THE VALUE OF TRAVEL TIME AND RELIABILITY- EMPIRICAL EVIDENCE FROM KATY FREEWAY

A Thesis

by

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ABSTRACT

Travelers place value on both time savings and reliability when choosing a route for a trip. The values of travel time (VOT) have long been an integral part of the appraisal of transport projects. Recently some transport planners have been incorporating the value of travel time reliability (VOR) into transportation project evaluation as well. Whereas VOT measurements have established guidelines, VOR measurement methods are not well established. This research used data that was collected during 2012, 2013, and 2014 that was generated by automated vehicle identification (AVI) sensors from Katy Freeway travelers. Lane choice models were developed to examine the factors influencing travelers' lane choice decisions in different traffic conditions and estimate their value of travel time. Models with two independent variables, travel time and toll, resulted in estimated values of travel time from $1.96/hour to $8.06/hour. The estimated value of time was higher for eastbound traffic than westbound traffic. The research could not draw any conclusion on whether the travel time reliability had any impact on travelers' lane choice decisions. However, it was observed that a bad trip experience on the general purpose lanes (GPLs) did not have a significant influence on lane choice decision. Furthermore, the percentage of manages lane (ML) trips was higher for the travelers who traveled the whole length of the MLs/GPLs compared to travelers who traveled only a part of the GPLs/MLs. The reason might be that the ends of the MLs provided easier access when compared to the midpoints of the MLs.

DEDICATION

I dedicate this thesis to my parents Mr. Ayub Ali and Mrs. Asma Banu. Everything I did in my life, my sole objective was to make you proud.

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All praise is due to the almighty for endowing me with opportunity, patience and knowledge to complete this work.

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NOMENCLATURE

AVI	Automated Vehicle Identification
GPLs	General Purpose Lanes
GPS	Global Positioning Systems
HOV	High Occupancy Vehicle
HOT	High Occupancy/Toll
HCTRA	Harris County Toll Road Authority
MLs	Managed Lanes
RP	Revealed Preference
RR	Reliability Ratio
SP	Stated Preference
TxDOT	Texas Department of Transportation
USDOT	United States Department of Transportation
VOR	Value of Travel Time Reliability
VOT	Value of Travel Time

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1. INTRODUCTION

Investment in improved transport infrastructure typically leads to a reduction in traveler's travel time and an increase in travel time reliability. The value of travel time (VOT) has long been an integral part in the appraisal of transport projects. In the case of travel time, transportation planners, engineers and economists try to estimate travelers' value of time (VOT). Value of time is the equivalent amount of money a traveler would pay for a reduction in the amount of time to complete a trip. For example: if a traveler would pay one dollar to reduce their travel time by six minutes then they would have a VOT of $10/hour.

Similarly, travelers also value trips where they can expect to arrive on time, which refers to the reliability of travel time. According to the Federal Highway Administration (FHWA), travel time reliability is the consistency or dependability of travel times, as measured from day-to-day and/or across different times of the day. Quantitatively, the economic worth of travel time variation is referred to as the value of reliability (VOR). VOR is equivalent to the amount of money a traveler would be willing to pay to reduce the variation in their expected travel time.

In recent years, agencies have recognized the importance of improved travel time reliability in the evaluation of transportation projects. Many countries, such as New Zealand, Australia, and the Netherlands, have published guidelines to incorporate travel time reliability into their economic appraisal of transportation projects. In the USA, the federal government provided funds for extensive research on travel time reliability. The second Strategic Highway Research Program (SHRP 2) was authorized by the United States congress to conduct research projects that focused, in part, on reliability-related issues.

In the last 40 years, the VOT has been comprehensively studied and most agencies have a guideline to estimate the VOT. On the other hand, methods of estimating the value of reliability are still a topic of debate. Different studies have used different reliability measures which lead to inconsistency among the obtained VORs. A majority of the researchers have used stated preference survey data to estimate VOR and the estimated values varied significantly based on survey design, location, sample size and methods of measuring reliability. Carrion and Levinson (2012) examined the shortcomings of the stated preference studies suggesting that most of the researchers did not focus on survey data validation, and that it is difficult to be certain about which estimates are more plausible than others. On the contrary, very few studies have used revealed preference (RP) data to estimate VOT and VOR. One of the main reasons is that a proper experimental design for a revealed preference study is difficult when compared to that of stated preference study.

One important issue to estimate VOR is determining how travelers perceive reliability. Several reliability measures such as standard deviation, 95th percentile of travel time, shorten right range, and buffer time index have been used in the literature. But a traveler may perceive reliability in his/her personal way which may not be well represented by the commonly used reliability measures. The travelers' familiarity with a route might have an influence on his/her perception of reliability. For example, a traveler might consider his/her previous 5 trips when deciding whether a route is reliable or not. In addition, to a particular traveler, reliability of a route may vary depending on the day of week and time of day.

To address the limitations of the previous studies on VOT and VOR, Alemazkoor et al. (2014) used data from Katy Freeway, Houston. Here travelers choose between more reliable Managed Lanes (MLs) and toll free General Purpose Lane (GPLs). The dataset consisted of records generated from automated vehicle identification (AVI) sensors placed at regular intervals along the freeway. The study indicated that travelers on the Katy freeway might not consider travel time reliability while making lane choice decisions or the reliability measures used in the study could not represent the reliability perception of the travelers. The study indicated that one potential reason why they could not get expected results as they have used only one month of data with no variation in toll schedule. Therefore, a more comprehensive study with data, collected for longer period with a varying toll schedule, may help to better understand the travelers' perception of reliability.

This study will use data generated from automated vehicle identification sensors from Katy Freeway travelers collected during 2012, 2013, and 2014. These data include travel times on all lanes and tolls paid to use the Katy Freeway Managed Lanes .Thus it is possible to know how much travelers spent to use the MLs , how much travel time they saved (if any) ,and how much more reliable the MLs were (if at all) as compared to the general purpose freeway lanes . In addition, the toll schedule has been updated twice during these three years. This provides additional variation in the toll (data) variable which generally leads to improved model prediction ability. Moreover, as the dataset allowed tracking all trips for a traveler on the Katy freeway, it provides an opportunity to see how previous trip experience and familiarity with the freeway impacted lane choice.

1.1 Research Problem and Objective

This research examines the impact of different factors, such as tolls, travel time saving, travel time reliability and familiarity on the traveler's choice between general purpose lanes and managed lanes. The study also compares the effectiveness of different reliability measures. This research investigates the effect of previous bad trip experience on lane choice decision models.

The main objectives of this study are:

1. To examine the factors that influence travelers' lane choice decision in different traffic conditions
2. To better understand how reliability impacts lane choice decision
3. To explore the influence of travelers' previous experience (based on number) of trips on lane choice decision
4. To estimate traveler willingness to pay for travel time saving and improved travel time reliability

2. LITERATURE REVIEW

2.1 The Value of Travel Time

The value of travel time (VOT) is the measure of travelers' willingness to pay for a reduction in their travel time. Existing literature on the VOT is very comprehensive and well developed. The first analysis of VOT was a 1925 Bureau of Public Roads report (U.S. Bureau of Public Roads and the Cook County Highway Department, 1925) which estimated VOT to be $3 per hour (in 1925 dollars, approximately $41 per hour when increased by inflation to 2015 dollars). Studies between 1925 and the 1970s generally used one of two methods to estimate VOT: (1) the VOT was assumed to be equal to the travelers wage rate or (2) how much travelers would be willing to pay to use a faster mode of travel. For example, how much more would a traveler be willing to pay to travel by car than by bus? Since then, most studies have used stated preference survey data to estimate value of time. These stated preference studies generally asked travelers to choose between modes and developed logit equations to predict mode choice. VOT was estimated based on the coefficients in those equations.

Concas and Kolpakov (2009) summarized many VOT studies (see Table 1). They found that many analyses had found a strong relationship between the traveler's hourly wage rate and their VOT. The estimated VOTs ranged from 20% to 100% of the traveler's hourly wage rate and most of the literature suggested that the VOT should be around 50% of hourly the wage rate for personal trips. This is similar to US DOT guidance (USDOT, 2003). Brownstone and Small (2005) conducted a study on SR-91 and I-15 in Southern California and estimated the VOT for personal trips to range from $20/hour to $40/hour. For commercial trips, VOT can be higher than the hourly wage rate. Waters (1992) found that travelers valued their time for commercial travel could be as high as 1.7 times their average wage rate.

The literature shows that the value of travel time depends on various factors: type of travel, personal characteristics (age and sex) of traveler, transportation mode (bus, car, bicycle or walk), and travel condition (level of service). Disrepair (1971) mentioned that time spent in any activity is a matter of choice as well as a matter of necessity. Thus, for an individual the value of travel time would depend on trip purpose. Many agencies have recommended using different values of time for different types of travel. The U.S. DOT (2003) recommended values of time were $10.60/hour for commuter travel and $21.46/hour for business travel. In New Zealand the recommended values of travel time were NZ$7.8 for commuter travel and NZ$23.85/hour for business travel. Cal fee and Winston (1998) gave an explanation about the lower estimation of commuters' value of travel time. They collected data from the National Family Opinion Survey which covered commuters from major U.S. metropolitan cities. They found that commuters' average value of travel time saving ranged from 14% to 26% of the gross wage. According to Calfee and Winston (1998), the value of travel time was insensitive to travel condition; commuters are able to adjust to congestion through their modal and departure time choice, as well as the choice of residential and workplace location (Concas and Kolpakov, 2009).

Several studies have tried to estimate the value of time on managed lanes. Using stated preference data, a study for the Georgia Department of Transportation (GDOT) found that the estimated value of time for autos would range from $7/ hour to $15/ hour, while a commercial vehicles trip can have a value of time of $23/hour (HNTB ,2010). Another study for the Florida Department of Transportation (FDOT) estimated the value of travel time for autos to be in range of $2.27/hour to $79.32/hour (Perk et al., 2011). A study on the Katy Freeway by Devarasetty et al. (2012) using stated preference survey data (Db-efficient design) estimated the value of travel time to be $22/passenger car hour.

Table 1 Empirical estimates of VOT

Study	Data Used	VOT Estimate
U.S. Bureau of Public Roads (1925)	Survey of highway transportation	$3.00
Beesley(1965)	Data from the survey of government employees in London, UK	31%-50% of wage rate
Lisco (1967)	Survey of multiple route choice models	60% of gross wage (on average)
Small (1992)	Values derived from multiple mode choice transportation models	20% to 100% of gross wage; 50% - reasonable average

Table 1 Continued

Study	Data Used	VOT Estimate
Waters (1996)	Travel data from 15 commuting studies in North America	40%-50% of after tax wage rate (mean: 59% of after tax wage rate; median: 42% of wage rate)
Small and Yan(2001)	Data on commute travelers on SR- 91 in California	Average VOT was \$22.87/hour, or 72% of sample wage rate
Brownstone and Small (2005)	Travel data from ETC facilities in HOT lanes on SR-91 and I-15 in Southern California	VOT saved on the morning commute: \$20-\$40 per hour, or 50%-90% of average wage rate in the sample
USDOT (Ayala, 2014)	Estimates are based on multiple sources of data	50%-120% of the wage rate depending on type of travel (personal vs. business); 50% of wage rate for personal local travel and 100% of wage rate for commercial local travel
USDOT (Ayala, 2014)	Compilation of many sources	Local travel, all purposes is \$12.80 in 2012 dollars.

Sources: Concas and Kolpakov (2009)

The value of travel time depends on various factors such as the type of travel, the characteristics of the traveler (for example, age and gender), transportation mode (for example, bus, car, or walk), travel condition, time of the year, or week, or day, location, and trip purpose. Many agencies have recommended using different values of time for different types of travel. The U.S. DOT recommended values of time were $10.60/hour for commuter travel and $21.46/hour for business travel. The latest update to these guidelines (USDOT, 2014) suggested values of time of $12.50 in 2009 dollars for all purposes of travel combined.

Most of the studies in the last 40 years have used stated preference (SP) surveys to estimate VOT. As mentioned by Carrion and Levinson (2012), early studies were based on questions that asked travelers to choose between hypothetical travel alternatives. For example, would they choose option 1 which takes 10 minutes and requires a $2 toll, or option 2 which takes 15 minutes but has no toll.

Carrion and Levinson (2012) found that in some cases researchers who conducted stated preference studies presented survey data in a format that reflected the researchers' intended outcome. Literature suggests that most researchers did not validate survey data, and that estimates were hard to evaluate for plausibility. Very few revealed preference studies were found that could be used to validate the outcome from stated preference studies.

Many countries have incorporated VOT into their economic evaluation of transportation projects. As mentioned by Ellison (2013), Dutch VOTs were estimated based on a national survey conducted in 1998. Since then the values have been adjusted every year for inflation and for real income changes. In 2010, the recommended values of travel time were €9.92/hour for commuter trip and €34.36/hour for business trip (approximately \$9/hour and \$31/hour in US dollars). New Zealand's Economic Evaluation Manual provides guidelines to incorporate VOT into economic evaluations for surface transportation projects (such as highway, transit and rail). New Zealand suggested different VOT ranges based on types of vehicles, roadway network and day of week. In 2013, the value of travel time ranged from NZ\$14.96/hour to NZ\$25.84/hour (approximately \$22/hour and \$38/hour in US dollars).

2.2 The Value of Travel Time Reliability

Although the concept of travel time reliability is not new, valuing travel time reliability is not well established. The value of reliability (VOR) is equivalent to the amount of money a traveler would be willing to pay to reduce the variation in their expected travel time. Researchers have attempted to quantify VOR and the estimated values are a subject of continuous debate (Carrion and Levinson, 2012). A main reason for the discrepancy is due to researchers using different approaches to measuring travel time reliability. Definitions of commonly used reliability measures are summarized in Table 2.

Table 2 Commonly used reliability measures

Reliability Performance Metric	Definition
Buffer Index (BI)	The difference between the 95th percentile travel time and the average (or median) travel time, divided by the average (or median) travel time
Failure/On-Time Measures	Percent of trips with travel times less than 1.1 × Median Travel Time or 1.25 × Median Travel Time
	Percent of trips with space mean speed less than 50 mph; 45 mph; or 30 mph
80th Percentile Travel Time Index	80th percentile travel time divided by the free-flow travel time
Planning Time Index	95th percentile travel time divided by the free-flow travel time
Skew Statistic	The 90th percentile travel time minus the median all divided by the median minus the 10th percentile
Misery Index (Modified)	The average of the highest 5 percent of travel times divided by the free-flow travel time
Standard Deviation of Travel Time or Travel Rate	Root-mean-square deviation of travel time $$\sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i-\mu)^2}$$ Where, x_i = Travel time of trip i μ = Average travel time N= Total number of observation
Shorten Right Range (SRR)	The difference between 90th percentile travel time and median travel time
Interquartile Range (IR)	The difference between 75th percentile and 25th percentile travel time

Sources: SHRP 2 Project L17 and SHRP 2 Project L03

Early studies used standard deviation as the measure of travel time reliability. More recent studies have used the difference between two percentile values within a travel time distribution (95th and 50th, 90th and 50th, or 80th and 50th) to estimate reliability. Tilahun and Levinson (2010) used three measures to estimate VOR, which were:

(1) Probability of early or late arrival compared to usual travel time,

(2) Difference between maximum travel time and median (the median travel time is the travel time where half of travelers were slower and half were faster), and

(3) Standard deviation.

Their findings suggested that all three approaches yielded a similar output.

Van Lint et al. (2008) found that using different measures of reliability would provide inconsistent results. They compared results from using the standard deviation, coefficient of variation, buffer index and misery index. Alemazkoor et al. (2014) examined how well different value of reliability measures matched actual traveler behavior data from Katy Freeway. Their results were inconclusive and possibly indicated that many travelers did not consider reliability, or it was far less important than other variables, when making their travel decisions.

The National Cooperative Highway Research Program (NCHRP Report-399, 1998) suggested using the standard deviation as a measure of travel time reliability. Many countries including New Zealand, Australia, the Netherlands, and the United Kingdom prefer using standard deviation as measure of travel time reliability for passenger travel.

Table 3 Empirical estimates of VOR

Study	Data Used	VOR Estimate	Definition of Reliability
Black and Towriss, (1993)	Data from SP survey of travelers in London	0.55-0.70 of travel time	Measured as standard deviation of travel time
Small, Noland, Chu and Lewis (1999)	SP survey of travelers in SR-91 corridor in Orange and Riverside counties in Southern California, conducted in 1995	Average of 2.37 of travel time for median income and all trips ($12.60/hour) Greater than 3 times of travel time for work trips and higher income	Reliability is measured by standard deviation of travel time
Lam and Small (2001)	Travel time data from loop detector from SR-91 and RP data through mail	$15.12/hour for men and $31.91/hour for women	standard deviation, and difference between 90th percentile and median travel time
Brownstone and Small (2003)	Travel data from ETC facilities in HOT lanes on SR-91 and I-15 in Southern California, 1996-2000	95%-140% of the median travel time	Difference between 90th and 50th percentile travel time
Tseng, Ubbels and Verhoef (2005)	Data from surveying Dutch commuters, 2004	VOR is valued at ½ of the VOT (5.3 Euros/hour, or $6.41/hour)	Difference between early /late arrival time and preferred arrival time. Early and late arrivals are modeled separately

Sources: Many are from Concas and Kolpakov (2009)

Table 3 Continued

Study	Data Used	VOR Estimate	Definition of Reliability
Small, Winston and Yan (2005)	Travel data from SR-91 in greater Los Angeles area, 1999-2000	VOR estimated at \$19.56/hour, or 85% of average wage rate	Difference between 75th and 25th percentile travel time
Tilahun and Levinson (2007)	Data from a SP route choice survey of University of Minnesota employees, Minneapolis/St. Paul, MN	Equivalent to VOT	Difference between actual late arrival and usual (mode) travel time
Devarasetty et al. (2012)	Internet based stated preference survey	\$28/hour	Coefficient of variability
Carrion and Levinson (2012)	GPS based RP data	\$0.32/hour-\$3.84/hour for men and \$4.9/hour-\$8.6/hour for women	Standard deviation

Sources: Many are from Concas and Kolpakov (2009)

The literature suggests that studies have used different reliability measures to estimate value of reliability. But a majority of the studies used stated preference data to estimate value of reliability (See Table 3). As mentioned earlier that the estimated value of reliability is not consistent. A study on the SR-91 in greater Los Angeles area by small et al. (2005) estimated the value of reliability to be 19.56/hour, or 85% of average wage rate of the sample. A study by Tilahun and Levinson (2007) found that the value of travel reliability would be equivalent to the value of travel time. Carrion and Levinson (2012) using GPS and RP data found that the value of reliability ranged from \$0.32/hour to \$8.6/hour. As the studies differed in data collection methods, location, sample size and measurement of reliability, it is not possible to decide which estimation is better than others.

2.3 Mathematical Framework to Estimate VOT and VOR

So far, three different frameworks have been used to mathematically describe travel time and reliability: (1) centrality dispersion or mean variance, (2) scheduling delay, and (3) mean lateness.

Centrality Dispersion, introduced by Jackson and Jucker (1982), is based on the concept where travelers want to minimize their disutility from travel time and travel time unreliability. The utility function used in this method is estimated using discrete choice methods. The utility or disutility function is formulated as Equation 1:

$$U(p) = \lambda_{1k}\mu_{Tp} + \lambda_{2k}\sigma_{Tp} + \lambda_{3k}C_p \tag{1}$$

Where, μ is the mean travel time , σ is the standard deviation of the travel time distribution , Cp is the cost associated with travel and λ is the coefficient which indicate the degree to which the independent variable affects traveler k's utility on route p. The value of time (VOT) and the value of reliability (VOR) can be obtained by computing marginal rate of substitution. These are defined as,

$$VOT = \frac{\delta U/_{\delta \mu_T}}{\delta U/_{\delta C}} \tag{2}$$

$$VOR = \frac{\delta U/_{\delta \sigma_T}}{\delta U/_{\delta C}} \tag{3}$$

Small(1982) developed scheduling delay approach considering that travelers utility was influenced by departure time and workplace constraints. According to the scheduling delay approach, utility/disutility is involved with early arrival as well as late arrival.

$$U(t_d)=\beta_1\, T+\beta_2\, SDE+\beta_3\, SDL+\beta_4\, DL+ \beta_5\, C \tag{4}$$

Equation 4 represents the utility function for departure time (t_d). Here, utility is described as a function of travel time (T), schedule delay early (SDE), schedule delay late (SDL), a dummy variable (DL) which depends on the value of SDL, and a cost variable (C). Here, β is the coefficient which indicates the degree to which the independent variable affects traveler's utility. The utility function can be used to estimate the value of time, the value of scheduling delays early (VSDE) and the value of scheduling delays late (VSDL).

$$VOT = \frac{\delta U/_{\delta T}}{\delta U/_{\delta C}} \tag{5}$$

$$VSDE = \frac{\delta U/_{\delta SDE}}{\delta U/_{\delta C}} \tag{6}$$

$$VSDL = \frac{\delta U/_{\delta SDL}}{\delta U/_{\delta C}} \tag{7}$$

The Association of Train Operating Companies (ATOC) introduced the mean lateness approach and it has become the standard for reliability analysis for rails travel in the United Kingdom. This approach used schedule journey time (SchedT) and mean lateness (L) to express the utility function. Here, β is the coefficient which indicates the degree to which the independent variable affects traveler's utility. If a cost variable is added in the utility function, value of lateness can be measured.

$$U(t_d)=\beta_1(SchedT)+\beta_2 L+ \beta_3 C \tag{8}$$

$$VOL = \frac{\delta U / \delta L}{\delta U / \delta C} \tag{9}$$

Black and Towriss (1993) introduced a term reliability ratio (RR) expressed as ratio of VOR and VOT. Many countries are using reliability ratio to predict VOR (Nevers et al., 2013), which can be further implemented in economic evaluation for transportation projects.

$$RR = \frac{VOR}{VOT} \tag{10}$$

The data used in this study contains the information not only about travelers' lane choice decision but also information about how much travel time they saved (if any) , how much toll they had to pay on MLs(if any) ,and how much more reliable the MLs were (if at all). These attributes (travel time, reliability and tolls) can be easily incorporated into the centrality dispersion framework which will be used in this study.

2.4 Stated Preference Studies

The literature indicates that most of the studies used stated preference (SP) surveys to estimate the value of travel time and the value of reliability. As mentioned by Carrion and Levinson (2012), early studies were based on paired comparison questions of hypothetical route alternatives. In a question, each hypothetical route had a "usual" travel time. Also, a delay component was assigned to one of the routes, usually the route with the shortest travel time. Jackson and Jucker (1982) used this kind of stated preference technique to gather data. In their study, in a pair, one alternative had a usual travel time (15, 20, 50 minutes etc.) which was higher than other alternative's travel time (10, 20, 30 minutes etc.). The later alternative corresponded with a range of delay (5-20, 10-40, 5-50 minutes etc.) and a delay occurrence frequency (once a week, twice a week, once a month etc.). The study found that the variability of travel time had a significant impact on route choice and the impact varies across individual. They also found that the mean variance approach provided extremely accurate prediction.

Black and Towriss (1993) used an approach that presented data in a different way. In their approach, each route had same mean travel time but different travel cost. For presenting variability they assigned several possible travel times to each route. The survey respondents chose one route from the two alternatives. Black and Towriss (1993) used the mean-variance approach to analyze the data. They found that travel time reliability was a significant factor, though the magnitude was less than the magnitude of mean travel time. Depending on their models the reliability ratio ranged from 0.55 to

0.7. Small et al. (1999) used Black and Towriss (1993)'s question format with some modifications. In their survey design, each alternative consisted of a mean travel time, a distribution of five arrival times with respect to an implied preferred time, and a travel cost. Using the survey data, Small et al.(1999) estimated mean-variance models, scheduling models and a econometric model that combined both of the approaches (mean-variance and scheduling). They found that the combined model lead to an estimate of the travel time reliability measure that was not statistically significant. It should be noted that their study found a reliability ratio of 3.22 which was much higher than the reliability ratios found in other contemporary studies. This indicated that the design of survey might have significant effect on estimation of value of travel time and value of reliability.

Many researchers have tried alternative presentations of survey data to estimate travelers' value of reliability. Hensher (2001) used bar diagrams with minute values for four components of the total travel time: free flow, slow down, stop/start and uncertainty. A travel cost component was associated with each alternative which allowed them to calculate tradeoffs between cost and the distinct component of travel time. As mentioned by Carrion and Levinson (2012), Hensher (2001) was focused on investigating the value that travelers assign to the distinct components of total travel time rather than travel time reliability. Cook et al. (1999) and Bates et al. (2001) proposed a design, for the presentation of variability, which consisted of representation of arrival time with respect to given preferred arrival time. They also included survey phases to familiarize the responders to their data presentation. Copley et al. (2002) used a qualitative approach to study different presentations of travel time variability: linear arrangement of possible travel times, circular arrangements of possible travel times, and histogram representation of possible travel times. They found that the histogram presentation was easier to understand and it can present large volume of information. Tseng et al. (2009) used face to face interviews to investigate the most preferable way to represent survey data. Tseng et al. (2009) asked the responders about the preferences with regards to the format. They also asked questions that tested respondents' choice consistency and logic of perception with regards to reliability presented in the questionnaires. The study found that respondents could easily understand if data was presented as Small et al. (1999)'s format. The values of time and the values of reliability observed in the stated preference studies are not consistent. Depending on the survey design and selection of the respondents the estimated values differed significantly.

Devarasetty et al. (2012) used survey data and actual usage data from Katy Freeway travelers to estimate their value of travel time reliability. During the survey, approximately half of the respondents received questions in pictorial format and other half received questions in text-only format. The respondents were given four options for each question: drive alone on general purpose lane, drive alone on toll lanes, carpool on general purpose lanes, and carpool on toll lanes. The study found that the survey format had no significant effect on the result. The research outcome showed that the combined estimate of the VOT and VOR base on stated preference data to be $50/hour, which was almost equal to the estimated VOT of $51/hour estimated from actual usage data.

In summary, it can be said that stated preference surveys were widely used to estimate value of travel time and value of reliability. One important point indicated by Carrion and Levinson (2012) was that, in stated preference studies, researchers might present the survey data in such ways that reflect their own intended outcome. The literature suggests that most of the researchers did not focus on survey data validation, and that it is difficult to be certain about which estimates are more plausible than others. There are very few revealed preference studies which can be used to validate the stated preference studies' outcome. The revealed preference studies will be discussed in the following section.

2.5 Revealed Preference Studies

In comparison to the large number of stated preference studies, there are very few studies that have used revealed preference (RP) data to estimate value of time and value of reliability. One of the main reasons is that a proper experimental design for revealed preference is difficult when compared to that of stated preference experiment design.

Lam and Small(2001) used loop detector data and survey data to estimate value of reliability for the travelers on State Route(SR) 91 in Orange County, California. They conducted a mail survey among the travelers (533 respondents) to gather information about the travelers' most recent trips. They also estimated the average travel time within the same time of day using loop detector data. One of the limitations of the study was the loop detector had been collected one year prior to the mail survey. The researchers then adjusted the travel times using data factor of 1.37 which implied that on that particular route in one year the travel time had increased by 37%. In addition, the travel times obtained using loop detector data were averaged over 15 minutes. Therefore, calculated travel times may not represent the actual travel time of the travelers. The study found that if the travel time reliability is expressed as the difference between 90th percentile and the median of travel time, it provides the best fit model. According to the model, the value of reliability was $15.12/hour for men and $31.91/hour for women.

