers data about the respondent's most recent trip on the I-495. The purpose of this section is to use respondent's experienced trip condition as the pivot point when designing the Stated Preference (SP) question. This ensures that the stated scenario in the SP be realistic for each respondent. The respondent is asked to describe his/her most recent trip information on the I-495 via the following constructs:

- Mode choice
- Number of passenger

- Trip purpose
- Departure time (DT)
- Preferred departure time given no roadway congestion (PDT)
- Total travel time (TT)
- Travel time given no queue in the roadway (BTT)
- Trip distance on the beltway (D) and total trip distance
- Entry and exit ramp
- Fuel cost (FC)
- Parking cost
- Toll cost
- Shortest (ST) and longest (LT) travel time experienced on the beltway
- Shortest (TT min) and longest (TT max) travel time experienced on the whole trip

Figure 2 shows the revealed preference questionnaire interface on the website.

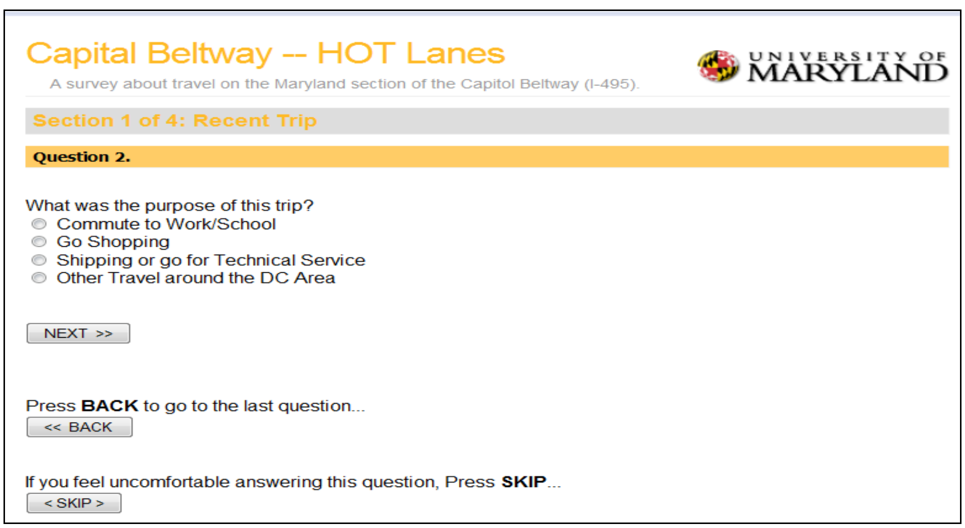


FIGURE 2 RP questionniare interface

4.1.2 Stated Preference (SP) Questionnaire

The Stated Preference (SP) portion of the survey presents respondent with two stated choice experiment: (1) Toll lane usage, and (2) Departure time choice. Each stated choice game generates 9 scenarios to respondents where variables changes from scenario to scenario. Respondents are instructed to make a realistic decision taking into account the situation presented during the scenarios.

A. Game1: Toll lane use

The HOT lane use game focuses on presenting respondents with different travel conditions on lane alternatives to investigate the acceptability of toll lane on the I-495 and the willingness to pay for reduced travel time subjected to congestion and uncertainty. This game consists of three alternatives and five variables. Each variable has up to three levels of variation per alternative.

Three alternatives: (1) Normal lane (refers to regular lane with regular traffic), (2) High Occupancy Toll (HOT) lane (refers to toll lane with single driver subjected to toll fees), and (3) High Occupancy Vehicle (HOV) lane (refers to toll lane when the total passenger is greater than or equal to two and no toll fee applies).

The variables of interest in the toll lane usage game include: normal travel time (without congestion), possible additional travel time due to congestion, possible additional travel time due to uncertainty (e.g. accident), fuel cost, and toll cost.

