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Estimating the Benefits of Managed Lanes

Final Report

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16. Abstract

Stated preference (SP) studies developed to estimate travelers' value of travel time savings (VTTS) on managed lanes (ML) may underestimate the VTTS. This study investigates survey design strategies and differentiating the VTTS for ordinary and six common urgent situations faced by the travelers in an attempt to improve on VTTS estimation. An internet based survey for Katy Freeway travelers was used to collect data for this study.

We used three different survey design strategies to produce surveys. We found that a random attribute level generation strategy, where the VTTS presented in the alternative was adjusted based on the answer to a previous SP question, performs better than other designs with respect to analysis of choice behavior and estimation of VTTS.

We analyzed SP choices for travelers facing ordinary and six common urgent travel situations. We found that travelers value their travel time savings much more when facing most of the urgent situations. Due to this significant increase in the VTTS for travelers on urgent trips it is possible that the majority of ML travelers are on urgent trips. This includes travelers from all income levels, as even low income travelers on urgent trips value their time more than many high income travelers on regular trips.

Therefore, using average VTTS will greatly underestimate the value of these MLs to travelers. This has significant policy implications since the benefits of MLs (and of most transportation investments) are primarily derived from travel time savings. Underestimating the value of ML travel time savings underestimates the benefits of MLs, reducing the likelihood of funding such facilities. Thus an important travel alternative would not be constructed. This study provides an important first step in proper estimation of these benefits using revised SP survey designs.

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DISCLAIMER

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EXECUTIVE SUMMARY

Stated preference (SP) studies developed to estimate travelers' value of travel time savings (VTTS) on managed lanes (ML) may underestimate the VTTS. This study investigates survey design strategies and differentiating the VTTS for ordinary and some common urgent situations faced by the travelers in an attempt to improve on VTTS estimation for travelers on MLs.

This study had three main objectives. The first objective was to study the effect of different survey design strategies, leading to a better design strategy for internet based stated preference surveys of potential managed lane travelers. The second objective was to estimate the difference in the VTTS for ordinary as compared to urgent travel situations for the managed lane travelers. The third objective was to better understand and estimate the benefits of managed lanes. An internet based survey for Katy Freeway travelers was used to collect data for this study. The data were characterized by choice sets which present different ML travel alternatives with different SP questions.

We used three different survey design strategies (including a D-efficient design) to produce surveys which were then used to elicit travel choice data. Stated choice behaviors including VTTS, non-trading, and lexicographic behaviors were examined to indentify the design strategy that minimized these traits. We observed differences in choice behavior depending on what design strategy was used. We found that a random attribute level generation strategy, where the value of travel time savings presented in the alternative was adjusted based on the answer to a previous SP question, performs better than other designs with respect to most of the above mentioned criteria.

In order to differentiate the VTTS for ordinary and urgent situations, we investigated six common urgent situations under which travelers may consider switching from the general purpose lanes to the managed lanes. We found that travelers value their travel time savings much more when facing most of the urgent situations, and the highest value was attached to the urgent situation when the traveler was running late for an important meeting/event. The mean of VTTS for this urgent situation was found to be 3.8 to 5.5 times greater than the mean of the implied VTTS corresponding to an ordinary situation.

Due to this significant increase in the VTTS for travelers on urgent trips it is possible that the majority of ML travelers are on urgent trips. This includes travelers from all income levels, as even low income travelers on urgent trips value their time more than many high income travelers on regular trips. Thus travelers on MLs are likely to be from all income categories, as their need for (and value of) MLs varies mostly by trip urgency.

Therefore, using average VTTS will greatly underestimate the value of these MLs to travelers. This has significant policy implications since the benefits of MLs (and of most transportation investments) are primarily derived from travel time savings. Underestimating the value of ML travel time savings underestimates the benefits of MLs, reducing the likelihood of funding such facilities. Thus an important travel alternative would not be constructed. This study provides an important first step in proper estimation of these benefits using revised SP survey designs.

1. INTRODUCTION

With increasing funding shortfalls for transportation capacity projects along with the increase in travel demand, various transportation policy and operation alternatives such as managed lanes (MLs) are being implemented all over the country. Managed lanes tend to offer a reliable and faster alternative to travelers, often encourage drivers to travel during less congested periods, and/or increase their vehicle occupancy (ride sharing). Two common types of managed lanes include High Occupancy Vehicle (HOV) lanes and High Occupancy/Toll (HOT) lanes. After successful implementation of some pilot projects, more managed lanes are being planned in the United States. Findings from the pilot projects conclude that the managed lanes offer a faster and reliable travel alternative, promote ridesharing and transit use, and offer a safer alternative (Collier and Goodin, 2002). However, there are still some issues that need more research in order to estimate true benefits of managed lanes.

Accurate estimation of the monetary value attached to the travel time savings offered by managed lanes is one issue which needs additional research. Value of travel time savings (VTTS) is one of the most important criteria used to quantify the benefits of the construction/operation of any transportation project, including managed lanes. VTTS estimation gets complicated if congestion pricing or variable pricing is implemented on the facility. Studies conducted on existing facilities have found that some travelers use managed lanes regularly while most use them occasionally. This may be due to the fact that the travelers might be placing different values of travel time savings on different occasions. Hence, it is necessary to identify out-of-the-ordinary/urgent situations under which travelers consider switching to managed lanes from general purpose lanes. This understanding of the travel behavior might help to better understand travelers' VTTS when using managed lanes, which is likely much higher than general travel. Some evidence to this issue is that predicted managed lane VTTS (using stated preference studies) are found to be lower than actual (Ghosh, 2001, Brownstone et al., 2003, Brownstone and Small, 2005). We investigate if accounting for urgent trips in the stated preference (SP) surveys helps in reducing this gap between the observed and estimated VTTS. We also investigate the effect of classifying urgent trips as ordinary trips on estimation of the benefits of the managed lanes to travelers.

The third issue that we examine is the effect of SP survey designs on understanding of travel decision-making and estimating VTTS for freeway travelers with managed lanes options. Well designed surveys reduce estimation error in the choice models and the VTTS. Survey design is also an active research area, where researchers are now using advanced survey design techniques developed specifically for discrete choice models. With increased computational abilities and advancement of survey design, it is now possible to estimate the discrete choice models which will have lower variance of parameter estimation. Survey design techniques also focus on reducing the sample size requirement, which can be critical in stated preference surveys for travelers.

This research examines three SP survey design techniques based on various efficiency criteria. Data collected from Katy Freeway travelers who had the option of using general purpose or managed lanes were used for this study. The study also examines if there is any difference in the implied VTTS for ordinary versus six urgent situations faced by a traveler for a given trip. This study will help to better understand SP survey design techniques and estimation of VTTS, when congestion pricing is implemented on the route, which in turn will help in demand estimation and pricing of managed lanes.

This report is organized as follows. First, the literature regarding managed lanes, stated preference survey methods, and estimation of the value of travel time savings is reviewed. The traveler survey used for this study is described in the next section with focus on the survey designs used, stated preference questions, followed by the data collection details and summary of data collected. Logit models estimated for these data are presented in the next section with focus on suggesting the best survey design strategy and VTTS estimation for ordinary and urgent situations. We also demonstrated how the study findings can be useful in estimating the benefits of managed lanes. The final section includes the conclusions drawn from this study and recommendations for future research.

2. LITERATURE REVIEW

Estimation of the value of travel time savings is an extensive research area. The review of literature related to managed lanes, survey designs, discrete choice models, and estimation of VTTS is presented in this section.

2.1. Managed Lanes

The Federal Highway Administration defines managed lanes as "highway facilities or a set of lanes where operational strategies are proactively implemented and managed in response to changing conditions" (FHWA, 2005). Managed lanes typically represent facilities which are:

- located within a freeway,
- separated from general purpose lanes,
- operated in order to actively manage traffic,
- respond to growth, and
- targeted to maintain a level of service through tools of pricing, vehicle eligibility, and/or access control.

2.1.1. Types of Facilities

Managed lanes include a broad range of facilities and typically use one or more of the three operational strategies to achieve the targeted level of service: pricing, vehicle eligibility, and access control. Various types of facilities such as HOV lanes, HOT lanes, toll lanes, express lanes, busways, etc., are possible by implementing these operation strategies as shown in Figure 1. For example, when pricing and vehicle eligibility are used as the operation strategy, the facility type is generally known as a HOT lane. Managed lanes thus include a wide range of facility types.

2.1.2. Value to Travelers

One of the goals of managed lanes is to provide a more reliable and/or faster alternative to general purpose lanes, which are normally congested during peak hours. Managed lanes with vehicle eligibility as an operating strategy (e.g., HOV or HOT lanes) also have an objective of increasing ride sharing and, frequently, promoting transit use. An efficiently operated managed lane can carry more traffic and serve more travelers than a general purpose lane. Thus managed lanes are expected to offer travel time savings along with fuel savings for those who use them. Managed lanes are also expected to cause less pollution and vehicle crashes due to less congestion (Collier and Goodin, 2002).

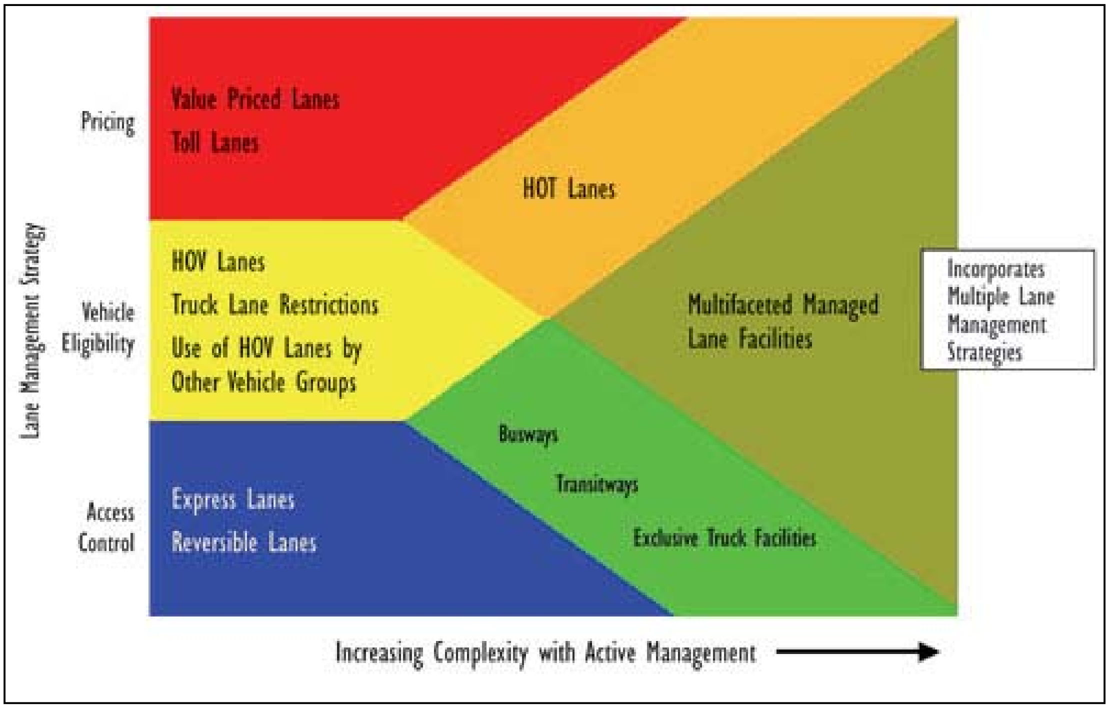

Figure 1 Operational Strategies and Types of Facilities for Managed Lanes Concept
(*Source: FHWA, 2005*)

Initially, managed lanes which allow vehicles for a toll were thought to cause an equity issue and were seen as favoring wealthier travelers. However, the latest research findings prove that managed lanes are used by travelers from all income categories and most travelers use them infrequently when in need of a reliable and fast alternative (Sullivan et al., 2000, Collier and Goodin, 2002). Since most managed lanes allow transit to use the lanes free of charge, they also tend to increase efficiency of transit by savings in travel time and improved reliability.

2.1.3. Existing Facilities in the United States

Due in part to early Federal Highway Administration (FHWA) Value Pricing Pilot Program efforts, managed lanes are becoming more and more popular in the United States. As a result, more managed lane facilities than ever are being planned and constructed. Managed lane facilities in operation in the United States as of July 2009 are listed in Table 1.

Table 1 Existing Managed Lanes Facilities in the United States (Source: Burris, 2009)

	Name of Facility	Location	Type
1	Katy Tollway/Managed Lanes	Houston, Texas	HOT lanes, tolls vary by time of day
2	Northwest US 290 QuickRide	Houston, Texas	HOT lanes with flat fee
3	State Route 91 Express Lanes	Orange County, California	Toll Express Lanes, tolls vary by time of day
4	Interstate 15 Express Lanes	San Diego, California	HOT lanes, tolls vary dynamically based on level of congestion
5	Interstate 394 MnPASS Express Lanes	Minneapolis, Minnesota	HOT lanes, tolls vary dynamically based on level of congestion
6	Interstate 25 HOV/Tolled Express Lanes	Denver, Colorado	HOT lanes, tolls vary by time of day
7	Interstate 15 Express Lanes	Salt Lake City, Utah	HOT lanes with flat fee
8	State Route 167 -HOT Lanes Pilot Project	Washington State	HOT lanes, tolls vary dynamically based on level of congestion
9	Interstate 95 Express Lanes	Miami-Dade County, Florida	HOT lanes, tolls vary dynamically based on level of congestion
10	San Joaquin, Foothill, and Eastern Toll Roads	California	Tolls vary by time of day
11	New Jersey Turnpike Authority Roads (except Garden State Parkway)	New Jersey	Tolls vary by time of day
12	Dulles Greenway	Virginia	Tolls vary by time of day

2.1.4. Katy Freeway Managed Lanes: History and Finance

Houston, Texas, is one of the largest cities in the United States with a 2007 U.S. Census population estimate of over 5.7 million people living in the Houston metropolitan area (Census, 2007). Houston has an extensive network of freeways with an outer freeway loop (Beltway 8) of about 25 miles in diameter (Figure 2).

Katy Freeway is one of a few key travel corridors in this network. It is located on the west side of the downtown Houston and is owned and operated by the Texas Department of Transportation (TxDOT). This 23 mile stretch of Interstate 10 connects the city of Katy with Interstate 610 west (inner loop) (TxDOT, 2009). Katy Freeway had three main lanes (or general purpose lanes) and two frontage-road lanes for most of its length in each direction. When constructed in 1960s, it was designed to carry 79,200 vehicles per day; however, in 2008 the freeway served more than 219,000 vehicles per day (TxDOT, 2009). It also has the highest daily truck volumes of any roadway in the state of Texas (FHWA, 2003). In the FHWA report, A Guide for HOT Lane Development (2003), traffic delays costing $85 million a year were reported for the Katy Freeway.

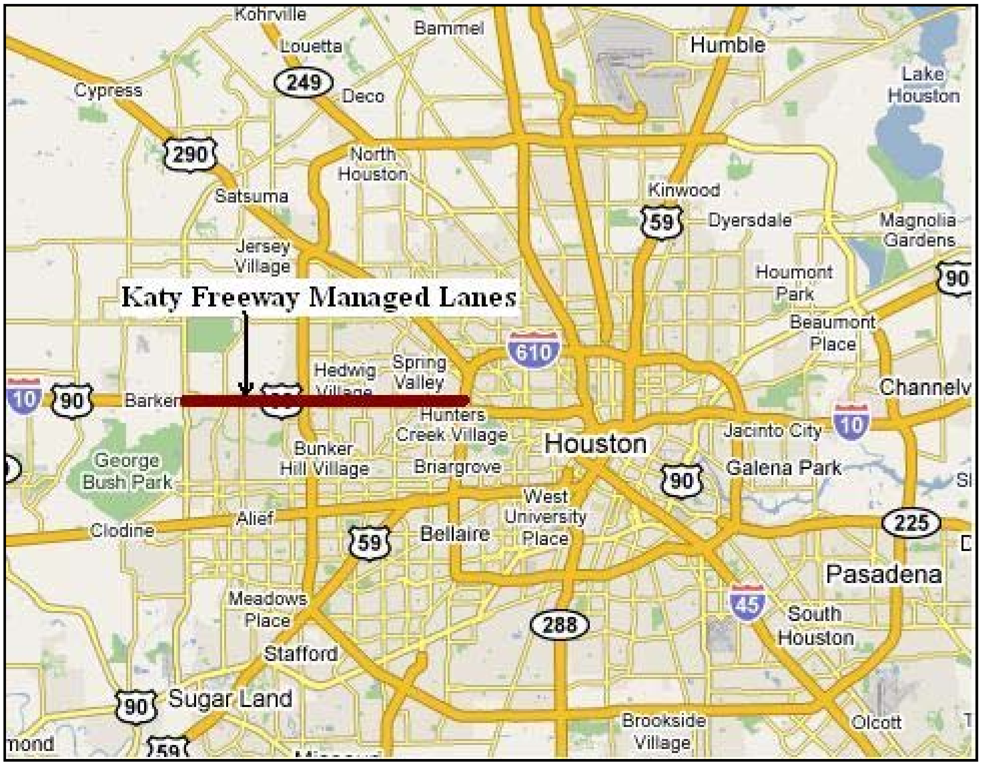

Figure 2 Freeway Network in and around City of Houston, Texas

In 1984 a HOV lane, constructed with support from Federal Transit Administration (FTA) funds, was opened by TxDOT and Houston Metro. The HOV lane was a reversible single lane in the middle of the freeway separated by a concrete barrier. In the beginning only buses and authorized vanpools were allowed to use the HOV lane. Later, eligibility requirements were relaxed to allow carpools of four or more, then three or more, and then two or more people. Allowing two-plus person carpools caused a large increase in traffic on the HOV lane; hence, more restrictive carpool rules were eventually reinstated. From 6.45 a.m. to 8.00 a.m. and from 5.00 p.m. to 6.00 p.m. the lane was restricted to carpools with three or more occupants. However, even with this restriction significant excess capacity existed on the HOV lane.

In 1998, Houston Metro and TxDOT launched the value pricing pilot program known as QuickRide on the existing 13 mile HOV lane, funded as an FHWA Priority Corridor Program. The HOV lane was converted to a HOT lane, which allowed registered two-person carpools to use the lane for a $2 fee during its greatest peaks (from 6.45 a.m. to 8.00 a.m. and from 5.00 p.m. to 6.00 p.m. Monday through Friday) and for free during other times. The QuickRide facility allowed buses and three-plus carpools for free while continuing to restrict single occupant vehicles (SOVs) at all times. QuickRide featured a fully automatic toll collection system, where the toll was paid by windshield-mounted electronic transponders issued by either Houston Metro or transponders issued by the Harris County Toll Road Authority (HCRTA).

In 2003, expansion of Katy Freeway started in order to build four continuous through-lanes and as many as eight freeway lanes at entrance and exit ramps, with the project costing approximately $2.7 billion (U.S.). The new project also added four MLs in the middle of the freeway separated by flexible "candlestick" barriers. These MLs were designed to better manage the congestion using peak-period pricing. The MLs are 12 miles long and run from Highway 6 to Interstate 610. The MLs opened to traffic in November 2008, operating as HOV lanes in which two-plus person carpools, motorcycles, and buses could travel for free. In April 2009, the MLs started operating as HOT lanes with the addition of time of day pricing for SOVs. The toll rate is set to vary by time of day ($4, $2, and $1 for peak, shoulder, and off-peak hours, respectively, for the 12 mile stretch); HOVs and motorcycles pay only during off-peak hours, and the toll can be paid by EZTag or TxTag only (HCTRA, 2009a). This provided an excellent test bed to determine how travelers value their trips on MLs using the latest techniques in survey design.

2.2. Stated Preference Survey Methods

Stated preference surveys have become a popular tool in the studies of mode choice modeling and estimation of value of travel time savings. Stated preference surveys allow researchers to study traveler response/behavior toward various travel alternatives which can be existing, future, or imaginary alternatives. A typical stated preference experiment consists of presenting some alternatives in stated preference questions to the respondent. The alternatives are described by means of attributes. For example, travel time and toll can be the attributes to describe the travel alternatives car, bus, and train. Respondents are asked to choose one of the presented alternatives. The values of attributes presented (levels of attributes) in an SP question help the respondent to consider the trade-offs between the alternatives and are used to estimate the choice models. The levels of attributes used in the SP experiment affect the estimation precision and the inferences drawn from mode choice model (Dallaer et al., 1999, Ohler et al., 2000, Hensher, 2004). Hence, choosing the combination of attribute levels to be presented using the underlying survey design is one of the important factors of SP surveying.