Small et al. (2005) used a combination of RP and SP data of travelers on SR 91 to estimate their VOR. Telephone interviews and mail-back surveys were conducted to collect the data. Though there were 522 participants in RP survey and 633 participants in SP survey, only 55 participants were found who participated in both surveys. Therefore, a combination of both datasets might cause errors in the study. Moreover, the researchers concluded that the RP data can never be representative of the real world scenario because there is a chance of perception error during the survey. The study estimated the median VOR of $19.56/hour.

Carrion and Levinson (2013) designed a GPS-based experiment to estimate the VOR of travelers on I-394 in Minnesota. The researchers used a web based application to recruit 18 regular commuters who had been using the study route. Relevant personal information was available from their application. The cars of the respondents were equipped with GPS devices to track their actual travel. For the first two weeks, the commuters traveled on each of the three alternatives (HOT lanes, general purpose lanes [GPLs] and adjacent signalized arterials) separately. During those two weeks they better understood the travel time and reliability on each route. After that they were instructed to travel on their preferred route. The design was able to depict a real world scenario, though the sample size was very small (18 respondents) to draw any unbiased conclusion. The study produced wide range of VOR depending on the travel time reliability definition.

Alemazkoor et al. (2014) used data from Katy Freeway, Houston, where travelers choose between Managed Lanes (MLs) and General Purpose Lane (GPLs). The dataset generated from automated vehicle identification (AVI) sensors placed at regular intervals along the freeway. They have attempted to find the best measure of reliability from standard deviation, 95^{th} percentile value, coefficient of variation, buffer time index, shorten right range, interquartile range, travel time index, and misery index. But many of the reliability measures lead to counter-intuitive results. Depending on the measures of reliability and traffic characteristics their estimated VOR varied from $1.98/hour to $24/hour. The study indicated that travelers on the Katy freeway might not consider travel time reliability when making lane choice decisions or the reliability measures used in the study could not represent the reliability perception of the travelers. The study indicated that one potential reason why they could not get expected results as they have used only one month of data with lack of variation in toll schedule. It should be noted that the current study will use similar data to what was used by Alemazkoor et al. (2014), but three years of travel data will be used instead of one month of data.

The revealed preference studies showed that the routes along high occupancy toll lanes are the most popular location for experiments. In general, travelers have two route alternatives: high occupancy toll lanes and parallel untolled lanes. In some of the revealed preference studies, the researchers approximated the travel time of the traveler using loop detector data or in field measurements (driving in similar traffic condition). There is a high possibility that travel data is different from the actual scenario. Using GPS device in respondents' car is an effective way to get actual travel time data but this method is costly and thus difficult to get a large enough sample to be representative of actual travelers.

In summary, the review of existing literature highlighted that comprehensive studies are available assessing VOT and most agencies have guidelines to estimate VOT to use in transport project appraisals. On the other hand, methods of estimating VOR are still a topic of debate. Most studies have used SP survey data to estimate VOT and VOR as a proper experiment design for RP data is complicated and generally not available. Moreover, estimated VOR vary significantly across studies based on estimation methodology and reliability measures used. As most of the researchers did not focus on survey data validation, it is difficult predict which estimates are more plausible than others. A few studies (Lam an Small, 2001, small et al. ,2005, and Carrion and Levinson, 2013)have used RP data to estimate VOR, but they either had a sample size too small to provide unbiased results or had to make some assumptions which might have an effect on the estimated value. The study by Alemazkoor et al. (2014) used one month of actual data and indicated that travelers might not consider travel time reliability while making lane choice decisions or the reliability measures used in the study could not represent the reliability perception of the travelers. Therefore, a more comprehensive study with RP data, collected for longer period with a varying toll schedule, may help to better understand the travelers' actual value of reliability and travel time saving.

3. DATA

3.1 Transponder Data

TxDOT collects transponder data using automated vehicle identification (AVI) sensors located on both the MLs and GPLs along the Katy Freeway. Figure 2 shows the location of the sensors where each number indicates a specific sensor. When a sensor detects a vehicle with transponder, it inserts a new record into a database where the sensor ID, detected vehicle's transponder ID, and detection time are recorded. All vehicles that pay a toll on the MLs are required to use a transponder. Many other vehicles traveling on GPLs also have transponders. The AVI data obtained from TxDOT contains all sensor detection records from most of 2012, 2013 and 2014. The data were obtained from TxDOT in October 2014 so the data only include up until September 2014. Also, some days at the end of December 2012 were missing and therefore, December 2012 was not included in the analysis.

The Harris County Toll Road Authority (HCTRA) operates AVI sensors along the MLs at the three toll plaza locations (see Figure 2 for HCTRA sensors). The data obtained from HCTRA included the unique transponder ID, toll plaza ID, and date and time of record for each vehicle traveling within the MLs for 2012, 2013 and 2014 (up through September as the data was obtained from HCTRA in October 2014). The primary objective of this research was to understand how much travelers were willing to pay to use the faster and more reliable MLs. Since the HOVs, during the HOV-free hours, did not pay a toll for using MLs they were not included in the analysis.

3.2 Toll Data

Based on the time of detection, and the toll schedule, tolls were assigned to the trips that were detected at toll plazas in the MLs. The total toll for each trip was equal to the sum of tolls paid at up to three toll booths. The toll rates and schedule are shown in Table 4 The toll schedule changed twice during the three years period where not only the toll rate was increased but also the span of peak and shoulder period were redefined

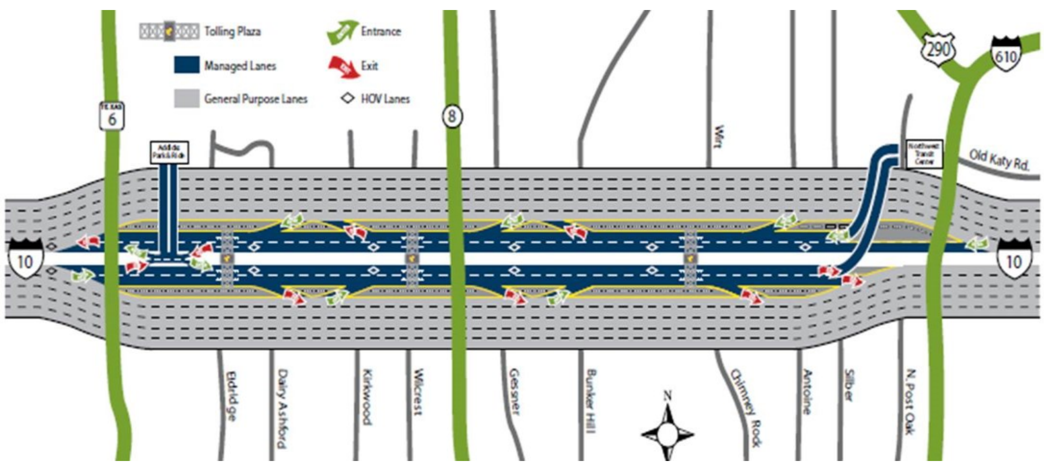

Figure 1 Katy Freeway (HCTRA, 2009)

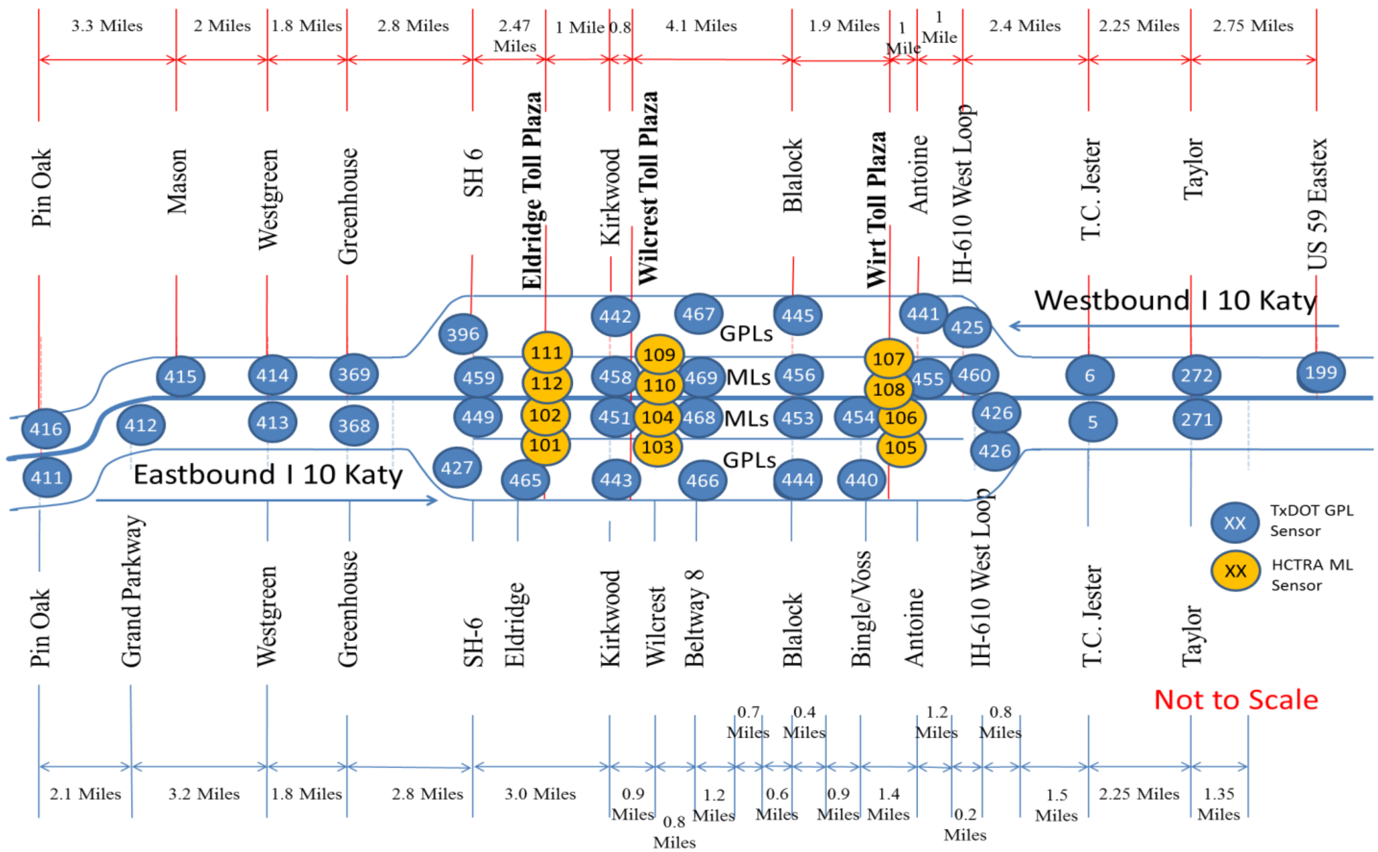

Figure 2 AVI sensors along Katy Freeway

Table 4 Katy managed lane toll rates

Dates	Direction	Time of Day	Toll at Eldridge (See Figure 2)	Toll at both Wilcrest and Wirt (See Figure 2)
Opening day (April 2009) to Sept 7, 2012	Westbound	Peak: 5-7pm weekdays	$1.60	$1.20
		Shoulder: 4-5 & 7-8 pm weekdays	$0.80	$0.60
		Off-peak: all other times	$0.40	$0.30
	Eastbound	Peak: 7-9am weekdays	$1.60	$1.20
		Shoulder: 6-7 & 9-10 am weekdays	$0.80	$0.60
		Off-peak: all other times	$0.40	$0.30
Sept 8, 2012 - Sept 7, 2013:	Westbound	Peak: 4-6 pm weekdays	$2.20	$1.40
		Shoulder: 3-4 & 6-7 pm weekdays	$1.10	$0.70
		Off-peak: all other times	$0.40	$0.30
	Eastbound	Peak: 7-9 am weekdays	$2.20	$1.40
		Shoulder: 6-7 & 9-10 am weekdays	$1.10	$0.70
		Off-peak: all other times	$0.40	$0.30
Sept 7, 2013 to today:	Westbound	Peak: 4-6 pm weekdays	$3.20	$1.90
		Shoulder: 3-4 & 6-7 pm weekdays	$2.10	$1.20
		Off-peak: all other times	$0.40	$0.30
	Eastbound	High Peak: 7-8 am weekdays	$3.20	$1.90
		Low Peak: 8-9 am weekdays	$2.60	$1.70
		High Shoulder: 6-7 am weekdays	$2.10	$1.20
		Low Shoulder: 9-10 am weekdays	$1.50	$1.00
		Off-peak: all other times	$0.40	$0.30

4. METHODOLOGY

This study will use data generated from automated vehicle identification (AVI) sensors from Katy Freeway travelers collected during most of 2012, 2013 and 2014. All transponder IDs were replaced with randomized ID after merging all data obtained from TxDOT and HCTRA. After randomizing the IDs, the raw AVI data had three attributes: randomized ID, sensor ID, and time of detection. From this raw dataset individual AVI records can be matched together based on the random ID to form a collective series of points that represent a trip. The GPL sensors were not originally designed to achieve 100% accuracy for all recorded trips, and some GPL trips were not accurately recorded. The total number of missed trips was unknown. However, millions of other trips were identified and a large enough sample size was found to perform the analysis. Travel time and distances from freeway travelers were calculated using the time and location of sequential detection of unique IDs. The time difference between two consecutive detections had to be less than 15 minutes to assume that each record was part of the same trip. Otherwise it was assumed the vehicle exited the freeway, possibly to purchase gas, coffee, etc., and then returned to the freeway and this would be two separate trips.

To estimate how much travelers value their travel time and travel time reliability it will be necessary to model the decision each traveler makes between the MLs and GPLs. Therefore, it is necessary to know both the attributes of the trip they made and the attributes of the trip on the alternate lanes. So for each trip on the MLs, the attributes of a similar trip on GPLs will needed, and vice versa. For each trip, simulated trip will be created for the lane set that was not chosen. Simulated trips should have the same start time and pass through the same section of the freeway but on the other set of lanes. For trips on the toll lane the simulated trip would be free on the GPLs. For trips on the GPLs there would be a tolled trip created.

Travel times will be calculated for each simulated trip by averaging travel times for similar freeway trips on the alternative lane (the lane that was not chosen). The simulated trips had to occur within the same 10-minute interval in which the actual trip was made. Average trip speeds will be used when no trips could be found from the alternative lane type. In this case, average speeds will be calculated using actual trips during the same time frame (off-peak, shoulder and peak), averaged across an entire month.

Statistical Analysis System (SAS) will be used to generate binary discrete-choice models of the two lane choices. Except for the randomized IDs, no information about the travelers, such as income, gender, purpose of trips, are available. This study will only use the information extracted from the trip data such as travel time, trip length, amount of tolls paid on MLs, and reliability of travel time. This study will use centrality dispersion framework (see Literature Review Section) to develop travelers' lane choice models:

$$U_{GPL} = \beta_{TT}\, TravelTime_{GPL} + \beta_{TTR}\, TravelTimeReliaiblity_{GPL} \tag{11}$$

$$\begin{aligned} U_{ML} = \beta_{ML} + \beta_{Toll}\, Toll + \beta_{TT}\, TravelTime_{ML} \\ + \beta_{TTR}\, TravelTimeReliaiblity_{ML} \end{aligned} \tag{12}$$

Where:

Ui = Utility derived by choosing lane i

ML = Managed Lane

GPL = General Purpose Lane

TT = Travel Time

TTR = Travel Time Reliability

β = coefficient derived from the logit model

Due to the size of the dataset it is possible to model each direction of traffic (eastbound and westbound) and time period (peak, off-peak and shoulder) separately. In this study, the commonly used measures of reliability, such as standard deviation (SD), coefficient of variation (CV), 95^{th} percentile value, shorten right range (SRR), interquartile range (IR) and buffer time index (BTI), will be used to develop the choice models. The definition of the reliability measures are described in Table 2.

In this study, reliability will be based on the consistency of travel times over the 20 weekdays prior to a given trip. To calculate the reliability measures for a given time of day and section of freeway, several statistical values such as mean, median, standard deviation and percentile (10th, 25th, 50th, 75th, 80th, 85th, 90th, and 95th) values of the travel time over the previous 20 weekdays will be calculated.

As the dataset allowed tracking all trips for a traveler on the Katy freeway, it provides an opportunity to see if a bad trip experience has an effect on his/her reliability perception or lane choice. For example, a bad trip experience on GPLs can lead a traveler to choose MLs for future trips. Perception of a bad trip experience may vary from traveler to traveler. To define a bad trip experience, the travel speed of that trip will be compared with the average speed during that time of day. The average speeds will be calculated for every 10 minute interval using the three years of travel data .In this study, a trip will be considered as a bad trip when the travel speed of that trip is less than a percentage (in this case 40%, 50%, 60%, and 75%) of the average travel speed.

Other trip attributes, such as number of trips on each lane which are indicators of travelers' familiarity with traffic condition on the Katy freeway, can be incorporated in the choice model. Familiarity with the traffic condition during a particular time of a day in certain direction can influence travelers' lane choice decision. For example, a traveler may choose managed lane in westbound direction during peak period because of his familiarity with bad traffic conditions during that time. Due to the size of the dataset it is possible to calculate traveler familiarity variable for each direction of traffic (eastbound and westbound) and time period (peak, off-peak and shoulder) separately. Models will be developed to see how the travelers' familiarity with the freeway and recent bad trip experience can affect their lane choice decision.

5. DATA ANALYSIS

5.1 Processing of Data

5.1.1 Cleaning, Merging and Randomization of Data

The data generated form AVI sensors were obtained from two sources: TxDOT and HCTRA. The first step was to remove all attribute other than transponder ID, time stamp and sensor ID from both dataset. Then all entries with a missing attribute were removed and two dataset were merged to obtain raw AVI dataset. The raw AVI dataset had three attributes: transponder ID, sensor ID, and date and time of detection.

To make sure that no transponder owner could be identified using the transponder IDs, each transponder ID was replaced by a unique random ID. Therefore, the dataset could never be used to identify a specific individuals traveling on the Katy Freeway, but the dataset could still be used to track the trips of vehicles throughout the three years based on the random ID that each vehicle was assigned.

5.1.2 Exclusion of Specific Entries

To estimate a logit model for lane choice, it was necessary to have details for trips in both lanes. This meant generating trips in alternate lane (MLs for GPLs and vice versa). Therefore, each AVI sensor passed as a part of a trip was matched with a sensor on the alternate lane group to generate an alternate trip. Moreover, there are more AVI sensors on MLs than on the GPLs, which results in having more than one alternate ML sensor for some of the GPL sensors(for example, for GPL sensor number 443 there are two alternate sensors on the MLs: 451 and 103). To address this discrepancy, the records obtained from the five TxDOT operated sensors (451, 454, 455, 458, and 459) were removed from data.

5.1.3 Trip Identification

Based on the AVI reads the trips of all vehicles with transponders along the freeway can be estimated. Individual AVI records can be matched together to form a collective series of points that represent a trip along the freeway. It should be noted that some GPL trips were not accurately recorded, as the AVI sensors operated by TxDOT were not originally designed to achieve 100% accuracy. The total numbers of missing data are unknown. However, millions of other trips were identified; therefore the sample is large enough to perform the analysis.

Travel time and distance traveled on the freeway were calculated using the time and location of the sequential detection of unique IDs. If the time difference between two consecutive detections was more than 15 minutes, those two detections were considered as part of two separate trips. It was assumed the vehicle exited the freeway, possibly to purchase gas, coffee, etc., and then returned to the freeway. Table 5shows the number and percentage of trips that would have decreased if a different time limit (20, 30, 40, 50, 60 minutes) were considered. Based on the fact very few additional trips would be added if the time limit were raised, it seemed that a 15 minute time limit would be reasonable

Table 5 Decrease in the number of trips based on time limit between detection

Time limit	Decrease in the Number of Trips	Percentage change in number of trips
20	1640	0.01%
30	19451	0.08%
40	64303	0.28%
50	111452	0.48%
60	140156	0.60%

* Three years of data (peak and shoulder period only) were considered and there were 23364508 trips during this period
* In the study 15 minutes were considered

5.1.4 Assigning Tolls and Removing HOV Trips

A toll was assigned to a trip when it was detected at one of the toll plazas. The toll was based on the time of detection and the corresponding toll value in the toll schedule (Table 4). As mentioned in an earlier section, during HOV-free hours HOVs can use the managed lane for free. Therefore, a vehicle detected by the HOV sensor during HOV-free hours was deleted from the dataset.

5.1.5 Alternate Trip Generation

For each trip an alternate trip was generated. This means if a traveler made a trip on MLs, his/her alternate trip would be a trip made during same time on the GPLs, and vice versa. The alternate trip should pass through the same freeway section but on the other set of lanes (GPL for ML trips and ML for GPL trips). It was assumed that the start time of an actual trip and its alternate trip were the same. The length of the alternate trip varied a small amount (up to 0.3 miles) depending on the relative location of sensors on both sets of lanes. The two trips were made equivalent by multiplying the travel time and some reliability measures for the alternate trips by the ratio of the actual trip length to the alternate trip length. For example, assume the actual trip was on the GPLs and the sensors were spaced 1 mile apart. Then the alternate trip would be on the MLs. If the corresponding ML sensors were located 1.1 miles apart then some ML data would be multiplied by 0.91 (1/1.1) to adjust it to be equivalent to the trip on the GPLs.

Table 6 Average travel speeds by period

Period	Average Speed on the Toll Lanes (in mph)	Average Speed on the GPLs (in mph)
Peak Period	53.1	40.8
Shoulder	61.8	55.1
Off-Peak Period	70.9	65.3

* The speed comparisons are for the entire trip identified, which may include short parts of the trip that are outside the 12 miles of the toll lane

Depending on the data availability, alternate trips can be divided into three types. Travel times were calculated for each simulated trip by averaging travel times for similar freeway trips on the alternative lane (the lane that was not chosen). The simulated trips had to occur within the same 10-minute interval in which the actual trip was made. Average trip speeds were used when no trips could be found from the alternative lane type. In this case, average speeds were calculated using actual trips during the same time frame (off-peak, shoulder and peak), averaged across an entire month (see Table 6).

The three types are:

1. Alternate trip type 1: Data from other travelers' actual trips were available to calculate the attributes of alternate trips.

2. Alternate trip type 2: Data from other travelers' actual trips were available in majority, but not all, segments in the alternate lane. For example, to calculate the attributes of an alternate trip (A-B-C-D) , when data from other travelers' actual trips were available in the segment of A-B and C-D and no actual trip identified during that time in the segment of B-C, travel time of B-C segment was approximated using average travel speed (see Table 6) and length of segment.

3. Alternate trip type 3: No actual trips were found in any segment of the potential alternate trip. Travel time was approximated using average travel speed (see Table 6) and length of segment.

Only 1.3% of the alternate trips' travel times were approximated during peak hours and 7.8% during the off-peak hours.

Table 7 Number of alternate trips by type

Time of Day	Type 1	Type 2	Type 3
Peak Hour	6014328	5929876	155378
Shoulder Hour	4004626	7077018	183282
Off-Peak Hour	9194560	62877649	6093964

Table 8 Percentage of alternate trips by type

Time of Day	Type 1	Type 2	Type 3
Peak Hour	49.7%	49.0%	1.3%
Shoulder Hour	35.5%	62.8%	1.6%
Off-Peak Hour	11.8%	80.4%	7.8%

5.1.6 Travel Time Reliability

In this study, reliability was based on the variability of travel times over the 20 weekdays prior to a given trip. To calculate the reliability measures for a given time of day and section of freeway, several statistical values such as mean, median, standard deviation and percentile (10th, 25th, 50th, 75th, 80th, 85th, 90th, and 95th) values of the travel time over the previous 20 weekdays were needed.

Reliability measures were calculated for every 10 minutes. The required statistical values of travel time between a given pair of sensors for a given time interval on a specific day were calculated using the average travel times observed during the previous 20 weekdays. For example, to calculate reliability for a trip between sensors 465 and 444 (see Figure 2) during 12:00 pm-12:10 pm on July, 29th 2012, the first step was to calculate average travel time observed between sensors 465 and 444 during 12:00 pm-12:10 pm on each weekday from July 1st to July 28th . The required statistical values were then calculated using these average travel times. Ideally there should be 20 travel times to use to calculate the reliability measures. However, there were often less than 20 days with traffic during specific periods of the day at specific locations - particularly overnight. If there were less than 3 days of data available then there was insufficient data to determine the reliability for that specific 10-minute period. This removed approximately 4% of the overall trip data. It should be noted that, in some cases, no trip was observed starting and ending at a pair of sensors located close together, as vehicles were traveling longer distances. In those cases the average travel time between a pair of closely-located sensors was approximated using data from longer trips, given that the travelers who made those longer trips also passed the closely-spaced sensors. Suppose, on a specific day during 12:00 pm -12:10 pm, there were no trips that started at sensor 443 and ended at sensor 466 (see Figure 2). However, on that day during that time period, there might be many trips from sensor 465 to sensor 466, from sensor 443 to sensor 444, or from sensor 465 to sensor 440. Form the trip data between the pairs of sensors mentioned above, the time required to travel between sensor 443 and 466 could be estimated based on the speeds of vehicles traveling between 465 to 466, 443 to 444, and 465 to 440. The estimated speed could be used to approximate the average travel time between sensor 443 and 466 during that that specific 10-munite period.

The free flow travel time was required to calculate some of the reliability measures. The free flow travel time is a function of free flow speed and trip length. The free flow speed is the speed of a traffic stream when the traffic density is very low. For this study, the median speed of vehicles that traveled between 11:00 pm and 12:00 pm during weekends in July 2012 and August 2012 was used as the free flow speed. The result suggests that the free flow speed was 68.8 mph on the managed lanes and 67.1 mph on the general purpose lanes.

5.2 Overview of Paid ML Trips

This section will discuss the initial examination of the general size and scope of the data used in this analysis. Approximately 3 million trips per month were assessed. The numbers of trips recorded during the three-year period are shown in

Table 9. It should be noted that these data exclude trips taken by vehicles without transponders, free ML trips (e.g. carpools or HOVs), and trips where the location of sensors restricted the capability of determining where a trip had occurred. Despite the high number, the sample is only a fraction of all Katy Freeway trips taken during the three-year period. However, this dataset should be well beyond what is needed to estimate travelers' willingness to pay for travel time savings and reliability, considering previous research has been based on a few hundred to a few thousand travelers.

Table 9 Number of recorded trips

Year	Number of Trips on the General Purpose Lane	Number of paid Trips on the Managed Lane	Total Trips
2012 (January - November)	31,247,230	2,011,608	33,258,838
2013 (January - December)	36,017,349	2,601,242	38,618,591
2014 (January - September)	32,053,989	2,400,737	29,653,252

The number and percentage of paid ML trips are shown in Table 10. A surprisingly large number of trips, almost 3.4 million, use the MLs during the off-peak period. This represents only 4.31% of the total trips recorded during the off-peak period. During peak hours the use of MLs increased significantly, 19.28% of transponders detected during the peak periods used the MLs. Figure 3 presents the toll those trips paid, and Figure 4 shows the travel time savings.