The toll lane usage game was designed to collect respondent behavior when confronted to toll lane alternatives. We assume that, by using toll lane, the total travel time will be significantly reduced due to less congestion and uncertainty. These multiple scenarios vary by level of variation to ensure that the presented alternatives are realistic based on respondent’s experience. The survey design rationale of each variable is described as followed:

Normal travel time: The normal travel time is the average travel time of the trip given no severe delay caused by congestion or accidents. Normal travel time is represented as two parameters, the normal travel time of the whole trip, and the normal travel time on the beltway (shown in the parenthesis in the questionnaire interface). The normal travel time is computed as the experienced shortest travel time on the beltway (ST) plus the factorized difference between the shortest and longest experience travel time on the beltway. The factor imposed to the travel time difference (ΔLS) is designed to be larger on normal lane (0.3) and smaller on the toll lane (0.1). The level of variation through percentage increase/decrease ensure the higher normal travel time on the normal lane compared to the toll lane. For normal travel time of the whole trip, the approximated travel time off the beltway (OT) is added to the normal travel time. The approximated travel time off the beltway (OT) is calculated as the difference between shortest experienced travel time of the whole trip (TTmin) and the shortest experienced travel time on the beltway (ST).

Possible additional travel time due to congestion: This is the travel time in addition to the normal travel time due to congestion. It is computed as 5 minutes based delay plus the factorized difference between the shortest and longest experience travel time on the beltway. The factor imposed to the travel time difference (ΔLS) is designed to be larger on normal lane (0.35) and smaller on the toll lane (0.1). The level of variation through percentage increase/decrease ensures the higher congestion delay on the normal lane compared to the toll lane.

Possible additional travel time due to uncertainty: This is the travel time in addition to the normal travel time due to uncertainty such as accidents. The normal speed on the beltway is assumed to be 60mph, when the accident occurs, we assume that speed reduce to 20 mph. The corresponded delay due to uncertainty is computed as travel time difference due to speed drop (60 mph to 20 mph) which is the ratio of distance (D) and speed multiplied by conversion factor to obtain delay in minutes.

Fuel Cost: The fuel cost is designed to reflect higher expense in normal lane due to longer travel time through level of variation. In case of HOV, if the fuel expense is shared by the travelers (information obtained in RP), the fuel expense shown in the questionnaire will be divided by number of passengers.

Toll Cost: Toll cost for toll lane usage consist of three price level \$2, \$4, and \$7. The toll price by time of day is further accounted for in SP Game2.

The questionnaire design of SP Game1 is shown in Table 3.

TABLE 3 Stated preference survey design

Variable	On normal lane after changing	HOT lane when you are in SOV	HOT lane when you have passengers, n=2
Normal Travel time (minute)	ST+(ΔLS*0.3)+OT ST+(ΔLS*0.3)	[ST+(ΔLS*0.1)]*(1-30%)+OT [ST+(ΔLS*0.1)]*(1-30%)	[ST+(ΔLS*0.1)]*(1-30%)+OT [ST+(ΔLS*0.1)]*(1-30%)
	[ST+(ΔLS*0.3)]*(1+40%)+OT [ST+(ΔLS*0.3)]*(1+40%)	[ST+(ΔLS*0.1)]*(1-10%)+OT [ST+(ΔLS*0.1)]*(1-10%)	[ST+(ΔLS*0.1)]*(1-10%)+OT [ST+(ΔLS*0.1)]*(1-10%)
	[ST+(ΔLS*0.3)]*(1+80%)+OT [ST+(ΔLS*0.3)]*(1+80%)	[ST+(ΔLS*0.1)] *(1+10%)+OT [ST+(ΔLS*0.1)]*(1+10%)	[ST+(ΔLS*0.1)] *(1+10%)+OT [ST+(ΔLS*0.1)]*(1+10%)
Possible Additional travel time due to congestion (minute)	5+(ΔLS *0.35)	5+ (ΔLS *0.1)*(1-40%)	5+ (ΔLS *0.1)*(1-40%)
	5+ (ΔLS *0.35) *(1+40%)	5+ (ΔLS *0.1)	5+ (ΔLS *0.1)
	5+ (ΔLS *0.35) *(1+80%)	5+ (ΔLS *0.1)*(1+50%)	5+ (ΔLS *0.1)*(1+50%)
Possible Additional travel time due to uncertainty (e.g. accident) (minute)	60 (D/20 – D/60)	60 (D/30 – D/60)	60 (D/30 – D/60)
	60 (D/20 – D/60)*(1+30%)	60 (D/30 – D/60)*(1+20%)	60 (D/30 – D/60)*(1+20%)
	60 (D/20 – D/60)*(1+60%)	60 (D/30 – D/60)*(1+40%)	60 (D/30 – D/60)*(1+40%)
Fuel cost ($)	FC*(1+10%) FC*(1+25%) FC*(1+50%)	FC*(1+10%) FC*(1+20%) FC*(1+30%)	If fuel cost is paid by the driver , FC*(1+10%) FC*(1+20%) FC*(1+30%) if fuel cost is shared, FC*(1+10%)/n FC*(1+20%)/n FC*(1+30%)/n
Toll cost (fixed) ($)	0	$2 / $4 / $7	0