2.2.1. Survey Designs

A choice design is made up of choice sets composed of several alternatives, each defined as combination of different attribute levels (Zwerina et al., 1996). The researcher, through the experimental design, specifies attribute levels in each stated preference experiment, which is evaluated by the respondent. Cumulative data from all the stated preference experiments are then used to model individual preferences by estimating the parameters corresponding to each of the attributes used to model the choice. Thus, the researcher can control certain factors within the study which affect parameter identification, model flexibility, and statistical efficiency of the estimators (Johnson et al., 2007). The experimental design can therefore influence the estimation of each attribute's contribution to the observed choices.

Experimental design in its linear form (a linear design) can be visualized as a matrix with columns representing different attributes of all the alternatives and rows representing choice situations (see Table 2). A choice situation or a stated preference question is also referred to as a "run" of an experiment. The attribute levels are used to populate the matrix.

Similarly, a choice design can be described as a matrix in which each column represents an alternative and each choice situation is represented by multiple rows corresponding to different attributes as shown in Table 3 (see, e.g., Bliemer and Rose, 2006).

Table 2 Survey Design in Linear Form (Linear Design)

Experiment Number	Drive Alone on General Purpose Lanes (Toll Free)	Drive Alone on Managed Lanes		2-Person Carpool on Managed Lanes		3-Person Carpool on Managed Lanes	
	Time (min)	Time (min)	Toll	Time (min)	Toll	Time (min)	Toll
1	45	27	$1.50	30	$0.75	30	$0.25
2	35	20	$1.25	25	$0.25	27	$0.00
3	30	20	$1.50	23	$0.50	25	$0.25

Table 3 Survey Design in Choice Design Form

Experiment Number	Alternatives / Attributes	Drive Alone on General Purpose Lanes (Toll Free)	Drive Alone on Managed Lanes	2-Person Carpool on Managed Lanes	3-Person Carpool on Managed Lanes
1	Time (min)	45	27	30	30
	Toll	N/A	$1.50	$0.75	$0.25
2	Time (min)	35	20	25	27
	Toll	N/A	$1.25	$0.25	$0.00
3	Time (min)	30	20	23	25
	Toll	N/A	$1.50	$0.50	$0.25

Some researchers also use a different form of choice design, in which the rows represent alternatives and columns represent attributes (see, e.g., Huber and Zwerina, 1996, Kanninen, 2002). This type of design is shown in Table 4. It is a transposition of the matrix presented in Table 3. Irrespective of the representation, a choice design is different than a linear design when model estimation is considered.

Almost all the studies have a constraint on the number of choice situations that can be used to gain information; hence, the researcher has to populate the design matrix such that the combination of the levels used in each choice situation will yield the maximum information.

When all possible combinations of attribute levels are listed in a design it becomes a full-factorial design, which is resource expensive and most of the time impractical to present to respondents. For example, even for a simple study with five factors, three at five levels and two at four levels (denoted as $5^3 4^2$), there are (5 x 5 x 5 x 4 x 4 =) 2000 combinations in the full-factorial design. The large number of choices makes it very difficult to use the full-factorial design, even though with the full-factorial design all the main effects, all two-way and higher order interactions are estimable.

A fractional factorial design is any design that has fewer rows than the full-factorial design. As a result of using fewer rows (choice situations) some attribute effects become confounded and they cannot be distinguished from each other. However, the (smaller) design size makes it possible to present all the choice situations to individuals (see Kuhfield, 2005, for details). Blocking of a design is one more way to reduce the number of choice situations per respondent, without changing the design size. Blocking refers to presenting the design (full or fractional factorial) to different respondents in sets which finally add up to the whole design.

Table 4 Survey Design in Choice Design Form- Alternate Representation

Experiment Number	Alternatives / Attributes	Time (min)	Toll
1	Drive Alone on General Purpose Lanes (Toll Free)	45	N/A
	Drive Alone on Managed Lanes	27	$1.50
	2-Person Carpool on Managed Lanes	30	$0.75
	3-Person Carpool on Managed Lanes	30	$0.25
2	Drive Alone on General Purpose Lanes (Toll Free)	35	N/A
	Drive Alone on Managed Lanes	20	$1.25
	2-Person Carpool on Managed Lanes	25	$0.25
	3-Person Carpool on Managed Lanes	27	$0.00

It is recommended that a good fractional factorial survey design should possess the properties of level balance and orthogonality, while the converse may not always be true (see Kuhfield, 2005, Rose and Bliemer, 2008). Level balance is achieved in a design when all the levels occur equally within each factor. Orthogonality is achieved by selecting the levels such that the attributes become statistically independent. Orthogonality thus reduces the possibility of inducing correlations in attributes due to design error (higher order correlations may still remain in an orthogonal design). The full-factorial design is an orthogonal design, even for higher order correlations. Orthogonal designs are mainly used for linear models, as they are easy to construct. When used for estimating linear models, orthogonal designs were found to remove multicollinearity and minimize variance of parameter estimates (Louviere et al., 2000, Rose and Bliemer, 2008). Studies in choice modeling have also depended on orthogonal designs due to lack of guidance and resources in the area of experimental designs for discrete choice modeling.

Despite their ease of construction, orthogonal designs are not an option in certain situations (Kuhfeld, 2005). It is not possible to use orthogonal designs when all the factor level combinations are not feasible or they do not make sense. For example, in the survey used for this study, the speeds (hence the travel times) of all managed lane alternatives cannot differ largely. Hence, the level combinations with extreme low and high speed levels for two managed lane alternatives would not create a feasible combination. Orthogonal designs are characterized by specific numbers of runs for specific numbers of factors with specific numbers of levels. Hence, when the desired number of runs is not available, using an orthogonal design is not an option. For example, for the survey used in this research the size of the design was limited by the number of characters in the survey code, which allowed only designs with up to 21 runs. Hence, an orthogonal design can be used only if it is available in that size. Further, in the case of discrete choice modeling the orthogonality of the design may not be preserved when the design is presented as a block (subset) to each respondent. Certain blocks are either over- or under-represented in the data (for example, due to non-response), which makes it difficult to retain the orthogonality of the design (Rose and Bliemer, 2008).

Choice studies differ from most of the studies involving linear models in one more ways, which may limit the advantage of using an orthogonal design. Choice studies typically use additional attributes apart from those used to select the design. These non-design attributes (such as age, gender) in choice studies may also remain constant over the alternatives for each respondent, creating correlations between themselves and other attributes (Rose and Bliemer, 2008).

Apart from these issues, in discrete choice studies, researchers also desire choice situations which do not have an extreme imbalance in the utilities of the alternatives presented to a respondent. Thus researchers avoid the situation in which one alternative is very attractive in comparison to all others, as this does not help to gain much information about the trade-offs between the alternatives (Bates, 1988). This is similar to the problem of infeasible factor level combinations mentioned above, which may limit the use and advantage of orthogonal designs.

Conversely, marginal choices (with comparable utilities of the alternatives) are not desirable for efficiency (Toner et al., 1998). Studies such as the one carried out by Toner et al. (1998) have concluded that fractional factorial orthogonal designs do not necessarily improve the efficiency of the parameter estimation of the disaggregate logit models. Thus an experimental design for discrete choice models needs special considerations in order to better estimate the parameters as well as model the choice and estimate of value of travel time savings.

2.2.2. Efficient Designs

Selecting a fractional factorial design for a survey out of numerous possibilities from a full-factorial design typically is done using an efficiency criterion. An efficient survey design is characterized as a design that minimizes variance (thus the standard error) of the estimated parameters and hence maximizes the t-ratios produced by that model. The variances of parameter estimation are drawn from the variance-covariance (VC) matrix of the model. For a linear model the VC matrix is given by Equation (1).

$$VC = \sigma^2 [X'X]^{-1} \tag{1}$$

where σ^2 is the model variance and

X is the matrix of attribute levels in the design or data.

The model variance (σ^2) acts as the scaling factor, hence the VC matrix is proportional to $[X'X]^{-1}$. Most of the efficiency criteria (statistics) are based on the eigenvalues of $[X'X]^{-1}$. Two of the efficiency measures are A-efficiency and D-efficiency, both based on averaging the variance (Equations 2 and 3).

$$\text{A-efficiency} = 100\times\frac{1}{N_D\, trace([X'X]^{-1})/p} \qquad (2)$$

$$\text{D-efficiency} = 100\times\frac{1}{N_D|(X'X)^{-1}|^{1/p}} \qquad (3)$$

where N_D = number of runs (rows in a linear design),

p = number of parameters (different attributes in the design), and

$trace([X'X]^{-1})$ = sum of the diagonal elements of the matrix $[X'X]^{-1}$.

Thus, A-efficiency is a function of the arithmetic mean, while D-efficiency is a function of the geometric mean of eigenvalues. Hence D-efficiency is not sensitive to the parameter scaling (weighing the standard errors of larger parameters heavily as they tend to be larger than those of smaller parameters) in minimization. Use of D-efficiency criteria also has advantages in ease of incorporating it into programming and the fact that the relative D-efficiency (ratio of D-efficiency) of any two designs is not dependent on the coding scheme (Kuhfeld, 2005, Rose and Bliemer, 2008). Hence, use of D-efficiency criteria dominates the research literature.

Finding an efficient design specifically for a discrete choice model is done in two ways. The first approach is based on the assumption that the design which is good for a general linear model is also good for the discrete choice model. Many researchers in the past have used efficient linear designs for estimating discrete choice models using this assumption (Louviere and Woodworth, 1983, Louviere, 1988, Batsell and Louviere, 1991, Lazari and Anderson, 1994, Kuhfeld et al., 1994, Huber and Zwerina, 1996, Kuhfeld, 2005, Johnson et al., 2007). The efficient linear design which is finally unfolded into a choice design tends to possess the qualities of level balance and orthogonality. Macros for searching this type of design are readily available in SAS software and are described in the sub-section 2.2.3 (Kuhfeld, 2005).

A second and more recent approach of searching an efficient design for a discrete choice model involves estimating the variance-covariance matrix for a particular choice model (Bliemer and Rose, 2006, Bliemer et al., 2009, Rose and Bliemer, 2008, Hess et al., 2008). The main argument in using this second approach is that, unlike in a linear model, the asymptotic variance-covariance matrix of a discrete choice model is based on the second derivative of the log-likelihood function underlying the estimation of the model (McFadden, 1974, Bliemer and Rose, 2006), which in turn is driven by the assumption of the error structure in the model. For example, the formal relevant probabilities of the simple multinomial logit model relate to the fact that the underlying error (random) terms follow the extreme value distribution, while the probit model assumes that the error terms follow a distribution that is cumulative-normal. In neither case is the error term generated by assuming a linear model and a normal distribution, as is the case in use of ordinary least squares estimation. The variance-covariance matrix (VC) for a multinomial logit model is given by Equation (4).

$$\mathrm{VC} = \frac{1}{\mathrm{M}}\left[\frac{\partial^2 \mathrm{LL}(\beta)}{\partial\beta\,\partial\beta'}\right] \tag{4}$$

where M = number of respondents, usually only one complete design for a single respondent, is considered for estimation of the D-error while searching for the D-efficient design,

LL = log-likelihood function for the multinomial logit model, and

β = the parameters used in the model.

As stated earlier, this approach uses design criteria specific to the specification of a choice model (such as multinomial logit, nested logit, or mixed logit). D-efficiency for a specific model thus depends on the asymptotic VC matrix for that particular model. Also, ideally, this approach requires knowledge of the estimated parameter values (or assumption of parameter priors) to estimate the log-likelihood function, LL. This suggests the use of Bayesian methods, or at least approaches that allow feedback between design and estimation. Several researchers have concluded at this point that the assumption about the parameter priors affects the efficiency, and they have recommended using pilot studies and prior knowledge about the parameter values (Huber and Zwerina, 1996, Kanninen, 2002, Carlsson and Martinsson, 2003, Rose and Bliemer, 2008). Bayesian techniques are also being used to provide the parameter values needed in finding the efficient design (Ferrini and Scarpa, 2007, Scarpa and Rose, 2008, Rose and Bliemer, 2008, Hess et al., 2008).

This study follows the first approach in which an efficient design is searched assuming a linear model for estimating the multinomial logit model. Apart from using an efficient design, this study also uses two random attribute level strategies which are discussed in section 3.5.

2.2.3. Efficient Design Searching Using SAS Macros

Macros for searching a D-efficient design are readily available in SAS software and are explained in detail in Kuhfeld (2005). A series of macros is run in order to search for an efficient design. The procedure is described in the following paragraphs (see Appendix A for SAS codes).

The first %MktRuns macro is run by specifying the number of attributes and the corresponding number of levels. This macro suggests the recommended sizes of the design. The macro also specifies the saturated design size which is the minimum size needed for estimation of the parameters and is equal to the number of parameters in the linear model. Next, another macro called %ResMac is used to specify the restriction during the design search. The restrictions are typically the level combinations corresponding to two or more attributes which are not feasible in the survey. For example, a restriction may be specified that in any given run, level four cannot be present in more than one of the attributes.

Next, the %MktEx macro is run by specifying the number of levels for each attribute, the size of the design to be searched, the restriction macro to be used, and the random number seed to be used in case the results need to be replicated later. The %MktEx macro searches and returns an efficient design along with its D-efficiency and A-efficiency. The levels in the design returned are specified as integers 1, 2, 3,.., etc. In order to run basic checks against this design the macro %MktEval is run. This macro first prints a matrix of canonical correlations between the attributes (such as travel time and toll). This matrix will be an identical matrix in case the design is an orthogonal design. Next, the macro prints all one-way frequencies for all attributes, all two-way frequencies, and all n-way frequencies. Equal or at least nearly equal one-way and two-way frequencies are desired, and we want to see that each combination occurs only once. Equal one-way frequencies is an indication that the design is balanced. Equal two-way frequencies indicate that the design is orthogonal. The n-way frequencies, all equal to one, means that there are no duplicate profiles. This type of design is a perfect design for a main-effects model.

In the next step the macro %MktLabs is used to assign variable names and actual values to the levels. This is followed by use of the %MktRoll macro to turn the linear design into the choice design. Finally, the macro %ChoicEff is used to evaluate efficiency of the design for a multinomial logit model. Readers are referred to Kuhfeld (2005) for more details and examples of searching an efficient design.

A list of commands to obtain an efficient survey design of 24 runs/rows (24 questions in eight blocks of three ordinary situation questions) is given in Appendix A.

2.3. Mode Choice Modeling

2.3.1. Multinomial Logit Model

In transportation planning, multinomial logit (MNL) models are typically used to predict the mode choice for an individual and are based on the concept of random utility maximization. The multinomial logit model is the most popular form of discrete choice model in which the utility of an alternative j =1,..., J for a individual q = 1,.., Q in a choice situation t =1,…, T is specified in Equation (5). It consists of a systematic part and a random (error) component.

$$U_{q,j,t} = \boldsymbol{\beta}'\mathbf{x}_{qjt} + \epsilon_{q,j,t} \tag{5}$$

where β = the coefficients to be estimated,

$\mathbf{x}_{qjt}$ = vector ($K\times$ 1) of K independent variables which include alternative specific constants, characteristics of the individuals, characteristics of the alternative, and other descriptive variables affecting the choice; and

$\epsilon_{q,j,t}$ = the error components which may be due to unaccounted measurement error, correlation in the parameters, unobserved individual preferences, and other similar unobserved characteristics of the choice-making.

The error components ($\epsilon_{q,j,t}$) are assumed to be distributed as identical independent type 1 extreme value which gives a closed-form multinomial logit model probability equation (Equation 6). This assumption, however, comes at a cost as it assumes the model has the independence from irrelevant alternatives (IIA) property. The IIA property of the MNL restricts the ratio of choice probabilities for any pair of alternatives to be independent of the existence and characteristics of other alternatives in the choice set. This restriction implies that the introduction of a new alternative (mode) or improvements to any existing alternative will affect all other alternatives proportionately. That is, in the case of mode choice study the new or improved mode will reduce the probability of existing modes in proportion to their probabilities before the change (Train, 2003). Not being able to account for individual heterogeneity (as the parameters are assumed to be fixed) is seen as another shortcoming of this model.

$$\text{Prob (choice } j \text{ |individual } q, \mathbf{X}_{q,t}\text{, choice setting } t) = \frac{\exp(\boldsymbol{\beta}'\mathbf{x}_{qjt})}{\sum_{q=1}^{J_i} \exp(\boldsymbol{\beta}'\mathbf{x}_{qjt})} \quad (6)$$

An example of the systematic part of the utility function is given in Equation (7) indicated as V_{qj}.

$$V_{qj} = \beta_0 + \beta_1 * TravelTime_{qj} + \beta_2 * TravelCost_{qj} + \beta_3 * Income_q \quad (7)$$

where β_k = the estimated coefficient of each independent variable *x,*

$TravelTime_{qj}$ = the travel time for mode j for individual *q,*

$TravelCost_{qj}$ = the cost of travel on mode *j* for individual *q,* and

$Income_q$ = the income of individual *q*.

This equation can be used to estimate the value of travel time savings for travelers if the coefficients β_1 and β_2 are included in the utility equations for all modes. The VTTS will then be given by the partial derivative of the utility equation with respect to time divided by the partial derivative of the utility equation with respect to cost; in this case this results in the ratio β_1/β_2.

Use of the multinomial logit model can be justified in the case of very basic travel options such as driving alone, taking a bus, and carpooling. However, increased use of, and examination of, concepts such as managed lanes and HOT lanes with variable pricing has complicated both an individual's travel options and the models necessary to estimate which mode an individual will choose. The options such as traveling alone on managed lanes during peak hours at a higher toll, traveling alone on managed lanes during non-peak hours at a lower toll, and carpooling on managed lanes during peak hours with or without passengers at discounted tolls must be included in the new global choice set. The travel alternatives are similar to each other due to shared attributes which are not included in the measured part of the utility functions. The presence of such highly similar options may cause violation of the IIA assumption. In such instances it is increasingly common to use a random parameter logit model (mixed logit model).

2.3.2. Mixed Logit Models

The mixed logit (or random parameter logit) model is one of the latest developments in choice modeling which has a very unrestrictive specification (see Train, 1998, Revelt and Train, 1998, Train, 2003). The mixed logit model is very flexible and it can approximate any random utility model (McFadden and Train, 2000). With developments in computational abilities and the theoretical framework, the mixed logit model has evolved from a basic specification which allows only the parameters to be distributed randomly to the model which can now accommodate repeated responses (as panel data or autocorrelation), scale differences in data sources, error structures, heteroscedasticity, and heterogeneity from various sources (see Brownstone and Train, 1999, Ben-Akiva et al., 2001, Bhat and Castelar, 2002, Greene et al., 2006, Greene and Hensher, 2007, Hensher et al., 2008). This research follows the notations and the specification used in Greene and Hensher (2007).

The simplest specification of the mixed logit model which allows the parameters to be distributed randomly specifies:

$$\beta_{qk} = \bar{\beta}_k + \sigma_k \upsilon_{qk}; \tag{8}$$

where $\bar{\beta}_k$ = the population mean for the k^{th} attribute,

υ_{qk} = the individual specific heterogeneity with mean zero and standard deviation (scaled to) one, and

σ_k = the standard deviation of the (assumed) distribution of the $\beta_{kq}{}'$s around $\bar{\beta}_k$.

Various empirical distributions can be assumed for one or all coefficients in the model including travel time and toll or travel cost coefficients. Assuming both travel time and toll as random parameters, however, adds complexity in estimation of their ratio, the VTTS. Inferences about the VTTS in such cases become complicated due to the fact that the travel cost coefficient drawn from the distribution may contain a zero, making the ratio inestimable. Using a distribution such as lognormal is one of the ways to ensure that the coefficient remains on one side of zero. The drawbacks of using lognormal distribution is that it has very long tail, which corresponds to unrealistically large values. Normal distribution also presents the problems of long tails and inclusion of zero. Further, part of normal distribution can take positive values, which are counterintuitive for time and toll parameters. The time and toll parameters are expected to take negative values, as travelers dislike longer trips and also to pay for travel.

Additionally, distributions which have estimated standard deviations greater than the estimated mean present behaviorally implausible inferences. One of the ways to handle this issue is to specify additional restrictions on the standard deviation of the distribution, making it a constrained distribution (Hensher and Greene, 2003, Hensher et al., 2005). The standard deviation can be restricted to take a value equal to a multiple of the mean, the multiple taking a value between zero and one (for example, standard deviation = 0.5 x mean).