Table 10 Paid trips on managed lane

Time Period (see Table 4 for times of day)	Number of Trips on the Managed Lanes	Percentage of All Trips that Were Paid Trips on the Managed Lanes
Off-Peak	3,379,635	4.31%
Shoulder	1,300,189	11.55%
Peak	2,333,763	19.28%

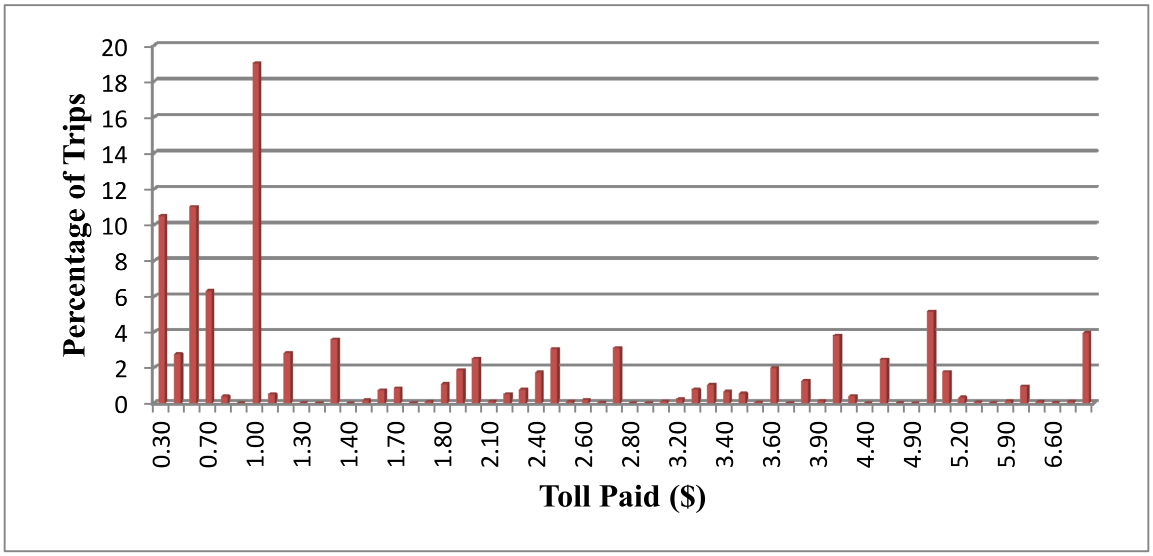

Figure 3 Total toll paid on the managed lanes

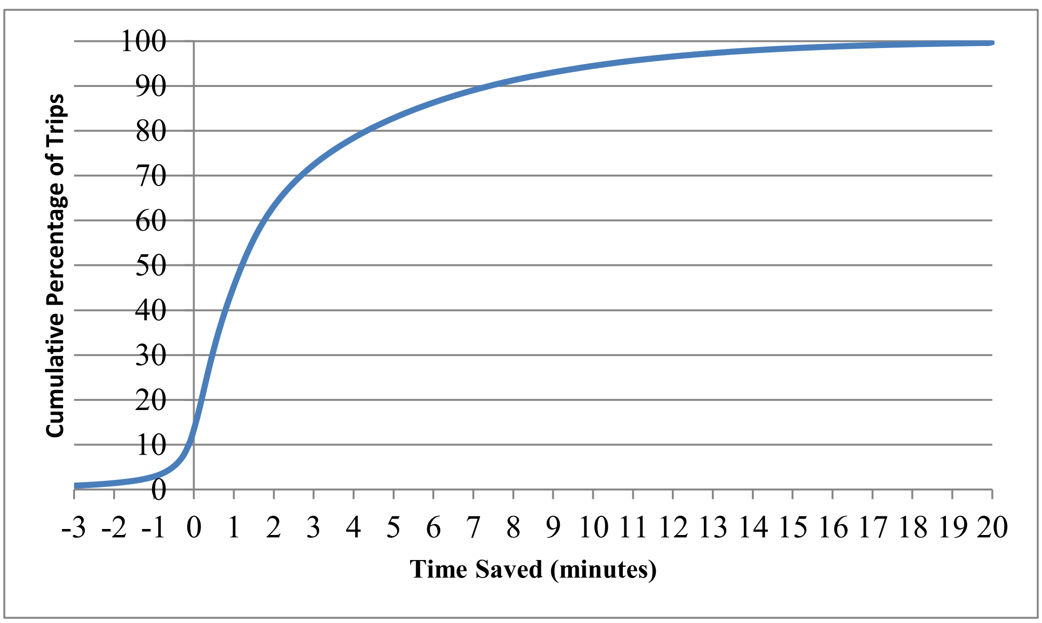

Figure 4 Travel time saved (minutes) on the managed lanes

The travel time saved on MLs ranged from -3.3 minutes (the MLs were slower) to over 20 minutes. Approximately 11% of all paid trips on the MLs did not save any travel time. The average travel time savings was 2.6 minutes. It should be noted that there were many short trips on the MLs (as can be seen from the tolls paid in Figure 3) and this likely accounts for many of the smaller time savings. The travel time savings were not similar in both directions. Westbound traffic averaged twice as much travel time savings as east bound traffic on the MLs (see Table 11). If the time saved for a specific ML trip is divided by the toll paid on that trip the result is shown in Figure 5.

Table 11 Travel time saving on the managed lane

	Travel time savings (minutes)		Travel time savings (minutes per mile)	
	Eastbound	Westbound	Eastbound	Westbound
Peak	2.7	5.9	0.4	0.7
Shoulder	1.7	3.6	0.2	0.4
off-Peak	0.7	1.4	0.1	0.2

Figure 6 summarizes the number of trips by the length driven in the study corridor. It should be noted that the length of a trip presented here is based on the location of sensors, so it is not possible to know their actual origin and destination, or the entire length of the trip. The most common trip length was between 4 miles to 8 miles. As trip length increased above 8 miles, the number of those trips decreased.

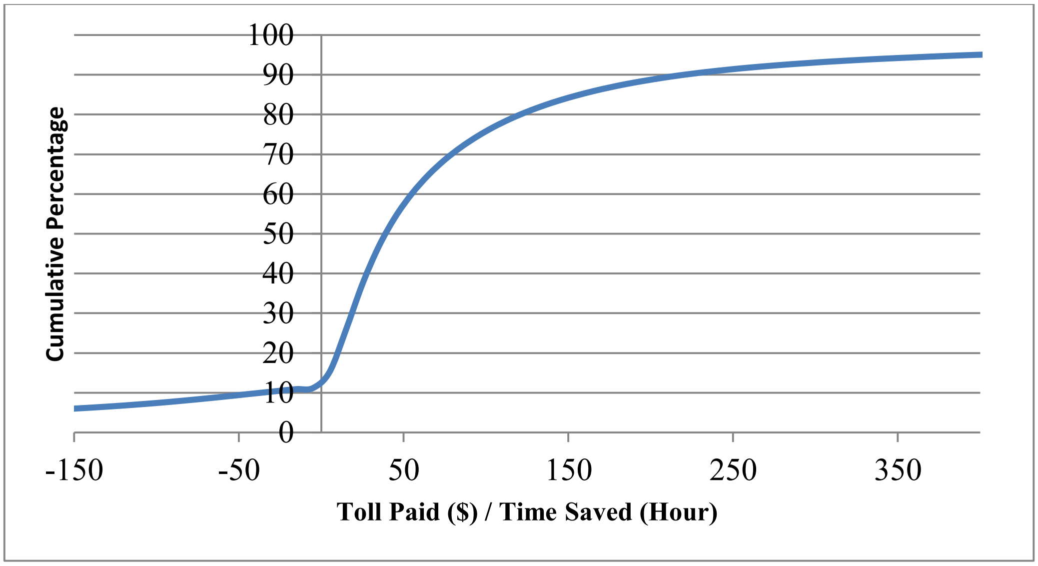

Figure 5 Toll paid divided by time saved

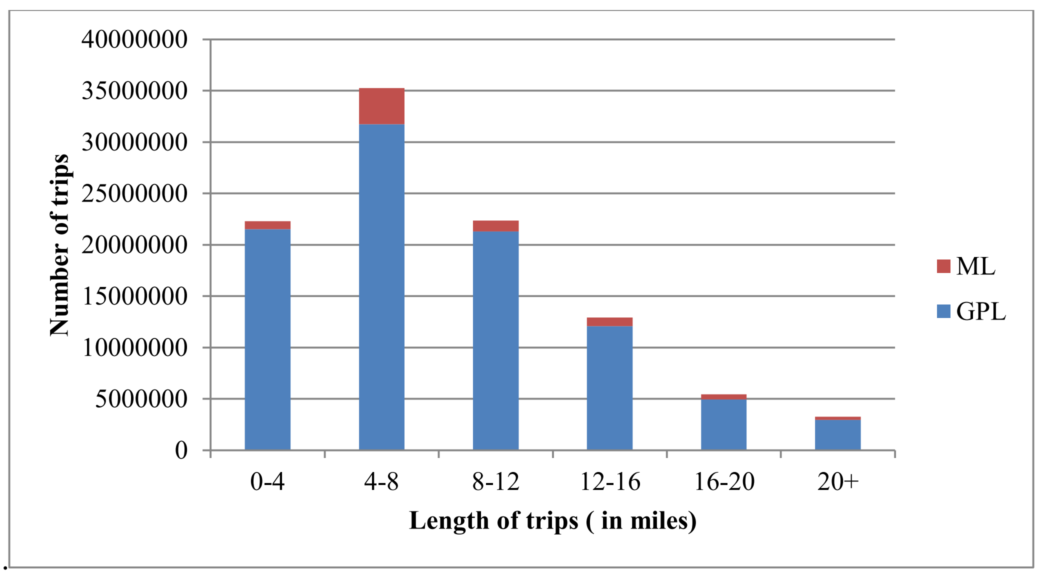

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Figure 6 Number of trips by length

5.2.1 Frequency of Paid ML Use

Next, the distribution of paid ML use by the different transponders was examined. A majority (79%) of the different transponder IDs, identified on the Katy Freeway, never used the MLs during this entire 3-year period (see Figure 7). They most likely purchased their transponders for travel on different toll facilities. The traveler's likelihood to use the paid MLs when they traveled on the Katy Freeway was also examined. As before, 79% of the travelers never used the MLs for any of their trips (see Figure 8). Approximately 9.4% used the lanes for a small percentage (1%-10%) of their Katy Freeway trips. Some travelers, almost 3.5 %, used the MLs for all of their Katy Freeway trips.

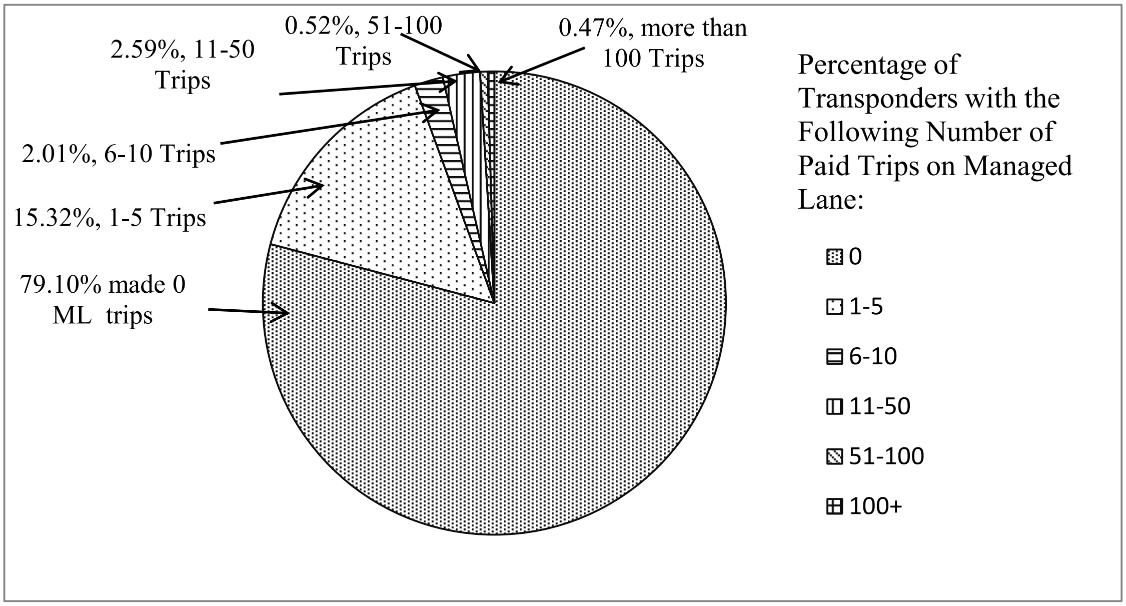

Figure 7 ML trips made by all transponders recorded on the freeway

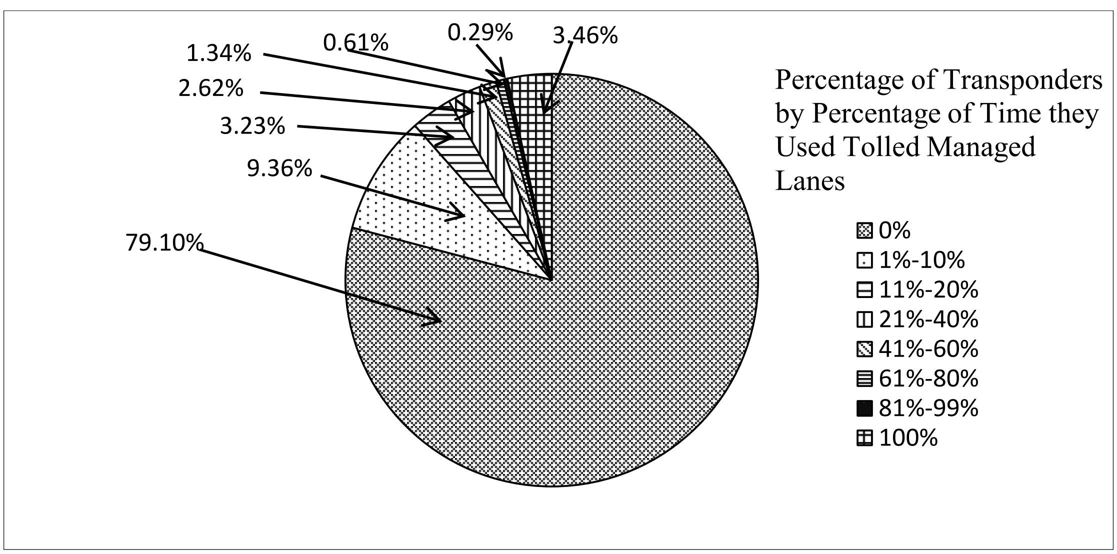

Figure 8 Percentage of trips that were paid ML trips by transponder

5.3 VOT and VOR Analysis

5.3.1 Value of Time Estimation Using Basic Models

Models were estimated using many combinations of trip data. Because of the size of the dataset it was possible to model each direction of traffic (eastbound or westbound) and time period (peak, off-peak and shoulder) separately and create one model per month.

First, simple models were developed with only two independent variables: travel time and toll. Intuitively, a decrease in travel time and toll should lead to an increase in utility. Models of two-way traffic had negative coefficients, as expected. The results suggested that the value of travel time varied from \$1.96/hour (May, 2013) to \$8.06/hour (September, 2012) (see Table 12). When separated by direction, models of westbound traffic had negative coefficients for both time and toll. In models of eastbound traffic, there were several cases where the coefficient of travel time was positive (see Table 12), which is counter-intuitive as it could only occur if travelers were paying tolls in the ML even though they were not saving travel time. When the models were separated for peak, off-peak and shoulder period, the values of time obtained from basic VOT models (see Table 13) showed a consistent pattern for eastbound traffic: the value of time increased from off-peak periods to shoulder periods to peak periods. But for westbound traffic there were many cases, especially during peak and off-peak hour, where the value of time was negative.

Table 12 Basic VOT results by month

Model: $U_{ML} = \beta_{Time} \times Time_{ML} + \beta_{Toll} \times Toll$, $U_{GPL} = \beta_{Time} \times Ttime_{GPL}$										
		Two-way			Eastbound			Westbound		
Year	Month	β_{Time}	β_{Toll}	VOT ($/hour)	β_{Time}	β_{Toll}	VOT ($/hour)	β_{Time}	β_{Toll}	VOT ($/hour)
2012	January	-0.264	-2.152	7.37	-0.141	-1.993	4.26	-0.320	-2.291	8.40
	February	-0.234	-2.018	6.97	-0.133	-1.828	4.36	-0.307	-2.214	8.34
	March	-0.188	-1.993	5.67	-0.078	-1.829	2.56	-0.268	-2.165	7.44
	April	-0.195	-1.871	6.28	-0.082	-1.669	2.96	-0.285	-2.091	8.19
	May	-0.091	-1.328	4.13	0.000	-1.181	-0.02	-0.156	-1.481	6.35
	June	-0.161	-1.770	5.47	0.012	-1.576	-0.46	-0.275	-1.984	8.32
	July	-0.182	-1.888	5.78	-0.029	-1.726	1.02	-0.256	-2.036	7.57
	August	-0.141	-1.441	5.89	-0.073	-1.394	3.15	-0.173	-1.482	7.04
	September	-0.174	-1.301	8.06	-0.190	-1.295	8.83	-0.167	-1.309	7.67
	October	-0.186	-1.432	7.80	-0.115	-1.411	4.91	-0.216	-1.448	8.95
	November	-0.144	-1.587	5.44	-0.037	-1.699	1.33	-0.192	-1.522	7.57
2013	January	-0.149	-1.545	5.80	-0.045	-1.643	1.66	-0.160	-1.435	6.71
	February	-0.125	-1.418	5.31	-0.029	-1.456	1.23	-0.164	-1.381	7.13
	March	-0.138	-1.602	5.20	-0.023	-1.681	0.83	-0.198	-1.546	7.70
	April	-0.139	-1.361	6.14	-0.027	-1.373	1.20	-0.183	-1.345	8.19
	May	-0.033	-1.014	1.96	0.015	-1.084	-0.87	-0.058	-0.954	3.68
	June	-0.069	-1.095	3.82	0.070	-1.028	-4.12	-0.124	-1.141	6.57
	July	-0.123	-1.363	5.42	0.007	-1.354	-0.33	-0.197	-1.402	8.45
	August	-0.063	-1.129	3.37	0.003	-1.271	-0.15	-0.095	-1.021	5.59
	September	-0.062	-0.825	4.56	-0.075	-0.899	5.01	-0.049	-0.762	3.93
	October	-0.058	-0.883	3.95	-0.073	-1.046	4.23	-0.042	-0.758	3.33
	November	-0.040	-1.105	2.19	-0.016	-1.156	0.84	-0.064	-1.066	3.63
	December	-0.066	-1.390	2.86	0.012	-1.514	-0.49	-0.122	-1.305	5.61
2014	January	-0.079	-0.938	5.07	-0.043	-0.990	2.63	-0.083	-0.885	5.68
	February	-0.042	-0.709	3.58	-0.042	-0.790	3.20	-0.032	-0.635	3.07
	March	-0.051	-0.814	3.80	0.019	-0.768	-1.51	-0.087	-0.858	6.10
	April	-0.072	-0.782	5.54	-0.081	-0.776	6.30	-0.069	-0.789	5.32
	May	-0.090	-0.752	7.20	-0.078	-0.735	6.42	-0.097	-0.767	7.58
	June	-0.067	-0.719	5.59	-0.024	-0.685	2.10	-0.087	-0.751	7.02
	July	-0.060	-0.770	4.71	0.018	-0.744	-1.46	-0.091	-0.795	6.87
	August	-0.062	-0.710	5.27	-0.010	-0.704	0.92	-0.079	-0.710	6.68
	September	-0.073	-0.666	6.62	-0.075	-0.644	7.00	-0.075	-0.686	6.58

Table 13 Value of travel time ($/hour) by time period

Model: $U_{ML} = \beta_{Time} \times Time_{ML} + \beta_{Toll} \times Toll$, $U_{GPL} = \beta_{Time} \times Ttime_{GPL}$										
		Peak period			Shoulder Period			Off-Peak Period		
Year	Month	Two-way	Eastbound	Westbound	Two-way	Eastbound	Westbound	Two-way	Eastbound	Westbound
2012	January	4.44	10.59	2.54	7.17	5.13	7.49	1.12	1.89	0.08
	February	6.11	14.12	3.67	6.77	3.84	7.56	1.47	2.39	0.42
	March	5.07	14.30	1.61	6.68	4.54	7.02	2.16	2.78	0.70
	April	5.36	11.57	3.22	6.96	3.02	7.78	2.02	2.68	0.71
	June	5.27	4.54	3.82	7.65	4.03	7.84	2.40	3.01	0.89
	July	5.65	8.61	4.51	6.86	3.77	7.2	1.62	2.46	0.24
	August	0.57	11.17	-13.40	5.82	3.14	5.24	1.64	2.74	-0.34
	September	5.60	19.48	-4.51	3.95	5.05	3.19	2.08	3.15	-0.27
	October	5.58	14.45	0.66	3.48	3.76	3.14	1.94	3.09	-0.59
	November	6.10	11.11	2.83	3.23	4.51	2.37	2.00	2.46	0.07
2013	January	3.90	6.57	1.21	2.16	2.05	1.71	1.49	2.47	-0.68
	February	4.79	11.99	-1.31	1.15	3.05	-0.17	1.97	2.63	0.14
	March	7.02	14.36	2.05	2.72	1.96	2.3	2.31	2.86	-0.12
	April	5.48	7.28	0.71	2.84	2.28	2.46	1.91	2.90	-0.38
	May	-8.92	2.72	-50.36	-3.54	-1.44	-6.5	1.85	2.62	-2.55
	June	-0.79	-8.11	-10.48	1.35	0.03	0.81	2.50	3.34	-0.73
	July	6.26	0.92	2.56	4.36	2.1	4.13	2.94	3.47	-0.65
	August	-2.12	6.13	-25.61	2.61	1.34	1.52	2.87	3.56	0.75
	September	2.51	20.79	-14.52	2.57	4.05	1.28	3.04	3.84	0.21
	October	3.07	16.72	-14.39	2.05	6.88	-0.78	2.55	3.63	0.18
	November	4.04	16.47	-3.98	2.32	8.48	-0.19	2.85	3.21	0.64
	December	7.42	15.36	5.11	2.55	1.83	1.97	2.81	3.34	0.30
2014	January	6.44	18.46	3.37	2.61	5.2	1.71	2.60	3.79	0.36
	February	1.95	16.55	-9.36	1.65	5.81	-0.93	2.59	3.97	0.35
	March	4.69	13.30	2.00	2.35	1.7	2.14	2.41	3.65	0.35
	April	3.14	16.93	-2.55	3.95	6.67	2.64	2.85	4.81	0.06
	May	7.61	21.36	2.35	4.79	6	3.84	3.13	5.20	-0.03
	June	5.29	12.85	0.61	4.45	6.71	3.18	3.55	5.40	-0.49
	July	5.35	0.75	1.37	4.25	4.25	3.01	3.24	5.08	-0.32
	August	6.56	16.94	0.92	3.52	2.03	2.49	3.22	5.02	0.15
	September	8.75	20.93	5.46	3.31	2.66	3.6	2.99	4.81	0.08

5.3.2 Basic VOT and VOR Models by Month

Next models were developed using travel time, toll, and a reliability measure. This study considered six potential measures of travel time reliability: standard deviation (SD), coefficient of variation (CV), 95th percentile value, shorten right range (SRR), interquartile range (IR) and buffer time index (BTI). The definitions of the reliability measures can be found in Table 2. Before proceeding to estimate models the correlation between travel time and travel time reliability was examined. As expected, travel time and 95th percentile value of travel time had a strong positive correlation (coefficient of correlation was 0.857). On the other hand, weak negative correlations were found for the coefficient of variation (-0.065) and buffer time index (-0.023) (see Table 14).

Table 14 Correlation between travel time and travel time reliability

Travel Time Reliability Measure	Correlation Coefficient			
	Time of Day			
	Whole day	Peak	Shoulder	Off-peak
Standard Deviation	0.556	0.687	0.589	0.406
Coefficient of Variation	-0.065	-0.154	-0.06	-0.058
95th Percentile value	0.857	0.863	0.845	0.818
Interquartile Range (IR)	0.513	0.609	0.536	0.347
Shorten Right Range (SRR)	0.464	0.535	0.468	0.402
Buffer Time Index	-0.023	-0.226	0.124	-0.064

An increase in one of these reliability measures indicates a decrease in reliability. Therefore, an increase in the reliability measure should lead to a decrease in utility. In this study, an expected result for a model means the model coefficients (time, toll, and reliability) are negatives. Table 15summarizes the frequency of expected results for different combinations of traffic data and reliability measures. As one model per month was created, there were 29 cases for each combination. During the off-peak period, the models of two-way and eastbound traffic had the expected results in all cases when standard deviation, 95th percentile, interquartile range, or shorten right range were used as reliability measures. For most reliability measures the models of westbound traffic had the expected results in less than 10 out of 29 cases, which could only occur if travelers were paying to use the MLs even though the MLs were less reliable and/or slower than the GPLs.

For most combinations of traffic data, only the models with buffer time index (BTI) as the reliability measure had expected results in 20 or more cases. The model results are documented in the Appendix A (from Table A1 to Table A12).

In summary, lane choice behavior is different in the eastbound and westbound directions. In the westbound direction no model with a reliability measure yielded expected results on a consistent basis. For eastbound and two-way traffic, during off-peak period, most of the models yielded anticipated results.

Table 15 Model results summary

Direction	Reliability Measure→ / Time of Day↓	Standard Deviation	Coefficient of Variation	95th Percentile	Interquartile Range	Shorten Right Range	Buffer Time Index
Two-way	Peak						
	Shoulder						
	Off-peak						
Eastbound	Peak						
	Shoulder						
	Off-peak						
Westbound	Peak						
	Shoulder						
	Off-peak						

1. Expected Results in 29 out of 29 cases
2. Expected Results in 20-28 out of 29 cases
3. Expected Results in 10-19 out of 29 cases
4. Expected Results in less than 10 out of 29 cases

* Expected results mean all model coefficients were negative

5.3.3 VOT and VOR Models without Uneconomical Trips and Non-switching Travelers

None of the reliability measures used in this study yielded the expected results on a consistent basis. One reason might be that approximately 11% of all paid trips on the MLs did not save any travel time (termed uneconomical trips). Therefore, new models were developed excluding these uneconomical trips. Exclusion of these uneconomical trips increased the number of cases with expected results (see Table 16), but again, no reliability measures yielded consistent results. Among the six reliability measures, 95th percentile value, shorten right range and buffer time index more often yielded the expected results.