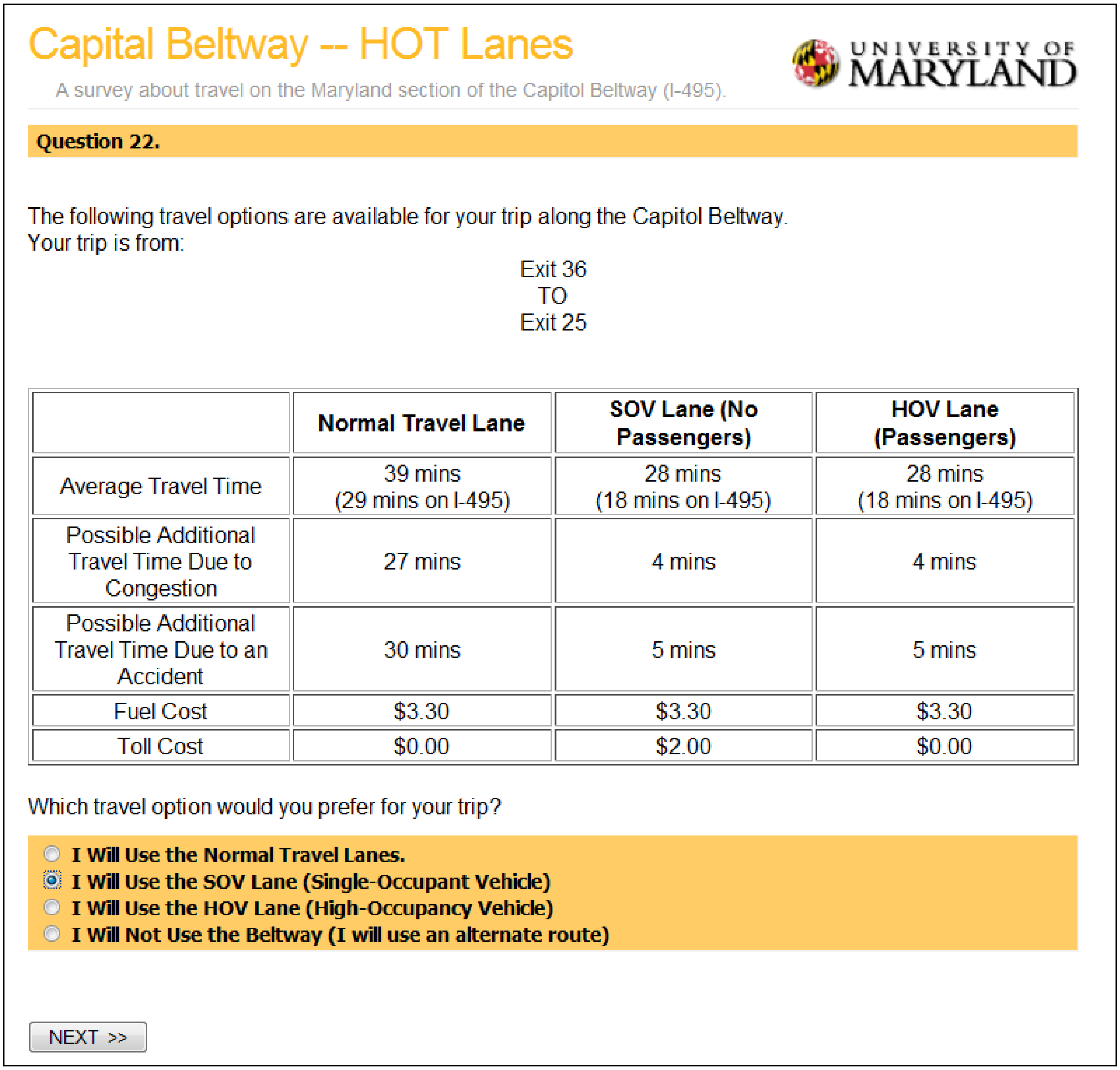
NOTE

1. ST= experienced shortest travel time on the beltway, LT= experienced longest travel time on the beltway, FC= fuel cost. This information is obtained in the RP part.