These random parameters β_{qk} can be further specified to accommodate the heterogeneity in the mean and the heteroscedasticity as given in Equation (9). The heterogeneity of the mean refers to the case in which the mean is not homogeneous or equal for all the segments (groups) in the sample. By contrast heteroscedasticity indicates that the variances of these means corresponding to each segment are different.

$$\beta_{qk} = \bar{\beta}_k + \boldsymbol{\delta}'_k \mathbf{z}_q + \gamma_{q,k} \upsilon_{q,k}; \tag{9}$$

where $\boldsymbol{\delta}'_k \mathbf{z}_q$ = the observed heterogeneity around the mean of the k^{th} random parameter ($\boldsymbol{\delta}_k$ is to be estimated and $\mathbf{z}_q$ is a data vector which may contain individual specific characteristics such as the socio-demographic factors),

$\upsilon_{q,k}$ = the vector which contains individual and choice specific, unobserved random disturbances with $E[\upsilon_{q,k}] = 0$ and $\text{Var}[\upsilon_{q,k}] = a_k^2$, a known constant, and

$\gamma_{q,k} = \sigma_k \exp[\boldsymbol{\eta}'_k \mathbf{h}_q]$ with $\exp[\boldsymbol{\eta}'_k \mathbf{h}_q]$ as the observed heterogeneity in the distribution of $\beta_{q,k}$ ($\boldsymbol{\eta}_k$ is to be estimated and $\mathbf{h}_q$ is a data vector which may contain individual specific characteristics).

This ability of specifying the heterogeneity around the mean can also be used for estimating the VTTS for different groups. For example, Hensher et al. (2005, p. 660-667) demonstrate how this specification can be used to estimate the preference heterogeneity around the means of the travel time and travel cost parameters for travelers in different cities. Similar logic can be used for investigating the preference heterogeneity around the mean of travel time and toll parameters for ordinary and six urgent travel situations.

Further, extension in the mixed logit model can account for the autocorrelation (which may exist in panel data or repeated choice situations) is specified as:

$$v_{q,k,t} = \rho_k v_{q,k,t-1} + w_{q,k,t}, \tag{10}$$

where ρ_k = autocorrelation parameters to be estimated and

$w_{q,k,t}$ = the new underlying structural random variable.

Correlation in the error patterns in this way would likely arise if the questions asked over "time" are essentially identical. For example, the usual panel model obtains the answer to a question such as household income at various points in time. It is easy to see in this case that the same household may have unobservables that lead to patterns in household income.

While the above extensions are related to random parameters only, the following extension can be specified to incorporate additional unobserved heterogeneity through effects that are associated with preferences within the alternatives. The utility function with this extension is specified as Equation (11) as in the kernel logit model (see Brownstone and Train, 1999, Ben-Akiva et al., 2001, Greene and Hensher, 2007, for details).

$$U_{q,j,t} = \boldsymbol{\beta}'_q \mathbf{x}_{q,j,t} + \epsilon_{q,j,t} + \sum_{m=1}^{M} c_{jm} W_{q,m}, \tag{11}$$

where $c_{jm} = 1$ if error component *m* appears in the utility function of alternative *j* and

$\mathrm{W}_{\mathrm{q,m}}$ = the normally distributed effects with zero mean.

The effects, $\mathrm{W}_{\mathrm{q,m}}$ are associated with individual preferences within choices (alternatives) and can account for unobserved heterogeneity such that

$$\mathrm{Var}[\mathrm{W}_{\mathrm{m,q}}] = [\theta_{\mathrm{m}} \times \exp(\tau'_{\mathrm{m}} \mathrm{h}_{\mathrm{q}})]^2. \tag{12}$$

where θ_{m} = the scale factor for error component m,

τ_{m} = parameters in the heteroscedastic variances of the error components, and

h_{q}= the data vector which contains individual choice invariant characteristics that produce heterogeneity in the variances of the error components.

The conditional choice probability with above extensions is given by Equation (13).

$$\mathrm{Prob}_{q,t}(j_t|\mathrm{X}_{it},\boldsymbol{\Omega},\mathbf{z}_q,\mathbf{h}_q,\mathbf{v}_q,\mathrm{W}_q) = \frac{\exp(\boldsymbol{\beta}'\mathbf{x}_{qjt}+\sum_{m=1}^{M} c_{jm} W_{mq})}{\sum_{j=1}^{J}\exp(\boldsymbol{\beta}'\mathbf{x}_{qjt}+\sum_{m=1}^{M} c_{jm} W_{mq})} \tag{13}$$

where $\mathbf{\Omega}$ = the parameter set which collects all the structural parameters (the underlying parameters in the model/equation).

These probabilities cannot be calculated exactly and hence are replaced by simulated probabilities. Thus the unconditional probability for this model has to be estimated by the maximum simulated likelihood method (see Train, 2003, for more information). As explained in Train (2003) in the mixed logit simulator: "the draws of the random terms are taken, utility is calculated for these draws, the calculated utilities are inserted into the logit formula, and the results are averaged." The number of draws taken during the estimation and the sample size affect the estimation procedure.

Further, the speed of estimation is affected by the method of taking these draws from densities. Using Halton draws instead of random draws has proven effective in the simulation. Bhat (2001) found that 100 Halton draws provided more precise results than 1,000 random draws for the mixed logit model he used. Similar findings from other studies confirmed the advantage of using Halton draws (Train, 2000, Munizaga and Alvarez-Daziano, 2001, Hensher, 2001).

The discrete choice models such as the mixed logit model are often used for estimating the implied VTTS as described in the next section.

2.4. Value of Travel Time Savings

Each traveler has to sacrifice time spent traveling, which could otherwise be utilized for earning income, for some leisure activities, or many other options. This sacrifice imposes an opportunity cost equal to the individual's value of time in the activity forgone. The value of travel time savings refers to the value of a change in the time duration of a given journey which is not necessarily marginal or infinitesimal (Bruzelius, 1979).

2.4.1 Estimation of Value of Travel Time Savings

Travelers' VTTS are typically estimated by conducting stated preference studies. In these studies an opinion survey of travelers is conducted to elicit information as to how much extra money they would be willing to pay for a reduction in travel time. As per Kroes and Sheldon (1988), the "stated preference methods refer to a family of techniques which use individual respondent's statements about their preferences in a set of transport options to estimate utility functions." Stated preference survey methods identify values of relative utilities for different options; therefore, they are immune to the errors due to respondents overestimating and underestimating their actual travel times and costs (Kroes and Sheldon, 1988). These methods are generally used along with revealed preference (RP) methods because in that case the RP data can be used to scale the utility function and generate the model. Combining SP and RP data potentially allows the consistency of the SP data with the RP data to be determined (see Adamowicz et al., 1994, Brownstone et al., 2000, Dosman and Adamowicz, 2006).

To analyze the data obtained by stated preference methods, the discrete choice models described in sub-section 2.3 are widely used. Route choice, mode choice, or speed choice models (see Chui and McFarland, 1985, McFarland and Chui, 1987, for examples) are occasionally used to evaluate the travel time and cost trade-offs studied for estimation of the implied VTTS.

There are many factors that affect the VTTS for a traveler. These are listed next.

2.4.2 Factors Affecting the Value of Travel Time Savings

Various travelers' characteristics affect their value of travel time savings. For example, the age of the traveler has an effect on their value of time. For example, a study carried out by Algers et al. (1998) concluded that people aged 45 or older seem less sensitive to travel time than younger travelers. Gender of the traveler also plays an important role in deciding some travel characteristics, such as commuting patterns and criteria for mode choice. It is observed that women were less likely to choose public transit but more likely to carpool than men. Commuting women were often less time sensitive than men (Patterson et al., 2005). Trip purpose is another factor which affects value of travel time savings. Value of travel time savings was generally found to be greater for commuting than leisure travel (Wardman, 1998).

It was also observed that the value of travel time savings frequently depends on the income of the individual (Fosgerau, 2005). On average, the value of travel time is estimated to be between 20% to 50% of the wage rate for work trips (Small et al., 1999, Calfee and Winston, 1998). Travel time and its variability also affect the value of time; Senna (1994) and Davis et al. (2009) reported that value of time does not only depend on (average) travel time but also on variability of travel time (reliability). Small et al. (1999) found that the travel time savings for congested travel was valued much higher than the travel time savings in uncongested conditions. They also found that the travel time reliability was valued highly and it can be more than the value of travel time savings.

These findings are critical in understanding the decision-making of travelers with the option of using variably priced managed lanes and estimation of their value of travel time savings under different travel scenarios. Highway project evaluations and travel behavior studies frequently use the estimates of value of travel time savings. VTTS estimates are also used in various calculations such as estimating the benefit-cost ratio of a transportation project, estimating cost of traffic congestion (see Schrank and Lomax, 2007), and finding the base for fixing the toll rates on a tolled facility. Demand estimation for toll roads and managed lanes greatly benefit by a more detailed knowledge of VTTS of the travelers rather than just a number representing the average VTTS for all travelers. Understanding the distribution of the VTTS across users of the facility helps to set the toll rates so that a required flow (level of service) can be maintained on the facility. Researchers are now focusing on estimation of the distribution of the VTTS (Hess et al., 2005, Fosgerau, 2006).

Further, it can also be expected that an individual will attach different values of travel time savings based on the occasion. For example a traveler may place more value on the travel time savings when he/she is late for work than that for a usual work trip when he/she is not delayed. This study will attempt to better estimate the VTTS by separating the situations under which the travel decision is made. The study will focus on differentiating the VTTS for ordinary and urgent situations. This study will also try to estimate the effect of survey design technique on estimation of the VTTS and its distribution in order to understand traveler decision-making when using variably priced managed lanes are a travel option.

3. STATED PREFERENCE SURVEY AND DATA

3.1. Katy Freeway Travelers Survey

This study collected data from travelers of Katy Freeway in Houston. The Katy Freeway was recently widened and additional variably priced managed lanes (HOT lanes) were added in the middle of the freeway. We used the advantage of collecting our choice data just when the Katy Freeway managed lanes opened. The surveys were conducted in November 2008 using the internet, which has disadvantages and advantages over mail or telephone surveys. The survey text was available in either Spanish or English. Every survey sample has potential sampling bias because respondents may volunteer or refuse to participate, or answer specific questions. And nearly every survey questionnaire involves potential errors in response, as the respondents may not understand concepts or questions.

3.2. Survey Sample

Since the survey was administrated over the internet, it naturally requires that the respondents have access to a computer to take the survey. As of 2007 about 75 percent of all U.S. households had a broadband connection, which was an increase of 21 percent over the previous year (Legatt, 2007). While not every household in the Houston area has access to the internet, the percentage of households in the United States that have access is increasing and potential bias from using this implementation approach will no doubt diminish, when compared to other survey approaches. Alternative approaches have potential biases too. For example, mail surveys sent to correct addresses do not have the initial selection problem, but mail surveys often suffer from poor response rates because households throw away what they perceive to be junk mail. Telephone surveys have become increasingly problematic as many households have caller-ID phones and do not answer unrecognized calls. Many other households switched to the use of mobile phone service only, and thus potential bias exists with this approach because listings of cell-phone numbers are not available and random digit dial approaches are precluded.

In addition, stated choice surveys can involve complex tasks. The more complex the task, the less likely some types of respondents will be to complete the survey or participate at all. An internet survey can aid the respondent in these tasks by allowing helpful visual materials and connections between responses that the respondent can more easily see than in a lengthy mail survey. These techniques were employed here in an effort to maximize response rate while minimizing confusion. The internet program was also designed such that consistency checks on responses were conducted, or which required the respondent to answer a question before advancing to the next question, thus potentially reducing item-response bias.

3.3. Data Collection/ Survey Administration

The study's main objective was to estimate the value of travel time savings of travelers considering general purpose lanes (GPL) and ML options. Hence, the sampling strategy targeted travelers who used the Katy Freeway (travelers who use the Katy Freeway regularly or have at least used it in the past week).

People living in proximity to the Katy Freeway were encouraged to take the survey online. The availability of the survey and its web address (www.katysurvey.org) were publicized through radio (www.sunny99.com), news websites (Houston Chronicle, www.chron.com, My Fox Houston, www.myfoxhouston.com, News Katy, http://instantnewskaty.com), and websites of Houston TranStar (www.houstontranstar.org) and West Houston Association (www.westhouston.org). Additionally, emails were sent to randomly selected travelers in Harris County who owned an electronic toll transponder.

In order to increase survey participation, two awards of $250 gas cards selected by a lottery were announced for those who completed the survey. Incentives to participate are often used in recruiting for surveys.

A total of 6,312 respondents took at least some portion of the online survey. Of these, 3,990 respondents fully completed the survey. The survey was designed for those travelers who were traveling by car (either alone or as carpooler) in conjunction with the actual opening of the expanded freeway, but 119 respondents who traveled by motorcycle or bus also took the survey. Their responses were not used, which decreased the sample size to 3,871.

Income, age, and gender are often the key variables in determining response rates in surveys, and hence it is necessary to check whether there is a biased group in this regard. In order to investigate this sampling bias based on distribution of income, age, and percentage of males we compared our survey sample with a sample from a previous survey (paper + internet) conducted in 2003 on Katy Freeway travelers and the population of travelers (Table 5).

Table 5 Analysis of Bias in the Sample with Respect to Income Age and Gender

Comparison Criterion	Katy Freeway Survey 2008 Sample	Along Katy Freeway Corridor Source: H-GAC, 2009	Katy Freeway Survey 2003 Sample
Annual Household Income < $25000	3%	11%	4%
Annual Household Income $25000 to $75000	29%	32%	33%
Annual Household Income > $75000	68%	57%	63%
Age 16-24 years	2%	NA	5%
Age 25-54 years	71%	NA	79%
Age 55 years and over	27%	NA	16%
Percentage of Males	58%	NA	63%

The population was defined as people living in the Traffic Analysis Zones (TAZ) along the Katy Freeway based on the latest household travel survey performed for the Houston-Galveston Council of Governments (H-GAC, 2009). Though the current survey oversamples from the higher income group and undersamples from the low income group and age group 16 to 24 years, the (current internet based) survey sample is not very different from the sample of the previous (paper + internet based) study sample based on all the criteria used. This previous survey was mailed to travelers observed on the Katy Freeway and therefore may be closer to true freeway user demographics than the general population data (see Burris and Figueroa, 2006, for details of this survey).

3.4. Description of Survey

The survey questionnaire begins by asking the respondent questions about their most recent trip on the Katy Freeway. These questions were followed by questions on respondent's general travel behavior on Katy Freeway, an introduction to the managed lanes concept, questions regarding their feelings toward this ML concept, stated preference questions, and finally key socio-economic questions (see Appendix B for the complete questionnaire). Note that some of these questions were about actual trips taken; these types of questions are known as revealed preference (RP) questions. In SP designs involving hypothetical questions that are outside of experiences respondents have, consistency checks can be invaluable, but again here, we expect that most of the choices provided to respondents are familiar to them.

In the third section of the survey questionnaire respondents were presented with three pairs of stated preference questions. Each pair of questions asked the respondent about their choice of travel mode for a trip in the case of an ordinary situation and also for an urgent travel scenario. In all three SP question pairs, one of six reasons was used to describe the urgent situation that a traveler may be facing. We tried to word these reasons so that they are applicable to numerous other urgent situations falling in that category, applicable to either direction of travel (toward/away from downtown), all days of the week (weekday/weekend), and all times of departure (peak/shoulder peak/off-peak). Note that not all of the situations mentioned below occur unexpectedly to the traveler, as some of them can be known and planned for in advance. The six urgent reasons and their implications are given in Table 6.

The travel time and toll (if any) related to the trip were the key attributes that define the alternatives in each SP scenario. A typical presentation of the stated preference question presented in the survey is shown in Figure 3. We purposefully chose a parsimonious specification to model the choices of alternatives, using only two key attributes of the travel choices, the travel time and toll. These are discussed below, but note that labels inform the respondent about whether the mode of travel they would use involves driving alone or carpooling, the use of a managed lane or a general purpose lane. These labels provide more information about the alternative, in the same way that labeling a soft-drink a "cola" or a "diet drink" would aid respondents in their choices among soft drink beverages. The specific levels or values of travel time and toll to be presented in the stated preference questions were determined using one of four experimental designs. These experimental designs are discussed in more detail in the next section.

Table 6 Urgent Situations Categories Presented in the SP Survey

Urgent Situation	Survey Wording	Description/Implication
Situation 1 *ImpAppt*	You are headed to an important appointment/meeting/event	The traveler may not necessarily have started late; however, he/she especially needs to arrive on time.
Situation 2 *LateAppt*	You are running late for an appointment or meeting	The traveler knows that he/she is already late and hence is in need of the fastest travel alternative.
Situation 3 *WorryTime*	You are worried about arriving on time	The traveler needs to arrive on time (as in Situation-1); however, now we have added the word worry in the description to analyze if the behavior is any different due to the underlined urgency. People worried might leave earlier than normal or they may plan to use the managed lanes. Also, this situation may or may not include an important appointment/meeting/event.
Situation 4 *BadWeather*	You expect potential traffic problems due to bad weather	The travel times may be longer than usual (for both GPLs and MLs) with possible additional unreliability in the travel time on the GPLs.
Situation 5 *LateML*	You left late knowing you could take advantage of the toll lanes	Even though similar to Situation-2, the traveler in this situation is expected to have higher value of travel time savings than that presented by the usual toll rates. Additionally, analysis of this situation may provide an interesting insight into travel behavior with respect to a dynamically priced facility and may help us understand how the traveler reacts when faced by tolls which are higher or lower than the usual.
Situation 6 *ExtraStops*	You need to make extra stops on the trip but still need to arrive on schedule	The traveler could make up the time using the MLs or leave earlier depending on flexibility of schedule.

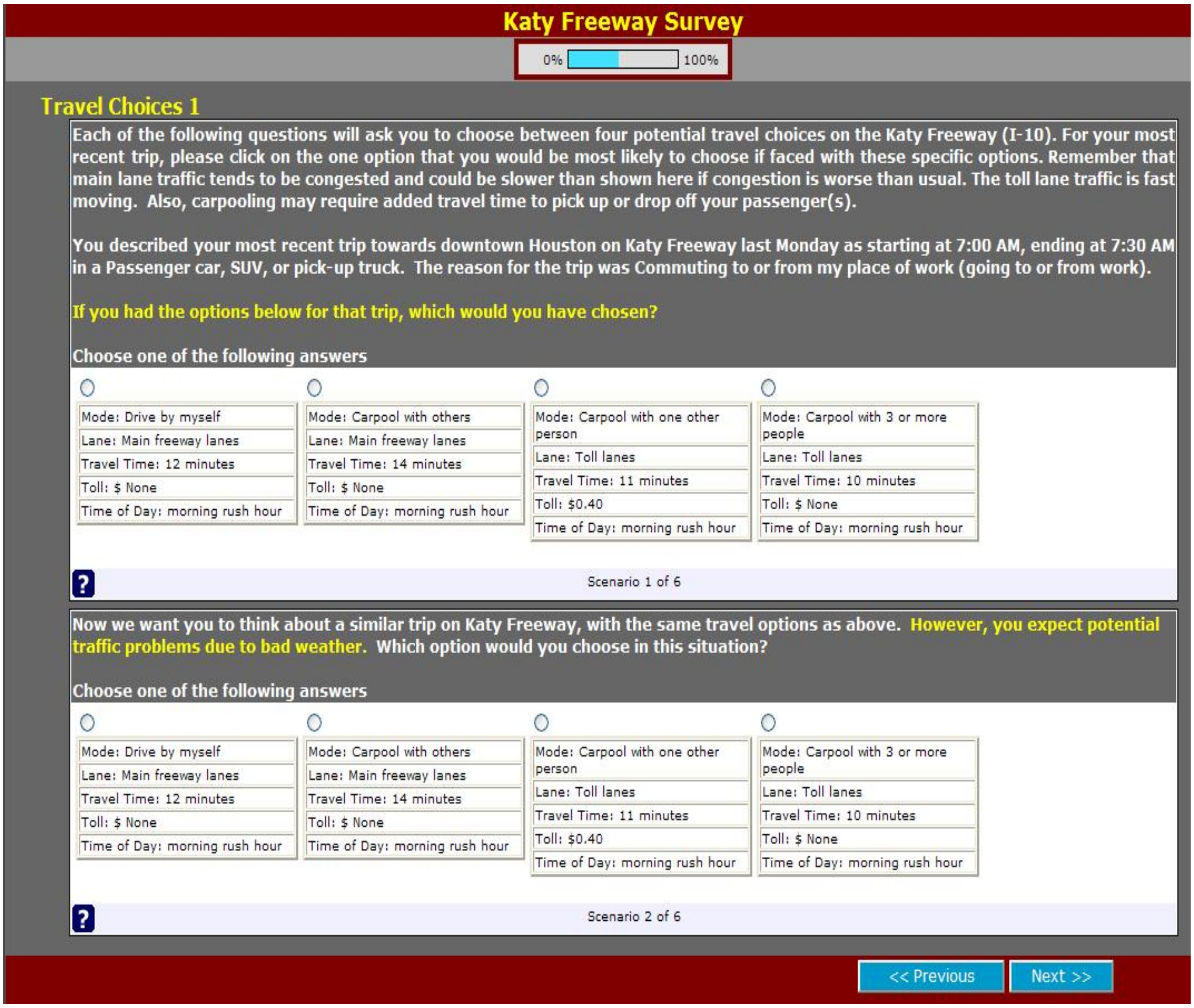

Figure 3 Typical Stated Preference Question in the Survey

3.5. Survey Design Details

Four different approaches were used to determine the specific levels of travel time and toll to be presented in the stated preference questions. Ideally, one wishes to provide the respondent with a wide range of realistic levels for the travel time and toll that they might face in a commuting or traveling situation. In all three of these approaches the respondents were presented with four out of five travel options (design alternatives) as follows:

1. Carpooling on general purpose lanes (CP-GPL),
2. Driving alone on general purpose lanes (DA-GPL),
3. Driving alone on managed lanes (DA-ML),
4. Carpooling with one other person on managed lanes (HOV2-ML), and
5. Carpooling with three or more people on managed lanes (HOV3+-ML).