Another reason might be that 82.6% of total detected transponder equipped vehicles never changed their lane choice: 79.1% of transponders always used the GPLs and 3.4% of transponders always used the MLs. Since these travelers appear to have a set lane and they do not deviate we decided to try to estimate the discrete choice models without them. Therefore, new models were developed using only those travelers who used each lane at least once during the three years of the analysis. The 17.4% of total detected transponders that used each lane at least once represented 55.4% of all trips. The 95th percentile value, shorten right range and buffer time index were tested as reliability measures as they yielded better results in the previous models. The exclusion of these 44.6% of all trips, which were mostly GPL trips, resulted in a large increase in the models providing results as expected (see Table 16 and Table 16). However, no reliability measure yielded consistent results.

Finally, models were developed that excluded both uneconomical trips and those transponders that always chose the same lane. This resulted in only a small reduction in the number of travelers included in the model: 17.3% of total transponders and 53.5% of total trips. The results yielded a small improvement in terms of expected results (Table 18). However, despite removing 46.5% of all trips from the dataset, no reliability measure consistently provided results as expected – many yielded VOT and VOR that were negative for at least some time periods in some directions.

Table 16 Model results summary for the travelers who had at least one trip on each lane

Direction	Reliability Measure→ Time of Day↓	95th Percentile	Shorten Right Range	Buffer Time Index
Two-way	Peak			
	Shoulder			
	Off-peak			
Eastbound	Peak			
	Shoulder			
	Off-peak			
Westbound	Peak			
	Shoulder			
	Off-peak			

1. Expected Results in 29 out of 29 cases
2. Expected Results in 20-28 out of 29 cases
3. Expected Results in 10-19 out of 29 cases
4. Expected Results in less than 10 out of 29 cases

* Expected results mean all model coefficients were negative

Table 17 Number of cases where anticipated result was seen

Direction	Traffic Data→ / Reliability Measure→ / Time of Day↓	All trips			All trips excluding Uneconomical trips		
		95th Percentile	Shorten Right Range	Buffer Time Index	95th Percentile	Shorten Right Range	Buffer Time Index
Two-way	Peak	3	9	6	29	29	27
	Shoulder	19	26	23	11	18	29
	Off-peak	29	29	28	29	29	22
Eastbound	Peak	22	22	16	29	27	12
	Shoulder	6	3	3	25	22	16
	Off-peak	29	29	19	5	3	2
Westbound	Peak	1	2	10	29	29	29
	Shoulder	11	10	8	2	9	23
	Off-peak	4	7	12	24	29	6
Total (out of 261 cases)		124	137	125	183	195	166

Table 18 Number of cases where anticipated result was seen (for travelers who had at least one trip on each lane)

Direction	Traffic Data→	Travelers who had at least one trips on each lane			Travelers who had at least one trips on each lane excluding Uneconomical trips		
	Reliability Measure→ / Time of Day↓	95th Percentile	Shorten Right Range	Buffer Time Index	95th Percentile	Shorten Right Range	Buffer Time Index
Two-way	Peak	8	16	26	17	27	29
	Shoulder	26	28	27	29	29	25
	Off-peak	29	29	28	29	29	27
Eastbound	Peak	25	23	20	25	24	20
	Shoulder	19	5	10	14	4	7
	Off-peak	29	29	20	29	28	16
Westbound	Peak	1	6	18	6	14	25
	Shoulder	23	27	24	29	29	22
	Off-peak	28	28	28	29	29	28
Total (out of 261 cases)		188	191	201	207	213	199

5.4 The Impact of a Bad Trip Experience on Lane Choice

As the dataset allowed tracking all trips for a traveler on the Katy freeway, it provides an opportunity to see how reliability of the lanes impacts lane choice. For example, a bad trip experience on GPLs might lead a traveler to choose MLs for future trips. Two dummy variables (BTE_{ML} and BTE_{GPL}) were introduced in the utility function to observe the effect of a bad trip on lane choice models. The dummy variable BTE_{ML} represented whether a traveler had at least one bad ML trip in his/her previous 5 trips and the dummy variable BTE_{GPL} represented whether a traveler had at least one bad GPL trip experience in his/her previous 5 trips. Therefore, to develop models using BTE variables, only travelers who had more than 5 trips in three years were used. Only 50.8% of the total detected transponders had more than 5 trips in three years, but they represented vehicles that took 96.7% of all trips.

Perception of a bad trip experience may vary from traveler to traveler. To define a bad trip experience, the travel speed of that trip was compared with the average speed during that time of day. The average speeds were calculated for every 10 minute interval using the three years of trip data.

Figure **9** shows the average travel time during weekdays for the three years. During off-peak period, the typical average speed was around 70 mph on the MLs and around 65 mph on the GPLs. During the evening peak period, the average speed dropped in all lanes. In this study, a trip is considered a bad trip when the travel speed of that trip is less than a percentage (in this case 40%, 50%, 60%, and 75%) of the average travel speed.

Two sets of models were estimated: one set was for whole data and other set was for travelers who had at least one trip on each lane. The results suggested that, for the both traffic datasets, the model coefficients of BTE_{ML} and BTE_{GPL} were large, significant, and positive in all cases (see Table 19 and Table 20), which implied that travelers were not willing to change their lane choice decision even though they had a recent bad trip experience on a given lane.

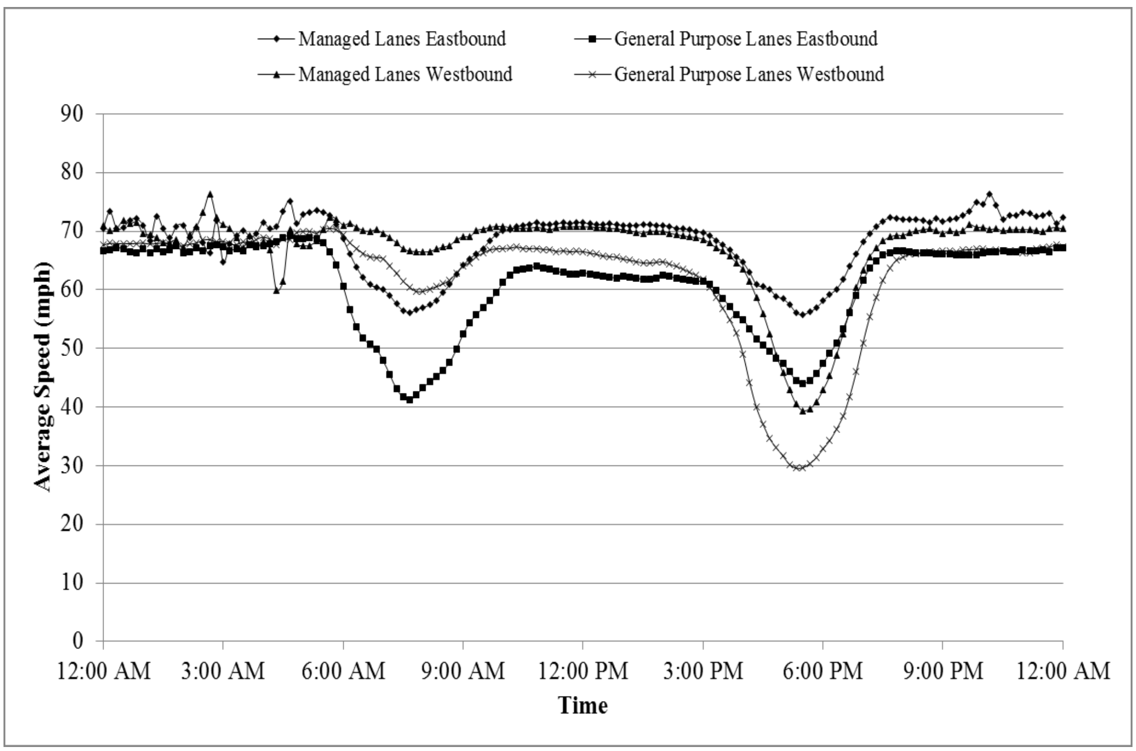

Figure 9 Average travel speed distribution

Table 19 Logit models with time and toll and bad trip experience as independent variable

Variable	Coefficient					
	Peak Period		Shoulder Period		Off-Peak Period	
	Eastbound	Westbound	Eastbound	Westbound	Eastbound	Westbound
Model: $U_{ML} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEML} \times BTE_{ML}$ $U_{GPL} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEGPL} \times BTE_{GPL}$ Bad trip experience (BTE) occurs when travel speed was less than 75% of typical average speed						
Time	-0.13	-0.02	-0.11	-0.06	-0.29	-0.07
Toll	-0.33	-0.19	-0.83	-0.63	-4.28	-5.93
BTE_{ML}	2.16	2.33	2.04	2.06	1.92	0.61
BTE_{GPL}	2.20	2.19	2.20	2.23	1.56	1.79
Model: $U_{ML} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEML} \times BTE_{ML}$ $U_{GPL} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEGPL} \times BTE_{GPL}$ Bad trip experience (BTE) occurs when travel speed was less than 60% of typical average speed						
Time	-0.12	-0.01	-0.07	-0.05	-0.28	-0.05
Toll	-0.38	-0.21	-0.91	-0.69	-4.50	-6.21
BTE_{ML}	1.86	1.82	1.78	1.66	1.58	0.48
BTE_{GPL}	1.67	1.70	1.72	1.84	1.42	1.89
Model: $U_{ML} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEML} \times BTE_{ML}$ $U_{GPL} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEGPL} \times BTE_{GPL}$ Bad trip experience (BTE) occurs when travel speed was less than 50% of typical average speed						
Time	-0.10	0.00	-0.05	-0.04	-0.28	-0.04
Toll	-0.41	-0.23	-0.94	-0.72	-4.44	-6.35
BTE_{ML}	1.90	1.65	1.75	1.51	1.52	0.42
BTE_{GPL}	1.74	1.87	1.77	1.99	1.33	2.00
Model: $U_{ML} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEML} \times BTE_{ML}$ $U_{GPL} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEGPL} \times BTE_{GPL}$ Bad trip experience (BTE) occurs when travel speed was less than 40% of typical average speed						
Time	-0.10	0.00	-0.04	-0.03	-0.27	-0.04
Toll	-0.42	-0.24	-0.96	-0.74	-4.54	-6.43
BTE_{ML}	1.90	1.51	1.66	1.42	1.67	0.50
BTE_{GPL}	1.84	2.04	1.76	2.12	1.48	2.04

Table 20 Logit models with time and toll and bad trip experience as independent variable (for travelers who had at least one trip on each lane)

Variable	Coefficient					
	Peak Period		Shoulder Period		Off-Peak Period	
	Eastbound	Westbound	Eastbound	Westbound	Eastbound	Westbound
Model: $U_{ML} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEML} \times BTE_{ML}$ $U_{GPL} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEGPL} \times BTE_{GPL}$ Bad trip experience (BTE) occurs when travel speed was less than 75% of typical average speed						
Time	-0.14	-0.03	-0.15	-0.09	-0.35	-0.14
Toll	-0.23	-0.05	-0.64	-0.40	-3.23	-4.66
BTE_{ML}	1.28	1.28	1.16	1.04	0.99	0.23
BTE_{GPL}	1.33	1.31	1.46	1.45	1.01	1.59
Model: $U_{ML} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEML} \times BTE_{ML}$ $U_{GPL} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEGPL} \times BTE_{GPL}$ Bad trip experience (BTE) occurs when travel speed was less than 60% of typical average speed						
Time	-0.12	-0.01	-0.11	-0.07	-0.35	-0.13
Toll	-0.27	-0.08	-0.70	-0.45	-3.34	-4.90
BTE_{ML}	1.41	1.18	1.24	0.99	1.06	0.05
BTE_{GPL}	1.43	1.50	1.52	1.61	1.10	1.69
Model: $U_{ML} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEML} \times BTE_{ML}$ $U_{GPL} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEGPL} \times BTE_{GPL}$ Bad trip experience (BTE) occurs when travel speed was less than 50% of typical average speed						
Time	-0.11	-0.01	-0.08	-0.06	-0.34	-0.12
Toll	-0.29	-0.10	-0.72	-0.48	-3.39	-5.01
BTE_{ML}	1.45	1.01	1.23	0.84	1.11	0.04
BTE_{GPL}	1.46	1.64	1.53	1.73	1.17	1.78
Model: $U_{ML} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEML} \times BTE_{ML}$ $U_{GPL} = \beta_{time} \times time + \beta_{toll} \times toll + \beta_{BTEGPL} \times BTE_{GPL}$ Bad trip experience (BTE) occurs when travel speed was less than 40% of typical average speed						
Time	-0.11	-0.01	-0.07	-0.06	-0.34	-0.11
Toll	-0.31	-0.11	-0.74	-0.49	-3.41	-5.08
BTE_{ML}	1.45	0.87	1.14	0.71	1.19	0.00
BTE_{GPL}	1.49	1.76	1.44	1.81	1.20	1.79

5.5 The Impact of Number of Trips on Lane Choice

A traveler's familiarity with traffic conditions can affect his/her lane choice decisions. For the next models, the traveler's familiarity with traffic condition was measured by their total number of trips (on GPLs and MLs) during the previous 30 days. Data from January, 2012 and January, 2013 were excluded since the December, 2011 and December, 2012 data were not available.

There is generally a negative relationship between the number of trips made by a traveler during the previous 30 days and probability of choosing the ML (see Table 21). It can be seen from Table 21 that travelers who made less than 30 trips during the previous 30 days had chosen the ML 7.0% of the time. A notable exception was the small number of travelers who made more than 120 trips during the previous 30 days. They had a much higher probability of choosing the MLs (11.9%) for the next trip.

There is a positive relationship between the number of ML trips during the previous 30 days and probability of choosing the ML (see Table 22). For instance, the travelers who made 31-40 ML trips during the previous 30 days had higher percentage of choosing the ML for their next trip than the travelers who made 0-10 ML trips during the previous 30 days.

Next, models were developed using the number of trips during the previous 30 days (T_{30}) and the number of ML trips during the previous 30 days (M_{30}) as variables with travel time and toll in the utility function of ML (see Equation 13 and Equation 14).

$$U_{ML} = \beta_{Time} \times Time_{ML} + \beta_{Toll} \times Toll + \beta_{T30} \times NumberOfTripsPrevious30Days$$
$$+\beta_{M30} \times NumberOfMLTripsPrevious30Days \qquad (13)$$

$$U_{GPL} = \beta_{Time} \times Ttime_{GPL} \qquad (14)$$

The model result suggested that, in all cases, the model coefficients of T_{30} were negative and model coefficients of M_{30} were positive (see Table 23). It means that frequent freeway travelers tended to use the MLs less. On the other hand, travelers with previous ML trip experience tended to use the MLs more when compared to others. Therefore, travelers' tendency to choose the MLs may largely depends on their travel history on the Katy Freeway.

Table 21 Traveler's total trips during the previous 30 days and current lane choice decision

Traveler's Total Trips During the Previous 30 Days	Number of Total Cases	Number of Cases Where the Traveler Chose the Managed Lane	Number of Cases Where the Traveler Chose the General Purpose Lane	Percentage of Trips When the Managed Lane was Chosen
0-30	95250489	6680322	88570167	7.0%
31-60	6156773	330002	5826771	5.3%
61-90	108229	2547	105682	2.3%
91-120	11871	322	11549	2.7%
>120	3319	394	2925	11.8%

Table 22 Traveler's MLs trips during the previous 30 days and current lane choice decision

Traveler's the ML Trips During the Previous 30 Days	Number of Total Cases	Number of Cases Where The Traveler Chose the Managed Lane	Number Of Cases Where The Traveler Chose the General Purpose Lane	Percentage Of Trips When the Managed Lane was Chosen
1-10	99565211	5639027	93926184	5.7%
11-20	1519349	977051	542298	64.3%
21-30	349548	306097	43451	87.6%
31-40	84849	80398	4451	94.8%
41-50	9022	8613	409	95.5%
51-60	1366	1231	135	90.1%
>60	1336	1170	166	87.6%

Table 23 Model results including the number of trips during the previous 30 days and the number of ML trips during the previous 30 days variables

Model: $U_{ML}= \beta_{Time} \times Time_{ML} + \beta_{Toll} \times Toll + \beta_{T30} \times NumberOfTripsPrevious30Days\ ,+\beta_{M30} \times NumberOfMLTripsPrevious30Days,$

$U_{GPL}= \beta_{Time} \times Ttime_{GPL}$

Year	Month	Two-way				Eastbound				Westbound			
		β_{Time}	β_{Toll}	β_{T30}	β_{M30}	β_{Time}	β_{Toll}	β_{T30}	β_{M30}	β_{Time}	β_{Toll}	β_{T30}	β_{M30}
2012	January	-0.31	-2.22	-0.39	1.31	0.06	-51.55	-0.15	0.02	-0.34	-2.13	-0.52	1.39
	February	-0.28	-2.06	-0.23	0.76	-0.20	-2.40	-0.28	1.27	-0.33	-1.98	-0.32	0.83
	March	-0.23	-1.99	-0.24	0.75	-0.18	-2.25	-0.16	0.73	-0.28	-1.89	-0.32	0.80
	April	-0.24	-1.89	-0.25	0.78	-0.13	-2.21	-0.17	0.72	-0.31	-1.84	-0.34	0.85
	May	-0.13	-1.36	-0.24	0.68	-0.14	-2.06	-0.18	0.74	-0.16	-1.26	-0.31	0.72
	June	-0.21	-1.78	-0.28	0.79	-0.06	-1.58	-0.17	0.66	-0.29	-1.74	-0.36	0.85
	July	-0.22	-1.83	-0.27	0.81	-0.06	-1.98	-0.20	0.75	-0.27	-1.75	-0.35	0.87
	August	-0.15	-1.33	-0.26	0.71	-0.09	-2.02	-0.20	0.78	-0.16	-1.18	-0.33	0.76
	September	-0.21	-1.34	-0.30	0.76	-0.10	-1.61	-0.19	0.68	-0.19	-1.17	-0.40	0.86
	October	-0.21	-1.33	-0.29	0.77	-0.24	-1.62	-0.22	0.71	-0.22	-1.17	-0.38	0.83
	November	-0.18	-1.49	-0.29	0.80	-0.16	-1.69	-0.21	0.76	-0.21	-1.29	-0.36	0.84
2013	January	-0.18	-1.51	-0.45	1.27	-0.09	-1.88	-0.32	1.25	-0.18	-1.31	-0.57	1.37
	February	-0.16	-1.38	-0.27	0.75	-0.08	-1.74	-0.19	0.73	-0.18	-1.21	-0.35	0.82
	March	-0.17	-1.57	-0.28	0.77	-0.08	-2.00	-0.20	0.74	-0.22	-1.38	-0.37	0.84
	April	-0.16	-1.26	-0.28	0.76	-0.05	-1.59	-0.20	0.75	-0.19	-1.12	-0.35	0.82
	May	-0.06	-0.92	-0.27	0.68	-0.03	-1.32	-0.19	0.67	-0.07	-0.74	-0.34	0.74
	June	-0.12	-1.13	-0.32	0.75	0.00	-1.40	-0.22	0.71	-0.15	-1.02	-0.42	0.83
	July	-0.15	-1.24	-0.32	0.79	-0.05	-1.62	-0.23	0.78	-0.20	-1.13	-0.40	0.84
	August	-0.11	-1.06	-0.30	0.73	-0.05	-1.52	-0.22	0.72	-0.13	-0.88	-0.37	0.78
	September	-0.10	-0.77	-0.31	0.72	-0.11	-1.07	-0.23	0.70	-0.09	-0.64	-0.42	0.83
	October	-0.08	-0.75	-0.30	0.69	-0.10	-1.18	-0.22	0.70	-0.07	-0.59	-0.39	0.77
	November	-0.08	-1.05	-0.30	0.73	-0.06	-1.39	-0.22	0.72	-0.11	-0.90	-0.42	0.82
	December	-0.10	-1.28	-0.32	0.79	-0.04	-1.76	-0.23	0.80	-0.14	-1.07	-0.43	0.87
2014	January	-0.10	-0.79	-0.30	0.83	-0.06	-1.05	-0.22	0.84	-0.10	-0.70	-0.40	0.91
	February	-0.06	-0.62	-0.28	0.69	-0.06	-0.93	-0.20	0.68	-0.05	-0.50	-0.38	0.78
	March	-0.08	-0.74	-0.31	0.70	-0.02	-0.95	-0.22	0.67	-0.10	-0.69	-0.43	0.82
	April	-0.10	-0.67	-0.29	0.69	-0.11	-0.89	-0.20	0.66	-0.09	-0.60	-0.41	0.80
	May	-0.11	-0.65	-0.31	0.69	-0.10	-0.83	-0.21	0.65	-0.11	-0.59	-0.41	0.80
	June	-0.09	-0.63	-0.32	0.71	-0.07	-0.80	-0.22	0.66	-0.10	-0.58	-0.46	0.85
	July	-0.09	-0.65	-0.33	0.74	-0.03	-0.85	-0.23	0.70	-0.10	-0.60	-0.46	0.86
	August	-0.09	-0.64	-0.31	0.69	-0.05	-0.83	-0.22	0.65	-0.10	-0.58	-0.44	0.81
	September	-0.10	-0.59	-0.30	0.66	-0.10	-0.74	-0.21	0.63	-0.10	-0.54	-0.41	0.77

For next analysis only travelers who had at least one trip on each lane were considered. The results showed a similar trend to the results of whole traffic data. There was generally a negative relationship between the number of trips made by a traveler during the previous 30 days and probability of choosing the ML (see Table 24), with an exception of the travelers who made more than 120 trip during the previous 30 days. There was generally a positive relationship between the number of ML trips during the previous 30 days and probability of choosing the ML (see Table 25).

Next, Models were developed for the travelers who had at least one trip on each lane, using the number of trips during the previous 30 days (T_{30}) and the number of ML trips during the previous 30 days (M_{30}) as variables with travel time and toll in the utility function of ML (see Equation 13 and Equation 14). The model result showed that the trend is similar to the model results for whole traffic data (see Table 23 and Table 26). , in all cases, the model coefficients of T_{30} were negative and model coefficients of M_{30} were positive. It means that frequent freeway travelers tended to use the MLs less. On the other hand, travelers with previous ML trip experience tended to use the MLs more when compared to others. Therefore, travelers' tendency to choose the MLs may largely depends on their travel history on the Katy Freeway.

Table 24 Traveler's total trips during the previous 30 days and current lane choice decision (for travelers who had at least one trip on each lane)

Traveler's Total Trips During the Previous 30 Days	Number of Total Cases	Number of Cases Where the Traveler Chose the Managed Lane	Number of Cases Where the Traveler Chose the General Purpose Lane	Percentage of Trips When the Managed Lane was Chosen
0-30	50244492	6009848	44234644	12.0%
31-60	4055385	311489	3743896	7.7%
61-90	68741	2225	66516	3.2%
91-120	7810	287	7523	3.7%
>120	2010	386	1624	19.2%

Table 25 Traveler's MLs trips during the previous 30 days and current lane choice decision (for travelers who had at least one trip on each lane)

Traveler's the ML Trips During the Previous 30 Days	Number of Total Cases	Number of Cases Where The Traveler Chose the Managed Lane	Number Of Cases Where The Traveler Chose the General Purpose Lane	Percentage Of Trips When the Managed Lane was Chosen
1-10	52553054	5089760	47463294	10%
11-20	1436752	894455	542297	62%
21-30	310937	267486	43451	86%
31-40	69120	64669	4451	94%
41-50	6802	6393	409	94%
51-60	802	667	135	83%
>60	971	805	166	83%

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Table 26 Model results including the number of trips during the previous 30 days and the number of ML trips during the previous 30 days variables (for travelers who had at least one trip on each lane)

Model: $U_{ML}= \beta_{Time} \times Time_{ML} + \beta_{Toll} \times Toll + \beta_{T30} \times NumberOfTripsPrevious30Days\ , + \beta_{M30} \times NumberOfMLTripsPrevious30Days,$
$U_{GPL}= \beta_{Time} \times Ttime_{GPL}$

Year		Two-way				Eastbound				Westbound			
	Month	Month	β_{Time}	β_{Toll}	β_{T30}	β_{M30}	β_{Time}	β_{Toll}	β_{T30}	β_{M30}	β_{Time}	β_{Toll}	β_{T30}
2012	January	-0.28	-1.29	-0.29	0.83	-0.27	-1.28	-0.23	0.79	-0.16	-0.98	-0.18	0.51
	February	-0.28	-1.16	-0.18	0.49	-0.25	-1.12	-0.14	0.46	-0.31	-1.33	-0.37	0.89
	March	-0.23	-1.06	-0.18	0.48	-0.20	-1.07	-0.15	0.46	-0.31	-1.24	-0.23	0.54
	April	-0.25	-1.03	-0.19	0.51	-0.22	-0.99	-0.15	0.47	-0.26	-1.11	-0.23	0.52
	May	-0.11	-0.58	-0.19	0.44	-0.13	-0.63	-0.15	0.42	-0.28	-1.09	-0.25	0.55
	June	-0.22	-0.95	-0.22	0.53	-0.14	-0.94	-0.17	0.49	-0.12	-0.58	-0.23	0.47
	July	-0.22	-0.98	-0.21	0.54	-0.17	-0.97	-0.17	0.50	-0.26	-1.02	-0.27	0.56
	August	-0.14	-0.61	-0.21	0.47	-0.17	-0.73	-0.16	0.45	-0.25	-1.04	-0.26	0.58
	September	-0.20	-0.66	-0.23	0.50	-0.30	-0.77	-0.19	0.46	-0.13	-0.56	-0.25	0.51
	October	-0.20	-0.70	-0.22	0.51	-0.24	-0.81	-0.18	0.49	-0.17	-0.61	-0.29	0.56
	November	-0.18	-0.78	-0.22	0.52	-0.16	-0.98	-0.18	0.51	-0.19	-0.66	-0.27	0.55
2013	January	-0.17	-0.82	-0.34	0.85	-0.16	-0.97	-0.27	0.82	-0.17	-0.76	-0.42	0.92
	February	-0.16	-0.71	-0.21	0.50	-0.16	-0.82	-0.17	0.48	-0.16	-0.68	-0.26	0.54
	March	-0.19	-0.82	-0.22	0.51	-0.17	-0.99	-0.17	0.48	-0.20	-0.77	-0.27	0.56
	April	-0.17	-0.63	-0.21	0.51	-0.15	-0.71	-0.17	0.49	-0.18	-0.62	-0.26	0.55
	May	-0.07	-0.36	-0.21	0.46	-0.11	-0.56	-0.16	0.44	-0.04	-0.29	-0.25	0.49
	June	-0.12	-0.50	-0.25	0.50	-0.11	-0.58	-0.19	0.47	-0.12	-0.49	-0.31	0.56
	July	-0.17	-0.63	-0.24	0.53	-0.14	-0.74	-0.19	0.52	-0.18	-0.61	-0.29	0.56
	August	-0.13	-0.48	-0.23	0.49	-0.15	-0.68	-0.19	0.48	-0.11	-0.40	-0.27	0.53
	September	-0.13	-0.36	-0.23	0.48	-0.20	-0.46	-0.19	0.45	-0.08	-0.31	-0.30	0.55
	October	-0.11	-0.36	-0.22	0.47	-0.19	-0.52	-0.18	0.45	-0.07	-0.29	-0.28	0.51
	November	-0.12	-0.50	-0.23	0.47	-0.15	-0.58	-0.18	0.46	-0.10	-0.46	-0.30	0.54
	December	-0.13	-0.63	-0.24	0.52	-0.12	-0.78	-0.19	0.51	-0.14	-0.58	-0.30	0.56
2014	January	-0.28	-1.29	-0.29	0.83	-0.27	-1.28	-0.23	0.79	-0.31	-1.33	-0.37	0.89
	February	-0.28	-1.16	-0.18	0.49	-0.25	-1.12	-0.14	0.46	-0.31	-1.24	-0.23	0.54
	March	-0.23	-1.06	-0.18	0.48	-0.20	-1.07	-0.15	0.46	-0.26	-1.11	-0.23	0.52
	April	-0.25	-1.03	-0.19	0.51	-0.22	-0.99	-0.15	0.47	-0.28	-1.09	-0.25	0.55
	May	-0.11	-0.58	-0.19	0.44	-0.13	-0.63	-0.15	0.42	-0.12	-0.58	-0.23	0.47
	June	-0.22	-0.95	-0.22	0.53	-0.14	-0.94	-0.17	0.49	-0.26	-1.02	-0.27	0.56
	July	-0.22	-0.98	-0.21	0.54	-0.17	-0.97	-0.17	0.50	-0.25	-1.04	-0.26	0.58
	August	-0.14	-0.61	-0.21	0.47	-0.17	-0.73	-0.16	0.45	-0.13	-0.56	-0.25	0.51
	September	-0.20	-0.66	-0.23	0.50	-0.30	-0.77	-0.19	0.46	-0.17	-0.61	-0.29	0.56

5.6 The Impact of the Length Traveled of MLs/GPLs Section on Lane Choice

The research explored if the starting and ending location of a trip on the freeway had an impact on the lane choice decision. The trips were divided into two categories: category 1 trips which started and ended outside the 12 mile section of MLs/GPLs, and category 2 trips which did not cover the whole 12 mile section of the MLs/GPLs. Category 1 trips comprise approximately 17.7% of total detected trips. Table 27 shows that the percentage of MLs trips is higher for the category 1 traffic during all times of day when compared to category 2 traffic.