2. ΔLS= LT-ST, OT=TTmin-ST (Approximated Travel Time Off the Beltway).

3. Possible Additional travel time due to uncertainty (e.g. accident): for normal lane, assume the normal speed is 60mph; when accident happens, the speed is 20mph. D= Distance, data is from RP survey; for HOT lane, assume the normal speed is 60mph, accident speed is 40mph.

Figure 3 shows the interface of the stated preference game1 on the website.


Capital Beltway -- HOT Lanes

A survey about travel on the Maryland section of the Capitol Beltway (I-495).

UNIVERSITY OF MARYLAND

Question 22.

The following travel options are available for your trip along the Capitol Beltway.
Your trip is from:

Exit 36
TO
Exit 25

	Normal Travel Lane	SOV Lane (No Passengers)	HOV Lane (Passengers)
Average Travel Time	39 mins (29 mins on I-495)	28 mins (18 mins on I-495)	28 mins (18 mins on I-495)
Possible Additional Travel Time Due to Congestion	27 mins	4 mins	4 mins
Possible Additional Travel Time Due to an Accident	30 mins	5 mins	5 mins
Fuel Cost	$3.30	$3.30	$3.30
Toll Cost	$0.00	$2.00	$0.00

Which travel option would you prefer for your trip?

- I Will Use the Normal Travel Lanes.
- I Will Use the SOV Lane (Single-Occupant Vehicle)
- I Will Use the HOV Lane (High-Occupancy Vehicle)
- I Will Not Use the Beltway (I will use an alternate route)

NEXT >>

FIGURE 3 SP Game1 questionnaire interface

B. Game2: Departure Time Choice

The Departure Time Choice game focuses on presenting respondents with different travel conditions corresponded to different departure time on three lane alternatives to investigate traveler departure time choice, and peak spreading corresponded to time-of-day traffic and congestion pricing scheme. This game consists of three alternatives and five variables. Each variable has up to five levels of variation per alternative.

Three alternatives: This SP survey presents respondent with 3 choice alternatives: 1) solo driver on normal lane, 2) HOT lane, and 3) HOV lane. Each lane alternative corresponds to different departure time which is pivoted around the respondent's observed departure time in the RP.

The variable of interest in the departure time choice game includes: departure time, travel time range, arrival time range, fuel cost, and toll. These five variables represent travel impedances which are designed to account for time-of-day conditions by considering whether the respondent's observed departure time occur in the peak or off peak period.

Departure time: The stated departure time is pivoted from respondent's observed departure time in the RP. This variable is an essential part in estimating the departure time choice model.

Total travel time range: This variable is designed to account for both time-of-day conditions based on the respondent's observed departure time and travel condition on toll lane. If the respondent's observed departure time is in the peak period (8:00 to10:00 a.m., and 3:00 to7:00 p.m.) (Crunkleton, 2008), travel times of the three alternatives are designed to be longer with larger range compared to case where observed departure time is in the off peak period. In comparison between normal lane and toll lane, travel time range for the normal lane is designed to be longer with larger range compared to toll lane.

Arrival time range: This variable is calculated in corresponded to the departure time and travel time range of each stated scenario.

Fuel cost: The fuel cost is designed to reflect higher expense in the peak period and on the normal lane. Similar to SP Game1, if the fuel expense is shared by the travelers (information obtained in RP), then the total cost will be divided by number of passengers.

