QUANTIFYING THE ATTRACTIVENESS OF HIGH OCCUPANCY TOLL (HOT) LANE UNDER VARIOUS TRAFFIC CONDITIONS USING TRAFFIC SENSOR DATA

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ABSTRACT

High Occupancy Toll (HOT) lane systems have been considered as a cost-effective countermeasure against freeway congestion and means of enhancing travel reliability. Under HOT lane operations, a Single Occupancy Vehicle (SOV) can pay a fee to access the HOT lane in exchange of travel time savings or a reliable trip. For existing HOT lane systems, the toll rates are dynamically adjusted based on the real-time traffic conditions on both HOT and General Purpose (GP) lanes. Different states have been using different tolling strategies on their HOT lane facilities and the performance of an HOT lane system ties directly to the tolling strategy. However, comparing tolling strategies has been a difficult problem due to the lack of field data as well as missing pieces of information critical to HOT lane operations analysis. For example, how SOVs choose the types of lanes to use under the effect of tolling and the flow friction between HOT and GP lanes remains unclear.

Therefore, this research aims at analyzing the heterogeneity among the SOV users of HOT lanes and quantifying the attractiveness of HOT lanes for SOV drivers using the field data collected by point traffic sensors and transponder toll tags on Washington State Route 167 (SR167). The SOVs are categorized into infrequent users and frequent users based on the frequency of their transponder IDs shown up in the database. Their Value of Time (VOT) distributions are studied at microscopic level separately. A logit-like model is further developed to quantify the relationship between SOVs demands and HOT lane utilizations under different traffic phases. The analysis results show that travel patterns on HOT and GP lanes can be better interpreted and modeled for performance enhancement with motorists' willingness to pay HOT lane tolls considered.

KEYWORDS: High-Occupancy Toll (HOT), Single Occupancy Vehicle (SOV), Utility Function, Toll Rate, Reliability.

INTRODUCTION

High Occupancy Toll (HOT) lane systems have been proposed as effective countermeasures to mitigate freeway congestion, reduce travel time, enhance trip reliability and maximize freeway facility operational efficiency *(1)*. HOT lanes are often conversions of existing High Occupancy Vehicle (HOV) lanes that still allows vehicles with 2 or more occupants to use for free. Single Occupancy Vehicles (SOVs) can choose to pay a fee to use the HOT lanes in exchange for a travel time saving and reliable trip. The fee is either dynamically set based on the real-time traffic conditions on both HOT and General Purpose (GP) lanes or scheduled by time of day. By adjusting the toll rate, traffic assigned to HOT lanes can be regulated to fully exploit excess capacity on HOT lanes. Oftentimes, SOVs need to purchase a transponder to drive in HOT lanes. The toll is automatically deducted from their transponder account.

There are ten HOT facilities in operation to date *(1)*, including I-10 and US 290 in Houston, Texas, I-394 MnPass in Minneapolis, Minnesota, I-95 in Miami, Florida, I-15 in San Diego, California, SR 91 in Orange County, California, SR 167 in Seattle, Washington, I-25 in Denver, Colorado, and I-15 in Salt Lake City, Utah. In these HOT lane projects, great research efforts are needed to analyze toll facility capacities, travel patterns of vehicles classified by different occupancies, and overall system performance to optimize HOT lane operations. Tolling policy may be customized for different facilities to achieve their specific objectives, whether it is to reduce emissions, to gather revenue, or to increase overall throughput. This will greatly affect how users respond to the pricing. However, in general, HOT lanes are operating as a safety valve for the overall system. When the GP lanes are experiencing congestion, some SOV drivers opt to pay to use the HOT lane to avoid congestion. As those vehicles are diverted to the HOT lane, the likelihood of GP lanes being breakdown is drastically decreased.

To better understand tolling mechanisms and their functionality to leverage traffic allocations and maximize overall HOT lane system performance, SOVs' lane choice preference under various traffic scenarios must be sufficiently studied and properly interpreted. Although the Highway Capability Manual (HCM 2000, *2*) provides valuable guidance for regular freeway facility performance analysis, the impacts of toll-driven travel pattern changes cannot be addressed appropriately under flexible congestion pricing strategies. Several important parameters that may affect solo drivers choosing HOT lane include people's Value of Time (VOT), system reliability, toll rate level, and travel time saving, etc. Based on the operational data collected under NCHRP project 3-96, Analysis of Managed Lanes on Freeway Facilities, this paper explores the travel patterns of SOVs under dynamic tolling strategies and further quantifies the attractiveness of HOT lanes under different traffic phases (pre-congestion, congested period, and post-congestion).