Table 27 ML and GPL trips by time of day and trip category

Time of Day	Trip Category 1 (Traveled whole length of ML/GPL Section)			Trip Category 2 (Traveled only part of ML/GPL Section)		
	Number of ML trips	Number of GPL Trips	Percentage of ML Trips	Number of ML trips	Number of GPL Trips	Percentage of ML Trips
Peak	748,018	1,116,262	40.1%	1,585,745	8,649,557	15.5%
Shoulder	981,636	13,726,746	21.4%	829,712	8,237,231	9.2%
Off-peak	470,477	1,727,506	6.7%	2,397,999	61,059,792	3.8%

When models were estimated using only time and toll variables, there were differences in terms of VOTs. For two-way traffic, the category 1 traffic had a higher VOT ($9.98/hr to $19.51/hr) compared to that of the category 2 traffic ($1.85/hr to $5.70/hr) (see Table 28 and Table 29). A possible explanation could be the ease of access on the MLs might be an important factor in travelers' lane choice decision. For instance, people who need to use only a partial section of the MLs for their trip might not take the extra effort to get on and/or off the MLs and just drive on the GPLs. This might be the result of easier accessibility at the start and end section of the MLs compared to the accessibility of mid-section. A vehicle traveling on the ML will have to cross up to 6 GPLs to exit the freeway. During peak hours, long queues can generate on both MLs and GPLs (see Figure 10), which can make crossing several lanes of traffic difficult. Another reason might be that using a short section of ML, results in small travel time savings (1 or 2 minutes), which is not enough for paying a toll - even though the toll is lower for a shorter distance.

Next, new models were developed for each category using travel time, toll and reliability measure variables. As mentioned before, in this study, an expected result for a model means the model coefficients (time, toll, and reliability) are negative. Table 30 and Table 31 summarize the frequency of the expected results for different combinations of traffic data and reliability measures. The models for the category 1 traffic have more cases with expected results when compared to the category 2 traffic. Most reliability measures for models of westbound traffic for both traffic categories had the expected results in less than 10 out of 29 cases. But most of the models for two way and eastbound traffic had the expected results in 20-28 out of 29 cases these results indicate that the category 1 traffic might have considered reliability in their lane choice decision. As the models didn't get the expected results for reliability for most of the category 2 traffic, there might be other factors like difficulty to ingress to and egress from the ML that dominated lane choice decision rather than reliability.

Figure 10 Traffic on the IH-10 Katy Freeway viewed facing west near Loop 610 on Thursday, April 11, 2013, in Houston (Houston Chronicle, 2014)

Table 28 Basic VOT results by month (category 1 traffic)

Model: $U_{ML}= \beta_{Time} \times TimeML + \beta_{Toll} \times Toll$, $U_{GPL}= \beta_{Time} \times Ttime_{GPL}$										
Year	Month	Two-way			Eastbound			Westbound		
		β_{Time}	β_{Toll}	VOT ($/hour)	β_{Time}	β_{Toll}	VOT ($/hour)	β_{Time}	β_{Toll}	VOT ($/hour)
2012	January	-0.243	-1.068	13.68	-0.239	-0.985	14.59	-0.284	-1.250	13.64
	February	-0.241	-1.060	13.66	-0.243	-0.985	14.79	-0.273	-1.222	13.40
	March	-0.220	-1.105	11.92	-0.182	-0.995	10.97	-0.280	-1.323	12.70
	April	-0.228	-1.055	12.97	-0.206	-0.950	13.00	-0.280	-1.267	13.24
	May	-0.170	-0.802	12.69	-0.135	-0.644	12.61	-0.280	-1.242	13.51
	June	-0.172	-0.975	10.58	-0.089	-0.870	6.12	-0.265	-1.214	13.07
	July	-0.203	-1.034	11.75	-0.142	-0.908	9.39	-0.282	-1.303	12.97
	August	-0.187	-0.846	13.27	-0.161	-0.745	12.98	-0.257	-1.118	13.79
	September	-0.256	-0.899	17.09	-0.310	-0.886	20.99	-0.238	-0.974	14.69
	October	-0.208	-0.803	15.54	-0.239	-0.800	17.93	-0.203	-0.828	14.69
	November	-0.172	-0.867	11.92	-0.128	-0.876	8.77	-0.189	-0.856	13.26
2013	January	-0.175	-0.726	14.50	-0.167	-0.758	13.24	-0.164	-0.666	14.74
	February	-0.197	-0.802	14.74	-0.170	-0.798	12.78	-0.206	-0.800	15.46
	March	-0.216	-0.938	13.84	-0.158	-0.979	9.70	-0.233	-0.884	15.82
	April	-0.199	-0.750	15.93	-0.136	-0.731	11.19	-0.230	-0.775	17.77
	May	-0.140	-0.648	12.98	-0.114	-0.611	11.25	-0.172	-0.728	14.20
	June	-0.147	-0.734	11.98	-0.078	-0.670	6.99	-0.207	-0.873	14.21
	July	-0.154	-0.812	11.38	-0.081	-0.787	6.19	-0.209	-0.893	14.04
	August	-0.149	-0.723	12.39	-0.132	-0.799	9.90	-0.136	-0.599	13.60
	September	-0.167	-0.562	17.81	-0.190	-0.614	18.58	-0.130	-0.470	16.52
	October	-0.137	-0.537	15.34	-0.164	-0.625	15.77	-0.093	-0.401	13.91
	November	-0.144	-0.641	13.46	-0.125	-0.676	11.12	-0.150	-0.581	15.53
	December	-0.123	-0.737	9.98	-0.070	-0.819	5.12	-0.141	-0.639	13.24
2014	January	-0.111	-0.438	15.28	-0.123	-0.476	15.55	-0.091	-0.368	14.81
	February	-0.122	-0.418	17.46	-0.154	-0.461	20.07	-0.089	-0.341	15.66
	March	-0.106	-0.439	14.50	-0.096	-0.422	13.66	-0.121	-0.476	15.21
	April	-0.132	-0.439	18.00	-0.173	-0.455	22.76	-0.116	-0.430	16.12
	May	-0.143	-0.469	18.30	-0.172	-0.447	23.14	-0.156	-0.552	16.97
	June	-0.120	-0.436	16.55	-0.130	-0.434	18.02	-0.119	-0.443	16.11
	July	-0.117	-0.454	15.44	-0.107	-0.454	14.18	-0.120	-0.454	15.83
	August	-0.131	-0.469	16.69	-0.140	-0.480	17.52	-0.121	-0.448	16.22
	September	-0.131	-0.403	19.51	-0.176	-0.425	24.89	-0.108	-0.394	16.44

Table 29 Basic VOT results by month (category 2 traffic)

Model: $U_{ML}= \beta_{Time} \times TimeML + \beta_{Toll} \times Toll$, $U_{GPL}= \beta_{Time} \times Ttime_{GPL}$										
Year	Month	Two-way			Eastbound			Westbound		
		β_{Time}	β_{Toll}	VOT ($/hour)	β_{Time}	β_{Toll}	VOT ($/hour)	β_{Time}	β_{Toll}	VOT ($/hour)
2012	January	-0.341	-3.760	5.45	-0.167	-4.135	2.42	-0.386	-3.514	6.59
	February	-0.288	-3.567	4.85	-0.150	-3.860	2.34	-0.357	-3.383	6.33
	March	-0.241	-3.489	4.14	-0.112	-3.840	1.76	-0.311	-3.285	5.68
	April	-0.253	-3.328	4.56	-0.116	-3.586	1.94	-0.340	-3.197	6.37
	May	-0.132	-2.478	3.19	-0.057	-2.961	1.16	-0.166	-2.211	4.51
	June	-0.245	-3.204	4.58	-0.069	-3.551	1.16	-0.340	-3.042	6.71
	July	-0.240	-3.210	4.48	-0.083	-3.649	1.36	-0.291	-2.965	5.88
	August	-0.165	-2.394	4.13	-0.094	-2.964	1.91	-0.176	-2.083	5.06
	September	-0.213	-2.573	4.97	-0.211	-3.143	4.02	-0.207	-2.259	5.50
	October	-0.248	-2.617	5.70	-0.143	-3.159	2.71	-0.273	-2.314	7.09
	November	-0.196	-2.896	4.06	-0.087	-3.651	1.43	-0.244	-2.520	5.81
2013	January	-0.191	-2.992	3.83	-0.068	-3.593	1.13	-0.199	-2.597	4.60
	February	-0.160	-2.817	3.41	-0.061	-3.348	1.10	-0.201	-2.495	4.85
	March	-0.172	-3.137	3.28	-0.072	-3.679	1.17	-0.237	-2.825	5.03
	April	-0.159	-2.629	3.62	-0.044	-3.101	0.85	-0.203	-2.348	5.19
	May	-0.043	-1.978	1.31	-0.019	-2.668	0.44	-0.064	-1.628	2.35
	June	-0.134	-2.296	3.49	0.001	-2.756	-0.03	-0.179	-2.054	5.22
	July	-0.184	-2.450	4.51	-0.050	-3.024	0.99	-0.253	-2.196	6.91
	August	-0.106	-2.174	2.92	-0.037	-2.846	0.77	-0.151	-1.840	4.94
	September	-0.093	-1.756	3.17	-0.100	-2.293	2.61	-0.098	-1.465	4.02
	October	-0.072	-1.746	2.47	-0.091	-2.420	2.27	-0.066	-1.381	2.85
	November	-0.074	-2.393	1.85	-0.059	-2.890	1.22	-0.105	-2.077	3.03
	December	-0.121	-2.833	2.56	-0.070	-3.454	1.22	-0.174	-2.459	4.24
2014	January	-0.143	-2.166	3.97	-0.086	-2.766	1.87	-0.141	-1.793	4.73
	February	-0.059	-1.583	2.24	-0.051	-2.149	1.43	-0.048	-1.272	2.26
	March	-0.086	-1.878	2.73	0.001	-2.157	-0.03	-0.125	-1.724	4.33
	April	-0.120	-1.683	4.27	-0.103	-1.957	3.16	-0.115	-1.522	4.52
	May	-0.123	-1.506	4.91	-0.088	-1.876	2.82	-0.124	-1.322	5.64
	June	-0.111	-1.539	4.33	-0.039	-1.705	1.37	-0.134	-1.450	5.56
	July	-0.103	-1.538	4.01	-0.002	-1.782	0.05	-0.130	-1.412	5.51
	August	-0.106	-1.567	4.06	-0.021	-1.838	0.69	-0.129	-1.419	5.44
	September	-0.107	-1.413	4.53	-0.081	-1.728	2.83	-0.108	-1.243	5.22

Table 30 Model result summary for category 1 traffic

Direction	Reliability Measure→ / Time of Day↓	Standard Deviation	Coefficient of Variation	95th Percentile	Interquartile Range	Shorten Right Range	Buffer Time Index
Two-way	Peak						
	Shoulder						
	Off-peak						
Eastbound	Peak						
	Shoulder						
	Off-peak						
Westbound	Peak						
	Shoulder						
	Off-peak						

1. Expected Results in 29 out of 29 cases
2. Expected Results in 20-28 out of 29 cases
3. Expected Results in 10-19 out of 29 cases
4. Expected Results in less than 10 out of 29 cases

* Expected results mean all model coefficients were negative

Table 31 Model result summary for category 2 traffic

Direction	Reliability Measure→ / Time of Day↓	Standard Deviation	Coefficient of Variation	95^{th} Percentile	Interquartile Range	Shorten Right Range	Buffer Time Index
Two-way	Peak						
	Shoulder						
	Off-peak						
Eastbound	Peak						
	Shoulder						
	Off-peak						
Westbound	Peak						
	Shoulder						
	Off-peak						

1. Expected Results in 29 out of 29 cases
2. Expected Results in 20-28 out of 29 cases
3. Expected Results in 10-19 out of 29 cases
4. Expected Results in less than 10 out of 29 cases

* Expected results mean all model coefficients were negative

6. SUMMARY AND CONCLUSIONS

The primary objective of this research was to understand how much travelers were willing to pay to use the faster and more reliable MLs. The data used in this research was collected by TxDOT and the Harris County Toll Road Authority (HCTRA) using automated vehicle identification (AVI) sensors located on both the MLs and the GPLs along the Katy Freeway from most of 2012, 2013 and 2014. It should be noted that each transponder ID was replaced by a unique randomized ID, therefore, it was possible to track the trips of a unique transponder ID throughout the three years without knowing the travelers identification. In addition to the AVI data, lane closures due to incidents, and precipitation data were available. Additionally, the toll schedule was changed twice during the three year period .The toll rate increased and the span of peak and shoulder periods were redefined. Therefore, this unique dataset provides historical information of travelers' lane choice decision as well as the actual traffic condition and tolls required for using the MLs.

Approximately 3 million trips per month were examined for this research. This excludes vehicles without transponders, free ML trips (e.g. carpools or HOVs during peak hours), and trips where the location of sensors restricted the capability of determining where a trip had occurred. The percentage of toll-paying trips increased from the off-peak period (4.3%) to the shoulder period (11.5%) to the peak period (19.3%). The average travel time savings on the MLs was around 2.6 minutes. One of the interesting findings of the study was that approximately 11% of all paid ML trips did not save any travel time. On average, the travel time saving for the westbound traffic was twice the travel time savings of the east bound traffic on the MLs.

A large amount of data made it possible to estimate lane choice models for each month using different combinations of trip data including each direction of travel and time period. Models with two independent variables: travel time and toll, resulted in an estimated value of travel time from \$1.96/hour (May, 2013) to \$8.06/hour (September, 2012). In most cases, models for two way traffic and west bound traffic had negative coefficients for both time and toll, as expected. In models of eastbound traffic, there were several cases where the coefficient of travel time was positive, which is counter-intuitive as it could only occur if travelers were paying tolls in the MLs even though they were not saving travel time. When the models were separated for peak, off-peak and shoulder period, the values of time obtained from the basic VOT models showed a consistent pattern for eastbound traffic: the value of time increased from off-peak periods to shoulder periods to peak periods. But for westbound traffic, there were many cases, especially during peak and off-peak hour, where the value of time was negative.

Next, models were developed using travel time, toll, and a reliability measure variables. This research considered six measures of travel time reliability: standard deviation (SD), coefficient of variation (CV), 95th percentile value, shorten right range (SRR), interquartile range (IR) and buffer time index (BTI). For most combinations of traffic data, the models with buffer time index (BTI) as the reliability measure were more consistent in terms of the number of cases with expected results(where the model coefficients for time, toll, and the reliability measures are all negative) than the models with other reliability measures. Lane choice behavior was different in the eastbound and westbound directions. In the westbound direction, no model with a reliability measure yielded expected results on a consistent basis. For eastbound and two-way traffic, during the off-peak period, most of the models yielded expected results, but some inconsistencies remained.

None of the reliability measures used in this study yielded the expected results on a consistent basis. One reason might be that approximately 11% of all paid trips on the MLs did not save any travel time (termed uneconomical trips). Therefore, new models were developed excluding these uneconomical trips. Exclusion of these uneconomical trips increased the number of cases with expected results (see Table 16), but again, no reliability measures yielded consistent results. Among the six reliability measures, 95th percentile value, shorten right range and buffer time index more often yielded the expected results compared to others. Another reason might be that 82.6% of total detected transponder equipped vehicles never changed their lane choice: 79.1% of transponders always used the GPLs and 3.4% of transponders always used the MLs.

Further discrete choice models were developed excluding the trip makers who never changed their lane choice. Although the exclusion of the 44.6% of all trips resulted in an increase in the number of models with expected results, still no reliability measure yielded consistent results. Even models excluding both uneconomical trips and those transponders that always chose the same lane did not consistently provide the expected results.

Next, the impact of a bad trip experience on lane choice was examined. A trip was considered a bad trip when the travel speed of that trip was less than a percentage (in this research 40%, 50%, 60%, and 75%) of the average travel speed. The result implied that travelers continued to use the same lane even though they had a recent bad trip experience (at least one bad trip among previous five trips) on a given lane.

Models were estimated to see if travelers' frequency of travel on the freeway affected their lane choice decision. It was observed that the frequent freeway travelers tended to use the MLs less. One reason might be that the daily use of the MLs would cost them a substantial amount of money over time. Another probable explanation of this finding could be the frequent users of the freeway knew the freeway route traffic condition and could adjust their start time to avoid being late even while using the GPLs. The results also showed that travelers with previous ML trip experience tended to use the MLs more when compared to others. It means travelers' tendency to choose the MLs may largely depend on their travel history on the Katy Freeway.

Finally, the research explored if the starting and ending location of a trip on the freeway had an impact on the lane choice decision. The trips were separated into two categories: category 1 trips which started and ended outside the 12 mile section of the MLs/GPLs, and category 2 trips which did not travel the full 12 mile section of the MLs/GPLs. VOT estimation of these two categories revealed that the category 1 traffic had a considerably higher value of time ($9.98/hr to $19.51/hr) compared to that of the category 2 traffic ($1.85/hr to $5.70/hr). A possible explanation could be the ease of access on the MLs might be an important factor in people's lane choice decision. For instance, people who need to use only a partial section of the MLs for their trips might not take the extra effort to get on and/or off the MLs and just drive on the GPLs. This might be the result of easier accessibility at the start and end section of the MLs compared to the accessibility of mid-sections. A vehicle traveling on the ML will have to cross up to 6 GPLs to exit the freeway. During peak hours, heavy traffic on the GPLs can make crossing several lanes of traffic difficult. Another reason might be that using a short section of ML results in small travel time saving (1 or 2 minutes).Many travelers may find this time saving too small to bother with- even though the toll is lower for a shorter distance. The results of the model with travel time, toll and reliability measure variables showed that the category 1traffic had generated a considerably higher number of expected results compared to the category 2 traffic.

In Summary, this thesis examined the factors that influenced travelers' lane choice decision in different traffic conditions. Models with two independent variables: travel time and toll resulted in an estimated value of travel time from $1.96/hour (May, 2013) to $8.06/hour (September, 2012). The estimated value of time was different for the eastbound and the westbound traffic: during the peak and the off-peak hour, the value of time for the eastbound traffic was higher when compared to the westbound traffic. The research could not draw any conclusion whether the travel time reliability has any impact on traveler's lane choice decisions. The models using time, toll and a reliability measure variable suggested that none of the reliability measures used in this study, yielded expected results (where the coefficients of time, toll and the reliability measures were all negative) on a consistent basis. The models with buffer time index (BTI) as a reliability measure was more consistent in terms of the number of cases with expected results when compared to other five reliability measures. The VOT and VOR estimated from the models with time toll and a reliability measure varied based on the reliability measures used in the model. For example, for whole day two-way traffic, the VOTs estimated from the model with time, toll and standard deviation variable ranged from $3.00/hr to $12.82/hr, whereas the VOTs estimated from the model with time, toll and interquartile range variable ranged from -$0.61/hr to $6.28/hr. In addition, the estimated VORs ranged from $-39.56/hr to $6.60/hr when standard deviation was used as a reliability measure, whereas the estimated VORs ranged from -$7.19/hr to $21.97/hr when interquartile range was used as a reliability measure. It should be noted that the interpretation of VOR depended on the reliability measure used in the model. Moreover, as mentioned by Alemazkoor et al (2015), VORs estimated using different reliability measures cannot be compared directly even when they have same unit (for example $/hr). Therefore, it was not possible to infer which reliability measures represented travelers' actual perception of travel time reliability. It was also found that a bad trip experience on the GPLs did not have any significant influence on the lane choice decision. In addition, it was seen that frequent freeway travelers tended to use the MLs less. It was also observed that the percentage of ML trips was higher for the travelers who traveled the whole length of the MLs/GPLs compared to travelers who traveled only a part of the GPL/ML. This might be the result of easier accessibility at end sections compared to that of mid points.

The thesis provides insights into the factors affecting lane choice decisions of travelers which may prove useful for future researches examining similar datasets as well as feasibility studies for future managed lanes along the corridor.

6.1 Limitations

There are some limitations of the research. In this research, it was considered that a unique transponder ID was assumed to represent a unique traveler. But one single car can be driven by multiple drivers with different lane preferences which couldn’t be captured by the models. In addition, the models couldn’t incorporate socio demographic characteristics of the travelers. Travelers’ demographic characteristics including age, gender, and income might have a considerable influence on their lane choice decisions and value of time. Moreover, the research only considered the freeway part of a trip which might be a fraction of a longer trip. Travelers, traveling the same section of the freeway, might have different value of time depending on their actual origin- destination and purpose of trip. This research tried to estimate a common value of time for all travelers, but in reality, the demographic characteristics and trip purpose might have a great influence on travelers’ lane choice decision and value of time which was not incorporated into this research.

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APPENDIX

TABLE A1 Model coefficients using different measures of reliability (for whole day two-way traffic)

Model: $U_{ML}= \beta_{Time} \times Time_{ML} + \beta_{Toll} \times Toll+ \beta_{TTR} \times TravelTmeRelaiiblity_{ML}$, $U_{GPL}= \beta_{Time} \times Ttime_{GPL}+\beta_{TTR} \times TravelTmeRelaiiblity_{GPL}$

Reliability measure		Standard Deviation			Coefficient of Variation			95th Percentile			Interquartile Range			Shorten Right Range			Buffer Time Index		
Year	Month	β_{Time}	β_{Toll}	β_{SD}	β_{Time}	β_{Toll}	β_{CV}	β_{Time}	β_{Toll}	β_{P95}	β_{Time}	β_{Toll}	β_{IR}	β_{Time}	β_{Toll}	β_{SRR}	β_{Time}	β_{Toll}	β_{BTI}
2012	February	-0.243	-1.995	0.073	-0.255	-1.863	4.640	-0.147	-2.326	-0.002	-0.168	-2.139	-0.371	-0.213	-2.122	-0.080	-0.234	-2.019	-0.006
	March	-0.193	-1.980	0.041	-0.212	-1.887	3.448	-0.122	-2.233	-0.002	-0.108	-2.152	-0.495	-0.172	-2.065	-0.057	-0.188	-1.993	0.007
	April	-0.189	-1.889	-0.054	-0.218	-1.764	3.506	-0.145	-2.051	-0.001	-0.136	-1.983	-0.362	-0.187	-1.915	-0.034	-0.198	-1.858	0.127
	May	-0.077	-1.373	-0.151	-0.098	-1.276	1.855	-0.040	-1.548	-0.002	-0.016	-1.516	-0.555	-0.082	-1.406	-0.059	-0.092	-1.328	0.007
	June	-0.139	-1.819	-0.160	-0.181	-1.693	2.488	-0.097	-1.984	-0.002	-0.105	-1.851	-0.329	-0.149	-1.824	-0.044	-0.164	-1.753	0.139
	July	-0.203	-1.817	0.208	-0.199	-1.726	5.137	-0.166	-1.956	-0.001	-0.123	-2.006	-0.341	-0.190	-1.843	0.036	-0.186	-1.852	0.320
	August	-0.157	-1.389	0.197	-0.142	-1.343	3.752	-0.109	-1.567	-0.001	-0.086	-1.551	-0.411	-0.140	-1.453	-0.008	-0.142	-1.414	0.189
	September	-0.170	-1.312	-0.033	-0.186	-1.205	2.841	-0.163	-1.340	0.000	-0.142	-1.357	-0.205	-0.179	-1.279	0.017	-0.177	-1.258	0.311
	October	-0.201	-1.402	0.137	-0.195	-1.349	3.634	-0.150	-1.528	-0.001	-0.135	-1.492	-0.295	-0.186	-1.435	-0.002	-0.187	-1.428	0.048
	November	-0.167	-1.544	0.170	-0.162	-1.463	4.331	-0.107	-1.701	-0.001	-0.114	-1.620	-0.123	-0.144	-1.590	-0.002	-0.144	-1.590	-0.023
2013	February	-0.165	-1.350	0.268	-0.152	-1.290	4.879	-0.104	-1.474	0.000	-0.094	-1.448	-0.128	-0.128	-1.409	0.008	-0.128	-1.404	0.148
	March	-0.175	-1.516	0.273	-0.161	-1.474	4.097	-0.114	-1.689	-0.001	-0.105	-1.652	-0.158	-0.138	-1.606	-0.003	-0.140	-1.593	0.083
	April	-0.164	-1.305	0.177	-0.155	-1.205	4.667	-0.093	-1.495	-0.001	-0.112	-1.401	-0.130	-0.128	-1.405	-0.036	-0.140	-1.359	0.020
	May	-0.049	-0.979	0.147	-0.051	-0.928	4.047	0.017	-1.164	-0.001	0.011	-1.075	-0.240	-0.022	-1.067	-0.048	-0.033	-1.014	0.009
	June	-0.069	-1.096	-0.002	-0.084	-1.026	3.049	-0.018	-1.215	-0.001	-0.022	-1.157	-0.244	-0.059	-1.134	-0.039	-0.071	-1.089	0.072
	July	-0.138	-1.340	0.084	-0.158	-1.236	4.458	-0.091	-1.435	-0.001	-0.112	-1.375	-0.051	-0.121	-1.369	-0.007	-0.123	-1.365	-0.019
	August	-0.114	-1.058	0.342	-0.108	-1.013	5.329	-0.036	-1.189	-0.001	-0.057	-1.135	-0.029	-0.061	-1.136	-0.007	-0.061	-1.140	-0.134
	September	-0.118	-0.734	0.444	-0.106	-0.706	6.187	-0.065	-0.821	0.000	-0.080	-0.810	0.097	-0.070	-0.808	0.032	-0.060	-0.830	-0.132
	October	-0.120	-0.772	0.509	-0.091	-0.763	5.550	-0.067	-0.865	0.000	-0.066	-0.874	0.042	-0.076	-0.843	0.063	-0.060	-0.879	0.070
	November	-0.110	-1.005	0.449	-0.091	-0.972	5.440	-0.056	-1.073	0.000	-0.066	-1.083	0.105	-0.063	-1.054	0.066	-0.043	-1.098	0.115
	December	-0.121	-1.267	0.281	-0.128	-1.087	6.860	-0.080	-1.352	0.000	-0.062	-1.397	-0.014	-0.089	-1.309	0.073	-0.071	-1.366	0.227
2014	February	-0.072	-0.668	0.185	-0.075	-0.592	6.365	-0.025	-0.736	0.000	-0.022	-0.730	-0.078	-0.049	-0.700	0.017	-0.044	-0.707	0.073
	March	-0.107	-0.732	0.378	-0.083	-0.689	6.606	-0.062	-0.795	0.000	-0.058	-0.807	0.026	-0.068	-0.778	0.055	-0.056	-0.802	0.246
	April	-0.116	-0.700	0.334	-0.082	-0.675	4.604	-0.084	-0.759	0.000	-0.076	-0.779	0.016	-0.086	-0.747	0.047	-0.079	-0.754	0.465
	May	-0.141	-0.660	0.384	-0.107	-0.627	5.746	-0.090	-0.754	0.000	-0.074	-0.776	-0.090	-0.101	-0.724	0.040	-0.098	-0.728	0.437
	June	-0.111	-0.647	0.307	-0.082	-0.603	5.860	-0.054	-0.741	0.000	-0.063	-0.724	-0.018	-0.072	-0.707	0.018	-0.073	-0.698	0.408
	July	-0.121	-0.676	0.415	-0.087	-0.636	6.464	-0.074	-0.750	0.000	-0.066	-0.765	0.027	-0.078	-0.733	0.064	-0.070	-0.741	0.569
	August	-0.112	-0.645	0.388	-0.072	-0.626	5.249	-0.059	-0.715	0.000	-0.071	-0.703	0.049	-0.069	-0.697	0.024	-0.069	-0.695	0.379
	September	-0.122	-0.586	0.322	-0.098	-0.534	6.042	-0.093	-0.632	0.000	-0.064	-0.676	-0.043	-0.092	-0.622	0.066	-0.084	-0.642	0.506