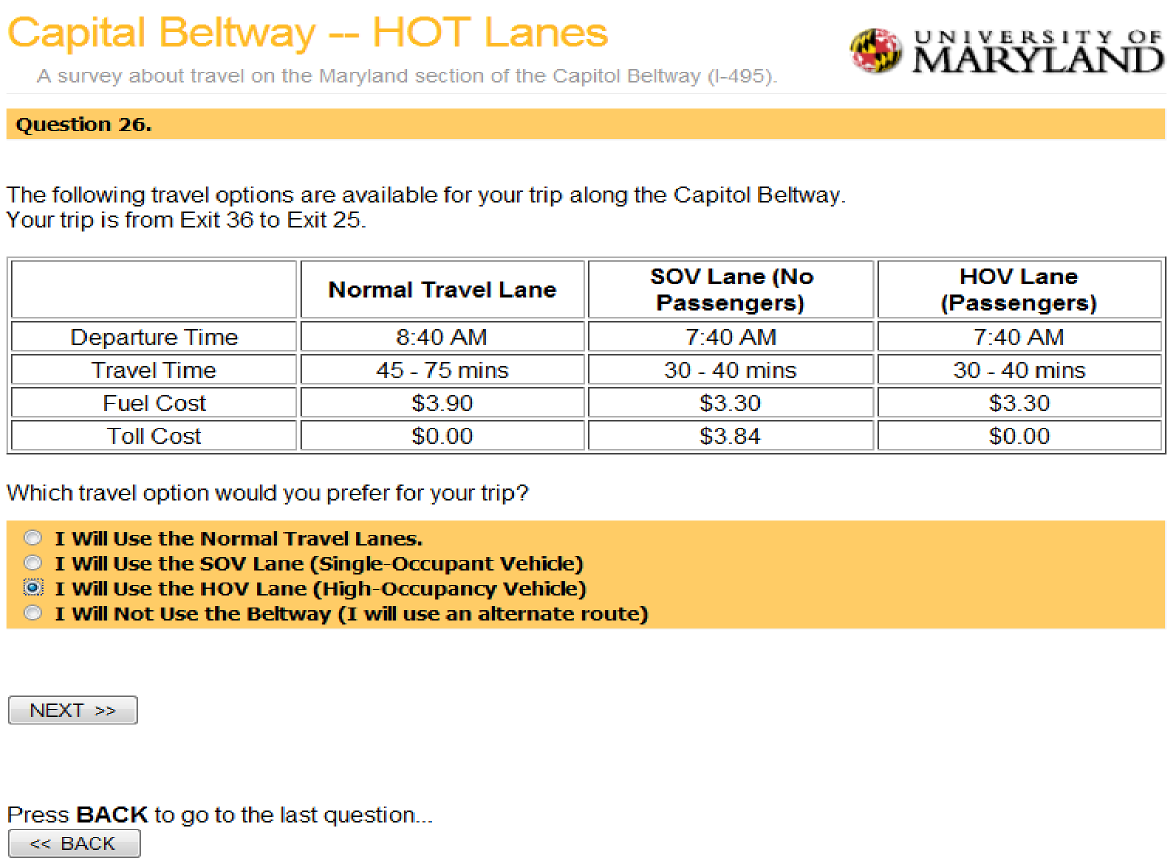
Toll cost: The toll rate for the HOT lane accounts for the peak and non-peak period by consisting of two separate ranges of toll variation for peak and non-peak period. The toll price design use the mileage based price obtained from the first segment of the Intercounty Connector toll policy (MDTA, 2010).

The questionnaire design of SP Game 2 is shown in Table 4.