BACKGROUND AND LITERATURE

Quite a few studies have been done to investigate how drivers respond to tolling using price elasticity analysis *(3)*. For example, Dahlgren *(4)* examined the circumstances in which HOT lanes could provide a more desirable alternative to HOV lanes. The question of how sensitive users are to the toll level was investigated using data from SR 91 in Orange County. It was found that eastbound toll lane traffic showed a very low elasticity with respect to tolls—between -.02 and -.16. This means that if tolls are reduced by 50%, toll lane volumes will increase by 1% to 8%. The westbound analysis found a positive relationship between tolls and toll lane traffic. This controversial result is likely due to a positive correlation between tolls and total freeway traffic volume and requires further study on the interaction between the two variables. Additionally, that analysis was, to a certain extent, biased because the data only covered two weeks and only hourly data were available for toll lanes. Song et al. *(5)* conducted a price elasticity analysis and developed a utility-based mode choice model for SOV behavior using traffic and tolling data from I-394 HOT facility in Minneapolis, Minnesota. The result indicated that SOV behavior was insensitive to toll level. And SOV behavior was influenced by the speed differential between HOT and GP lanes.

Besides price elasticity analysis, it is also important to understand how travel time and its reliability are valued by travelers, which oftentimes are measured using two behavioral parameters: VOT and Value of Reliability (VOR). They are crucial to the evaluation of travel behaviors. VOT is considered as the marginal cost of travel time in a travelers' indirect utility function; while VOR measures willingness to pay for reductions in the day-to-day variability of travel times associated with a particular trip *(6)*. Currently, many studies have been conducted to estimate VOT through similar data metrics and model estimation procedures. For example, the most widely used approaches established a multinomial logit model to identify VOT using revealed preference (RP) and/or stated preference (SP) data from surveys *(7, 8 and 9).* The University of California Transportation Center has been conducting VOT related research utilizing the SR 90 and I-15 congestion pricing project data over the past several years.

One of the most similar studies using real-time traffic measurement data was conducted by Steimetz and Brownstone *(7)*, in which motorists' responses to the actual pricing were analyzed using data collected from I-15 HOT lanes in San Diego, California. They obtained the transponder data and matched toll rate data with the time when the vehicles identified by the transponders IDs were reported reaching the facility. A panel survey was also conducted to gather necessary information (demographic) about the I-15 commuters to conduct mode-choice analysis. The drawback of this study is that for most of the samples, reliable travel time savings information were missing, so a multiple imputation approach was applied to fill in the missing data. The latest related study was conducted by Goodall and Smith *(10)*. They modeled SOVs responses to toll rate when the drivers were faced with a set of traffic conditions and toll levels. Data used for their study were collected from the dynamically-tolled I-394 HOT lane facility in Minneapolis, Minnesota. They used data from both loop detectors and transponder readers to model actual drivers' responses to minute-to-minute changes in toll rates and traffic conditions. Two types of users on the HOT lanes were classified: "every day" users who are using the HOT lanes as "insurance" against unanticipated congestion, and price sensitive drivers who are influenced by cost per unit travel time saved. By accounting for both types of drivers separately and then combining them together in the final model, traffic assignments between GP lanes and HOT lanes can be predicted. This method is reasonable in nature; however, the number of "every day" drivers is determined by assuming an average portion based on time-of-day. This lack-of-precision may greatly hinder the accuracy of the model and its further applications.