TABLE A2 Model coefficients using different measures of reliability (for whole day eastbound traffic)

Model: $U_{ML}= \beta_{Time}\times Time_{ML} + \beta_{Toll}\times Toll+ \beta_{TTR}\times TravelTmeRelaiiblity_{ML}\,, U_{GPL}= \beta_{Time}\times Ttime_{GPL}+\beta_{TTR}\times TravelTmeRelaiiblity_{GPL}$

Year	Month	β_{Time}	β_{Toll}	β_{SD}	β_{Time}	β_{Toll}	β_{CV}	β_{Time}	β_{Toll}	β_{95}	β_{Time}	β_{Toll}	β_{IR}	β_{Time}	β_{Toll}	β_{SRR}	β_{Time}	β_{Toll}	β_{BTI}
2012	February	-0.139	-1.808	0.068	-0.156	-1.694	3.363	-0.135	-1.820	0.000	-0.077	-1.951	-0.417	-0.150	-1.763	0.095	-0.140	-1.822	0.327
	March	-0.075	-1.840	-0.028	-0.099	-1.732	2.011	-0.084	-1.812	0.000	-0.013	-2.028	-0.515	-0.095	-1.780	0.061	-0.086	-1.816	0.293
	April	-0.101	-1.618	0.163	-0.113	-1.536	3.147	-0.112	-1.579	0.001	-0.041	-1.757	-0.295	-0.114	-1.576	0.126	-0.102	-1.633	0.754
	May	-0.015	-1.133	0.176	-0.018	-1.086	2.524	-0.034	-1.048	0.002	0.052	-1.294	-0.373	-0.021	-1.073	0.151	-0.013	-1.128	0.854
	June	-0.028	-1.503	0.286	-0.026	-1.460	2.905	-0.051	-1.434	0.002	0.042	-1.604	-0.154	-0.045	-1.458	0.194	-0.018	-1.512	1.054
	July	-0.080	-1.583	0.474	-0.070	-1.571	3.879	-0.100	-1.505	0.003	-0.010	-1.761	-0.136	-0.083	-1.563	0.241	-0.056	-1.691	0.997
	August	-0.095	-1.335	0.241	-0.095	-1.303	2.808	-0.124	-1.228	0.002	-0.034	-1.473	-0.330	-0.106	-1.270	0.178	-0.093	-1.347	0.899
	September	-0.194	-1.285	0.033	-0.209	-1.206	2.275	-0.224	-1.191	0.001	-0.150	-1.404	-0.363	-0.228	-1.184	0.151	-0.215	-1.238	0.930
	October	-0.133	-1.380	0.159	-0.145	-1.338	2.996	-0.131	-1.376	0.001	-0.068	-1.483	-0.399	-0.146	-1.354	0.116	-0.129	-1.406	0.437
	November	-0.078	-1.600	0.358	-0.076	-1.502	4.801	-0.076	-1.586	0.001	-0.024	-1.717	-0.074	-0.078	-1.585	0.170	-0.055	-1.660	0.854
2013	February	-0.061	-1.385	0.259	-0.074	-1.333	3.985	-0.081	-1.322	0.002	0.007	-1.509	-0.220	-0.076	-1.341	0.171	-0.048	-1.445	0.570
	March	-0.066	-1.585	0.283	-0.072	-1.507	3.924	-0.074	-1.561	0.001	0.008	-1.728	-0.170	-0.065	-1.578	0.124	-0.042	-1.648	0.610
	April	-0.065	-1.280	0.300	-0.070	-1.201	4.147	-0.062	-1.281	0.001	-0.003	-1.415	-0.152	-0.060	-1.288	0.120	-0.041	-1.352	0.496
	May	-0.016	-1.027	0.240	-0.029	-0.994	3.628	-0.025	-0.990	0.001	0.043	-1.114	-0.139	-0.022	-1.002	0.136	-0.007	-1.066	0.740
	June	0.032	-0.978	0.248	0.026	-0.953	3.204	0.002	-0.928	0.002	0.117	-1.078	-0.250	0.015	-0.956	0.162	0.047	-1.013	0.678
	July	-0.056	-1.264	0.365	-0.056	-1.226	4.069	-0.051	-1.256	0.002	-0.002	-1.345	0.043	-0.048	-1.281	0.149	-0.012	-1.340	0.551
	August	-0.067	-1.188	0.421	-0.058	-1.150	4.518	-0.071	-1.158	0.002	-0.001	-1.268	0.020	-0.055	-1.191	0.157	-0.027	-1.244	0.903
	September	-0.134	-0.814	0.460	-0.131	-0.769	5.756	-0.128	-0.816	0.002	-0.071	-0.904	-0.024	-0.122	-0.843	0.189	-0.094	-0.892	0.818
	October	-0.134	-0.941	0.428	-0.126	-0.884	5.424	-0.118	-0.957	0.001	-0.070	-1.051	-0.019	-0.123	-0.962	0.149	-0.095	-1.022	0.783
	November	-0.083	-1.031	0.428	-0.076	-0.967	5.044	-0.072	-1.033	0.002	-0.023	-1.148	0.033	-0.067	-1.049	0.147	-0.035	-1.125	0.676
	December	-0.070	-1.289	0.416	-0.068	-1.152	5.446	-0.068	-1.301	0.002	-0.006	-1.486	0.060	-0.058	-1.301	0.186	-0.024	-1.403	1.181
2014	February	-0.073	-0.747	0.206	-0.091	-0.693	4.439	-0.068	-0.754	0.001	-0.019	-0.823	-0.136	-0.080	-0.751	0.100	-0.074	-0.766	1.047
	March	-0.034	-0.700	0.364	-0.037	-0.668	5.104	-0.037	-0.686	0.002	0.006	-0.755	0.056	-0.033	-0.706	0.164	-0.010	-0.744	1.133
	April	-0.115	-0.716	0.252	-0.112	-0.682	3.577	-0.117	-0.714	0.001	-0.079	-0.780	-0.015	-0.117	-0.720	0.110	-0.104	-0.737	0.979
	May	-0.141	-0.628	0.506	-0.127	-0.623	5.211	-0.135	-0.638	0.002	-0.056	-0.771	-0.153	-0.126	-0.665	0.191	-0.113	-0.715	1.412
	June	-0.055	-0.638	0.227	-0.064	-0.618	3.618	-0.050	-0.649	0.001	-0.024	-0.686	-0.003	-0.055	-0.649	0.112	-0.044	-0.675	0.828
	July	-0.036	-0.687	0.323	-0.037	-0.679	3.622	-0.025	-0.697	0.001	-0.018	-0.718	0.156	-0.024	-0.712	0.109	0.000	-0.737	0.558
	August	-0.092	-0.655	0.493	-0.078	-0.647	4.701	-0.077	-0.652	0.002	-0.061	-0.679	0.243	-0.062	-0.680	0.135	-0.030	-0.704	0.583
	September	-0.128	-0.565	0.373	-0.121	-0.527	4.622	-0.128	-0.554	0.002	-0.068	-0.651	-0.037	-0.124	-0.571	0.163	-0.104	-0.610	1.175

TABLE A3 Model coefficients using different measures of reliability (for whole day westbound traffic)

Model: $U_{ML}= \beta_{Time}\times Time_{ML} + \beta_{Toll}\times Toll+ \beta_{TTR}\times TravelTmeRelaiiblity_{ML}\,, U_{GPL}= \beta_{Time}\times Ttime_{GPL}+\beta_{TTR}\times TravelTmeRelaiiblity_{GPL}$

Reliability measure		Standard Deviation			Coefficient of Variation			95th Percentile			Interquartile Range			Shorten Right Range			Buffer Time Index		
Year	Month	β_{Time}	β_{Toll}	β_{SD}	β_{Time}	β_{Toll}	β_{CV}	β_{Time}	β_{Toll}	β_{P95}	β_{Time}	β_{Toll}	β_{IR}	β_{Time}	β_{Toll}	β_{SRR}	β_{Time}	β_{Toll}	β_{BTI}
2012	February	-0.319	-2.185	0.085	-0.328	-2.055	6.003	-0.159	-2.889	-0.004	-0.238	-2.333	-0.345	-0.267	-2.523	-0.163	-0.307	-2.232	-0.103
	March	-0.284	-2.133	0.117	-0.295	-2.084	5.074	-0.148	-2.718	-0.004	-0.182	-2.275	-0.444	-0.237	-2.384	-0.129	-0.268	-2.177	-0.078
	April	-0.245	-2.187	-0.295	-0.305	-2.010	4.098	-0.160	-2.650	-0.003	-0.209	-2.212	-0.409	-0.253	-2.358	-0.148	-0.285	-2.102	-0.065
	May	-0.104	-1.629	-0.509	-0.159	-1.463	1.072	-0.019	-2.232	-0.005	-0.055	-1.743	-0.721	-0.131	-1.867	-0.211	-0.159	-1.541	-0.331
	June	-0.191	-2.189	-0.587	-0.285	-1.946	1.732	-0.117	-2.703	-0.005	-0.192	-2.142	-0.505	-0.230	-2.347	-0.202	-0.275	-2.015	-0.173
	July	-0.255	-2.043	-0.018	-0.264	-1.884	6.541	-0.191	-2.434	-0.002	-0.168	-2.231	-0.465	-0.247	-2.155	-0.065	-0.257	-2.016	0.110
	August	-0.185	-1.439	0.157	-0.163	-1.392	4.491	-0.097	-1.905	-0.002	-0.110	-1.615	-0.453	-0.164	-1.650	-0.082	-0.174	-1.480	0.010
	September	-0.153	-1.341	-0.095	-0.176	-1.205	3.636	-0.117	-1.516	-0.001	-0.144	-1.342	-0.129	-0.156	-1.417	-0.059	-0.167	-1.289	0.098
	October	-0.229	-1.417	0.124	-0.214	-1.361	4.086	-0.154	-1.672	-0.002	-0.171	-1.502	-0.238	-0.207	-1.529	-0.055	-0.216	-1.459	-0.073
	November	-0.204	-1.503	0.081	-0.200	-1.449	3.503	-0.121	-1.758	-0.002	-0.160	-1.555	-0.119	-0.184	-1.608	-0.063	-0.193	-1.551	-0.205
2013	February	-0.211	-1.312	0.291	-0.179	-1.255	5.442	-0.114	-1.531	-0.001	-0.145	-1.396	-0.067	-0.153	-1.439	-0.036	-0.164	-1.376	0.035
	March	-0.227	-1.471	0.239	-0.203	-1.460	3.797	-0.146	-1.804	-0.002	-0.168	-1.591	-0.129	-0.188	-1.642	-0.053	-0.199	-1.555	-0.051
	April	-0.202	-1.305	0.121	-0.188	-1.217	4.889	-0.106	-1.634	-0.002	-0.160	-1.380	-0.105	-0.159	-1.487	-0.081	-0.184	-1.359	-0.083
	May	-0.064	-0.939	0.059	-0.055	-0.865	4.425	0.041	-1.327	-0.003	-0.006	-1.043	-0.301	-0.033	-1.157	-0.131	-0.060	-0.981	-0.179
	June	-0.103	-1.188	-0.183	-0.128	-1.089	2.426	-0.021	-1.512	-0.003	-0.080	-1.210	-0.235	-0.103	-1.358	-0.140	-0.125	-1.157	-0.106
	July	-0.176	-1.443	-0.128	-0.209	-1.281	4.201	-0.119	-1.642	-0.002	-0.174	-1.428	-0.109	-0.183	-1.518	-0.082	-0.198	-1.425	-0.154
	August	-0.132	-0.955	0.277	-0.124	-0.912	5.769	-0.024	-1.250	-0.002	-0.081	-1.032	-0.061	-0.082	-1.117	-0.078	-0.093	-1.061	-0.341
	September	-0.103	-0.664	0.437	-0.082	-0.652	6.618	-0.028	-0.816	-0.001	-0.083	-0.737	0.188	-0.045	-0.781	-0.024	-0.046	-0.783	-0.304
	October	-0.102	-0.642	0.571	-0.061	-0.672	5.494	-0.030	-0.784	0.000	-0.059	-0.740	0.102	-0.047	-0.743	0.021	-0.041	-0.766	-0.095
	November	-0.135	-0.991	0.455	-0.104	-0.987	5.801	-0.053	-1.090	0.000	-0.113	-1.040	0.177	-0.073	-1.046	0.024	-0.064	-1.068	-0.011
	December	-0.136	-1.278	0.073	-0.162	-1.056	8.575	-0.083	-1.422	-0.001	-0.102	-1.337	-0.063	-0.118	-1.328	-0.020	-0.122	-1.313	-0.065
2014	February	-0.063	-0.592	0.182	-0.059	-0.510	8.376	0.004	-0.703	-0.001	-0.017	-0.651	-0.051	-0.028	-0.646	-0.014	-0.031	-0.640	-0.092
	March	-0.142	-0.762	0.386	-0.103	-0.715	7.779	-0.079	-0.879	0.000	-0.088	-0.857	0.005	-0.092	-0.840	0.019	-0.088	-0.850	0.115
	April	-0.118	-0.694	0.378	-0.071	-0.684	5.303	-0.069	-0.791	0.000	-0.078	-0.780	0.039	-0.076	-0.764	0.026	-0.074	-0.759	0.384
	May	-0.136	-0.688	0.292	-0.102	-0.634	6.379	-0.060	-0.866	-0.001	-0.085	-0.786	-0.064	-0.091	-0.796	-0.026	-0.099	-0.747	0.225
	June	-0.138	-0.656	0.361	-0.083	-0.588	7.972	-0.057	-0.824	-0.001	-0.082	-0.758	-0.022	-0.085	-0.767	-0.015	-0.089	-0.722	0.332
	July	-0.152	-0.661	0.477	-0.089	-0.595	8.766	-0.092	-0.794	0.000	-0.077	-0.812	-0.067	-0.099	-0.753	0.046	-0.092	-0.742	0.566
	August	-0.113	-0.630	0.330	-0.065	-0.608	5.671	-0.055	-0.767	-0.001	-0.071	-0.722	-0.050	-0.078	-0.716	-0.005	-0.080	-0.683	0.344
	September	-0.118	-0.606	0.280	-0.093	-0.545	8.094	-0.070	-0.697	0.000	-0.065	-0.700	-0.050	-0.081	-0.667	0.022	-0.081	-0.664	0.349

TABLE A4 Model coefficients using different measures of reliability (for peak period two-way traffic)

Model: $U_{ML} = \beta_{Time} \times Time_{ML} + \beta_{Toll} \times Toll + \beta_{TTR} \times TravelTmeRelaiiblity_{ML}$, $U_{GPL} = \beta_{Time} \times Ttime_{GPL} + \beta_{TTR} \times TravelTmeRelaiiblity_{GPL}$

Reliability measure		Standard Deviation			Coefficient of Variation			95th Percentile			Interquartile Range			Shorten Right Range			Buffer Time Index		
Year	Month	β_{Time}	β_{Toll}	β_{SD}	β_{Time}	β_{Toll}	β_{CV}	β_{Time}	β_{Toll}	β_{P95}	β_{Time}	β_{Toll}	β_{IR}	β_{Time}	β_{Toll}	β_{SRR}	β_{Time}	β_{Toll}	β_{BTI}
2012	February	-0.079	-0.513	0.184	-0.053	-0.495	3.089	0.000	-0.631	-0.001	-0.066	-0.540	0.051	-0.022	-0.612	-0.090	-0.048	-0.560	-0.387
	March	-0.062	-0.498	0.157	-0.042	-0.493	2.183	0.022	-0.689	-0.002	-0.066	-0.498	0.114	-0.015	-0.635	-0.126	-0.039	-0.560	-0.523
	April	-0.056	-0.485	0.071	-0.046	-0.451	2.699	0.025	-0.605	-0.001	-0.057	-0.477	0.076	-0.001	-0.582	-0.121	-0.034	-0.523	-0.664
	May	0.047	-0.306	-0.087	0.043	-0.267	0.732	0.096	-0.477	-0.002	0.045	-0.309	-0.064	0.046	-0.445	-0.160	0.035	-0.342	-0.886
	June	-0.059	-0.498	0.085	-0.045	-0.464	2.695	0.025	-0.622	-0.001	-0.056	-0.496	0.084	-0.012	-0.590	-0.102	-0.040	-0.537	-0.457
	July	-0.068	-0.498	0.165	-0.041	-0.482	3.192	-0.026	-0.590	-0.001	-0.068	-0.510	0.096	-0.043	-0.562	-0.034	-0.049	-0.546	-0.210
	August	-0.013	-0.327	0.118	0.004	-0.322	1.693	0.048	-0.451	-0.001	-0.007	-0.343	0.026	0.015	-0.417	-0.078	-0.006	-0.376	-0.403
	September	-0.043	-0.309	0.093	-0.026	-0.238	3.456	0.005	-0.396	-0.001	-0.038	-0.320	0.050	-0.012	-0.391	-0.073	-0.030	-0.342	-0.138
	October	-0.050	-0.363	0.165	-0.020	-0.321	3.938	0.052	-0.488	-0.002	-0.049	-0.374	0.090	0.000	-0.442	-0.120	-0.029	-0.398	-0.481
	November	-0.071	-0.406	0.237	-0.035	-0.380	4.098	0.032	-0.543	-0.002	-0.072	-0.412	0.155	-0.007	-0.515	-0.151	-0.038	-0.460	-0.688
2013	February	-0.054	-0.364	0.174	-0.027	-0.303	4.877	0.061	-0.479	-0.002	-0.048	-0.379	0.073	0.032	-0.475	-0.157	-0.022	-0.416	-0.659
	March	-0.084	-0.403	0.276	-0.048	-0.415	2.934	-0.008	-0.517	-0.001	-0.075	-0.427	0.109	-0.023	-0.504	-0.079	-0.049	-0.462	-0.255
	April	-0.070	-0.323	0.233	-0.026	-0.260	5.172	0.041	-0.450	-0.001	-0.049	-0.353	0.076	0.015	-0.429	-0.099	-0.027	-0.387	-0.399
	May	0.027	-0.221	0.122	0.037	-0.219	2.039	0.115	-0.383	-0.002	0.032	-0.237	0.034	0.071	-0.345	-0.125	0.044	-0.275	-0.730
	June	0.017	-0.312	-0.136	0.005	-0.280	0.676	0.133	-0.424	-0.002	0.010	-0.297	-0.036	0.060	-0.390	-0.192	0.013	-0.327	-0.992
	July	-0.026	-0.421	-0.088	-0.051	-0.376	2.582	0.082	-0.505	-0.002	-0.061	-0.390	0.119	0.033	-0.464	-0.208	-0.021	-0.425	-1.068
	August	0.012	-0.296	-0.011	0.002	-0.266	3.300	0.138	-0.438	-0.003	-0.006	-0.288	0.086	0.070	-0.379	-0.199	0.035	-0.318	-1.167
	September	-0.044	-0.212	0.281	-0.016	-0.185	4.845	0.043	-0.320	-0.001	-0.056	-0.234	0.252	0.021	-0.295	-0.125	0.004	-0.265	-0.821
	October	-0.045	-0.237	0.336	-0.010	-0.232	3.585	0.046	-0.336	-0.001	-0.035	-0.263	0.148	0.012	-0.299	-0.077	-0.005	-0.283	-0.396
	November	-0.053	-0.314	0.300	-0.026	-0.312	3.941	0.035	-0.422	-0.001	-0.061	-0.322	0.236	0.019	-0.395	-0.135	-0.003	-0.359	-0.927
	December	-0.064	-0.429	0.056	-0.055	-0.362	3.460	0.004	-0.531	-0.001	-0.075	-0.405	0.105	-0.024	-0.518	-0.138	-0.047	-0.467	-0.732
2014	February	-0.003	-0.243	-0.032	-0.012	-0.171	4.061	0.089	-0.342	-0.002	-0.020	-0.226	0.054	0.048	-0.308	-0.156	0.008	-0.254	-0.838
	March	-0.042	-0.269	0.129	-0.023	-0.245	3.997	0.085	-0.370	-0.002	-0.044	-0.270	0.103	0.044	-0.334	-0.164	-0.009	-0.294	-0.760
	April	-0.045	-0.203	0.235	-0.008	-0.189	3.222	0.044	-0.308	-0.001	-0.030	-0.232	0.093	0.021	-0.298	-0.096	-0.008	-0.257	-0.350
	May	-0.067	-0.206	0.258	-0.030	-0.191	3.900	0.035	-0.311	-0.001	-0.043	-0.236	0.067	0.009	-0.291	-0.103	-0.021	-0.254	-0.489
	June	-0.029	-0.249	0.045	-0.021	-0.237	1.513	0.076	-0.334	-0.002	-0.029	-0.252	0.029	0.029	-0.316	-0.139	-0.010	-0.270	-0.761
	July	-0.022	-0.292	-0.028	-0.025	-0.268	1.773	0.064	-0.358	-0.002	-0.043	-0.281	0.083	0.016	-0.334	-0.147	-0.016	-0.297	-0.731
	August	-0.023	-0.258	-0.035	-0.026	-0.250	0.588	0.080	-0.320	-0.002	-0.029	-0.254	0.008	0.030	-0.301	-0.145	-0.013	-0.263	-0.958
	September	-0.025	-0.239	-0.054	-0.032	-0.201	1.924	0.033	-0.297	-0.001	-0.028	-0.235	-0.034	0.003	-0.273	-0.113	-0.019	-0.235	-0.693

TABLE A5 Model coefficients using different measures of reliability (for peak period eastbound traffic)

Model: $U_{ML}= \beta_{Time} \times Time_{ML} + \beta_{Toll} \times Toll + \beta_{TTR} \times TravelTmeRelaiiblity_{ML}$, $U_{GPL}= \beta_{Time} \times Ttime_{GPL} + \beta_{TTR} \times TravelTmeRelaiiblity_{GPL}$