The travel time and toll were presented in the SP questions to describe each alternative; however, the levels of these attributes in turn depended on the trip length for each respondent. In other words, it was recognized that realistically a total package of the trip that the respondent would choose might well depend on the length of the total trip he or she took as part of their actual travel. Hence, the speed of the vehicle and the toll rate per mile were used as the specific design attributes to calculate the levels of travel time and toll by using the reported actual trip length for each respondent. The respondent's specific trip length was calculated based on the Katy Freeway on and off-ramps the respondent indicated they had used on a recent trip. Also, if the trip length of the respondent was more than 12 miles (the length of the MLs), then an additional component of travel time on the highway section beyond the ML section was included in the individual's travel time. This was calculated using speed equal to 60 miles per hour since travel this far from downtown Houston was often free flow.

For example, if a respondent's trip length exceeded 15 miles then the travel time was calculated for two sections, the uncongested section and the congested section. The uncongested section in this example was (15 – 12 =) 3 miles long and the corresponding travel time was 3 minutes (calculated using the speed of 60 mph). Further, the congested section travel time for this example was calculated for the remaining 12 mile length using the GPL and ML speed levels obtained from the design. Hence, if the GPL speed level was 40 mph and ML speed level was 60 mph, the travel time for the congested section was (60 * 12/40 =) 18 minutes . The total travel times presented for GPL and ML alternatives for both sections were (3 + 18 =) 21 minutes and (3 + 12 =) 15 minutes, respectively. Only the congested section length was used to calculate the toll presented in an ML alternative. For example, if the toll rate as obtained from the design was $0.15 /mile for the travel alternative DA-ML, then the toll presented in the question was (15 * 12/100 =) $1.80 (along with travel time of 15 minutes) for the respondent in the above example.

In all the designs the travel alternatives that involve GPLs were presented with no toll and with longer travel times than the ML travel alternatives (MLs with variable pricing are operated such that they provide a faster and more reliable travel option than GPLs). One of the three design approaches described in the following sections was randomly assigned to each respondent. The specific levels used for speed and toll rate are also described in the following sections.

3.5.1 D-efficient Design

A D-efficient survey design of 24 runs/rows (24 questions in eight blocks of three ordinary situation questions) obtained by running the %MkTex macro of SAS was used as one of three designs randomly selected for a respondent. The stated preference questions were presented such that each respondent who received this version of the survey (with D-efficient design) is presented in all the SP questions with the alternative of driving alone on the general purpose lanes, which was travel mode used by most of the respondents.

The survey design was structured to present only three out of the remaining four travel alternatives to each respondent. This mixture of alternatives was achieved by adding an additional level of availability (not available, NA) in the travel times (attributes) of these four modes so that the attribute level combination in the full-factorial design with level "NA" represents that the corresponding alternative is not available in that design row (question). In addition, a constraint was added during the search of the efficient design such that the total number of alternatives in any given run was equal to four. Thus the runs with travel time level NA present as one of the travel time attributes of more than one travel mode were not considered in searching for the D-efficient design. While this strategy will limit the size of the choice set to four, it also adds a bias in the estimation of the mode choice model, as the frequency of each alternative in the choice sets of all the respondents will not be equal. The attributes and levels used for this design for peak period travelers are given in Table 7. Higher speeds on GPLs and lower toll rates on MLs were used for off-peak period travelers. Finally, three additional and alternative design strategies were used to generate the values of travel time and toll in stated preference questions. These are the random attribute level approach and the smart adjusting random attribute level generation approach and the reverse smart adjusting random level generation approach described in the following sections.

Table 7 Attributes and Levels Used for the D-efficient Design

Alternative (Travel Mode)	Attributes	Peak Period Levels	Off-Peak Period Levels
Drive alone on GPLs	Speed (mph)	25, 35, 45	45, 50, 55
	Toll Rate (cents/mile)	0	0
Carpool on GPLs	Speed (mph)	25, 35, 45, NA	45, 50, 55, NA
	Toll Rate (cents/mile)	0	0
Drive alone on MLs	Speed (mph)	55, 60, 65, NA	55, 60, 65, NA
	Toll Rate (cents/mile)	10, 20, 35	5, 10, 17.5
Carpool with one other person on MLs	Speed (mph)	55, 60, 65, NA	55, 60, 65, NA
	Toll Rate (cents/mile)	5, 10, 20	2.5, 5, 10
Carpool with three or more people on MLs	Speed (mph)	55, 60, 65, NA	55, 60, 65, NA
	Toll Rate (cents/mile)	0, 5, 10	0, 2.5, 5

3.5.2 Random Attribute Level Generation (Random)

In the random attribute level generation design approach the choice alternatives and attribute levels were generated differently than using the D-efficient design approach. Every respondent was presented with two fixed travel alternatives: their current actual travel mode (drive alone [SOV] or carpool [HOV] on GPLs) and a similar occupancy travel mode (SOV/HOV) on MLs. They were also presented in the choice set with two other alternatives that were randomly chosen from the remaining three travel modes.

For example, if the respondent’s current actual travel mode was to drive alone on GPLs, they were always presented with the modes: drive alone on GPLs and drive alone on MLs. In the case where the respondent’s current actual travel mode was to carpool on GPLs (first fixed alternative for the respondent) the respondent was always presented with the ML option to carpool with two more people (50 percent of the time) or carpool with three or more people (50 percent of the time) as the second fixed alternative. This approach of choosing the four alternatives out of five as described above made it possible to make use of a respondent’s RP information and make the choice set more realistic for each respondent.

No fixed numbers of experimental design runs or attribute levels were used in this approach (and as will be seen below, in the smart adjusting random approach). Instead, a combination of base rate plus a variable portion was used as specified in Table 8.

Table 8 Attributes and Level Ranges Used for the Random Design Approach

Alternative (Travel Mode)	Attributes	Range of Level for Peak Period *	Range of Level for Off-Peak Period*
Drive alone on GPLs	Speed (mph)	20 + (0 to 25)	40 + (0 to 25)
	Toll Rate (cents/mile)	0	0
Carpool on GPLs	Speed (mph)	20 + (0 to 25)	40 + (0 to 25)
	Toll Rate (cents/mile)	0	0
Drive alone on MLs	Speed (mph)	40 + (0 to 25)	50 + (0 to 20)
	Toll Rate (cents/mile)	7 + (0 to 6) 15 + (0 to 10) 28 + (0 to 14)	3.5 + (0 to 3) 7.5 + (0 to 5) 14 + (0 to 7)
Carpool with one other person on MLs	Speed (mph)	40 + (0 to 25)	50 + (0 to 20)
	Toll Rate (cents/mile)	0 4 + (0 to 2) 8 + (0 to 4) 17 + (0 to 6)	0 2 + (0 to1) 4 + (0 to 2) 8.5 + (0 to 3)
Carpool with three or more people on MLs	Speed (mph)	40 + (0 to 25)	50 + (0 to 20)
	Toll Rate (cents/mile)	0 4 + (0 to 2) 8 + (0 to 4) 13 + (0 to 6)	0 2 + (0 to 1) 4 + (0 to 2) 6.5+ (0 to 3)

*numbers in parentheses correspond to range of random part used for creating levels

For toll rates, one of three or four base levels was randomly selected and then the corresponding random part was added to the base level. For example, the toll for the mode, "drive alone on managed lane in peak periods" was a randomly selected base rate from 7, 15, and 28 and the corresponding variable portion was chosen from (0-6), (0-10), or (0-14), depending on the base level selected. If more than one GPL (or ML) alternative was available in the choice set the travel times (speed) presented for those two GPL (or ML) alternatives were the same. In case the randomly selected travel time for GPL alternatives were less than or equal to those presented for ML alternatives, the travel times of the GPL were adjusted to be the travel time on the ML plus an additional 3 minutes.

3.5.3 Smart Adjusting Random Attribute Level Generation (Smart Random)

In this design approach the alternatives to be presented were generated in the same way as they were in the random attribute level generation (the second) design approach. For the first choice question the attribute levels were chosen randomly. In the second and third questions the speed levels were chosen randomly; however, the toll rates were increased or decreased (up to

200 percent) if the choice made in the previous question was a tolled or a toll-free travel mode, respectively. Thus, the VTTS offered for a similar travel mode on the managed lanes was increased or decreased (adaptive) depending on the choice in the previous question. This is akin to the double-bounded contingent valuation approach used by many economists (see Hanemann et al., 1991, Kanninen, 1993), and of course, the discrete response contingent valuation approach is just a special case of a choice modeling exercise.

This approach is little different from the computer adaptive conjoint designs, as it does not search for a run from an efficient design after every question. Hence, it does not take as much time to generate the stated preference attribute levels to be presented in next question. However, this approach did not guarantee that the respondent would see a higher (lower) VTTS if they selected a tolled (non-tolled) alternative. It only guaranteed the increase (decrease) in toll rate, but a random change in travel time could result in VTTS that did not increase (decrease) as the toll increased (decreased). Therefore, the respondents who had the smart adjusting random design were split into two groups:

1. Smart Adjusting Random - the toll and VTTS changed as expected,
2. Reverse Smart Adjusting Random - the VTTS did not change in the same direction as the toll did.

This study was largely dependent on the data collected from travelers. For this research a survey was developed for travelers of the Katy Freeway. Details of the survey administration, sample and possible sampling biases, survey questionnaire used, and implemented survey designs were presented in this section. The extensive data collected were used to achieve the objectives of studying the effect of survey designs on mode choice modeling and estimation and comparison of VTTS for ordinary and urgent trips. The data analysis carried out for achieving the research objectives is presented in the next section.

4. DATA ANALYSIS

The goal of this study was to better estimate the benefits offered by managed lanes. Detailed analyses of the survey data were carried out in order to investigate the effect of various survey designs on estimation of VTTS and to estimate the difference between the VTTS for ordinary and urgent trips. These analyses are presented in this section.

4.1. Comparison of Survey Designs

The analysis of different survey designs used in the Katy Freeway survey is presented in the following sections. Apart from VTTS estimation, the responses corresponding to each design were compared for different survey-taking behavior and goodness of fit provided for the model.

4.1.1. Descriptive Analysis of Survey Respondents by Survey Design

In order to compare the four design approaches a descriptive analysis was carried out on the data from respondents of each design (see Table 9). Results in Table 9 illustrate that there are no major differences in the samples corresponding to each of the design approaches except for the sample size and the frequency of alternatives presented in the SP questions: these differences were are as planned. To check for other differences, the samples corresponding to each of the designs were analyzed for non-trading, lexicographic, and other behaviors (see Hess et al., 2008). Non-trading behavior corresponds to the situation when a respondent chooses the same single alternative in all SP questions. This is consistent with a focus on only one attribute, rather than all of the key attributes that might determine choices. For example, in some choice experiments respondents may ignore all but a dominant attribute, such as price, and always choose an alternative with the cheapest price, no matter what the levels of other attributes are.

Lexicographic behavior can involve violation of transitivity (Choice A preferred to B and B to C, so choice A should be preferred to choice C) and may also arise when a respondent apparently uses only one attribute to base their decisions in all SP questions. We identified respondents from each sample as the respondents with apparent lexicographic behavior if they always selected the fastest (with least travel time), the cheapest (no toll), or the alternatives with lowest occupancy (drive alone alternatives).

The results of the non-trading and lexicographic behavior for each of the design approaches are summarized in Table 9. It can be observed that the smart adjusting random approach performs better than other design alternatives in that it results in less non-trading and fewer respondents always choosing the cheapest alternative. The percentage of respondents always choosing same occupancy mode and fastest alternatives were similar for all these designs.

Table 9 Descriptive Analysis of Responses by Design Strategies

Data Characteristic	D-Efficient	Random	Smart Adjusting Random	Reverse Smart Random
Number of respondents	1240	1303	355	973
Peak period travelers	50%	51%	57%	45%
Morning peak travelers	30%	29%	32%	26%
Evening peak travelers	20%	22%	25%	19%
Average trip length (miles)	11.7	11.9	12.2	11.5
Trip purpose as Commute/work	57%	54%	61%	53%
Male respondents	57%	57%	59%	60%
Carpoolers	36%	36%	36%	39%
Traveling toward downtown	47%	48%	48%	48%
Age < 25 years	2%	2%	2%	1%
Age 25 to 65 years	91%	91%	91%	92%
Age > 65 years	7%	7%	7%	7%
Annual Household Income < $25000	3%	3%	4%	2%
Annual Household Income $25000 to $75000	29%	29%	28%	28%
Annual Household Income > $75000	67%	68%	68%	70%
% of times alternative 1 presented	18%	20%	20%	18%
% of times alternative 2 presented	25%	22%	22%	21%
% of times alternative 3 presented	19%	22%	22%	26%
% of times alternative 4 presented	19%	18%	19%	18%
% of times alternative 5 presented	19%	18%	17%	17%
Non-trading and Lexicographic Behavior				
Non-trading	33.9%	30.8%	22.6%	32.9%
Always choosing fastest alternative	2.2%	3.4%	3.2%	4.1%
Always choosing cheapest alternative	36.6%	32.1%	24.0%	33.4%
Always choosing alternative with lowest occupancy	62.7%	60.4%	60.0%	61.9%

4.1.2. Efficiency in Estimation of Parameters and Comparison of Estimated VTTS

The samples corresponding to each design approach were used to estimate four different simple multinomial logit models. Since the aim of this part of the study was to compare the survey designs, we used this simple MNL specification (instead of nested logit or mixed logit specification) with just travel time and toll/hourly wage rate coefficients in the utility functions, along with alternate specific constants. The hourly wage rate was estimated as the respondents' annual household income divided by 2000 (approximate number of work hours in a year). In all the models the mode DA-GPL was set as the base alternative.

After estimating an MNL model for samples corresponding to each design approach we also calculated the D-error and A-error for each. Next, using the travel time and toll/hourly wage rate coefficients (β_t and β_c, respectively) we estimated the implied marginal VTTS as percentage of wage rate for travelers from each sample (VTTS = β_t / β_c , after converting into comparable units). The confidence intervals for the VTTS values ($V_{S,I}$) as derived by Armstrong et al. (2001) were also estimated using the t-ratio method equation (Equation 14).

$$V_{S,I} = \left(\frac{\beta_t.t_c}{\beta_c.t_t}\right).\frac{(t_t t_c - \rho t^2)}{(t_c^2 - t^2)} \pm \left(\frac{\beta_t.t_c}{\beta_c.t_t}\right).\frac{\sqrt{(\rho t^2 - t_t t_c)^2 - (t_t^2 - t^2)(t_c^2 - t^2)}}{(t_c^2 - t^2)} \qquad (14)$$

where t_t = t-ratio for parameter estimates β_t,

t_c = t-ratio for parameter estimates β_c,

t = critical value of the statistic given the degree of confidence required, and

ρ = coefficient of correlation between β_t and β_c.

The model estimation results and estimated VTTS along with its confidence interval at the 95 percent level of confidence are summarized in Table 10. The log-likelihood values, adjusted ρ_0^2, and adjusted ρ_c^2 are also reported for each model (Equations 15 and 16).

$$\text{Adjusted } \rho_0^2 = 1 - \frac{LL(\hat{\beta}) - K}{LL(0)} \qquad (15)$$

where $LL(\hat{\beta})$ =log-likelihood for the estimated model,

K = Number of parameters in the estimated model, and

$LL(0)$ = log-likelihood with zero coefficients model (which results in equal likelihood of choosing each available alternative).

$$\text{Adjusted } \rho_c^2 = 1 - \frac{LL(\hat{\beta}) - K}{LL(C) - Kc} \qquad (16)$$

where $LL(C)$ = log-likelihood for the constants only model, and

Kc = number of parameters in the constants only model.

Table 10 Estimation Results for MNL Models Corresponding to Different Design Strategies

	D-Efficient Design		Random Level Generation		Smart Adjusting Random Level Generation		Reverse Smart Adjusting Random	
Observations (Number of choice situations)	3720		3909		1065		2675	
	Estimate	t-ratio	Estimate	t-ratio	Estimate	t-ratio	Estimate	t-ratio
ASC-Carpool on GPLs	-2.02	-30.38	-1.76	-30.28	-1.96	-16.01	-1.67	-24.97
ASC-Drive alone on MLs	-1.47	-19.96	-1.34	-19.83	-0.96	-7.57	-1.71	-21.61
ASC-Carpool with one other person on MLs	-2.30	-30.02	-2.06	-28.69	-1.98	-14.13	-2.15	-25.51
ASC-Carpool with three or more people on MLs	-3.14	-32.12	-2.73	-33.06	-3.12	-17.20	-2.70	-27.70
Travel Time (minutes)	-0.10	-14.74	-0.10	-14.91	-0.11	-9.27	-0.09	-11.93
Toll/wage rate ($/hr)	-11.17	-6.85	-11.03	-8.81	-16.95	-7.14	-3.86	-3.59
Log-likelihood	-3418.38		-4097.45		-1074.80		-2825.14	
Adjusted ρ_0^2	0.3360		0.2428		0.2679		0.2365	
Adjusted ρ_c^2	0.0924		0.1034		0.1501		0.0916	
D-error	0.0059		0.0043		0.0166		0.0055	
A-Error	1.1794		1.0803		1.3374		1.0289	
VTTS (% of wage rate in $/hr)	55%		52%		40%		145%	
C.I. for VTTS	(41%, 79%)		(41%, 69%)		(28%, 57%)		(93%, 314%)	

Since the market shares (percentage of trips using each travel mode/alternative) are not exactly equal in this study, it would be appropriate to use the adjusted ρ_c^2 to make inferences about the goodness of fit of the models (Koppelman and Bhat, 2006). Using this criterion the model corresponding to the smart adjusting random strategy provides a better fit than other models.

All the designs provide estimates of the alternate specific constants (ASCs), travel time, and toll coefficients with signs (direction of influence on the choices) as per our prior expectations. A close look at the ASCs reveals that when compared to the mode for DA-GPL, all other modes have negative ASCs and hence are less attractive (which is as expected), other things being equal. HOV3+-ML appears to be the least attractive travel mode to the sample. This is consistent with added inconvenience travelers face in terms of coordinating a carpool with multiple parties.

We also compared the crosstabs (table of prediction success for a model listing summary of predicted versus actual choices) obtained from these models to investigate the influence of design and found that all random attribute level generation strategies' models are predicting the market share of the less favorite modes more accurately than the D-efficient design model (Table 11). Note that the managed lane modes and CP-GPL mode have smaller trip shares (DA-GPL is the most popular mode); hence, a model/design approach which predicts these modes more accurately is more useful to transportation policy makers.