TABLE 4 Departure Time Choice SP Survey Design

	On normal lane after changing	HOT lane when you are in SOV	HOT lane when you have passengers, n=2
Departure time	DT-40min	DT-40min	DT-40min
	DT-20min	DT-20min	DT-20min
	DT	DT	DT
	DT+20min	DT+20min	DT+20min
	DT+40min	DT+40min	DT+40min
Total travel time range (minute)	**If DT in peak hour** TTmin+20 to TTmin+30; TTmin+20 to TTmin+40; TTmin+20 to TTmax; TTmin+20 to TTmin+45; TTmin+20 to TTmin+35; **If DT not in peak hour,** TTmin+10 to TTmin+20; TTmin+10 to TTmin+30; TTmin+10 to TTmax-10; TTmin+10 to TTmax-20; TTmin+10 to TTmax-30;	**If DT in peak hour** TTmin+10 to TTmin+20; TTmin+10 to TTmin+25; TTmin+10 to TTmin+30; TTmin+10 to TTmin+25; TTmin+10 to TTmin+20; **If DT not in peak hour,** TTmin+5 to TTmin+10; TTmin+5 to TTmin+15; TTmin+5 to TTmin+20; TTmin+5 to TTmin+15; TTmin+5 to TTmin+10;	**If DT in peak hour** TTmin+10 to TTmin+20; TTmin+10 to TTmin+25; TTmin+10 to TTmin+30; TTmin+10 to TTmin+25; TTmin+10 to TTmin+20; **If DT not in peak hour,** TTmin+5 to TTmin+10; TTmin+5 to TTmin+15; TTmin+5 to TTmin+20; TTmin+5 to TTmin+15; TTmin+5 to TTmin+10;
Arrival time RANGE	**Calculate with the previous two rows**		
Fuel cost ($)	**If DT in peak hour** FC(1+10%) FC(1+20%) FC(1+30%) **If DT not in peak hour,** FC*(1+10%) FC(1+15%) FC(1+20%)	**If DT in peak hour** FC FC(1+10%) FC*(1+20%) **If DT not in peak hour,** FC FC(1+15%) FC(1+20%)	**If DT in peak hour** If Q2 in section 1 is a, FC FC(1+10%) FC*(1+20%) if b, n=2 (hypothesis) (FC)/n FC(1+10%)/n FC*(1+20%)/n **If DT not in peak hour,** FC FC(1+15%) FC(1+20%) **Or** FC/n FC(1+15%)/n FC(1+20%)/n
Toll ($)	**0**	**If DT in peak hour** $0.3/mile*D $0.35/mile*D $0.4/mile*D $0.45/mile*D $0.5/mile*D **If DT not in peak hour,** $0.1/mile*D $0.15/mile*D $0.2/mile*D $0.25/mile*D $0.3/mile*D	**0**

Figure 4 shows the interface of the stated preference game 2 on the website.



Capital Beltway -- HOT Lanes

A survey about travel on the Maryland section of the Capitol Beltway (I-495).

UNIVERSITY OF MARYLAND

Question 26.

The following travel options are available for your trip along the Capitol Beltway.
Your trip is from Exit 36 to Exit 25.

	Normal Travel Lane	SOV Lane (No Passengers)	HOV Lane (Passengers)
Departure Time	8:40 AM	7:40 AM	7:40 AM
Travel Time	45 - 75 mins	30 - 40 mins	30 - 40 mins
Fuel Cost	$3.90	$3.30	$3.30
Toll Cost	$0.00	$3.84	$0.00

Which travel option would you prefer for your trip?

- I Will Use the Normal Travel Lanes.
- I Will Use the SOV Lane (Single-Occupant Vehicle)
- I Will Use the HOV Lane (High-Occupancy Vehicle)
- I Will Not Use the Beltway (I will use an alternate route)

NEXT >>

Press **BACK** to go to the last question...

<< BACK

FIGURE 4 SP Game2 Questionnaire Interface

4.2 Model structure

4.2.1 Modeling approach

Logit model is adopted in our study to model lane choice and departure time; given the nature of the data collected joint RP/SP models will be developed. Forecasting the demand for new infrastructure in transportation requires information about users' preferences for the services that do not exist in the current system. Stated Preference data are commonly used to collect behavioral choice information in hypothetical contexts. As outlined by Morikawa in the early 90s, SP data should be combined with Revealed Preference data in order to gain information about respondents' actual behavior (Morikawa 1989). Morikawa, Ben-Akiva and Yamada used joint RP and SP data to estimate a mode choice model made by intercity travelers in Netherlands and to forecast market shares before/after the introduction of a new train service in Japan (Morikawa et al 1991). David Brownstone, et al. also highlighted the advantages of merging SP and RP data in their study about alternative-fuel vehicle models; they used the mixed logit model with error component formulation in the paper published in 2000 (Brownston and Train 2000). Vrtic and Axhausen in 2003 estimated a combined RP and SP route choice model for public transportation trips and selected in-vehicle time, number of transfers, transfer time, headway and price as explanatory variables. Recently, Hess et al. illustrated the advantages of SP data in their paper presented in 2006; they assert that SP data can retrieve a significant and meaningful effect of changes in air fares while impacts of airline allegiance can often not be identified in RP studies (Hess et al 2007).