Reliability measure		Standard Deviation			Coefficient of Variation			95th Percentile			Interquartile Range			Shorten Right Range			Buffer Time Index		
Year	Month	β_{Time}	β_{Toll}	β_{SD}	β_{Time}	β_{Toll}	β_{CV}	β_{Time}	β_{Toll}	β_{P95}	β_{Time}	β_{Toll}	β_{IR}	β_{Time}	β_{Toll}	β_{SRR}	β_{Time}	β_{Toll}	β_{BTI}
2012	February	-0.126	-0.730	-0.438	-0.142	-0.597	0.485	-0.119	-0.741	-0.002	-0.127	-0.714	-0.287	-0.140	-0.663	-0.094	-0.144	-0.614	-0.121
	March	-0.132	-0.739	-0.308	-0.148	-0.584	1.278	-0.120	-0.777	-0.002	-0.146	-0.651	-0.032	-0.145	-0.680	-0.080	-0.152	-0.630	0.155
	April	-0.087	-0.651	-0.346	-0.107	-0.556	0.068	-0.080	-0.671	-0.002	-0.101	-0.583	-0.065	-0.105	-0.593	-0.087	-0.107	-0.561	-0.192
	May	0.009	-0.424	-0.337	-0.006	-0.384	-1.664	0.010	-0.411	-0.001	0.009	-0.401	-0.159	-0.005	-0.382	-0.092	-0.001	-0.349	-0.342
	June	-0.040	-0.575	-0.067	-0.042	-0.561	0.084	-0.042	-0.567	0.000	-0.044	-0.545	0.080	-0.040	-0.558	0.019	-0.041	-0.561	0.089
	July	-0.080	-0.608	-0.119	-0.082	-0.564	0.895	-0.085	-0.576	0.000	-0.081	-0.594	-0.040	-0.081	-0.572	0.039	-0.081	-0.582	0.296
	August	-0.093	-0.518	-0.043	-0.092	-0.485	0.778	-0.097	-0.493	0.000	-0.093	-0.515	-0.027	-0.094	-0.501	0.012	-0.092	-0.495	0.299
	September	-0.141	-0.530	-0.190	-0.145	-0.398	1.886	-0.149	-0.492	0.000	-0.130	-0.514	-0.155	-0.157	-0.455	0.039	-0.155	-0.450	0.672
	October	-0.106	-0.516	-0.198	-0.104	-0.434	2.109	-0.085	-0.545	-0.001	-0.115	-0.484	-0.013	-0.114	-0.491	-0.039	-0.117	-0.481	0.209
	November	-0.101	-0.557	-0.040	-0.096	-0.522	1.216	-0.091	-0.581	-0.001	-0.106	-0.531	0.059	-0.101	-0.554	-0.021	-0.101	-0.548	-0.086
2013	February	-0.096	-0.532	-0.102	-0.091	-0.445	2.205	-0.099	-0.517	0.000	-0.092	-0.533	-0.098	-0.101	-0.513	-0.013	-0.102	-0.498	0.394
	March	-0.129	-0.661	-0.215	-0.142	-0.560	1.360	-0.123	-0.673	-0.001	-0.134	-0.623	-0.078	-0.135	-0.640	-0.070	-0.144	-0.598	0.072
	April	-0.035	-0.523	-0.274	-0.050	-0.408	1.722	-0.018	-0.558	-0.002	-0.047	-0.478	-0.076	-0.042	-0.518	-0.129	-0.054	-0.461	-0.180
	May	-0.019	-0.388	0.021	-0.018	-0.390	0.219	-0.011	-0.418	0.000	-0.021	-0.383	0.040	-0.015	-0.406	-0.033	-0.014	-0.390	-0.196
	June	0.067	-0.397	-0.246	0.045	-0.376	-1.233	0.065	-0.414	-0.001	0.049	-0.358	-0.012	0.035	-0.389	-0.104	0.044	-0.360	-0.348
	July	-0.008	-0.488	0.006	-0.008	-0.504	-1.146	0.015	-0.531	-0.002	-0.044	-0.453	0.244	-0.026	-0.506	-0.194	-0.019	-0.487	-1.088
	August	-0.037	-0.485	-0.213	-0.045	-0.450	0.470	-0.035	-0.489	-0.001	-0.043	-0.462	-0.038	-0.047	-0.476	-0.068	-0.047	-0.460	-0.233
	September	-0.135	-0.394	-0.008	-0.137	-0.318	3.282	-0.116	-0.424	-0.001	-0.132	-0.398	-0.029	-0.135	-0.394	-0.007	-0.139	-0.393	0.157
	October	-0.107	-0.459	-0.170	-0.113	-0.392	1.812	-0.078	-0.489	-0.001	-0.117	-0.435	-0.024	-0.110	-0.447	-0.064	-0.117	-0.430	-0.230
	November	-0.122	-0.464	-0.048	-0.118	-0.421	1.477	-0.102	-0.506	-0.001	-0.132	-0.437	0.071	-0.118	-0.475	-0.061	-0.121	-0.459	-0.570
	December	-0.109	-0.606	-0.230	-0.136	-0.475	1.516	-0.100	-0.617	-0.001	-0.143	-0.500	0.059	-0.127	-0.567	-0.074	-0.135	-0.527	-0.011
2014	February	-0.080	-0.391	-0.172	-0.099	-0.320	1.631	-0.060	-0.413	-0.001	-0.101	-0.350	0.019	-0.083	-0.382	-0.083	-0.097	-0.355	-0.067
	March	-0.070	-0.343	-0.081	-0.070	-0.308	1.272	-0.067	-0.348	0.000	-0.071	-0.336	-0.028	-0.073	-0.331	-0.006	-0.071	-0.323	0.388
	April	-0.104	-0.251	0.282	-0.084	-0.226	3.554	-0.105	-0.269	0.001	-0.089	-0.331	-0.029	-0.098	-0.279	0.089	-0.096	-0.269	1.329
	May	-0.122	-0.304	0.100	-0.116	-0.285	2.236	-0.111	-0.333	0.000	-0.110	-0.335	-0.048	-0.116	-0.320	0.013	-0.119	-0.324	0.290
	June	-0.059	-0.352	-0.165	-0.068	-0.321	-0.351	-0.059	-0.353	-0.001	-0.064	-0.333	-0.064	-0.070	-0.329	-0.040	-0.067	-0.316	-0.021
	July	0.005	-0.370	-0.222	-0.018	-0.369	-2.303	0.002	-0.358	-0.001	-0.012	-0.324	0.084	-0.019	-0.354	-0.066	-0.015	-0.340	-0.447
	August	-0.054	-0.386	-0.595	-0.096	-0.371	-3.212	-0.052	-0.402	-0.002	-0.077	-0.350	-0.129	-0.088	-0.371	-0.195	-0.086	-0.335	-1.404
	September	-0.055	-0.361	-0.443	-0.097	-0.278	0.055	-0.050	-0.346	-0.002	-0.068	-0.317	-0.209	-0.086	-0.300	-0.071	-0.093	-0.282	-0.372

TABLE A6 Model coefficients using different measures of reliability (for peak period westbound traffic)

Model: $U_{ML} = \beta_{Time} \times Time_{ML} + \beta_{Toll} \times Toll + \beta_{TTR} \times TravelTmeRelaiiblity_{ML}$, $U_{GPL} = \beta_{Time} \times Ttime_{GPL} + \beta_{TTR} \times TravelTmeRelaiiblity_{GPL}$

Reliability measure		Standard Deviation			Coefficient of Variation			95th Percentile			Interquartile Range			Shorten Right Range			Buffer Time Index		
Year	Month	β_{Time}	β_{Toll}	β_{SD}	β_{Time}	β_{Toll}	β_{CV}	β_{Time}	β_{Toll}	β_{P95}	β_{Time}	β_{Toll}	β_{IR}	β_{Time}	β_{Toll}	β_{SRR}	β_{Time}	β_{Toll}	β_{BTI}
2012	February	-0.081	-0.441	0.378	-0.042	-0.501	4.831	0.041	-0.716	-0.001	-0.065	-0.483	0.170	0.007	-0.661	-0.113	-0.022	-0.550	-0.472
	March	-0.050	-0.408	0.308	-0.024	-0.485	3.021	0.059	-0.746	-0.002	-0.054	-0.422	0.206	0.017	-0.640	-0.146	-0.003	-0.503	-0.682
	April	-0.059	-0.404	0.216	-0.042	-0.432	5.006	0.056	-0.683	-0.002	-0.050	-0.418	0.153	0.022	-0.658	-0.154	-0.015	-0.517	-0.821
	May	0.059	-0.209	0.035	0.065	-0.184	2.313	0.122	-0.690	-0.003	0.061	-0.226	-0.007	0.041	-0.622	-0.219	0.042	-0.361	-1.057
	June	-0.051	-0.375	0.180	-0.029	-0.365	4.139	0.039	-0.697	-0.002	-0.038	-0.410	0.099	-0.004	-0.643	-0.129	-0.027	-0.496	-0.499
	July	-0.055	-0.401	0.238	-0.028	-0.443	3.982	-0.014	-0.607	-0.001	-0.056	-0.427	0.133	-0.031	-0.548	-0.043	-0.036	-0.510	-0.265
	August	0.029	-0.160	0.158	0.044	-0.196	1.788	0.098	-0.397	-0.001	0.036	-0.172	0.048	0.059	-0.322	-0.095	0.035	-0.247	-0.664
	September	-0.004	-0.211	0.157	0.013	-0.166	5.073	0.077	-0.387	-0.001	-0.001	-0.219	0.154	0.053	-0.403	-0.127	0.019	-0.305	-0.541
	October	-0.029	-0.270	0.286	0.009	-0.258	4.688	0.100	-0.483	-0.002	-0.025	-0.291	0.142	0.035	-0.436	-0.150	0.001	-0.344	-0.593
	November	-0.055	-0.307	0.325	-0.012	-0.304	5.022	0.075	-0.523	-0.002	-0.052	-0.321	0.184	0.027	-0.497	-0.187	-0.013	-0.397	-0.777
2013	February	-0.028	-0.252	0.222	-0.005	-0.209	7.271	0.122	-0.430	-0.002	-0.030	-0.253	0.147	0.088	-0.435	-0.203	0.017	-0.340	-1.022
	March	-0.058	-0.291	0.347	-0.020	-0.347	3.050	0.026	-0.405	-0.001	-0.050	-0.283	0.190	0.016	-0.395	-0.076	-0.007	-0.341	-0.320
	April	-0.057	-0.187	0.351	-0.002	-0.160	6.868	0.058	-0.377	-0.001	-0.031	-0.231	0.137	0.034	-0.355	-0.089	0.000	-0.292	-0.369
	May	0.066	-0.056	0.184	0.091	-0.028	4.718	0.169	-0.318	-0.002	0.075	-0.084	0.047	0.113	-0.269	-0.139	0.079	-0.172	-0.803
	June	0.038	-0.191	-0.084	0.033	-0.144	2.454	0.155	-0.409	-0.003	0.035	-0.182	-0.025	0.077	-0.379	-0.214	0.031	-0.262	-1.104
	July	-0.009	-0.294	-0.019	-0.024	-0.215	4.758	0.094	-0.466	-0.002	-0.026	-0.272	0.092	0.044	-0.430	-0.205	0.000	-0.338	-0.953
	August	0.052	-0.130	0.079	0.043	-0.128	4.058	0.197	-0.377	-0.003	0.039	-0.130	0.114	0.127	-0.279	-0.215	0.088	-0.188	-1.250
	September	0.000	-0.123	0.350	0.029	-0.135	5.692	0.110	-0.270	-0.002	-0.020	-0.169	0.337	0.085	-0.243	-0.152	0.059	-0.200	-0.990
	October	-0.001	-0.128	0.455	0.039	-0.150	3.764	0.107	-0.239	-0.001	0.006	-0.167	0.225	0.074	-0.198	-0.080	0.052	-0.182	-0.389
	November	-0.031	-0.254	0.422	0.001	-0.282	5.342	0.096	-0.383	-0.002	-0.033	-0.273	0.290	0.088	-0.348	-0.178	0.048	-0.297	-1.059
	December	-0.052	-0.353	0.113	-0.041	-0.318	4.428	0.024	-0.483	-0.001	-0.054	-0.347	0.108	0.009	-0.467	-0.163	-0.020	-0.409	-0.901
201	February	0.021	-0.149	0.018	0.013	-0.093	5.364	0.126	-0.309	-0.002	0.011	-0.143	0.056	0.084	-0.265	-0.173	0.039	-0.184	-0.907
	March	-0.036	-0.235	0.169	-0.019	-0.228	5.242	0.122	-0.397	-0.002	-0.041	-0.239	0.141	0.077	-0.353	-0.214	0.013	-0.266	-1.067
	April	-0.021	-0.172	0.190	0.004	-0.179	3.077	0.097	-0.321	-0.002	-0.017	-0.187	0.123	0.069	-0.298	-0.152	0.024	-0.219	-0.852
	May	-0.051	-0.154	0.299	-0.010	-0.147	5.017	0.079	-0.330	-0.002	-0.028	-0.188	0.103	0.045	-0.300	-0.144	0.006	-0.227	-0.733
	June	-0.019	-0.189	0.102	-0.002	-0.179	2.598	0.111	-0.335	-0.002	-0.015	-0.197	0.054	0.057	-0.315	-0.173	0.011	-0.236	-0.981
	July	-0.013	-0.213	0.058	-0.005	-0.190	3.194	0.083	-0.335	-0.002	-0.023	-0.215	0.085	0.039	-0.298	-0.166	0.004	-0.240	-0.749
	August	-0.008	-0.182	0.050	0.000	-0.181	1.135	0.107	-0.335	-0.002	-0.007	-0.186	0.032	0.047	-0.291	-0.148	0.007	-0.214	-0.848
	September	-0.021	-0.210	0.009	-0.023	-0.190	3.171	0.054	-0.317	-0.002	-0.020	-0.211	0.002	0.021	-0.285	-0.127	-0.003	-0.222	-0.772

TABLE A7 Model coefficients using different measures of reliability (for shoulder period two-way traffic)

Model: $U_{ML} = \beta_{Time} \times Time_{ML} + \beta_{Toll} \times Toll + \beta_{TTR} \times TravelTmeRelaiiblity_{ML}, U_{GPL} = \beta_{Time} \times Ttime_{GPL} + \beta_{TTR} \times TravelTmeRelaiiblity_{GPL}$

Reliability measure		Standard Deviation			Coefficient of Variation			95th Percentile			Interquartile Range			Shorten Right Range			Buffer Time Index		
Year	Month	β_{Time}	β_{Toll}	β_{SD}	β_{Time}	β_{Toll}	β_{CV}	β_{Time}	β_{Toll}	β_{P95}	β_{Time}	β_{Toll}	β_{IR}	β_{Time}	β_{Toll}	β_{SRR}	β_{Time}	β_{Toll}	β_{BTI}
2012	February	-0.207	-1.378	0.348	-0.179	-1.241	6.062	-0.094	-1.753	-0.002	-0.171	-1.516	0.001	-0.136	-1.675	-0.106	-0.167	-1.541	-0.210
	March	-0.199	-1.404	0.269	-0.176	-1.305	4.676	-0.071	-1.781	-0.002	-0.178	-1.487	0.068	-0.116	-1.697	-0.126	-0.162	-1.544	-0.262
	April	-0.195	-1.407	0.214	-0.187	-1.291	5.486	-0.087	-1.703	-0.002	-0.187	-1.446	0.100	-0.141	-1.608	-0.108	-0.168	-1.493	-0.185
	May	-0.105	-1.096	0.058	-0.101	-1.044	2.345	-0.014	-1.352	-0.002	-0.071	-1.153	-0.166	-0.067	-1.255	-0.113	-0.096	-1.156	-0.353
	June	-0.160	-1.444	-0.117	-0.195	-1.371	1.838	-0.034	-1.659	-0.003	-0.135	-1.456	-0.216	-0.100	-1.566	-0.166	-0.167	-1.460	-0.464
	July	-0.208	-1.346	0.359	-0.182	-1.344	4.755	-0.124	-1.554	-0.001	-0.136	-1.494	-0.140	-0.156	-1.480	-0.031	-0.165	-1.450	-0.008
	August	-0.137	-1.025	0.400	-0.111	-1.003	4.273	-0.073	-1.271	-0.001	-0.104	-1.150	-0.054	-0.104	-1.187	-0.029	-0.110	-1.140	-0.002
	September	-0.100	-0.978	0.223	-0.076	-0.869	4.672	-0.042	-1.136	-0.001	-0.090	-1.026	0.107	-0.061	-1.109	-0.036	-0.070	-1.052	0.024
	October	-0.104	-1.091	0.281	-0.064	-1.000	6.166	-0.037	-1.213	-0.001	-0.062	-1.162	-0.019	-0.062	-1.171	-0.014	-0.068	-1.152	0.084
	November	-0.111	-1.148	0.279	-0.081	-1.022	6.522	-0.044	-1.270	0.000	-0.076	-1.215	0.030	-0.064	-1.230	-0.006	-0.066	-1.221	0.024
2013	February	-0.073	-1.049	0.277	-0.042	-1.027	4.665	0.017	-1.156	-0.001	-0.048	-1.085	0.088	-0.004	-1.131	-0.033	-0.020	-1.102	-0.034
	March	-0.087	-1.140	0.253	-0.058	-1.112	3.178	-0.031	-1.297	-0.001	-0.075	-1.200	0.064	-0.046	-1.262	-0.034	-0.055	-1.222	-0.007
	April	-0.106	-1.036	0.355	-0.056	-0.954	6.603	-0.005	-1.224	-0.001	-0.084	-1.095	0.117	-0.031	-1.182	-0.054	-0.051	-1.146	-0.209
	May	0.011	-0.783	0.419	0.057	-0.732	6.057	0.086	-0.960	-0.001	0.044	-0.863	0.048	0.059	-0.917	-0.041	0.052	-0.893	-0.189
	June	-0.050	-0.923	0.161	-0.043	-0.826	5.094	0.039	-1.073	-0.001	-0.040	-0.944	0.076	0.005	-1.050	-0.082	-0.019	-0.979	-0.178
	July	-0.109	-1.102	0.123	-0.108	-0.999	4.931	0.001	-1.239	-0.001	-0.109	-1.113	0.084	-0.044	-1.208	-0.096	-0.074	-1.161	-0.414
	August	-0.074	-0.976	0.163	-0.071	-0.897	5.270	0.039	-1.129	-0.002	-0.056	-1.001	0.042	-0.014	-1.102	-0.114	-0.034	-1.059	-0.683
	September	-0.079	-0.587	0.407	-0.040	-0.535	6.612	-0.002	-0.692	-0.001	-0.066	-0.625	0.223	-0.018	-0.688	-0.065	-0.023	-0.680	-0.588
	October	-0.072	-0.624	0.443	-0.024	-0.610	4.715	-0.004	-0.735	0.000	-0.055	-0.669	0.163	-0.022	-0.712	-0.010	-0.020	-0.720	-0.287
	November	-0.087	-0.748	0.301	-0.056	-0.715	4.108	-0.014	-0.815	0.000	-0.094	-0.782	0.190	-0.024	-0.806	-0.013	-0.024	-0.809	-0.238
	December	-0.076	-0.866	0.142	-0.095	-0.712	6.827	0.002	-0.959	-0.001	-0.061	-0.889	0.050	-0.016	-0.947	-0.056	-0.032	-0.923	-0.270
2014	February	-0.053	-0.580	0.187	-0.032	-0.510	7.577	0.042	-0.647	-0.001	-0.030	-0.599	0.033	0.003	-0.620	-0.053	-0.011	-0.613	-0.358
	March	-0.092	-0.612	0.329	-0.058	-0.553	7.677	0.013	-0.690	-0.001	-0.076	-0.630	0.152	-0.009	-0.674	-0.038	-0.023	-0.660	-0.115
	April	-0.096	-0.570	0.414	-0.032	-0.546	4.926	-0.012	-0.668	-0.001	-0.098	-0.603	0.236	-0.029	-0.656	-0.041	-0.040	-0.641	-0.155
	May	-0.123	-0.526	0.434	-0.057	-0.501	5.202	-0.031	-0.621	0.000	-0.084	-0.576	0.141	-0.044	-0.609	-0.011	-0.049	-0.598	0.080
	June	-0.099	-0.551	0.300	-0.043	-0.497	5.216	-0.006	-0.648	-0.001	-0.094	-0.582	0.149	-0.027	-0.646	-0.061	-0.043	-0.617	-0.157
	July	-0.099	-0.589	0.244	-0.077	-0.527	5.819	0.008	-0.674	-0.001	-0.075	-0.619	0.094	-0.021	-0.656	-0.052	-0.045	-0.630	0.001
	August	-0.085	-0.543	0.338	-0.027	-0.497	5.434	0.004	-0.625	-0.001	-0.068	-0.575	0.128	-0.021	-0.618	-0.050	-0.032	-0.599	-0.190
	September	-0.062	-0.494	0.177	-0.041	-0.424	4.566	-0.009	-0.565	0.000	-0.049	-0.522	0.064	-0.021	-0.557	-0.031	-0.029	-0.540	-0.068

TABLE A8 Model coefficients using different measures of reliability (for shoulder period eastbound traffic)

Model: $U_{ML}= \beta_{Time}\times Time_{ML} + \beta_{Toll}\times Toll+ \beta_{TTR}\times TravelTmeRelaiiblity_{ML}, U_{GPL}= \beta_{Time}\times Ttime_{GPL}+\beta_{TTR}\times TravelTmeRelaiiblity_{GPL}$

Reliability measure		Standard Deviation			Coefficient of Variation			95th Percentile			Interquartile Range			Shorten Right Range			Buffer Time Index		
Year	Month	β_{Time}	β_{Toll}	β_{SD}	β_{Time}	β_{Toll}	β_{CV}	β_{Time}	β_{Toll}	β_{P95}	β_{Time}	β_{Toll}	β_{IR}	β_{Time}	β_{Toll}	β_{SRR}	β_{Time}	β_{Toll}	β_{BTI}
2012	February	-0.106	-1.459	0.202	-0.085	-1.339	4.096	-0.103	-1.487	0.001	-0.091	-1.559	-0.095	-0.092	-1.438	0.107	-0.092	-1.493	0.684
	March	-0.117	-1.571	-0.017	-0.116	-1.466	1.735	-0.112	-1.600	0.000	-0.118	-1.565	-0.001	-0.119	-1.539	0.030	-0.114	-1.517	0.620
	April	-0.083	-1.473	0.108	-0.078	-1.396	3.210	-0.075	-1.498	0.000	-0.081	-1.485	0.055	-0.074	-1.470	0.061	-0.075	-1.490	0.440
	May	-0.020	-1.101	0.248	-0.007	-1.057	2.961	-0.022	-1.060	0.001	-0.004	-1.165	-0.035	0.006	-1.077	0.127	0.003	-1.109	0.881
	June	-0.077	-1.500	-0.231	-0.098	-1.470	-0.115	-0.085	-1.499	-0.001	-0.050	-1.513	-0.508	-0.098	-1.464	0.009	-0.098	-1.465	0.103
	July	-0.124	-1.433	0.426	-0.105	-1.466	2.488	-0.132	-1.378	0.004	-0.055	-1.537	-0.328	-0.095	-1.461	0.270	-0.097	-1.518	0.512
	August	-0.085	-1.267	0.248	-0.078	-1.261	2.211	-0.098	-1.200	0.002	-0.051	-1.352	-0.206	-0.081	-1.225	0.158	-0.077	-1.297	0.670
	September	-0.093	-1.161	-0.053	-0.096	-1.102	1.144	-0.101	-1.119	0.000	-0.095	-1.153	-0.028	-0.099	-1.089	0.081	-0.097	-1.115	0.562
	October	-0.075	-1.217	-0.085	-0.073	-1.184	1.273	-0.076	-1.205	0.000	-0.067	-1.240	-0.253	-0.065	-1.174	0.106	-0.075	-1.208	0.266
	November	-0.108	-1.363	0.167	-0.093	-1.293	3.565	-0.114	-1.349	0.001	-0.104	-1.397	-0.010	-0.096	-1.345	0.101	-0.102	-1.379	0.744
2013	February	-0.072	-1.202	0.263	-0.064	-1.227	2.032	-0.092	-1.144	0.002	-0.064	-1.265	-0.021	-0.062	-1.186	0.156	-0.066	-1.265	0.207
	March	-0.052	-1.321	0.175	-0.034	-1.237	4.270	-0.062	-1.297	0.001	-0.039	-1.385	-0.093	-0.040	-1.313	0.095	-0.040	-1.343	0.746
	April	-0.072	-1.159	0.392	-0.040	-1.099	4.888	-0.056	-1.203	0.001	-0.054	-1.214	0.135	-0.041	-1.201	0.077	-0.045	-1.232	0.317
	May	0.011	-0.982	0.321	0.027	-0.910	5.391	0.008	-0.961	0.001	0.019	-1.030	0.106	0.032	-0.984	0.114	0.026	-1.022	0.945
	June	-0.014	-1.025	0.163	-0.003	-1.000	2.234	-0.015	-1.005	0.001	0.000	-1.049	-0.006	0.008	-1.013	0.096	0.003	-1.038	0.519
	July	-0.043	-1.208	0.005	-0.046	-1.193	1.005	-0.022	-1.247	-0.001	-0.058	-1.197	0.126	-0.044	-1.214	-0.043	-0.043	-1.206	-0.409
	August	-0.045	-1.189	0.322	-0.031	-1.160	4.658	-0.043	-1.174	0.001	-0.013	-1.226	-0.156	-0.022	-1.190	0.159	-0.025	-1.220	0.708
	September	-0.070	-0.730	0.250	-0.056	-0.701	3.813	-0.064	-0.733	0.001	-0.071	-0.731	0.193	-0.054	-0.747	0.090	-0.052	-0.761	0.163
	October	-0.104	-0.836	0.174	-0.091	-0.794	3.200	-0.101	-0.865	0.000	-0.103	-0.850	0.082	-0.099	-0.851	0.042	-0.100	-0.869	0.082
	November	-0.130	-0.956	-0.102	-0.125	-0.884	1.397	-0.128	-0.956	0.000	-0.132	-0.925	0.018	-0.132	-0.941	-0.019	-0.131	-0.936	-0.201
	December	-0.028	-1.030	-0.029	-0.034	-0.953	2.036	-0.033	-1.017	0.000	-0.031	-1.022	0.000	-0.031	-1.011	0.021	-0.031	-1.012	0.346
2014	February	-0.092	-0.664	0.433	-0.070	-0.647	5.111	-0.083	-0.677	0.001	-0.075	-0.693	0.150	-0.063	-0.693	0.127	-0.069	-0.713	0.949
	March	-0.046	-0.610	0.635	-0.011	-0.600	6.378	-0.048	-0.595	0.002	-0.035	-0.643	0.232	-0.004	-0.630	0.210	-0.010	-0.669	1.237
	April	-0.087	-0.657	0.282	-0.075	-0.661	2.398	-0.085	-0.670	0.001	-0.085	-0.677	0.174	-0.075	-0.678	0.077	-0.076	-0.691	0.645
	May	-0.108	-0.559	0.684	-0.071	-0.554	6.827	-0.093	-0.572	0.002	-0.081	-0.628	0.200	-0.065	-0.598	0.195	-0.068	-0.646	1.254
	June	-0.087	-0.641	0.233	-0.069	-0.627	2.919	-0.085	-0.654	0.001	-0.082	-0.657	0.151	-0.071	-0.654	0.080	-0.070	-0.667	0.844
	July	-0.039	-0.724	-0.142	-0.054	-0.679	1.836	-0.018	-0.766	-0.002	-0.078	-0.691	0.222	-0.054	-0.725	-0.081	-0.050	-0.706	-0.037
	August	-0.050	-0.635	0.466	-0.028	-0.618	5.461	-0.036	-0.641	0.001	-0.041	-0.654	0.180	-0.020	-0.650	0.102	-0.021	-0.664	0.398
	September	-0.017	-0.546	-0.124	-0.023	-0.519	0.031	-0.023	-0.518	0.000	-0.032	-0.506	0.091	-0.022	-0.511	0.015	-0.020	-0.508	0.206

TABLE A9 Model coefficients using different measures of reliability (for shoulder period westbound traffic)

Model: $U_{ML}=\beta_{Time}\times Time_{ML}+\beta_{Toll}\times Toll+\beta_{TTR}\times TravelTmeRelaiiblity_{ML}, U_{GPL}=\beta_{Time}\times Ttime_{GPL}+\beta_{TTR}\times TravelTmeRelaiiblity_{GPL}$