Table 11 Percent of Correct Prediction for Each Alternative

Design Strategy	CP-GPL	DA-GPL	DA-ML	HOV2-ML	HOV3+-ML	All Modes
D-efficient	10.9%	69.4%	21.9%	12.3%	5.8%	51.9%
Random	17.7%	63.4%	25.8%	18.2%	11.0%	43.9%
Smart Random	17.0%	62.5%	35.6%	22.1%	6.7%	45.4%
Reverse Smart Random	19.4%	64.2%	21.6%	18.6%	10.3%	43.9%

After comparing the implied VTTS (in terms of percent of wage rate) for all three samples it can be seen that the alternative design strategies do affect the estimated VTTS. The exceptionally high (and seemingly implausible) estimate of VTTS for the reverse smart random strategy underscores the need of using attribute levels with caution. Nevertheless, our results here (except for the reverse smart random approach) support the literature that commuting time saved is valued close to 50 percent of the wage rate. The results for the basic random strategy (that predicts a VTTS of approximately 52 percent of the individual's wage rate) and the D-efficient design (predicting a VTTS of 55 percent of wage rate) are higher than the VTTS obtained by the smart adjusting random strategy (predicting a VTTS of about 40 percent of wage rate). An earlier study conducted for the VTTS of Katy Freeway travelers (data collected in 2003) estimated the value as 39% of the wage rate (Burris and Patil, 2006). Specifically, the results here for these three strategies are not dissimilar to other findings like these that indicate a VTTS that is around half of the wage rate. Further, the close estimates of VTTS for the D-efficient and basic random strategy may be due to the use of the same attribute level range for the travel time and toll. (Note that the attribute level range for toll was changed by a factor for the smart random approach depending on the answer to previous question.) Another possible confounding influence of the design results pertains to sample sizes for the surveys, which are unequal.

Comparison of the estimated confidence intervals for the VTTS indicates that the confidence intervals for the random design strategies' (except the reverse smart random) models are smaller than those for the D-efficient design model estimate. Since the reverse smart random strategy failed to produce a valid VTTS estimate, we dropped it from further investigation of survey designs.

Since the D-error and A-error values depend on the sample size, we additionally compare the D-error and A-error values for the specific samples corresponding to first three designs, doing so using random draws from each (Table 12). We calculate the D-error and A-error for different sample sizes, using 150, 200, 500, 700, and 1000 randomly drawn responses (choices) from the sample corresponding to each design approach. It should be noted that the sample size of less than 150 SP responses (obtained from 50 respondents in this study) is less likely, as most of the studies for VTTS for MLs with internet based sampling are expected to generate larger samples. We took 50 draws of a given sample size (e.g., 200) to estimate the average value of the D-error and A-error statistics. Two sample t-tests on the D-error and A-error values were constructed to compare them.

Table 12 Efficiency of Designs for Different Sample Sizes

Sample Size (# choice situations)	150	200	500	700	1000	Full Sample D-eff = 3720 Random = 3909 Smart Random = 1065
*D-error**						
D-efficient design	0.531	0.119	0.048	0.034	0.024	0.006
Random Level Generation	0.127	0.091	0.036	0.026	0.018	0.004
Smart Random	0.138	0.103	0.040	0.028	0.019	0.017
*A-error**						
D-efficient design	4.349	1.946	1.702	1.584	1.491	1.179
Random	1.891	1.776	1.534	1.452	1.383	1.080
Smart Random	1.921	1.832	1.553	1.473	1.376	1.337
*Adjusted Rho Squared**						
D-efficient design	0.083	0.085	0.093	0.097	0.091	0.092
Random	0.107	0.101	0.103	0.103	0.103	0.103
Smart Random	0.144	0.148	0.154	0.151	0.152	0.150

*Based on 50 random draws corresponding to each sample size

For all the sample sizes up to 1000 the D-error and A-error corresponding to the D-efficient design were significantly (alpha = 0.05) greater than those corresponding to both the random and smart adjusting random strategies (Table 12). Comparison of the D-error and A-error thus indicates that the random strategy yields the most efficient parameter estimates followed by the smart adjusting random strategy and then the D-efficient design.

A similar analysis was carried out for the adjusted ρ_c^2 (Table 12). The smart random strategy model was found to provide a better model fit with a statistically significant larger value of adjusted ρ_c^2. The D-efficient design sample model provided the smallest adjusted ρ_c^2 among the samples corresponding to these three design approaches. This may be in part due to the ability of random design strategies to select four out of five alternatives depending on the respondent's current mode as obtained from the RP part of the survey. Note that only DA-GPL mode was present in all the questions for all the respondents presented with D-efficient design. Hence, the respondents who had their current travel mode as CP-GPL may or may not have received their current mode in the SP question depending on the block of design presented to them.

Based on these simple MNL models, the smart adjusting random and D-efficient designs both appear to be superior to the random design. The reverse smart random strategy was clearly the worst design strategy. However, implementing a D-efficient design was more restrictive than the random strategies since it wasn't possible to customize the design for a respondent. Additional difficulties were presented by use of the SAS macro, as it was not possible to use same attribute levels for more than one alternative. For example, the SAS macro method doesn't allow use of same speed (travel time) for both alternatives on GPLs. Hence with D-efficient design it was difficult to make the survey more realistic and make it comparable to the actual travel options a traveler may face.

Nevertheless, the analysis in this section clearly demonstrates the factors that need consideration in survey design and how these designs can affect the VTTS estimation for ML travelers. Next, the effect of travel urgency on VTTS for ML travelers is analyzed.

4.2. Analysis of Ordinary and Urgent Situations

To begin, we estimated an MNL and a mixed logit model for each mode choice (see Table 13). Each includes the reasons for urgent travel. Key variables including the commuting trip length, trip purpose, the traveler's age, gender, household type, size of household, number of vehicles in the household, and vehicle occupancy for the individual's most recent trip were found to be significant in the basic (MNL) model.

The mixed logit model procedure we employed used 350 Halton draws to minimize simulation variance. Note that previous studies have concluded that use of Halton sequences rather than random draws decreases the estimation time and smoothens the simulation (Bhat, 2001, Train, 2003). We use 350 Halton draws[1] primarily because use of more draws takes multiple days for estimation of this complex model and it is not uncommon to use 200 to 500 Halton draws (Greene et al., 2006, Greene and Hensher, 2007, Hensher et al., 2008). We specified the alternative specific parameters and travel time parameter as random parameters, while the other parameters are assumed fixed, as in the MNL. We assumed a normal distribution for the ASCs because we had no priors on them being of a particular distribution, and a constrained triangular distribution (spread = mean, $\bar{\beta}_{time}$) was assumed for the travel time parameter. We tried to fit an unconstrained triangular distribution, but it did not provide a behaviorally meaningful sign[2] for travel time parameter for all the population.

[1] See, Hensher and Greene (2003) for discussion on required number of Halton draws for stability in estimation
[2] The travel time parameter is expected to be negative as it represents increased disutility for increased travel time. The positive sign will infer that the traveler actually enjoys longer travel, which is counterintuitive for the present study.

Table 13 Model Estimation Results for Ordinary and Urgent Situation Data

Attribute	Alternative(s)	MNL Model		Mixed Logit Model	
		Coeff.	t-ratio	Coeff.	t-ratio
ASC-CP-GPL	CP-GPL	-0.66	-10.53	R:-2.22	-11.49
ASC-DA-ML	DA-ML	-1.04	-8.20	R:-2.44	-7.66
ASC-HOV2-ML	HOV2-ML	-0.58	-4.45	R:-1.82	-8.74
ASC-HOV3+-ML	HOV3+-ML	-1.95	-14.23	R:-4.64	-21.82
Travel Time (min)	All	-0.11	-24.16	R:-0.24	-31.41
Toll ($)/wage rate ($/hr)	All	-0.90	-19.17	-1.81	-42.02
Drove alone for last trip (dv)	CP-GPL	-2.99	-28.77	-5.59	-23.28
Trip purpose commute/work (dv)	CP-GPL	0.14	1.87		
Male (dv) (male = 1, female = 0)	CP-GPL	-0.17	-2.40		
Age between 25 and 54 (dv)	CP-GPL			0.53	2.49
Drove alone for last trip (dv)	DA-ML	-0.27	-5.04		
Trip Length (miles)	DA-ML	0.01	4.14	0.04	5.12
Toll tag subscriber (dv) (1 = owns a toll tag)	DA-ML	0.57	5.13	1.12	3.75
Drove alone for last trip (dv)	HOV2-ML	-2.41	-30.42	-4.07	-25.33
Trip purpose commute/work (dv)	HOV2-ML	0.22	3.23		
Trip Length (miles)	HOV2-ML	0.02	4.77	0.04	3.81
Age between 25 and 54 (dv)	HOV2-ML	-0.28	-3.80		
Number of people in household	HOV2-ML	0.08	2.80		
Male (dv) (male = 1, female = 0)	HOV2-ML	-0.49	-7.56	-0.82	-5.68
Single Adult Household (dv)	HOV2-ML	-0.36	-3.40	-0.47	-2.29
Number of vehicles in the household	HOV2-ML	-0.08	-2.39		
Drove alone for last trip (dv)	HOV3+-ML	-2.88	-25.36	-5.26	-20.14
Trip Length (miles)	HOV3+-ML	0.01	2.49		
Male (dv) (male = 1, female = 0)	HOV3+-ML	-0.22	-2.49		
Age between 25 and 54 (dv)	HOV3+-ML	0.32	3.08		
Standard deviation of Random Parameters					
ASC-CP-GPL	CP-GPL			3.35	30.08
ASC-DA-ML	DA-ML			1.92	25.74
ASC-HOV2-ML	HOV2-ML			2.37	24.54
ASC-HOV3+-ML	HOV3+-ML			3.61	20.71
Travel Time† (min)	All			0.24	31.41
Urgent to ordinary situations scale parameter	All			0.64	6.68

TABLE 13- *Continued*

Attribute	Alternative(s)	MNL Model		Mixed Logit Model	
		Coeff.	t-ratio	Coeff.	t-ratio
Interactions in MNL /Heterogeneity in mean in mixed logit					
Travel Time* *ImpAppt*	All	0.00	-0.40	0	
Travel Time* *LateAppt*	All	-0.02	-1.72	-0.07	-4.32
Travel Time* *WorryTime*	All	-0.07	-5.22	-0.11	-5.18
Travel Time* *BadWeather*	All	-0.03	-2.19	0	
Travel Time* *LateML*	All	-0.02	-2.04	-0.06	-2.91
Travel Time* *ExtraStops*	All	0.00	-0.39	0	
Toll ($)* *ImpAppt*	All	0.54	10.14	1.05	15.21
Toll ($)* *LateAppt*	All	0.72	15.29	1.28	17.01
Toll ($)* *WorryTime*	All	0.47	9.10	0.98	11.60
Toll ($)* *BadWeather*	All	0.36	6.32	0.78	10.42
Toll ($)* *LateML*	All	0.44	8.06	0.77	8.63
Toll ($)* *ExtraStops*	All	0.13	1.98	0.21	2.90
Toll ($)* Medium Household Income ($50-100,000) (dv)	All	0.01	0.33	-0.14	-5.50
Toll ($)*High Household Income(>$100,000) (dv)	All	0.16	3.87	0.14	5.49
Error Components for alternatives and nests of alternatives parameters					
Standard deviation , θ_1	GPL alts.			0.27	3.42
Standard deviation , θ_2	ML alts.			2.10	7.27
Heterogeneity around standard deviation of error components effect					
Male (dv) (male = 1, female = 0)	GPL alts			1.63	6.03
Number of vehicles in the household	GPL alts			0.16	3.93
Male (dv) (male = 1, female = 0)	ML alts			-1.06	-5.99
Number of vehicles in the household	ML alts			-0.06	-1.10
Log-likelihood at convergence		-13467.43		-10722.10	
Adjusted ρ_c^2		0.28		0.42	

Notes: dv = dummy variable, R: Mean of the random parameter estimates, Adjusted $\rho_c^2 = 1 - \frac{LL(\hat{\beta}) - K}{LL(C) - Kc}$ where, $LL(\hat{\beta})$ = log-likelihood for the estimated model, K = number of parameters in the estimated model, $LL(C)$ = log-likelihood for the constants only model, Kc = number of parameters in the constants only model, ┼ = Represents spread of the distribution (std. dev.= spread/√6), ASC = Alternative Specific Coefficient.

We used the technique described in Brownstone et al. (2000) and Hensher et al. (2008) to estimate a scale parameter (λ_{qt}) for the urgent situation trips (the ordinary situations scale parameter was normalized to 1.0). This is similar to what is done in models that use both SP and RP data and allow for possibility of different sources of random preferences over SP and RP choices (see Small et al., 2005).

Six dummy variables were used to incorporate the preference heterogeneity in the means (refer to Chapter 2.3.2 for details) of the travel time and toll parameters, with one dummy variable for each of the six situations (an ordinary situation corresponds to a zero value for all the six urgent situations dummy variables, and is the base case). The resulting marginal utility expressions of the parameters for the time and toll variables are given in Equations (17) and (18).

$$\beta_{time} = \bar{\beta}_{time} + \delta_{1t} \times ImpAppt + \delta_{2t} \times LateAppt + \delta_{3t} \times WorryTime + \delta_{4t} \times BadWeather + \delta_{5t} \times LateML + \delta_{6t} \times ExtraStops + \bar{\beta}_{time} \times t \quad (17)$$

$$\beta_{c} = \bar{\beta}_{c} + \delta_{1c} \times ImpAppt + \delta_{2c} \times LateAppt + \delta_{3c} \times WorryTime + \delta_{4c} \times BadWeather + \delta_{5c} \times LateML + \delta_{6c} \times ExtraStops + \delta_{7c} \times IncMed + \delta_{8c} \times IncHigh \quad (18)$$

where $\bar{\beta}_{time}$ and $\bar{\beta}_{c}$ are the estimated population means of the constrained triangular and non-stochastic distributions corresponding to the time and toll/wage rate parameters, respectively,

δ_{1t},.., δ_{6t} and δ_{1c},.., δ_{8c} are heterogeneities in the means of travel time and toll parameters, respectively,

ImpAppt, *LateAppt*, *WorryTime*, *BadWeather*, *LateML*, and *ExtraStops* are the dummy variables corresponding the six urgent situations (refer to Table 2 for details),

IncMed and *IncHigh* are dummy variables for medium ($50,000-100,000) and high (greater than $100,000) annual household income, and

t is randomly drawn from a triangular distribution (which is obtained by transforming a continuous uniform distribution with a range between 0 and 1, see Hensher et al., 2005, pp. 641 for details).

Using Equations (17) and (18), the implied mean VTTS for the low household income category identified by $IncMed = 0$ and $IncHigh = 0$ can be calculated for the ordinary situations (μ_{ord}) and six urgent situations ($\mu_1, .., \mu_6$) as shown in Equations (19) and (20). The implied mean VTTS for the medium and high household categories can be similarly calculated by adding the estimates of δ_{7c} and δ_{8c} , respectively, in the denominator of Equations (19) and (20).

$$\mu_{ord} = \frac{\bar{\beta}_{time}}{\bar{\beta}_{c}} \quad (19)$$

$$\mu_{i} = \frac{\bar{\beta}_{time} + \delta_{it}}{\bar{\beta}_{c} + \delta_{ic}}, i = 1, .., 6 \quad (20)$$

With the exception of heterogeneities for the variables *ImpAppt*, *BadWeather*, and *ExtraStops* (δ_{1t}, δ_{4t}, and δ_{6t}) in travel time, all other situations were statistically significant sources of influence on preference heterogeneity for both travel time and toll parameters (p = 0.05 for all statistical inferences). The preference heterogeneity variables relating to the medium and high income groups (δ_{7c} and δ_{8c}) were also found to be significant.

We added the observed heterogeneity around the standard deviation of the travel time parameter (η_k) with respect to gender, but it was found to be statistically insignificant. It indicates that male travelers are not heterogeneous in terms of the marginal disutility associated with the travel time of all the modes when compared with female travelers.

To account for additional sources of preference heterogeneity not accounted for by the random parameterization and its associated decomposition, we further grouped the GPL alternatives and the ML alternatives (across both ordinary and the urgent data sets) in their error components. An example of such a preference heterogeneity associated with these two groups can be the travel time reliability associated with the travel modes in these two groups. The travel times of two GPL alternatives are expected to be less reliable than those of three ML alternatives. The standard deviation parameters (θ_1 and θ_2) which capture the heterogeneity profile of additional unobserved effects associated with these two groups of alternatives were therefore additionally estimated and were found to be statistically significant. This suggests a noticeable amount of preference heterogeneity associated with both groups (general purpose and managed lanes alternatives) that is not accounted for by the random parameters (ASCs).

Further, male and female travelers can be expected to have different travel behavior, and the travel behavior can be expected to be significantly affected by number of vehicles in the household. Hence, these groups can have different preferences due to possible differences in ride sharing abilities. The influence of gender (τ_{11} and τ_{12}) and the number of vehicles in the household (τ_{21} and τ_{22}) on preference heterogeneity was estimated. The corresponding coefficients τ_{11} and τ_{12} were found to be positive and significant, and this suggests that for male travelers and those households with an increasing number of vehicles the standard deviation of the error component associated with GPLs-(θ_1) increases, leading to an increase in preference heterogeneity from these unobserved effects. Similarly, τ_{21} was found to be negative and significant indicating that for male travelers the standard deviation of the error component associated with the managed lanes-(θ_2) decreases, leading to a decrease in the preference heterogeneity for male travelers.

Apart from these random parameters and parameters related to the heterogeneity and heteroscedasticity, various non-random or fixed parameters were also included in the model which we report in Table 13. The estimate of urgent situations to ordinary situations scale parameter was statistically significant (significantly different from 1) and less than one (0.68) suggesting a higher variance on the unobserved effects associated with the urgent situations. The mixed logit model provided overall improvement in the model fit over the simple MNL model as indicated by the higher adjusted ρ_c^2 and the improved log-likelihood value. We carried out a likelihood ratio test to determine if the improvements obtained by the mixed logit specification over the MNL model are statistically significant. The test statistic rejected the MNL model in favor of the mixed logit model with a very high significance (p-value < 0.0001). Hence, we used only the mixed logit model for estimation of the individual's VTTS in the following section.

4.2.1. VTTS Estimation for Ordinary and Urgent Situation

The parameter estimates for the mixed logit model were used to estimate the distribution of the implied VTTS for ordinary and urgent situations for the three income groups. The implied mean of VTTS was estimated (Table 14) as the ratio of the travel time to the estimated toll parameter using the heterogeneity in mean corresponding to each urgent situation and to each income group (Equations 17 to 20). For example, for low income group travelers facing the *LateAppt* situation the implied VTTS distribution will be given by Equation (21).

$$VTTS_2 = \frac{\bar{\beta}_{time}+\delta_{it}+\bar{\beta}_{time}\times t}{\bar{\beta}_c+\delta_{ic}} = 60*\frac{-0.24-0.07-0.24\times t}{-1.81+1.28} = 35.2-27.17\times t \quad (21)$$

where t is randomly drawn from a triangular distribution and takes values from (-1 to 1) as described in Equation (18). Thus implied VTTS of travelers facing this situation will range from (35.2 – 27.17 =) 8.03 to (35.2 + 27.17 =) 62.37.

Table 14 VTTS for Different Urgent Situations

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

The estimated VTTS is much higher for all of the six urgent situations than for non-urgent situations (see Table 14). The maximum estimate of the mean of VTTS was observed for the situation *LateAppt*, when the traveler is running late for an important appointment or meeting. The mean VTTS for situation *LateAppt* is 3.8 to 5.5 times greater than the mean of the implied VTTS corresponding to an ordinary situation. The estimates of the mean of VTTS for all other urgent situations, except for the situation *ExtraStops*, were also very high as compared to the mean of VTTS corresponding to the ordinary situation. This suggests that travelers do not value travel time savings very highly (in comparison to the ordinary situation scenario) when they need to make extra stops on the trip, but still need to arrive on schedule. They may be depending more on the possibility of making an early departure and less on paying/carpooling to use the managed lanes in order to make up for the extra time needed.

Implied means of the VTTS are also significantly different for different income groups; the low and high income groups have higher VTTS estimates compared to the medium income group. The higher estimate for the low income group in comparison to the medium income group could possibly be attributed to the schedule inflexibility of people in this group, possibly associated with the many lower paying jobs likely having much less flexibility in work hours.

In order to further illustrate and compare the distributions of the implied VTTS corresponding to all these situations, we took a draw of 1000 sample points from the triangular distribution (the distribution used for the travel time parameter) and estimated the VTTS values for the low income group. Note that although the spread of the distribution for the travel time parameter was fixed to be equal to the mean, the heterogeneity in the means of travel time and toll parameters gives different shapes to the distributions of VTTS corresponding to different situations (Figure 4). The VTTS for the situation *LateAppt* does not only have a large mean but it also has a large spread as compared the ordinary and other urgent situations (see Figure 4), resulting in the large variability of the VTTS for travelers late for an appointment.