RESEARCH OBJECTIVES

To better understand how SOV travelers respond to tolling, their lane choice preferences need to be carefully studied using real time traffic measurements or transponder data. To assist this process, heterogeneous attributes of different SOV travelers need to be appropriately distinguished for VOT estimation. It is intuitive that travelers' lane choice between a free congested lane and a paid "express lane" is a function of a series of attributes. This study, in particular, identified several important factors from high-resolution field observations to model the SOV travel patterns. The goal of this research is to quantitatively explore the interaction between the SOVs on HOT lanes usage and the traffic conditions in different phases. Specific objectives of the research include these:

1. Estimating the VOT distribution for heterogeneous SOV travelers;
2. Evaluate system reliability using a probability approach; and
3. Modeling SOVs' response to the tolling strategy and their incentives in travel time saving and system reliability under different traffic conditions.

To achieve these objectives, traffic sensor data and transponder data were collected from the SR 167 HOT lane system in Seattle, Washington. These data enable the calculation of VOT and the modeling of SOVs' travel pattern at much finer time resolution levels.

STUDY SITE AND DATA COLLECTION

Study Site

The SR 167 HOT lane system is the very first and only HOT lane project in Washington State. It was opened to public in May 2008. By converting the pre-existing HOV lanes into HOT lanes, SR 167 now allows solo drivers to pay for using the "express lane" previously reserved for carpools and buses.

The single lane HOT facility runs concurrently with the parallel two GP lanes for 10.76 miles northbound and 7.69 miles southbound between Renton and Auburn, Washington. Carpools, buses, and motorcycles continue to use the HOT lane free of charge. HOT lanes operate daily from 5 a.m. to 7 p.m. Toll rates are adjusted with the level of congestion to maintain a free-flow condition in the HOT lane *(11)*.

The SR 167 HOT lanes pilot project divides the whole corridor into six segments northbound and four segments southbound with a weaving area between two consecutive segments called an access point (See Figure 1). A thick double white line separates the HOT lane from the GP lanes. It is illegal to cross the double line. At the weaving area, the double white line becomes dashed lines, which indicates that drivers can freely enter or exit the HOT lane. At each access point, an overhead sign is installed to display the current toll rate. The toll rate can change at any time, but an SOV pays only the rate at the time it entered the HOT lane.