4.2.2 RP/SP Joint Model

The utility functions for Revealed and Stated Preference are specified as following:

$$\begin{aligned} U_{in}^{RP} &= \alpha_{in}^{RP} + \beta x_{in}^{RP} + \beta^{RP} x_{in}^{RP} + \varepsilon_{in}^{RP} \qquad \forall i \in C^{RP} \\ U_{in}^{SP} &= \alpha_{in}^{SP} + \beta x_{in}^{SP} + \beta^{SP} x_{in}^{SP} + \varepsilon_{in}^{SP} \qquad \forall i \in C^{SP} \end{aligned} \tag{2}$$

where β are coefficients common to RP and SP utilities, while β^{RP} and β^{SP} are coefficients specific to the utilities of RP and SP alternatives respectively.

The probability functions includes scale factors, λ^{RP} and λ^{SP} representing the scales (proportional to the standard deviations) of the distributions of unobserved factors around these means in revealed- and stated- preference situations, respectively (Train 2003). It is not possible to determine both λ^{RP} and λ^{SP} , instead we normalize λ^{RP} to 1, which makes the other scale parameter equal the ratio of the two original scale parameters. It should be noted that the coefficients in the model now are divided by a parameter $1/\lambda^{SP}$ for the stated-preference observations.

Scale factors are estimated with β, β^{RP} and β^{SP} at the same time on both types (RP and SP) of data. Meanwhile, the alternative-specific constants are estimated separately for RP and SP data to reflect market share for existing and new modes (as described in previous Section). The probability functions are equations (3) and (4).

$$P_i^{RP} = \frac{\exp\left[\lambda^{RP} + \beta x_i^{RP} + \beta^{RP} x_i^{RP}\right]}{\sum_{j=C^{RP}} \exp\left[\lambda^{RP} + \beta x_j^{RP} + \beta^{RP} x_j^{RP}\right]} \tag{3}$$

$$P_i^{SP} = \frac{\exp\left[\lambda^{SP} + \beta x_i^{SP} + \beta^{SP} x_i^{SP}\right]}{\sum_{j=C^{SP}} \exp\left[\lambda^{SP} + \beta x_j^{SP} + \beta^{SP} x_j^{SP}\right]} \tag{4}$$

4.2.3 Variables and structures

In RP model the alternatives considered are: (1) single occupancy vehicle (SOV) and (2) high occupancy vehicle (HOV) both on normal lanes. Variables are: cost, travel time, possible additional travel time due to congestion (ADT); possible additional travel time due to uncertainty (ADTT), travel time variability (TV).

Utility models are presented in equation (5).

$$\begin{aligned} U_{SOV} &= const + \cos t_s \alpha_{\cos t} + time_s \beta_{time} \\ U_{HOV} &= \cos t_h \alpha_{\cos t} + time_h \beta_{time} \end{aligned} \tag{5}$$

In SP1 model, three choices are available: normal lane, HOT lane with single driver, HOT lane with passengers. Variables to be considered include travel time in normal condition, travel time variability, cost (fuel cost plus toll cost). Utility models are presented in equation (6).

$$\begin{aligned} U_{ntoll} &= \cos t_n \alpha_{\cos t} + time_n \beta_t + ADT_n \theta_t + ADTT_n \mu_t + TV_n \alpha_{tv} \\ U_{tolls} &= const_s + \cos t_s \alpha_{\cos t} + time_s \beta_{tt} + ADT_s \theta_{tt} + ADTT_s \mu_{tt} + TV_s \alpha_{ttv} \\ U_{tollh} &= const_h + \cos t_h \alpha_{\cos t} + time_h \beta_{tt} + ADT_h \theta_{tt} + ADTT_h \mu_{tt} + TV_h \alpha_{ttv} \end{aligned} \tag{6}$$

For SP2 data, our model adopts the framework proposed by De Jong et al. (2003) and Börjesson (2008). The scheduling disutility is formulated as departure time shifts from the most preferred departure time (PDT). Two time shift variables, schedule delay early (SDE), and schedule delay late (SDL) are defined as:

$$SDE_{in}=\max[PDT_{in}-DT_{in}, 0]$$

$$SDL_{in}=\max[DT_{in}-PDT_{in},0]$$

Where DT_{in} is departure time of alternative *i* and individual *n*. Schedule delay could also base on arrival time by substituting PDT_{in} and DT_{in} with PAT_{in} and AT_{in} respectively. Preferred arrival time (PAT) is defined as PDT plus the time driver would face given no queue on the roadway.