From the analysis in this section it can be concluded that travelers value the travel time savings on MLs very highly when faced by urgent travel situations. This finding has important implications in estimating the benefits of MLs. This analysis is presented in the sub section 4.3.

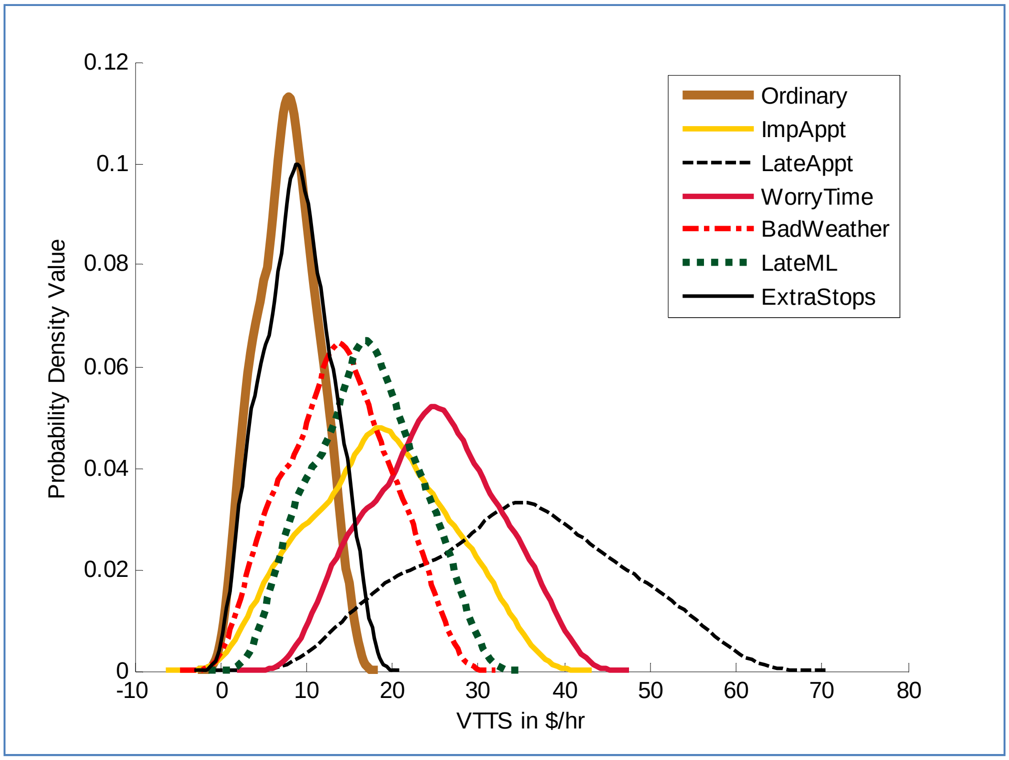

Figure 4 Distribution of the Implied VTTS for the Low Household Income (<$50,000) Group

4.3. Estimating the Benefits of MLs

The preceding analysis clearly indicates a significant difference between a traveler's typical VTTS on an ML and a traveler's VTTS in urgent situations. It is the former VTTS (based on typical travel) which generally serves as the basis to calculate travelers' willingness to pay for an ML. Therefore, engineers and planners are missing the added value that MLs have for travelers on urgent trips. Based on previous studies and anecdotal evidence/ quotes from ML travelers, we know many only use or are interested in using MLs in urgent situations (Zmud and Arce, 2008, HCTRA, 2009b). This added value is therefore unmeasured and the true value of MLs is underestimated. We developed the following scenarios to illustrate this underestimation. These scenarios make a number of assumptions regarding traffic on a freeway with MLs:

Assumptions:

- Total travelers on the freeway = 8000 veh/hr,
- Percent of travelers facing an urgent situation = 0, 10, 20, and 30. Of these
    - 25 percent face the urgent situation- *ImpAppt*,
    - 25 percent face the urgent situation- *LateAppt*,
    - 12.5 percent face the urgent situation- *WorryTime*,
    - 12.5 percent face the urgent situation-*BadWeather*,
    - 12.5 percent face the urgent situation- *LateML*,
    - 12.5 percent face the urgent situation- *ExtraStops*,
- Percent of ML travelers with low incomes (less than $50,000) = 25,

- Percent of ML travelers with medium incomes ($50,000 to $100,000) = 37,
- Percent of ML travelers with high incomes (greater than $100,000) = 38.

Note that the percentages of travelers on urgent trips used in above assumptions were just plausible guesses. The percentages of travelers in each income group were obtained for people living near Katy Freeway corridor from the study conducted by Houston Galveston Area Council of Governments (H-GAC, 2009). Using the above assumptions and the VTTS estimates from Chapter 4.2 we can estimate the potential willingness to pay (WTP) for MLs in variety of scenarios. These willingness to pay estimates can be used to estimate the required toll rate for available space on MLs. We estimated these benefits for an increasing number of toll paying vehicles, which is the number of vehicles that can fit on the managed lanes (see Figure 5).

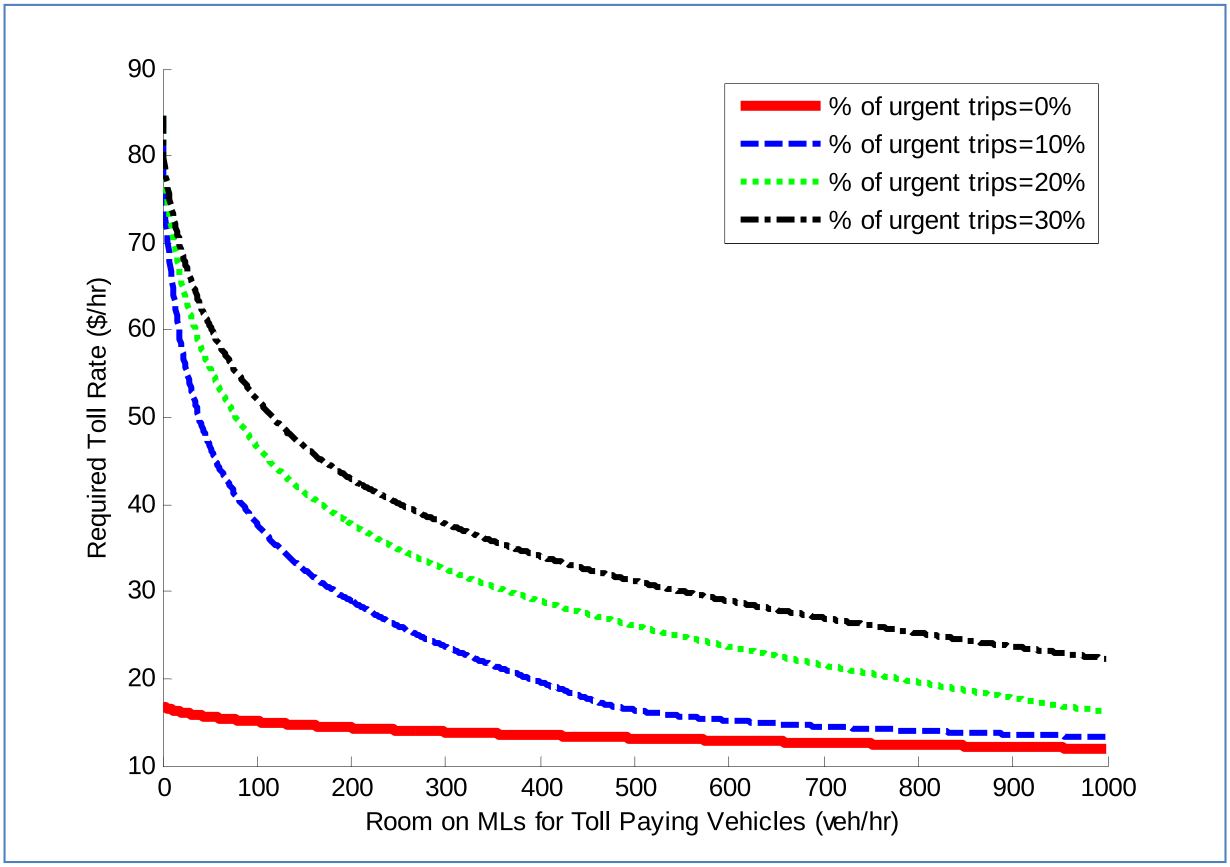

Figure 5 Estimated Toll Rates for Required Number of Vehicles on MLs

It can be clearly observed from Figure 5 that assuming all travelers are on ordinary trips can lead to great underestimation of the value of travel time savings benefits obtained from the managed lanes. For example, as shown in Figure 6, if there is room for 100 vehicles on MLs, the assumption that all travelers are facing ordinary trips will yield the hourly benefits marked by area below the curve corresponding to the ordinary situations, which is approximately calculated as [15.1 * 100 + (17.6 – 15.1) * 100/2 =] $1635. However, if we assume just 10 percent of all the travelers are facing urgent trips the hourly benefits increase to area marked by a + b + c + d (c and d are approximated as a triangle for ease of calculation), which is [37.8 * 100 + (50 – 37.8) * 39 + (50 – 37.8) * (100 – 39)/2 + (84.5 – 50) * 39/2 =] $5300.65. Hence, the average value of MLs to travelers assuming no urgent trips will be approximately = 1635/100 = $16.35. The average value of MLs to the travelers assuming 10 percent are on urgent trips = 5300.65/100 = $53.01. Thus, if managed lanes saved 10 minutes of travel time, considering all 100 trips to be ordinary trips will yield travelers' benefits (100 * 16.35 * 10/60 = $272.50) and with 10 percent urgent trips the benefits will be (100 * 53.01 * 10/60 = $883.40). Hence (wrongly) classifying the 10 percent of urgent trips as ordinary trips will miss the value of benefits by [(883.4 – 272.5) / 272.5 * 100 =] 224 percent.

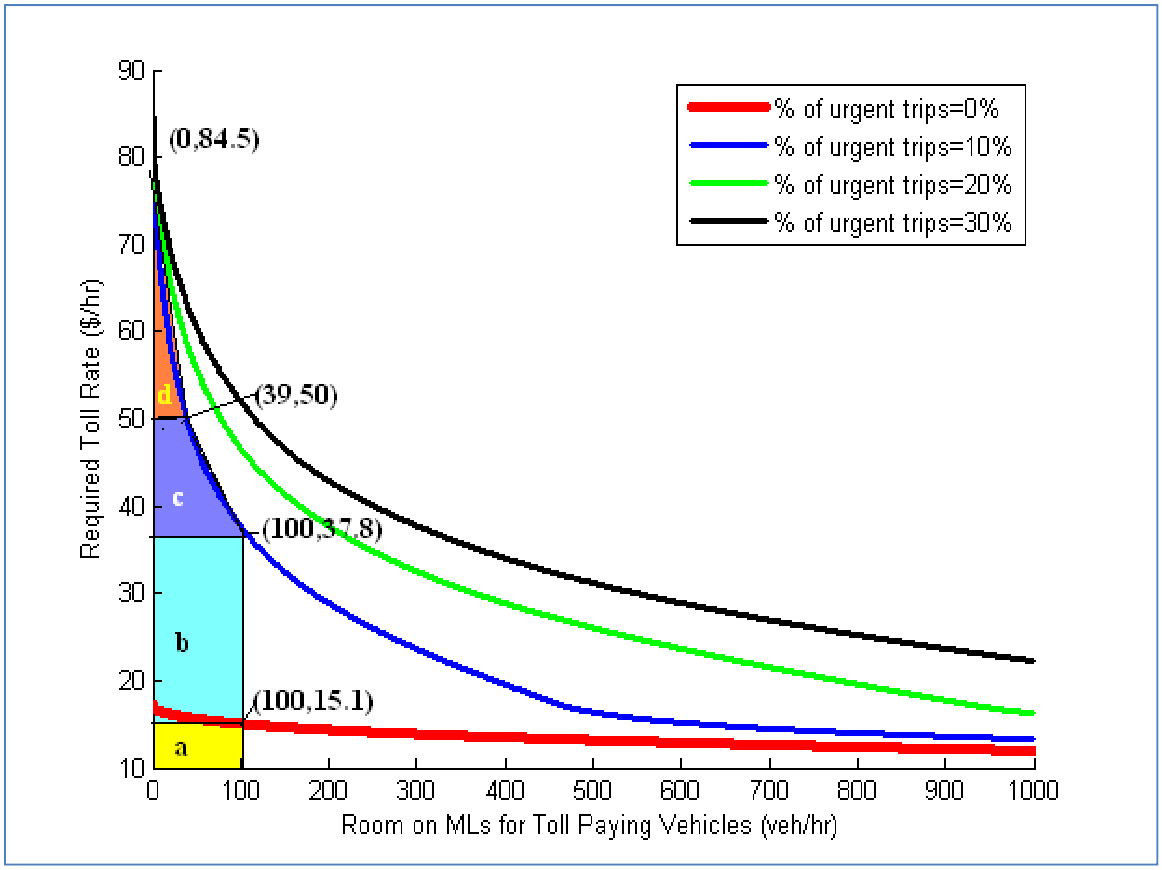

Figure 6 Benefits of the Managed Lanes

These calculations also demonstrate that the percentage of urgent trips affects the value of these benefits; hence, it calls for accurate estimation of percentage of travelers facing urgent trips and the percentage of urgent trips of each type using the traveler surveys. When there is a room for 100 toll paying travelers on MLs and when the there are approximately 10 minutes of travel time savings offered by MLs, the resulting percentage increase in benefits for various percentages of urgent trips are plotted in Figure 7. Note that the percentage increase in managed lane benefits depends on the percentage of urgent trips.

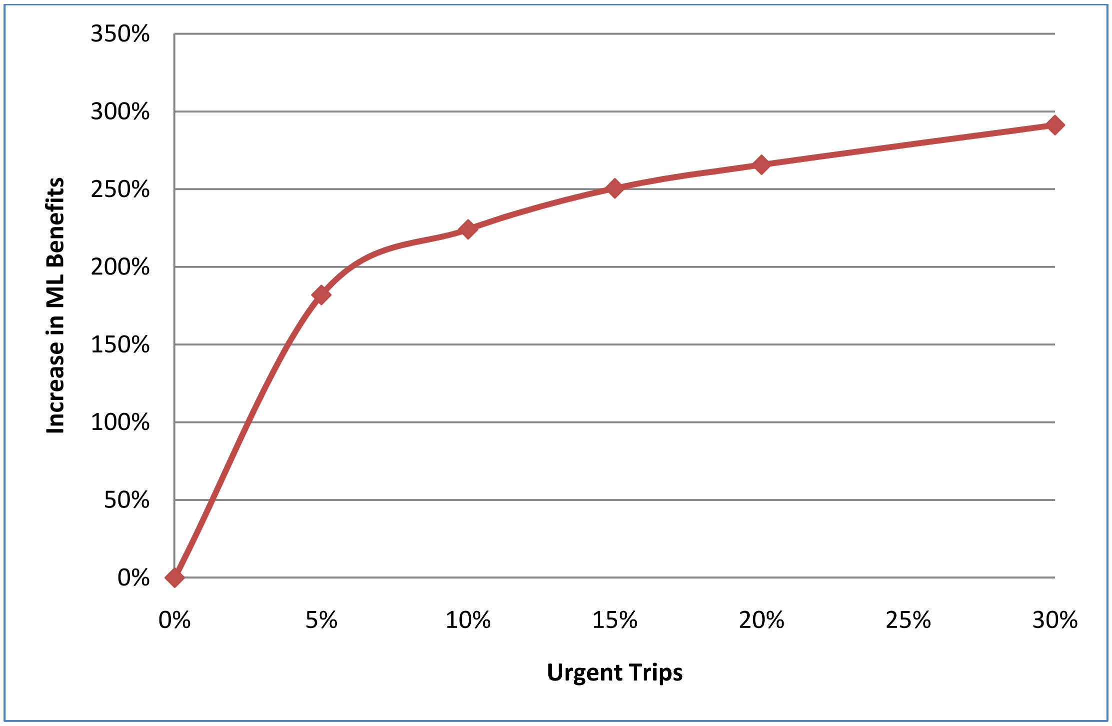

Figure 7 Benefits of Managed Lanes for 100 Toll Paying Vehicles

Note that the plots in Figure 5 are actually demand curves in each scenario and these can be also be used to set the toll rates on MLs. When setting the toll rate for MLs it is the travelers with the highest VTTS who use MLs, and therefore this group is the one by which the ML toll is set. Based on the estimated VTTS distributions for the low income group travelers (Figure 4), 60 percent of travelers facing the urgent situation-*ImpAppt*, 95 percent facing the urgent situation-*LateAppt*, 87 percent facing the urgent situation-*WorryTime*, 32 percent facing the urgent situation-*BadWeather*, 52 percent facing the urgent situation-*LateML*, and 1 percent facing the urgent situation-*ExtraStops* will have higher VTTS than the highest VTTS ($16.72/hr) of high income traveler group in a non-urgent (ordinary) situation (see Figure 8). For comparison, the percentage of medium and high income travelers on various trip types with VTTS greater than $16.72/hr are shown in Figure 9 and Figure 10. Depending on the room for toll paying travelers on the managed lanes and the percentage of travelers on urgent trips, the entire group of toll paying travelers could be on urgent trips, which had a significantly higher willingness to pay (value) than typical trips.