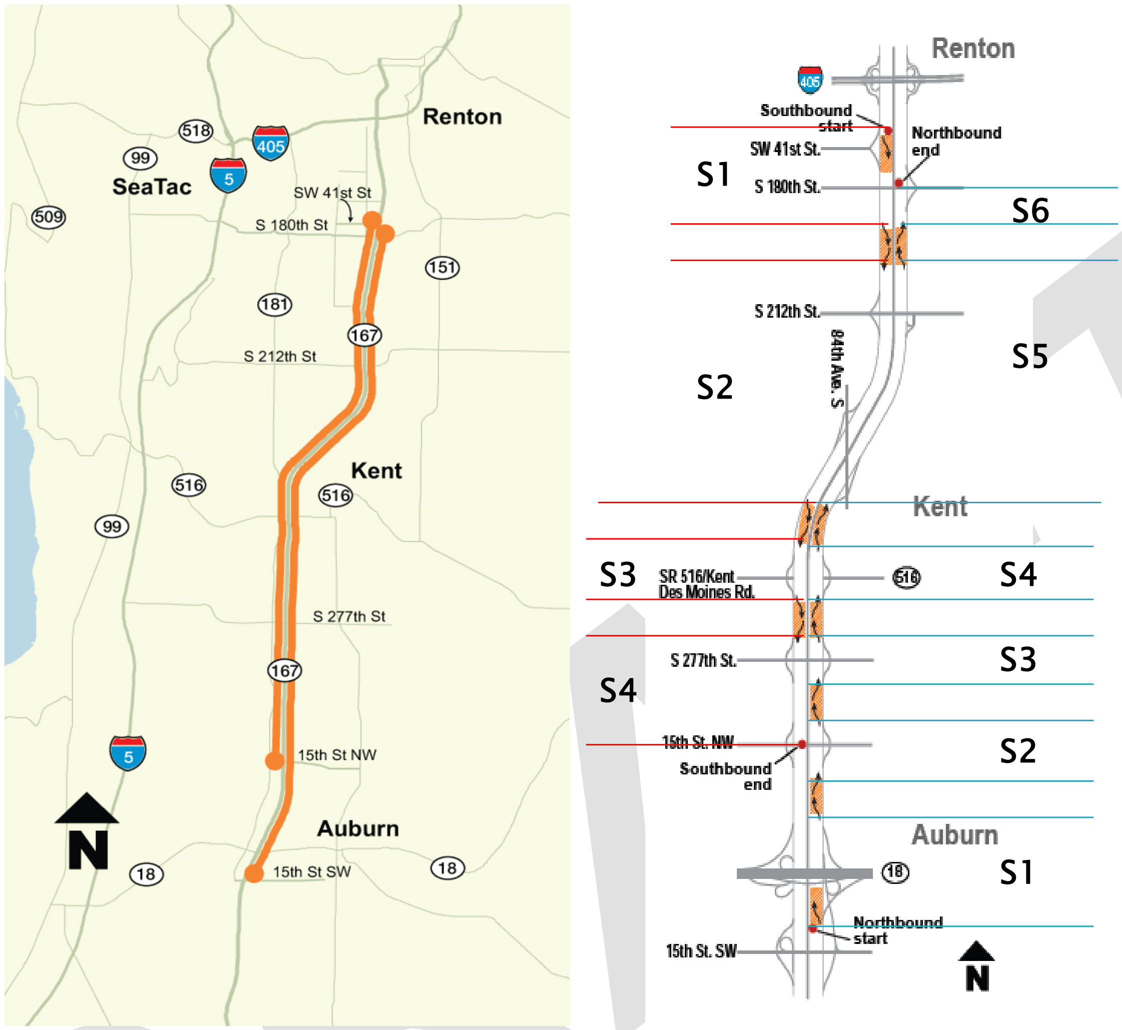


FIGURE 1 Location of SR 167 HOT lane and segmentation information (S:segment).

Field Data Collection

There are a total of 26 loop detector stations deployed along the SR 167 HOT lane corridor. These loop stations measure traffic volume and lane occupancy data periodically every 20 seconds. The Traffic System Management Center (TSMC) of the Washington State Department of Transportation (WSDOT) archives traffic speeds calculated using Athol's approach *(12)* and the original loop detector measurements aggregated at one minute intervals. This allows extraction of one minute interval speed and volume data for SR 167 for the 26 loop detector stations.

Solo drivers who wish to use the HOT lanes must create "*Good To Go!*" accounts and obtain transponders. A transponder serves as an electronic ID that maps toll transactions to a specific "*Good to Go!*" account. A transponder reader detects transponders at the entrances to the HOT lane system and charges the mapped accounts based on the toll rates at the time of entrance. By matching the transponder IDs at the HOT lane access points, the Origin and Destination (OD) of each SOV traveling on the HOT lane and its travel time can be collected. Then the total travel time savings of vehicles using HOT lane over the GP lanes can be calculated.

The loop detector data and transponder data were collected from the NB SR 167 during the morning peak period from 5:00 A.M. to 10:00 A.M. The data were reviewed in detail and the erroneous detector readings were screened out. In total, 21 days worth of data was obtained from the site during February and March, 2009.

METHODOLOGY

Previous research indicates that, the value of travel time savings distribution would be different for frequent users and infrequent users of HOT lanes *(10)*. The assumption is that the incentives to use HOT lanes are believed to be different between these two user types. For the frequent users, they are more likely to use the HOT lanes even when there is no apparent benefit in travel time savings. They would rather buy in to use the lanes as “insurance” for reliability of travel time regardless of any indication of congestion downstream. Infrequent users, on the other hand, value the immediate visible travel time savings more than trip reliability, making their choices more sensitive to the relative difference in traffic conditions between the HOT and GP lanes.

To examine whether these two groups of users have such a difference, SOVs are classified into frequent users and infrequent users in this study based on the frequency of transponder IDs shown up in the database. A usage frequency threshold is chosen to separate the two user groups (14 days is chosen as the threshold in this study). To calculate the VOT distribution at an individual level, the volume, speed, travel time data at the time when an individual SOV enters the HOT lane must be extracted and used for calculation. The VOT can then be determined by the toll the SOV paid divided by the travel time difference between its HOT lane travel time and the corresponding GP lane travel time, which is expressed as follows:

$$VOT = \frac{Toll}{\frac{D}{S_{GP}} - \frac{D}{S_{HOT}}} \qquad (1)$$

where D stands for the distance each SOV traveled on HOT lane, S_{GP} and S_{HOT} are the traffic speeds on GP lanes and HOT lanes when that SOV was traveling, respectively.