Reliability measure		Standard Deviation			Coefficient of Variation			95th Percentile			Interquartile Range			Shorten Right Range			Buffer Time Index		
Year	Month	β_{Time}	β_{Toll}	β_{SD}	β_{Time}	β_{Toll}	β_{CV}	β_{Time}	β_{Toll}	β_{P95}	β_{Time}	β_{Toll}	β_{IR}	β_{Time}	β_{Toll}	β_{SRR}	β_{Time}	β_{Toll}	β_{BTI}
2012	February	-0.242	-1.206	0.537	-0.198	-1.114	7.395	-0.079	-1.924	-0.003	-0.207	-1.420	0.116	-0.131	-1.830	-0.161	-0.181	-1.532	-0.295
	March	-0.221	-1.212	0.479	-0.181	-1.169	6.432	-0.049	-1.897	-0.003	-0.191	-1.371	0.161	-0.104	-1.779	-0.159	-0.160	-1.492	-0.342
	April	-0.224	-1.235	0.393	-0.199	-1.145	6.759	-0.088	-1.845	-0.003	-0.213	-1.332	0.190	-0.154	-1.705	-0.137	-0.181	-1.449	-0.198
	May	-0.114	-1.030	0.004	-0.119	-0.986	2.051	0.037	-1.596	-0.003	-0.075	-1.104	-0.213	-0.046	-1.427	-0.201	-0.113	-1.142	-0.543
	June	-0.169	-1.328	-0.023	-0.195	-1.235	2.853	-0.011	-1.839	-0.003	-0.154	-1.355	-0.098	-0.080	-1.719	-0.226	-0.164	-1.413	-0.502
	July	-0.207	-1.178	0.431	-0.168	-1.159	6.190	-0.112	-1.643	-0.002	-0.155	-1.407	-0.055	-0.150	-1.500	-0.066	-0.165	-1.389	-0.071
	August	-0.099	-0.701	0.549	-0.060	-0.700	5.356	-0.045	-1.200	-0.001	-0.092	-0.901	0.107	-0.079	-1.052	-0.043	-0.082	-0.936	-0.014
	September	-0.107	-0.785	0.382	-0.054	-0.637	6.965	-0.012	-1.142	-0.001	-0.085	-0.912	0.152	-0.037	-1.117	-0.063	-0.052	-0.983	-0.043
	October	-0.117	-0.921	0.435	-0.036	-0.792	7.997	-0.022	-1.218	-0.001	-0.066	-1.096	0.031	-0.051	-1.146	-0.021	-0.058	-1.090	0.098
	November	-0.109	-0.913	0.398	-0.059	-0.790	7.672	-0.021	-1.150	0.000	-0.063	-1.041	0.064	-0.040	-1.095	-0.012	-0.043	-1.077	0.004
2013	February	-0.065	-0.889	0.308	-0.020	-0.824	6.256	0.059	-1.078	-0.001	-0.039	-0.929	0.117	0.035	-1.043	-0.053	0.003	-0.967	-0.039
	March	-0.078	-0.929	0.308	-0.042	-0.947	3.074	-0.022	-1.182	-0.001	-0.080	-1.012	0.120	-0.034	-1.144	-0.032	-0.041	-1.079	-0.007
	April	-0.104	-0.867	0.402	-0.047	-0.830	6.884	0.009	-1.169	-0.001	-0.083	-0.940	0.147	-0.016	-1.110	-0.057	-0.040	-1.044	-0.200
	May	0.022	-0.577	0.499	0.082	-0.575	6.076	0.128	-0.861	-0.001	0.063	-0.684	0.074	0.091	-0.800	-0.057	0.076	-0.755	-0.245
	June	-0.052	-0.757	0.246	-0.029	-0.632	6.166	0.056	-1.082	-0.001	-0.036	-0.810	0.110	0.018	-1.073	-0.108	-0.010	-0.898	-0.199
	July	-0.115	-0.931	0.224	-0.087	-0.771	6.100	0.005	-1.228	-0.001	-0.105	-0.979	0.112	-0.041	-1.197	-0.097	-0.068	-1.092	-0.363
	August	-0.084	-0.667	0.365	-0.042	-0.564	6.715	0.056	-1.010	-0.002	-0.051	-0.776	0.107	0.003	-0.991	-0.114	-0.017	-0.919	-0.655
	September	-0.083	-0.441	0.555	-0.018	-0.402	7.703	0.020	-0.632	-0.001	-0.056	-0.535	0.237	0.000	-0.636	-0.073	-0.009	-0.629	-0.614
	October	-0.063	-0.458	0.586	0.006	-0.496	4.897	0.030	-0.628	0.000	-0.038	-0.530	0.213	0.011	-0.600	-0.012	0.011	-0.613	-0.268
	November	-0.078	-0.647	0.374	-0.035	-0.642	4.588	0.025	-0.738	0.000	-0.082	-0.676	0.221	0.013	-0.724	-0.018	0.010	-0.729	-0.245
	December	-0.089	-0.724	0.228	-0.109	-0.519	10.281	0.016	-0.878	-0.001	-0.066	-0.757	0.085	0.006	-0.876	-0.074	-0.018	-0.836	-0.346
2014	February	-0.029	-0.483	0.168	-0.012	-0.405	8.750	0.091	-0.594	-0.001	-0.008	-0.503	0.035	0.045	-0.557	-0.084	0.016	-0.537	-0.522
	March	-0.094	-0.569	0.323	-0.059	-0.494	8.386	0.044	-0.718	-0.001	-0.080	-0.591	0.159	0.018	-0.698	-0.084	-0.015	-0.653	-0.313
	April	-0.093	-0.489	0.478	-0.012	-0.476	5.644	0.022	-0.649	-0.001	-0.096	-0.529	0.270	-0.001	-0.637	-0.072	-0.022	-0.600	-0.288
	May	-0.114	-0.451	0.433	-0.041	-0.438	4.954	-0.002	-0.609	-0.001	-0.075	-0.516	0.146	-0.022	-0.594	-0.041	-0.035	-0.560	-0.043
	June	-0.095	-0.448	0.372	-0.019	-0.383	6.239	0.015	-0.619	-0.001	-0.086	-0.493	0.175	-0.007	-0.628	-0.081	-0.028	-0.570	-0.218
	July	-0.102	-0.468	0.357	-0.055	-0.407	6.744	0.012	-0.620	-0.001	-0.063	-0.534	0.114	-0.011	-0.598	-0.041	-0.029	-0.556	0.066
	August	-0.079	-0.396	0.451	0.003	-0.359	5.908	0.011	-0.574	-0.001	-0.061	-0.474	0.163	-0.012	-0.570	-0.047	-0.021	-0.533	-0.151
	September	-0.095	-0.460	0.296	-0.055	-0.363	7.453	0.003	-0.603	-0.001	-0.055	-0.528	0.063	-0.016	-0.594	-0.049	-0.030	-0.559	-0.135

TABLE A10 Model coefficients using different measures of reliability (for off-peak period two-way traffic)
Model: $U_{ML}= \beta_{Time} \times Time_{ML} + \beta_{Toll} \times Toll + \beta_{TTR} \times TravelTmeRelaiiblity_{ML}$, $U_{GPL}= \beta_{Time} \times Ttime_{GPL} + \beta_{TTR} \times TravelTmeRelaiiblity_{GPL}$

Reliability measure		Standard Deviation			Coefficient of Variation			95th Percentile			Interquartile Range			Shorten Right Range			Buffer Time Index		
Year	Month	β_{Time}	β_{Toll}	β_{SD}	β_{Time}	β_{Toll}	β_{CV}	β_{Time}	β_{Toll}	β_{P95}	β_{Time}	β_{Toll}	β_{IR}	β_{Time}	β_{Toll}	β_{SRR}	β_{Time}	β_{Toll}	β_{BTI}
2012	February	-0.148	-6.644	-0.269	-0.164	-6.515	0.650	-0.108	-7.173	-0.004	-0.106	-6.733	-0.839	-0.134	-6.931	-0.225	-0.155	-6.613	-0.403
	March	-0.201	-6.471	-0.325	-0.230	-6.311	0.280	-0.152	-6.942	-0.004	-0.152	-6.492	-0.894	-0.182	-6.739	-0.208	-0.219	-6.406	-0.392
	April	-0.171	-6.362	-0.494	-0.202	-6.170	-0.647	-0.138	-6.815	-0.004	-0.133	-6.319	-0.809	-0.162	-6.619	-0.215	-0.199	-6.242	-0.437
	May	-0.066	-5.538	-0.682	-0.101	-5.377	-1.962	-0.042	-5.993	-0.004	-0.022	-5.435	-0.898	-0.073	-5.781	-0.235	-0.107	-5.431	-0.582
	June	-0.166	-5.925	-0.628	-0.215	-5.731	-1.229	-0.139	-6.399	-0.004	-0.121	-5.875	-0.783	-0.175	-6.147	-0.234	-0.218	-5.784	-0.487
	July	-0.124	-5.968	-0.433	-0.155	-5.761	-0.119	-0.094	-6.420	-0.004	-0.091	-5.993	-0.764	-0.117	-6.205	-0.204	-0.149	-5.851	-0.383
	August	-0.123	-5.239	-0.334	-0.139	-5.127	-0.154	-0.103	-5.553	-0.003	-0.068	-5.313	-0.997	-0.123	-5.381	-0.130	-0.136	-5.198	-0.301
	September	-0.148	-6.019	-0.687	-0.187	-5.792	-1.488	-0.139	-6.321	-0.003	-0.120	-5.964	-1.039	-0.160	-6.138	-0.184	-0.191	-5.812	-0.377
	October	-0.128	-6.345	-0.844	-0.175	-6.113	-2.517	-0.103	-6.806	-0.005	-0.100	-6.209	-1.220	-0.135	-6.588	-0.286	-0.180	-6.144	-0.783
	November	-0.163	-6.335	-0.466	-0.198	-6.210	-0.930	-0.127	-6.743	-0.004	-0.133	-6.274	-0.484	-0.159	-6.530	-0.218	-0.194	-6.261	-0.647
2013	February	-0.147	-6.058	-0.497	-0.185	-5.864	-0.688	-0.121	-6.407	-0.003	-0.106	-6.019	-0.704	-0.148	-6.221	-0.183	-0.179	-5.937	-0.515
	March	-0.186	-6.110	-0.397	-0.223	-5.943	-0.504	-0.142	-6.511	-0.003	-0.146	-6.092	-0.620	-0.181	-6.297	-0.190	-0.216	-6.012	-0.540
	April	-0.139	-5.790	-0.487	-0.173	-5.590	-0.578	-0.102	-6.283	-0.004	-0.092	-5.815	-0.773	-0.135	-6.027	-0.238	-0.167	-5.673	-0.615
	May	-0.078	-5.175	-0.693	-0.136	-4.990	-1.626	-0.050	-5.620	-0.004	-0.015	-5.094	-0.787	-0.102	-5.343	-0.234	-0.142	-5.034	-0.618
	June	-0.121	-5.240	-0.813	-0.176	-5.062	-3.067	-0.100	-5.600	-0.004	-0.075	-5.184	-1.018	-0.151	-5.358	-0.224	-0.194	-5.045	-0.591
	July	-0.168	-5.664	-0.723	-0.236	-5.386	-2.020	-0.141	-6.123	-0.005	-0.144	-5.502	-0.658	-0.189	-5.865	-0.278	-0.244	-5.427	-0.818
	August	-0.197	-5.074	-0.321	-0.237	-4.880	0.287	-0.148	-5.435	-0.003	-0.144	-5.114	-0.549	-0.188	-5.240	-0.168	-0.220	-5.038	-0.717
	September	-0.227	-4.953	-0.201	-0.258	-4.783	1.329	-0.171	-5.394	-0.004	-0.155	-5.123	-0.689	-0.211	-5.131	-0.171	-0.232	-4.940	-0.661
	October	-0.185	-4.900	-0.176	-0.212	-4.712	0.970	-0.131	-5.311	-0.003	-0.117	-5.059	-0.550	-0.163	-5.098	-0.148	-0.189	-4.899	-0.619
	November	-0.226	-5.313	-0.165	-0.258	-5.130	1.157	-0.176	-5.652	-0.002	-0.169	-5.415	-0.413	-0.209	-5.492	-0.130	-0.237	-5.300	-0.439
	December	-0.196	-5.710	-0.378	-0.262	-5.355	0.801	-0.153	-6.089	-0.003	-0.175	-5.624	-0.306	-0.201	-5.853	-0.184	-0.244	-5.547	-0.537
2014	February	-0.136	-4.949	-0.543	-0.198	-4.639	-0.234	-0.103	-5.272	-0.004	-0.109	-4.868	-0.545	-0.134	-5.080	-0.200	-0.185	-4.727	-0.543
	March	-0.146	-4.956	-0.456	-0.189	-4.653	0.228	-0.139	-5.147	-0.002	-0.088	-5.073	-0.613	-0.164	-4.946	-0.114	-0.182	-4.727	-0.258
	April	-0.209	-4.735	-0.136	-0.232	-4.543	1.579	-0.184	-4.988	-0.002	-0.136	-4.967	-0.589	-0.205	-4.812	-0.066	-0.222	-4.649	0.015
	May	-0.208	-4.654	-0.340	-0.235	-4.455	0.280	-0.181	-5.036	-0.003	-0.155	-4.769	-0.765	-0.212	-4.761	-0.139	-0.230	-4.534	-0.265
	June	-0.215	-4.558	-0.464	-0.258	-4.254	0.580	-0.185	-5.024	-0.004	-0.173	-4.621	-0.649	-0.228	-4.678	-0.178	-0.252	-4.355	-0.264
	July	-0.207	-4.466	-0.288	-0.242	-4.175	1.433	-0.178	-4.857	-0.003	-0.130	-4.748	-0.791	-0.204	-4.617	-0.144	-0.230	-4.325	-0.148
	August	-0.193	-4.476	-0.345	-0.231	-4.260	0.221	-0.166	-4.784	-0.003	-0.145	-4.572	-0.658	-0.195	-4.583	-0.136	-0.223	-4.357	-0.324
	September	-0.172	-4.451	-0.352	-0.216	-4.137	0.754	-0.147	-4.794	-0.003	-0.110	-4.563	-0.638	-0.176	-4.564	-0.137	-0.206	-4.258	-0.199

TABLE A11 Model coefficients using different measures of reliability (for off-peak period eastbound traffic)

Model: $U_{ML} = \beta_{Time} \times Time_{ML} + \beta_{Toll} \times Toll + \beta_{TTR} \times TravelTmeRelaiiblity_{ML}$, $U_{GPL} = \beta_{Time} \times Ttime_{GPL} + \beta_{TTR} \times TravelTmeRelaiiblity_{GPL}$

Reliability measure		Standard Deviation			Coefficient of Variation			95th Percentile			Interquartile Range			Shorten Right Range			Buffer Time Index		
Year	Month	β_{Time}	β_{Toll}	β_{SD}	β_{Time}	β_{Toll}	β_{CV}	β_{Time}	β_{Toll}	β_{P95}	β_{Time}	β_{Toll}	β_{IR}	β_{Time}	β_{Toll}	β_{SRR}	β_{Time}	β_{Toll}	β_{BTI}
2012	February	-0.200	-6.262	-0.534	-0.234	-6.088	-1.017	-0.178	-6.563	-0.004	-0.162	-6.299	-0.731	-0.219	-6.215	-0.133	-0.241	-6.021	0.079
	March	-0.205	-6.040	-0.572	-0.252	-5.811	-1.473	-0.183	-6.303	-0.003	-0.186	-5.951	-0.727	-0.218	-6.051	-0.183	-0.257	-5.754	-0.367
	April	-0.198	-5.827	-0.504	-0.237	-5.588	-1.133	-0.185	-6.029	-0.003	-0.174	-5.734	-0.604	-0.211	-5.801	-0.138	-0.241	-5.536	-0.250
	May	-0.113	-4.979	-0.590	-0.153	-4.756	-1.429	-0.121	-5.044	-0.002	-0.058	-4.920	-0.748	-0.147	-4.796	-0.086	-0.162	-4.616	-0.001
	June	-0.190	-5.338	-0.531	-0.243	-5.062	-0.825	-0.185	-5.534	-0.003	-0.145	-5.288	-0.615	-0.223	-5.228	-0.110	-0.250	-4.976	-0.008
	July	-0.173	-5.494	-0.426	-0.207	-5.269	-0.744	-0.168	-5.637	-0.002	-0.146	-5.567	-0.644	-0.192	-5.389	-0.091	-0.213	-5.193	0.014
	August	-0.178	-4.660	-0.361	-0.200	-4.527	-0.658	-0.179	-4.698	-0.001	-0.125	-4.784	-0.781	-0.204	-4.484	-0.003	-0.212	-4.424	0.313
	September	-0.183	-5.303	-0.699	-0.237	-4.995	-1.748	-0.189	-5.369	-0.003	-0.173	-5.270	-0.880	-0.214	-5.141	-0.132	-0.248	-4.867	-0.177
	October	-0.179	-5.544	-0.798	-0.240	-5.251	-2.312	-0.174	-5.759	-0.004	-0.145	-5.444	-1.081	-0.204	-5.517	-0.210	-0.246	-5.185	-0.668
	November	-0.167	-5.701	-0.529	-0.215	-5.473	-0.971	-0.153	-5.948	-0.003	-0.153	-5.557	-0.362	-0.189	-5.663	-0.148	-0.220	-5.396	-0.066
2013	February	-0.160	-5.222	-0.488	-0.207	-5.027	-0.978	-0.157	-5.340	-0.002	-0.115	-5.224	-0.641	-0.189	-5.134	-0.100	-0.215	-4.956	-0.059
	March	-0.197	-5.260	-0.320	-0.239	-5.047	-0.139	-0.172	-5.467	-0.002	-0.162	-5.280	-0.481	-0.212	-5.227	-0.093	-0.241	-5.026	0.037
	April	-0.162	-5.089	-0.596	-0.219	-4.773	-0.983	-0.135	-5.395	-0.004	-0.131	-5.034	-0.636	-0.175	-5.077	-0.201	-0.217	-4.748	-0.437
	May	-0.090	-4.255	-0.585	-0.159	-4.016	-1.113	-0.085	-4.412	-0.003	-0.043	-4.193	-0.594	-0.140	-4.110	-0.104	-0.168	-3.944	-0.145
	June	-0.140	-4.248	-0.587	-0.196	-4.062	-2.020	-0.132	-4.347	-0.003	-0.089	-4.267	-0.796	-0.183	-4.096	-0.102	-0.205	-3.962	-0.401
	July	-0.161	-4.776	-0.615	-0.227	-4.460	-1.851	-0.141	-5.051	-0.004	-0.159	-4.577	-0.455	-0.184	-4.770	-0.213	-0.222	-4.476	-1.068
	August	-0.190	-4.440	-0.367	-0.243	-4.220	-0.479	-0.164	-4.631	-0.002	-0.157	-4.456	-0.433	-0.207	-4.404	-0.109	-0.243	-4.209	-0.198
	September	-0.238	-4.194	-0.214	-0.271	-3.958	1.412	-0.199	-4.501	-0.003	-0.171	-4.430	-0.583	-0.245	-4.170	-0.066	-0.263	-4.052	0.158
	October	-0.206	-4.442	-0.354	-0.252	-4.139	0.072	-0.170	-4.749	-0.003	-0.154	-4.518	-0.485	-0.211	-4.446	-0.126	-0.245	-4.209	-0.315
	November	-0.186	-4.776	-0.385	-0.236	-4.525	-0.436	-0.163	-4.998	-0.003	-0.165	-4.744	-0.378	-0.199	-4.801	-0.140	-0.230	-4.589	-0.555
	December	-0.215	-5.057	-0.299	-0.268	-4.669	0.489	-0.198	-5.243	-0.002	-0.206	-4.928	-0.201	-0.243	-4.946	-0.076	-0.265	-4.712	0.105
2014	February	-0.151	-4.284	-0.752	-0.237	-3.854	-1.365	-0.136	-4.419	-0.004	-0.136	-4.168	-0.688	-0.175	-4.173	-0.202	-0.238	-3.788	-0.355
	March	-0.138	-4.033	-0.609	-0.210	-3.708	-1.189	-0.146	-4.044	-0.002	-0.110	-4.061	-0.496	-0.190	-3.799	-0.099	-0.222	-3.589	0.130
	April	-0.227	-3.987	-0.484	-0.287	-3.704	-0.736	-0.206	-4.126	-0.003	-0.207	-3.975	-0.444	-0.253	-3.851	-0.108	-0.295	-3.624	0.142
	May	-0.287	-3.654	-0.188	-0.308	-3.482	0.473	-0.258	-3.872	-0.002	-0.201	-3.916	-0.768	-0.302	-3.552	-0.016	-0.313	-3.456	0.442
	June	-0.239	-3.654	-0.546	-0.289	-3.354	-0.900	-0.197	-3.973	-0.004	-0.224	-3.605	-0.451	-0.264	-3.540	-0.149	-0.290	-3.318	-0.284
	July	-0.223	-3.578	-0.423	-0.270	-3.339	-0.725	-0.195	-3.799	-0.003	-0.188	-3.738	-0.517	-0.239	-3.509	-0.122	-0.265	-3.342	-0.470
	August	-0.219	-3.697	-0.470	-0.276	-3.423	-0.612	-0.172	-3.995	-0.004	-0.219	-3.625	-0.368	-0.228	-3.683	-0.165	-0.265	-3.468	-0.666
	September	-0.227	-3.823	-0.413	-0.279	-3.409	0.293	-0.210	-4.009	-0.003	-0.162	-3.990	-0.650	-0.250	-3.689	-0.095	-0.277	-3.433	0.050

TABLE A12 Model coefficients using different measures of reliability (for off-peak period westbound traffic)
Model: $U_{ML} = \beta_{Time} \times Time_{ML} + \beta_{Toll} \times Toll + \beta_{TTR} \times TravelTmeRelaiiblity_{ML}$, $U_{GPL} = \beta_{Time} \times Ttime_{GPL} + \beta_{TTR} \times TravelTmeRelaiiblity_{GPL}$

Reliability measure		Standard Deviation			Coefficient of Variation			95th Percentile			Interquartile Range			Shorten Right Range			Buffer Time Index		
Year	Month	β_{Time}	β_{Toll}	β_{SD}	β_{Time}	β_{Toll}	β_{CV}	β_{Time}	β_{Toll}	β_{P95}	β_{Time}	β_{Toll}	β_{IR}	β_{Time}	β_{Toll}	β_{SRR}	β_{Time}	β_{Toll}	β_{BTI}
2012	February	-0.052	-6.999	0.077	-0.062	-6.935	2.154	0.007	-7.694	-0.005	-0.026	-7.077	-0.704	-0.013	-7.571	-0.282	-0.037	-7.141	-0.549
	March	-0.090	-6.853	0.125	-0.102	-6.810	1.990	0.005	-7.443	-0.004	-0.043	-6.912	-0.969	-0.013	-7.337	-0.229	-0.059	-6.999	-0.473
	April	-0.073	-6.742	-0.145	-0.090	-6.661	1.612	-0.008	-7.452	-0.005	-0.027	-6.776	-1.168	-0.028	-7.322	-0.287	-0.064	-6.845	-0.538
	May	0.069	-5.960	-0.508	0.049	-5.885	-1.088	0.167	-6.849	-0.006	0.068	-5.839	-0.888	0.126	-6.722	-0.387	0.062	-6.135	-0.891
	June	-0.071	-6.336	-0.385	-0.092	-6.272	-0.153	-0.001	-7.067	-0.006	-0.046	-6.323	-1.045	-0.028	-6.904	-0.344	-0.079	-6.436	-0.690
	July	-0.016	-6.279	-0.155	-0.042	-6.150	2.211	0.073	-7.056	-0.005	0.028	-6.290	-0.816	0.040	-6.915	-0.306	-0.011	-6.395	-0.562
	August	0.031	-5.693	0.020	0.024	-5.659	1.444	0.085	-6.265	-0.004	0.061	-5.709	-1.245	0.063	-6.186	-0.223	0.041	-5.865	-0.522
	September	0.029	-6.602	0.031	0.022	-6.576	1.367	0.083	-7.163	-0.003	0.059	-6.584	-0.741	0.061	-7.073	-0.213	0.042	-6.750	-0.480
	October	0.085	-7.073	-0.286	0.067	-7.028	0.162	0.186	-7.785	-0.006	0.090	-6.995	-0.599	0.149	-7.649	-0.350	0.097	-7.177	-0.876
	November	-0.008	-6.879	-0.004	-0.014	-6.874	0.628	0.091	-7.359	-0.004	0.006	-6.863	-0.485	0.067	-7.242	-0.262	0.025	-6.965	-0.848
2013	February	0.001	-6.873	-0.268	-0.019	-6.764	0.488	0.079	-7.514	-0.004	0.006	-6.813	-0.382	0.055	-7.403	-0.263	0.012	-6.977	-0.756
	March	0.017	-6.849	-0.066	0.008	-6.822	0.632	0.093	-7.399	-0.004	0.030	-6.837	-0.385	0.063	-7.282	-0.256	0.038	-6.946	-0.738
	April	0.032	-6.495	0.165	0.027	-6.493	1.755	0.104	-7.101	-0.004	0.061	-6.546	-0.419	0.076	-6.982	-0.253	0.061	-6.663	-0.731
	May	0.238	-5.894	0.354	0.240	-5.912	1.967	0.319	-6.685	-0.005	0.258	-5.929	-0.210	0.262	-6.563	-0.345	0.266	-6.145	-0.887
	June	0.080	-6.048	-0.182	0.074	-6.028	-0.045	0.142	-6.738	-0.005	0.093	-6.024	-0.642	0.107	-6.607	-0.321	0.089	-6.198	-0.722
	July	0.069	-6.248	-0.035	0.062	-6.198	1.425	0.130	-6.937	-0.005	0.083	-6.260	-0.505	0.097	-6.814	-0.302	0.080	-6.419	-0.805
	August	-0.081	-5.592	0.269	-0.083	-5.568	2.398	-0.031	-6.116	-0.003	-0.054	-5.696	-0.412	-0.047	-6.019	-0.198	-0.058	-5.819	-0.906
	September	-0.031	-5.736	0.113	-0.046	-5.691	1.849	0.076	-6.276	-0.004	-0.013	-5.780	-0.157	0.053	-6.156	-0.258	0.024	-5.858	-0.946
	October	-0.041	-5.435	0.344	-0.044	-5.415	2.626	0.033	-5.872	-0.002	-0.008	-5.576	-0.158	0.018	-5.787	-0.142	0.008	-5.645	-0.711
	November	-0.104	-5.912	0.513	-0.103	-5.872	4.359	-0.001	-6.352	-0.002	-0.045	-6.102	-0.167	-0.019	-6.274	-0.119	-0.040	-6.130	-0.451
	December	-0.037	-6.147	0.067	-0.070	-5.947	4.347	0.094	-6.831	-0.005	0.006	-6.255	-0.311	0.059	-6.686	-0.289	-0.004	-6.313	-0.779
2014	February	-0.028	-5.736	-0.046	-0.062	-5.581	3.025	0.075	-6.278	-0.003	0.036	-5.795	-0.370	0.050	-6.167	-0.215	-0.001	-5.827	-0.659
	March	-0.034	-5.985	-0.014	-0.049	-5.858	2.085	0.006	-6.474	-0.002	-0.001	-6.102	-0.472	-0.007	-6.376	-0.149	-0.021	-6.083	-0.414
	April	-0.033	-5.629	0.398	-0.036	-5.590	3.492	0.019	-6.033	-0.001	0.041	-5.921	-0.499	0.012	-5.982	-0.066	0.000	-5.851	-0.132
	May	0.007	-5.521	-0.062	-0.012	-5.413	2.052	0.072	-6.190	-0.004	0.044	-5.611	-0.553	0.041	-6.058	-0.250	0.016	-5.666	-0.587
	June	0.032	-5.265	0.160	0.008	-5.139	3.787	0.116	-6.026	-0.004	0.075	-5.433	-0.489	0.089	-5.921	-0.248	0.055	-5.477	-0.482
	July	0.009	-5.198	0.407	0.000	-5.054	4.917	0.068	-5.892	-0.003	0.057	-5.498	-0.590	0.053	-5.817	-0.175	0.032	-5.478	-0.261
	August	-0.015	-5.288	0.032	-0.032	-5.185	2.179	0.035	-5.723	-0.002	0.020	-5.377	-0.595	0.023	-5.655	-0.146	-0.001	-5.439	-0.425
	September	-0.015	-5.002	0.105	-0.037	-4.865	3.384	0.053	-5.594	-0.003	0.036	-5.141	-0.394	0.036	-5.503	-0.171	0.002	-5.172	-0.358