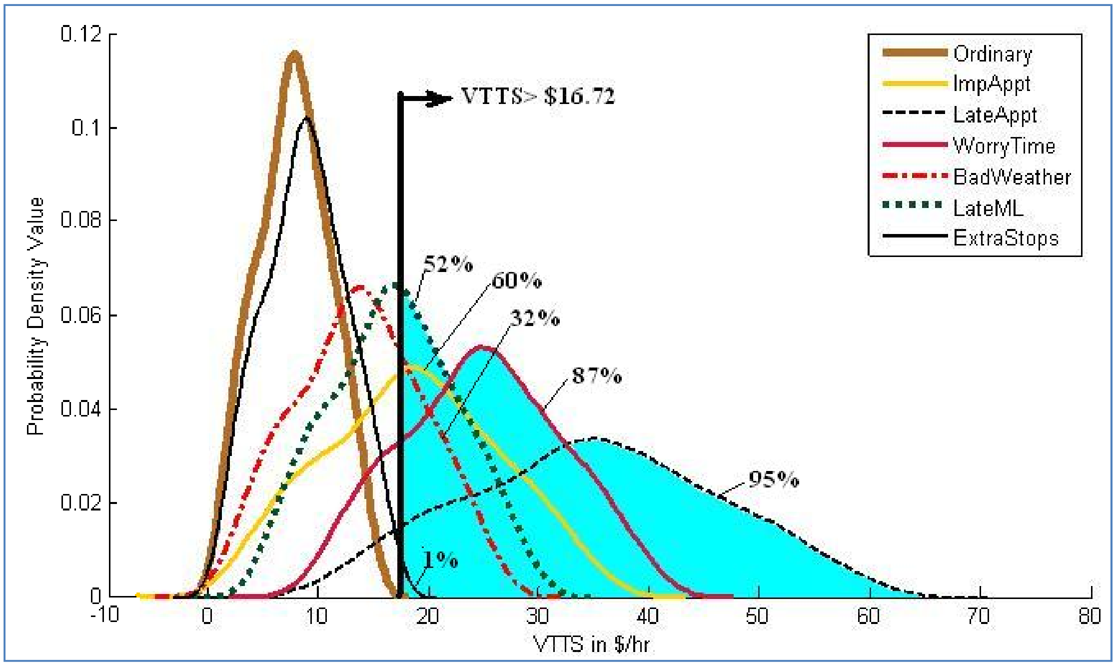

Figure 8 Percent of Low Income Group Travelers with VTTS Greater Than $16.72/hr

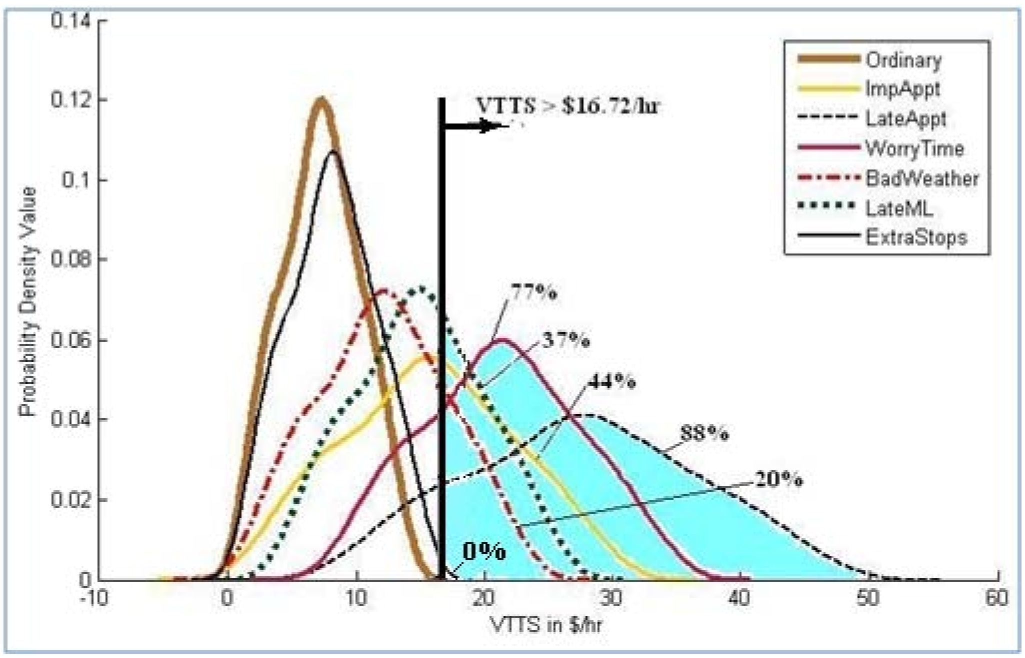

Figure 9 Percent of Medium Income Group Travelers with VTTS Greater Than $16.72/hr

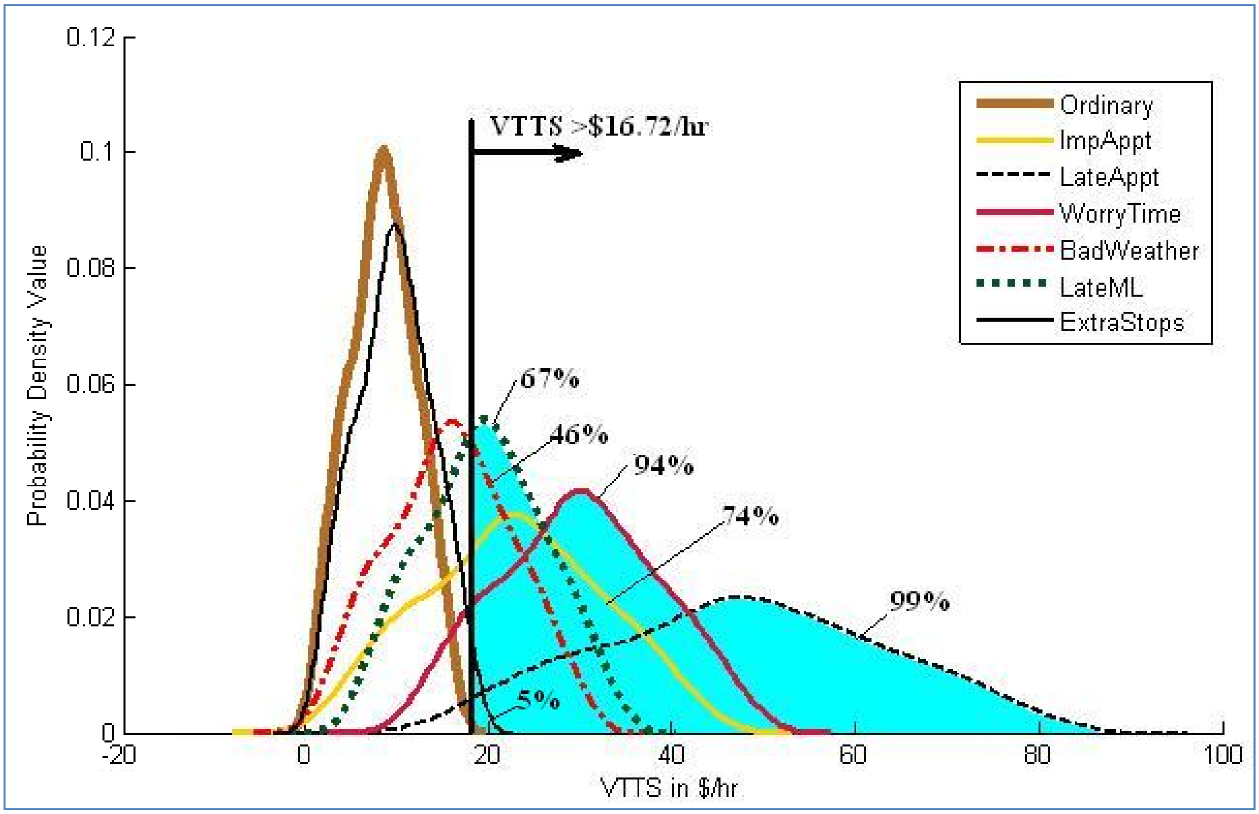

Figure 10 Percent of High Income Group Travelers with VTTS Greater Than $16.72/hr

5. CONCLUSIONS

5.1 Best Survey Design for Estimation of the VTTS

The first objective of this study was to investigate the influence of survey design strategies on stated preference choice behavior for travelers in managed lanes corridors. The study used four different experimental designs in a single survey. Each respondent was randomly assigned to one of these designs. The study used a D-efficient design, a random attribute level generation strategy (random), and a smart adjusting random attribute level generation strategy based on VTTS and the respondent's answer to the previous SP question (smart random). As an additional fourth design strategy (reverse smart random), responses were used that were identified by the VTTS not changing in the same direction as the toll within the smart adjusting method. Thus the toll values presented in the reverse smart random design strategy followed logic that was exactly opposite of smart random design strategy. This strategy was found to provide poor results.

The choice behaviors such as non-trading and lexicographic behaviors were found to be significantly different for the different survey design strategies. For the large sample sizes used in this study we found that the two random attribute level generation strategies were less susceptible to the non-trading behavior than the D-efficient design. These strategies were also found to perform better in comparison to the D-efficient design with respect to the lexicographic behavior criteria (based on behavior when the respondent chooses the cheapest and lowest occupancy alternative) except for one criterion in which the respondent always chooses the fastest alternative.

The efficiency of parameter estimation (measured by D-efficiency and A-efficiency) was found to be higher for the random and smart random strategies as compared to the D-efficient design. The smart random strategy also produced a better model fit (with larger adjusted ρ_c^2) as compared to the D-efficient and random strategy designs.

The survey design strategies yielded different point estimates for the implied VTTS but all were close to the values estimated in previous studies. The D-efficient design and random strategies (which used a fixed and narrower range for the toll attribute level) yielded higher point estimates of VTTS as compared to the smart random strategy. The confidence intervals for both the random strategies, however, were narrower than the D-efficient design.

Designing an SP survey using random attribute level generation based on the VTTS and answer to the previous SP question seems to be promising. Surprisingly, it out-performs D-efficient design in almost every category (although the D-efficient design was modified slightly to select only four of five alternatives). Additionally, the random strategies proposed in this study can adjust the SP questions so that they use more information from the revealed preference part of the survey and also the choice sets can handle the availability of alternatives with more ease than the D-efficient design. Better performance of the smart random strategy may be in part due to these abilities. Future studies may help to confirm the findings of this study.

5.2 Difference in the VTTS for Ordinary and Urgent Situations

The second objective of the study was to compare the values of travel time savings for ordinary situations and six different urgent situations commonly faced by managed lanes travelers. An ordinary situation was defined as a typical trip in the week prior to the survey. Urgent situations were represented by expected and unexpected events potentially affecting an ordinary trip which has previously arranged budgeted times and schedules. An urgent situation thus affects both travel time and the possibility of arriving at a given location within the budgeted time.

The findings of this study indicate that the travelers value their travel time very highly when faced with most of the urgent situations we considered. These include: headed to an important appointment/ meeting/ event, running late for an important meeting/ event/ appointment, worried about arriving on time, expecting potential traffic problems due to bad weather, and left late knowing they can take advantage of the toll lanes. The mean of VTTS corresponding to most of these urgent situations ranged from $8 to $47.5 per hour as compared to the estimate of $7.4 to $8.6 per hour for the ordinary situations for all income groups. Further, the study found that the implied means of VTTS for low and medium income group travelers facing an urgent situation were higher than the high income group travelers in an ordinary situation.

The findings thus add to the understanding of travel behavior for the managed lanes travelers and help in understanding of the occasional use of the facility by the travelers from all income groups. The study also shows how the stated preference survey can be modified to obtain various estimates of the VTTS for a managed lanes traveler.

5.3 Benefits of Managed Lanes and Policy Implications of the Study

The third objective was to better understand and estimate the value of managed lanes. It was shown that classifying urgent trips as ordinary trips will greatly underestimate the benefits of managed lanes to travelers. The example in Section 4 had just 10 percent of travelers on urgent trips and only 10 minutes of travel time savings on a managed lane that could fit 100 toll paying vehicles. Under these circumstances the benefits of managed lanes would be more than three times as much as predicted assuming only ordinary trips. Thus, the results of this study can be used in accurately calculating the benefit-cost ratio for proposed managed lanes. Additionally, the findings have a potential to affect the policy decision of construction of new managed lanes.

The study also demonstrated how the knowledge of percentage of travelers facing urgent situations of each type can be useful in estimating the efficient toll rates for managed lanes with variable pricing. These findings can be particularly useful to the agencies operating the managed lanes, as they can help to maintain a desired level of service on the facility.

It was also demonstrated that depending on the toll values the whole group of travelers on managed lanes can be the travelers facing urgent situations and hence managed lanes would provide significant travel time savings benefit to travelers from all income groups. Managed lanes thus can cater to high valued trips from all income groups and hence they can be great assets to the travelers. The study thus helps to project the managed lanes as a reliable travel alternative for travelers from all income groups.

6. RECOMMENDATIONS FOR FUTURE WORK

Additional survey design techniques which can combine the D-efficient designs and the smart adjusting random attribute level generation strategy can be investigated. A revealed preference study can be carried out to further support the estimation of difference in VTTS for ordinary and urgent situations. More urgent trip reasons can be investigated and similar studies can be carried out for other parts of the country or for other freeways with managed lanes.

An additional survey can be conducted to estimate the percentage of infrequent travelers, how often does atypical infrequent traveler use the managed lanes, and to enlist common urgent situations faced by travelers.

REFERENCES

Adamowicz, W., Louviere, J., and Williams, M., 1994. Combining stated and revealed preference methods for valuing environmental amenities, *Journal of Environmental Economics and Management* 26**,** 271–292.

Algers, S., Bergstroem, P., Dahlberg, M., and Dillen, J.L., 1998. Mixed Logit Estimation of the Value of Travel Time. Working Paper, Department of Economics, Uppsala University, Sweden.

Armstrong, P.M., Garrido, R.A., and Ortuzar, J.deD., 2001. Confidence intervals to bound the value of time*, Transportation Research* E 37, 143-161.

Bates, J.J., 1988. Reflections on stated preference: Theory and practice. Paper presented at 7th International Conference on Travel Behavior Research, Chile.

Batsell, R.R., and Louviere, J.J., 1991. Experimental analysis of choice*, Marketing Letters* 2, 99-214.

Ben-Akiva, M., Bolduc, D., and Walker, J., 2001. Specification, identification and estimation of the logit kernel (or continuous mixed logit) model, MIT Working paper, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Bhat, C.R., 2001. Quasi-random maximum simulated likelihood estimation of the mixed multinomial logit model, *Transportation Research* B 35 (7), 677–693.

Bhat, C.R., and Castelar, S., 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* B 36(7), 593–616.

Bliemer, M.C.J, Rose J.M., and Hensher, D.A., 2009. Efficient stated choice experiments for estimating nested logit models, *Transportation Research* B 43(1), 19-35.

Bliemer, M.C.J., and Rose, J.M., 2006. Designing stated choice experiments: State-of-the art. Paper presented at the 11th International Conference on Travel Behaviour Research, Kyoto, Japan, August, 2006.

Brownstone, D., and Train, K., 1999. Forecasting new product penetration with flexible substitution patterns, *Journal of Econometrics* 89, 109–129.

Brownstone, D., Bunch, D.S., and Train, K., 2000. Joint mixed logit models of stated and revealed references for alternative-fuel vehicles, *Transportation Research* B 34, 315-338.

Brownstone, D., Ghosh, A., Golob, T.F., and Van Amelsfort, D., 2003. Drivers willingness-to-pay to reduce travel time: evidence from the San Diego I-15 congestion pricing project. *Transportation Research* A 37, 373-387.

Brownstone, D., and Small, K.A., 2005. Valuing time and reliability: assessing the evidence from road pricing demonstrations, *Transportation Research* A, 39(4), 279-293.

Bruzelius, N., 1979. *The Value of Travel Time*: Theory and Measurement, London, Croon Helm.

Burris, M.W., 2009. Variable priced highway facilities, https://ceprofs.civil.tamu.edu/mburris/pricing.htm, Accessed June 15, 2009.

Burris, M.W., and Figueroa, C.F., 2006. Analysis of traveler characteristics by mode choice in HOT corridors, *Journal of the Transportation Research Forum*. 45(2), 103–117.

Burris, M., and Patil, S., 2006. Estimation of travelers' values of time using a stated-preference survey with variable pricing options, Southwest University Transportation Center (SWUTC), Texas Transportation Institute, College Station, Texas.

Calfee, J., and Winston, C., 1998. The value of automobile travel time: Implications for congestion policy, *Journal of Public Economics* 69, 83-102.

Carlsson, F., and Martinsson, P., 2003. Design techniques for stated preference methods in health economics, *Health Economics*. 12, 281-294.

Census, 2007, State and county QuickFacts, U.S. Census Bureau, http://quickfacts.census.gov/qfd/index.html. Accessed May 15, 2009.

Chui, M.K., and McFarland, W.F., 1985. The value of travel time: New estimates developed using a speed choice model, Texas Transportation Institute, Texas A&M University, College Station, Texas.

Collier, T., and Goodin, G.D., 2002. Managed lanes: More efficient use of the freeway system, TTI Research Report 4160-5-p1, Texas Transportation Institute, Texas A&M University, College Station, Texas.

Dallaert, B., Brazell, J., and Louviere, J.J., 1999. The effect of attribute variation on consumer choice consistency, *Marketing Letters* 10(2), 139-147.

Davis, R., Sinha, K.C., and Mannering, F.L., 2009. Factors affecting willingness to pay for high-occupancy-toll lanes, Transportation Research Board, National Research Council, Washington, D.C.

Dosman, D., and Adamowicz, W., 2006. Combining stated and revealed preference data to construct an empirical examination of intrahousehold bargaining, *Review of the Economics of the Household* 4, 15-34.

Ferrini, S. and Scarpa, R. 2007. Designs with a priori information for nonmarket valuation with choice experiments: A Monte Carlo study. *Journal of Environmental Economics and Management*, 53, 342-363.

FHWA, 2005. Managed lanes: A primer, Publication number- FHWA-HOP-05-031, U.S. Department of Transportation.

FHWA, 2003. A guide for HOT lane development http://www.its.dot.gov/JPODOCS/REPTS_TE/13668_files/chapter_7.htm/. Accessed May 15, 2009.

Fosgerau, M., 2005. Unit income elasticity of the value of travel time savings, 8th NECTAR Conference, Las Palmas G.C., June 2-4, 2005.

Fosgerau, M., 2006. Investigating the distribution of the value of travel time savings, *Transportation Research Part B: Methodological* 40, 688–707.

Ghosh, A., 2001. Valuing time and reliability: commuters' mode choice from a real time congestion pricing experiment, Ph.D. Dissertation, Department of Economics, University of California at Irvine.

Greene, W.H., Hensher, D.A., and Rose, J., 2006. Accounting for heterogeneity in the variance of unobserved effects in mixed logit models. *Transportation Research* B 4(1), 75–92.

Greene, W.H., and Hensher, D.A., 2007. Heteroscedastic control for random coefficients and error components in mixed logit, *Transportation Research* E 43, 610–623.

Hanemann, W.M., Loomis, J., and Kanninen, B., 1991. Statistical efficiency of double-bounded dichotomous choice contingent valuation, *American Journal of Agricultural Economics* 73, 1255-1263.

HCTRA 2009a, Harris County Toll Road Authority, Toll road information – overview https://www.hctra.org/tollroads/. Accessed May 15, 2009.

HCTRA 2009b, Harris County Toll Road Authority, Katy managed lanes frequently asked question, https://www.hctra.org/katymanagedlanes/faq.html. Accessed September 16, 2009.

Hensher, D.A., 2001. The valuation of commuter travel time savings for car drivers in New Zealand: Evaluating alternative model specifications, *Transportation* 28, 101–118.

Hensher, D.A., 2004. Identifying the influence of stated choice design dimensionality on willingness to pay for travel time savings, *Journal of Transport Economics and Policy* 38(3): 425-446

Hensher, D. and Greene, W.H., 2003. The mixed logit model: the state of practice, *Transportation*, 30, 133–176.

Hensher, D.A., Rose, J., and Greene, W.H., 2005. *Applied Choice Analysis: A Primer.* Cambridge University Press, Cambridge.

Hensher, D.A., Rose, M.J., and Greene, W.H., 2008. Combining RP and SP data: Biases in using the nested logit 'trick'-contrasts with flexible mixed logit incorporating panel and scale effects, *Journal of Transport Geography* 16, 126-133.

Hess, S., Bierlaire, M., and Polak, J. W., 2005. Estimation of value of travel time savings using mixed logit models, *Transportation Research Part A: Policy and Practice* 39, 221-236.

Hess, S., Smith, C., Falzarano, S., and Stubits, J., 2008. Measuring the effects of different experimental designs and survey administration methods using an Atlanta managed lanes stated preference survey. In *Transportation Research Record, Journal of the Transportation*

Research Board, No. 2049, Transportation Research Board of the National Academies, Washington, D.C., 144-152.

H-GAC. 2009. Houston-Galveston Area Council of Government 2007-09 Regional Household Activity/Travel Survey, Unpublished data.

Huber, J., and Zwerina, K. 1996. The importance of utility balance in efficient choice designs. *Journal of Marketing Research* 33, 307-317.

Johnson, F.R., Kanninen, B.J., Bingham, M., and Ozdemir, S., 2007. Experimental design for stated choice studies. Chapter 7 in Kanninen, B.J. (ed.), *Valuing Environmental Amenities Using Stated Choice Studies,* Virginia, USA: Springer.

Kanninen, B.J., 2002. Optimal Design for Multinomial Choice Experiments, *Journal of Marketing Research*, 39, 214-217.

Kanninen, B.J., 1993. Optimal experimental design for double-bounded dichotomous choice contingent valuation, *Land Economics* 69(2), 138-146.

Koppelman, F.S., and Bhat, C.R., 2006. A self instructing course in mode choice modeling: Multinomial and nested logit models. Prepared for the U.S. Department of Transportation Federal Transit Administration, Washington, D.C., 79-80.

Kroes, E.P., and Sheldon, R.J., 1988. Stated preference methods: An introduction, *Journal of Transportation Economics and Policy* 22(1), 11-26.

Kuhfeld, W.F., 2005. Marketing research methods in SAS, SAS Institute Inc., Cary, NC (USA). http://support.sas.com/techsup/technote/ts722.pdf. Accessed Jan. 1, 2008.

Kuhfeld, W., Tobias, R., and Garratt, M., 1994. Efficient experimental design with marketing research applications, *Journal of Marketing Research* 31, 545-557.

Lazari, A., and Anderson, D.A., 1994. Designs of discrete choice set experiments for estimating both attribute and availability cross effects, *Journal of Marketing Research* 31, 375-383.

Legatt H., BizReport 2007, http://www.bizreport.com/2007/07/threequarters_of_us_households_have_broadband.html. Accessed May 15, 2009.

Louviere, J.J., 1998. Conjoint analysis modeling of stated preferences: A review of theory, methods, recent developments and external validity, *Journal of Transport Economics and Policy* 10, 93-119.

Louviere, J.J., and Woodworth, G.G., 1983. Design and analysis of simulated consumer choice or allocation experiments: An approach based on aggregate data, *Journal of Marketing Research* 20, 350-367.

Louviere, J.J., Hensher, D.A., and Swait, J.D., 2000. Stated choice methods: Analysis and application, Cambridge University Press, Cambridge.