The choices in SP2 are the same as in SP1. Variables included in model formulation will be similar to those defined by Börjesson (2008) and in particular: travel time, travel cost, travel time variability, schedule delay early (SDE), schedule delay late (SDL). In addition, Börjesson (2008) considered the respondent's possession of season ticket for the transit, which is not relevant in our case, while De Jong et *al*. (2003) also include time difference between the presented time of day and the observed time of day (minutes) as well as socioeconomic variable.

The general utility function for the 3 choice alternatives could be written as:

$$\begin{aligned}
U_{solo} &= TIME_{solo}\beta_{solo} + COST_{solo}\alpha_{solo} + TTV_{solo}\alpha_{solo} + SDE_{solo}\eta_{solo} + SDL_{solo}\mu_{solo} + TIMDIF_{solo}\phi_{solo} \\
U_{hot} &= const_{hot} + TIME_{hot}\beta_{h} + COST_{hot}\alpha_{\mathrm{h}} + TTV_{hot}\alpha_{solo} + SDE_{hot}\eta_{\mathrm{h}} + SDL_{hot}\mu_{h} + TIMDIF_{hot}\phi_{h} \\
U_{hov} &= const_{hov} + TIME_{hov}\beta_{h} + COST_{hov}\alpha_{\mathrm{h}} + TTV_{hov}\alpha_{solo} + SDE_{hov}\eta_{\mathrm{h}} + SDL_{hov}\mu_{h} + TIMDIF_{hov}\phi_{h}
\end{aligned} \tag{7}$$

Where

TIME=Mean Travel Time (minutes)

COST=Travel Cost ($)

TTV=Travel Time Variability (minutes), $(T_{max}-T_{min})/2$

SDE, SDL =Schedule Delay Early and Late respectively

TDIF= time difference between the presented time of day and the observed time of day (minutes)

SDE and SDL can be defined with respect to either departure or arrival time. Börjesson (2008) results show that for the SP data, the model fit and the SDL parameter improve significantly when SDL is defined with respect to arrival time due to ability to capture disutility more realistically; in fact, researchers suggest that late arrival is usually more constrained than late departure.

5 Conclusion and future work

Currently the project team is executing the survey and collecting preliminary data. In November 2010, 200 flyers were distributed on the Exit 25, WB of the I-495 during the morning peak hours (8:00-10:00 a.m.). The pilot test resulted in the response rate of 5.0 percent; a total of 10 respondents completed the survey online. Based on the results of the pilot, we are adjusting the survey design by incorporating new consideration deriving from the experience acquired in the field. The adjustment aims to improve the survey design in terms of scenario variations, and at collecting data efficiently in order to estimate good departure time model. The sample size planned for this project is 300-400 individuals; based on the response rate, it is expected that two months are necessary to complete the data collection.

To conclude, in this study, the toll lane usage and departure time choice model is proposed based on the joint RP/SP data. The method is appropriate for new transportation alternative where no RP data currently exist for the analysis. The proposed joint RP/SP model is expected to employ the data collected from RP and SP games designed and executed with in house software.

The joint RP/SP from SP game 1 focuses on traveler’s choice of three lane alternatives where variables in terms of travel time, travel cost, additional travel time due to congestion, additional travel time due to uncertainty, and travel time variability are specified. The joint RP/SP from SP game 2 focuses on traveler’s choice of departure time corresponding to the three lanes alternatives. The method adopted is based on schedule delay. Variables consist of travel time, travel cost, travel time variability, schedule delay early (SDE), schedule delay late (SDL), and time difference between the presented time of day and the observed departure time of day. The model estimation results will be used for computing willingness to pay (WTP) and value of travel time (VOT) such as WTP to avoid congestion, WTP to avoid departure time shift, WTP to avoid schedule delay, and VOT by time-of-day.

The proposed model is appropriate to incorporate time-of-day and peak spreading analysis for travel demand model application. This departure time model can be employed to facilitate strategic decisions and to support various policy/land use scenario analyses at the corridor/project level, regional level, and even statewide level. In particular, the model can be used to analyze the impact of future travel demand on corridor congestion, assess how major land use projects along the corridor influence congestion, route choice, departure time scheduling, and estimate route diversions resulting from accidents and other emergency-related congestion.

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