McFadden, D., 1974. Conditional logit analysis of qualitative choice behavior, In Zarembka, P. (ed.), *Frontiers in Econometrics*, Academic Press, New York, 105-142.

McFadden, D., and Train, K., 2000. Mixed MNL models of discrete response, *Journal of Applied Econometrics*, 15, 447-470.

McFarland, W.F., and Chui, M., 1987. The value of travel time: New elements developed using a speed choice model, *Transportation Research Record* 1116, 15-21.

Munizaga, M., and Alvarez-Daziano, R., 2001. Mixed logit versus nested logit and probit, Working Paper, Departmento de Ingeniera Civil, Universidad de Chile.

Ohler, T., Li, A., and Louviere, J., 2000. Attribute range effects in binary response tasks, *Marketing Letters* 11, 249-260.

Patterson, Z., Haider, M., and Ewing, G., 2005. A gender-based analysis of work trip mode choice of suburban Montreal commuters using stated preference data. http://www.milute.mcgill.ca/Research/Senior/finalcommutingtrb.pdf. Accessed May 15, 2009.

Revelt, D., and Train, K., 1998. Mixed logit with repeated choices: Households' choices of appliance efficiency level, *Review of Economics and Statistics* 80, 1–11.

Rose, J., and Bliemer, M., 2008. Stated preference experimental design strategies, In *Handbook of Transport Modeling*, Hensher, D.A., and Button, K.J. (eds.), Elsevier Oxford, U.K., 151-79.

Scarpa, R., and Rose, J.M., 2008. Designs efficiency for nonmarket valuation with choice modelling: how to measure it, what to report and why. *The Australian Journal of Agricultural and Resource Economics*, 52, 253-282.

Schrank, D., and Lomax, T., 2007. The 2007 urban mobility report, Texas Transportation Institute, Texas A&M University System, College Station, Texas. http://mobility.tamu.edu/ums/. Accessed May 15, 2009.

Senna, L.A., 1994. The influence of travel time variability on the value of time, *Transportation* 21, 203-228.

Small, K.A., Winston, C., and Yan, J., 2005. Uncovering the distribution of motorists' preferences for travel time and reliability, *Econometricia*, 73 (4), 1367-1382.

Small, K.A., Noland, R., Chu, X., and Lewis, D., 1999. Valuation of travel-time savings and predictability in congested conditions for highway user-cost estimation, National Cooperative Highway Research, Report 431, Transportation Research Board, National Research Council, Washington, D.C., 1999.

Sullivan, E., Blakely, K., Daly, J., Gilpin, J., Mastako, K., Small, K., and Yan, J., 2000. Continuation study to evaluate the impacts of the SR91 value-priced express lanes: final report. California Polytechnic State University at San Luis Obispo, December 2000, http://ceenve.ceng.calpoly.edu/sullivan/SR91.

Toner, J. P., Clark, S.D., Grant-Muller, S.M., and Fowkes, A.S., 1998. Anything you can do, we can do better: a provocative introduction to a new approach to stated preference design. Presented at the 8th World Conference on Transport Research (WCTR), Antwerp, July, 12–17, 1998.

Train, K., 1998. Recreation demand models with taste differences over people. *Land Economics* 74, 230–239.

Train, K., 2000. Halton sequences for mixed logit. Working paper No. E00-278, Department of Economics, University of California, Berkeley, California.

Train, K., 2003. *Discrete Choice Methods with Simulation*. Cambridge University Press, Cambridge.

TxDOT, 2009. Katy Freeway Website, Texas Department of Transportation, www.katyfreeway.org/. Accessed May 15, 2009.

Wardman, M., 1998. The value of travel time: A review of British evidence, *Journal of Transportation Economics and Policy* 32, 285-316.

Zmud, J., and Arce, C., 2008. Compilation of Public Opinion Data on Tolls and Road Pricing, Washington, D.C.: Transportation Research Board, National Cooperative Highway Research Program Synthesis 377, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_377.pdf. Accessed September 16, 2009.

Zwerina K, Huber, J., and Kuhfeld, W.F., 1996. A General Method for Constructing Efficient Choice Designs. Fuqua School of Business, Duke University: Durham.

APPENDIX A

SAS commands for Searching a D-efficient Design

```
title 'Design for peak with availability';

%mktruns(3 4 4 4 4 3 3 3)

/*4 th level represents availability */


%macro resmac; /*put restrictions so that choice set has only 4 alts*/

navail=((x2<4)+(x3<4)+(x4<4)+(x5<4));

if (navail^=3)then bad=1;

else bad=0;

%mend;


%mktex(3 4 4 4 4 3 3 3, n=24, restrictions = resmac, seed=1024433)

%mkteval;


%mktlab(data=randomized, vars=x1-x8,out=Peak_LinDes)

/* one can change the variable order through vars to avoid main variables having interaction*/


data key1;

missing N;

input x1-x8;

datalines;

25 25 55 55 55 10 5  0

35 35 60 60 60 20 10 5

45 45 65 65 65 35 20 10

. N N N N . . .

;
```

```
%mktlab(data= Peak_LinDes, key=key1,out=Peak_LinDes1)
proc print data= Peak_LinDes1 (obs=24);
var x1-x8;
run;

title 'Peak travelers';
data key;
input Mode $ 1-4 (TT Toll) ($);  /*name to be read from columns 1 to4*/
datalines;
SGP  x1  .
HGP  x2  .
SMP  x3  x6
H2MP x4  x7
H3M  x5  x8

; /* Maintain the column format- spacing is critical*/
%mktroll(design= Peak_LinDes1, key=key, alt=Mode,
out=Peak_ChDes)
proc print data= key;
run; /* Varify if the key is coded correctly*/

proc print data= Peak_LinDes1 (obs=24);
var x1-x8;
run; /* Print the linear design*/
proc print data= Peak_ChDes (obs=30);
id set; by set;
run; /* Print the first 6 questions of rolled design*/
```

```
data Peak_ChDes;
set Peak_ChDes;
if Mode = 'SGP' then do; Toll = 0; end;
if Mode = 'HGP' then do; Toll = 0; end;
run;
proc print data= Peak_ChDes (obs=30);
id set; by set;
run;

title2 'Evaluate the Choice Design';
%choiceff(data= Peak_ChDes, init= Peak_ChDes (keep=set),
nsets=24, nalts=5, beta=zero, intiter=0,
model=class(Mode /zero= 'SGP' separators='' ' ')
identity(TT)identity(Toll)
/ lprefix=0 cprefix=0)
/* D-eff=   zero=SGP */

%mktblock(data=Peak_ChDes, nalts=5, nblocks=8, factors=TT Toll,out=Peak_ChBlckd,
seed=472)
/*change the seed for desired frequency of a factor in a block*/

proc print data= Peak_ChBlckd (obs=120);
id Block; by Block;
run;
%mkteval(blocks=block)
```

APPENDIX B

Katy Freeway Traveler Survey

Welcome Screen

Dear Houston Traveler,

The Texas Transportation Institute is examining ways to improve traffic flow along the Katy (I-10) Freeway. We need your help with this. This survey should take about 15 minutes to complete.

While you are not obligated to answer the questions on the survey, the information you provide will be very valuable as we work to improve travel on the Katy Freeway. Your answers on the survey will be confidential and not used in any way to identify you.

Two randomly selected surveys will win a $250 gas card. To be eligible the survey must be complete and contact information entered in the last question. Your contact information is stored separately and cannot be linked to your responses to these questions. If you have any questions regarding the survey, please contact me at (979) 845-9875 or mburris@tamu.edu.

Thank you for your participation.

Sincerely,

Mark Burris, Ph.D.

Research Director/Associate Research Engineer

Texas Transportation Institute

This research study has been reviewed by the Human Subjects' Protection Program and/or the Institutional Review Board at Texas A&M University. For research-related problems or questions regarding your rights as a research participant, you can contact these offices at (979)458-4067 or irb@tamu.edu.

Recent Travel Section

Please tell us about your most recent trip on the Katy Freeway (I-10) traveling away from downtown Houston during the work week (Monday through Friday). A "trip" is any time you traveled on Katy Freeway.

What was the purpose of your most recent trip? Choose one of the following answers:

- Commuting to or from my place of work (going to or from work)

- Recreational / Social / Shopping / Entertainment / Personal Errands
- Work related (other than to or from home to work)
- To attend class at school or educational institute
- Other

On what day of the week was your most recent trip away from downtown Houston? Choose one of the following answers:

- Sunday
- Monday
- Tuesday
- Wednesday
- Thursday
- Friday
- Saturday

What time of day did that trip start? (for example, when did you leave work)?

Choose one of the following answers:

12.00 AM 12.30 AM …11.30 PM

Is this a trip you regularly take (at least once every 2 weeks)?

- Yes
- No

Do you usually start your trip at that time when you travel on the Katy Freeway?

- Yes
- No

Would it have been possible for you to start your trip earlier or later?

Choose one of the following answers:

- Yes, I could have easily made the trip a little earlier or later
- Yes, I could have made the trip at any time that day
- No, I could not take the trip at any other time

Did you allow for extra travel time due to possible traffic congestion on the Katy Freeway (I-10) for your last trip?

- Yes
- No

Where did you get ON and OFF the Katy Freeway (I-10)?

ON OFF

- An exit West of 1463-Katy Road
- 1463 - Katy Road
- Pin Oak Road
- Katy Mills
- Katy Fort Bend Road
- Grand Pkwy
- Mason Road
- Westgreen Blvd.
- Fry Road
- Greenhouse Road / Baker Road
- Barker Cypress Road
- Park Row / Park 10
- Highway 6
- Eldridge Pkwy
- Dairy Ashford
- Kirkwood Road
- Sam Houston Pkwy / Wilcrest Dr.
- Gessner Road
- Blalock Road
- Bingle Road / Campbell
- Wirt Road
- Antoine Drive / Chimney Rock
- Silber Road / N Post Oak Road
- Loop 610
- Washington Ave / Westcott St
- T C Jester Blvd
- Durham Dr. / Shepherd Dr. / Patterson St.
- Studemont St. / Heights Blvd.
- Taylor Street
- I-45 Downtown Houston
- An exit East of I-45 Downtown Houston

What time of day did your trip end (for example, when did you arrive at home)?

Choose one of the following answers:

12.00 AM 12.30 AM …11.30 PM

What kind of vehicle did you use for your most recent trip?

Choose one of the following answers:

- Motorcycle
- Passenger car, SUV, or pick-up truck

- Bus

If you traveled by Passenger Car/ SUV/Pick-up Truck, how many people including you, were in the vehicle?

Choose one of the following answers:

- 1
- 2
- 3
- 4
- 5 or more

Did you have to pay to park in Houston?

- Yes
- No

We want you to now think about all of your trips on the Katy Freeway during the last full week.

How many total trips did you make during the past full work week (Monday to Friday) on the Katy Freeway either into, or out of Houston? (Each direction of travel is one trip, include trips on the HOV lane or main lanes)

- Trips per week:

Consider your usual trip into or out of Houston on the Katy Freeway:

On your usual trip, how much do you enjoy the travel?

Choose one of the following answers:

- I do not enjoy it at all
- I usually dislike it
- Neutral - neither dislike or like
- I usually enjoy the trip
- I always enjoy the time during my travel

Which of the following describes your activities during your usual travel on Katy Freeway? Check any that apply:

- I answer/make phone calls or text messages
- I listen to the radio, music, a book on tape, etc.
- I carpool and talk with fellow passengers
- I do not have to drive - so I can get reading or work done on the trip
- I focus only on driving

Do you own an electronic toll collection transponder - for example an EZ-Tag or TxTag?

- Yes

- No

Do you sometimes use a route into the Houston area other than the Katy Freeway to make trips with a similar purpose to your usual trip?

- Yes
- No

Introduction to New Toll Lanes

Prior to this survey, had you heard of the soon to open toll lanes on the Katy Freeway (I-10)?

- Yes
- No

Description of the Proposed Toll Lanes

The new Katy Tollway lanes are scheduled to open in the fall of 2008 and the facility will begin west of SH 6 and end at the I-10/I-610 interchange. The road will include 4 main lanes in each direction, 2 toll lanes in each direction and will be operated by Harris County Toll Road Authority (HCTRA) (See figure below). The tolls for the toll lanes will vary in cost to keep traffic moving quickly. During the rush hour the toll will be higher and during other times the toll will be lower. Drivers will have multiple entrances and exit locations to get on the toll lanes from both the eastbound and the westbound mainlanes of I-10. The facility will probably be in operation 24 hours a day and will probably be an EZ Tag only facility. Qualifying high-occupancy vehicles can travel for free during the peak hours. Metro buses will not be charged with the toll anytime.

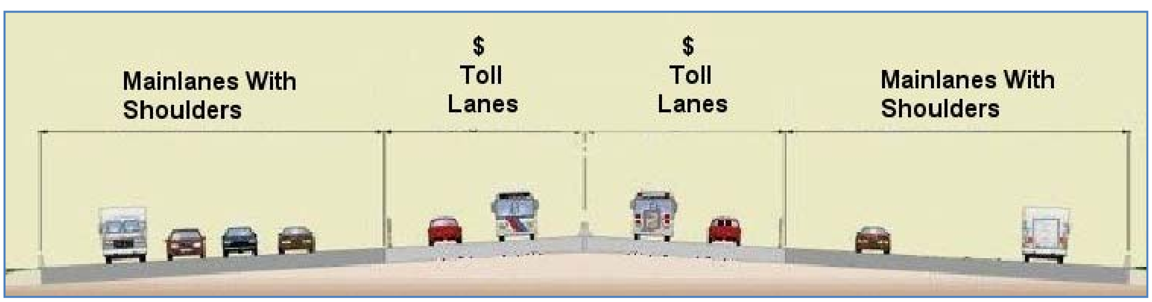

Figure A-1 Schematic Diagram of New Katy Toll Lanes (source www.katyfreeway.org)

Now that you know about the toll lanes on the Katy Freeway do you think you would be interested in using them?

Choose one of the following answers

- Yes
- No
- Maybe

What interests you the most about the toll lanes?

Check any that apply

- The toll lanes are safer / less stressful than driving on the main freeway lanes
- During the peak hours the toll lanes will not be congested
- Being able to use the toll lanes for free as a carpool
- Travel times on the toll lanes are consistent and predictable
- Other

The questions in this part of the survey are to find out your views on a number of potential options for the operation of the proposed toll lanes. The options raised here are for research purposes, and not official policies.

To maintain a smooth traffic flow, the toll that you pay on the toll lanes could change with the time of day you go through the station. As shown in the graph below, lower tolls could be charged for travel at specific times (for example, 6:30 a.m. to 7:00 a.m.) and higher tolls during the most congested times (for example, 7:00 a.m. to 8:00 a.m.).

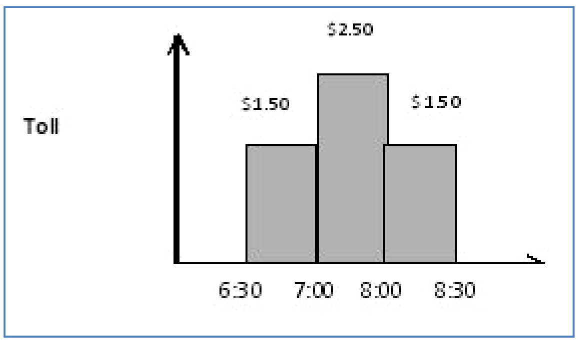

Figure A-2 Concept of Time of Day Pricing

What is your initial feeling regarding this option?

Choose one of the following answers

- Very unfavorable
- Somewhat unfavorable
- Neutral / No Opinion
- Somewhat favorable
- Very favorable

The toll on the proposed toll lanes could also change with the amount of traffic on the toll lanes. For example, if the toll lanes were not congested then the toll might be lower. However, if the toll lanes were very congested the toll might be higher to maintain the smooth flow of traffic. What is your initial feeling regarding this option?

Choose one of the following answers

- Very unfavorable

- Somewhat unfavorable
- Neutral / No Opinion
- Somewhat favorable
- Very favorable

Travel Choices 1

Each of the following questions will ask you to choose between four potential travel choices on the Katy Freeway (I-10). For your most recent trip, please click on the one option that you would be most likely to choose if faced with these specific options. Remember that main lane traffic tends to be congested and could be slower than shown here if congestion is worse than usual. The toll lane traffic is fast moving. Also, carpooling may require added travel time to pick up or drop off your passenger(s).

You described your most recent trip away from downtown Houston on Katy Freeway last Monday as starting at 8:30 AM, ending at 9:30 AM in a Passenger car, SUV, or pick-up truck. The reason for the trip was Commuting to or from my place of work (going to or from work).

If you had the options below for that trip, which would you have chosen?

Choose one of the following answers

- Mode: Drive by myself

  Lane: Main freeway lanes

  Travel Time: 26 minutes

  Toll: $ None

  Time of Day: afternoon rush hour

- Mode: Drive by myself

  Lane: Toll lanes

  Travel Time: 10 minutes

  Toll: $3.15

  Time of Day: afternoon rush hour

- Mode: Carpool with one other person

  Lane: Toll lanes

  Travel Time: 9 minutes

  Toll: $1.60

Time of Day: afternoon rush hour

- Mode: Carpool with 3 or more people

  Lane: Toll lanes

  Travel Time: 9 minutes

  Toll: $0.75

  Time of Day: afternoon rush hour

Now we want you to think about a similar trip on Katy Freeway, with the same travel options as above. However, you are headed to an important appointment / meeting / event. Which option you would choose in this situation?

Choose one of the following answers:

- Mode: Drive by myself

  Lane: Main freeway lanes

  Travel Time: 26 minutes

  Toll: $ None

  Time of Day: afternoon rush hour

- Mode: Drive by myself

  Lane: Toll lanes

  Travel Time: 10 minutes

  Toll: $3.15

  Time of Day: afternoon rush hour

- Mode: Carpool with one other person

  Lane: Toll lanes

  Travel Time: 9 minutes

  Toll: $1.60

  Time of Day: afternoon rush hour

- Mode: Carpool with 3 or more people

  Lane: Toll lanes

Travel Time: 9 minutes

Toll: $0.75

Time of Day: afternoon rush hour

Travel Choices 2

Contains similar choices as travel choices-1 with different set of travel time and toll values.

Travel Choices 3

Contains similar choices as travel choices-1 with different set of travel time and toll values.

Demographics

The following questions will be used for statistical purposes only and answers will remain confidential. All of your answers are very important to us and in no way will they be used to identify you or released to any other person outside the research team.

What is your age?

Choose one of the following answers

- 16 to 24
- 25 to 34
- 35 to 44
- 45 to 54
- 55 to 64
- 65 and over

What is your gender?

Choose one of the following answers

- Male
- Female

Please describe the type of household you live in.

Choose one of the following answers:

- Single adult
- Unrelated adults
- Married without children
- Married with child(ren)
- Single parent family

- Other

Including yourself, how many people live in your household?

All together, how many motor vehicles (including cars, vans, trucks, and motorcycles) are available for use by members of your household?

What category best describes your occupational or work status?

Choose one of the following answers

- Professional / Managerial
- Sales
- Stay-at-home homemaker / parent
- Administrative / Clerical
- Student
- Self employed
- Manufacturing
- Technical
- Retired
- Unemployed / seeking work
- Other

What was the last year of school that you have completed?

Choose one of the following answers

- Less than high school
- High school graduate
- Some college or vocational school
- College graduate
- Postgraduate degree

We know that your income is private and that us asking for it is a sensitive issue. However, we really need to know because we use this information to figure out how much your time is worth to you, which is important in explaining your transportation decisions. Remember, we will never use this information in conjunction with anything that identifies you by name, and all information is kept confidential. What was your gross annual household income before taxes in 2007? Include all sources of income, including wages, payments from retirement accounts, earnings from stocks and bond, etc.

Choose one of the following answers

- Less than $10,000
- $10,000 to $14,999
- $15,000 to 24,999

- $25,000 to $34,999
- $35,000 to $49,999
- $50,000 to $74,999
- $75,000 to $99,999
- $100,000 to $199,999
- $200,000 or more
- Its easier to tell my hourly wage rate:

Thank you for taking the time to fill in this survey. Your responses will be helpful as we work to improve travel in the Houston area. If you have any general comments about travel on the Katy Freeway, or Houston in general, please type them below. Thanks!

Please finish the survey by hitting "Submit" below. You will then have a chance to enter your contact information to be eligible to win one of the $250 gas cards. Your contact information is stored separately and cannot be linked to your responses to these questions.

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