Since the loop sensors deployed along the SR 167 HOT lane corridor are single loop detectors, traffic speed must be calculated from single-loop measurements, i.e. volume and occupancy. WSDOT uses Athol’s algorithm for speed calculations, while other speed estimation algorithms also exist (see for example *13, 14, and 15*). The Athol’s algorithm is expressed as:

$$v=q/(o*g) \qquad (2)$$

where v is the estimated space-mean speed (miles per hour); q is the vehicle volume (vphpl); o is the lane occupancy per lane (in percentage); and g is the speed estimation parameter.

The speed estimation parameter g is determined by the mean effective vehicle length for each calculation interval. However, since vehicle length data are not available from single loops, g is often assumed to be constant in practice. WSDOT assumes g=2.4 in speed calculations. Due to segmentation errors of loop measurements *(15)*, traffic speed calculated from Athol’s algorithm can be unbelievably high or low. Because of this, the calculated speed is capped at 60 mph and also at 5 mph. This is because that the margin of error becomes too great for the speed calculation algorithm to be accurate outside the range. Therfore, speed is modified to 60 mph or 5 mph, respectively, if the calculated result is greater than 60 mph or less than 5 mph *(16)*.

By examining the VOT distribution of the two user groups, it is easy to identify whether heterogeneous users have different responses to the tolling policy. This study further investigates, at a macroscopic level, how SOV HOT lane demand varies with changing traffic conditions. It is assumed that under different traffic conditions, SOVs would react differently to tolling and the indicating factors that their lane choices are based on would be varied as well. Therefore, the traffic condition is classified into three different phases: pre-congestion, congestion period, and post congestion.

It is assumed that a SOV faces an actual lane choice at time *t* among alternatives *j*. The lane choice decision is modeled between two alternatives for SOVs in an actual market setting: (1) Solo travel in the GP lane parallel to the HOT lane, and (2) Solo travel in the HOT lane. To quantify the attractiveness of these two alternatives, the utility functions for choosing each alternative are defined to represent SOVs preferences and reasons indirectly about the preferences. The utility functions of the lane choice model to be used in this study are:

$$U_{HOT} = \alpha * TT_{HOT} + \omega * R_{HOT} + \beta * TR \tag{3}$$

$$U_{GP} = \alpha * TT_{GP} + \omega * R_{GP} + C \tag{4}$$

where *TT* and *R* stand for travel time and trip reliability, respectively. They are generic attributes which will impact the utilities of different lane types in the same way. *TR* is the HOT-specific attribute (toll rate) and *C* is the constant.

The percentage of SOVs choosing the HOT lane is modeled in a logit model format, which is the lane choice model format adopted widely from survey data. In this logit-like model, the probability of an SOV choosing to travel in a HOT lane is substituted by the percentage of SOVs demand choosing the HOT lane in the approaching SOV traffic. The model is written as:

$$P_{HOT} = \frac{e^{U_{HOT}}}{e^{U_{HOT}} + e^{U_{GP}}} = \frac{1}{1 + e^{U_{GP} - U_{HOT}}} \tag{5}$$

where P_{HOT} is the percentage of SOV choosing the HOT lane in the approaching SOV traffic; U_{HOT} is the utility function of HOT lane; and U_{GP} is the utility function of GP lanes.

Among all the independent variables in the model, system reliability is relatively hard to measure and quantify. This study uses a probability-based approach to measure the travel time reliability on both HOT lane and GP lanes. Several studies have been done to express travel time reliability in terms of probabilistic measures *(17, 18)*. The travel time reliability in this study is defined as the probability that a trip can be made successfully within a specified interval of time. This probability is a function of time of day. Assume that for a study period, the travel time at a specific time of day follows a normal distribution, with mean and standard deviation of the distribution determined by historical data at each time of day. The travel time reliability is expressed as:

$$Reliability = \Pr(t < t_{r_i}) = 1 - \Pr(t > t_{r_i}) \tag{6}$$

where t is the actual travel time for a given time of day; and t_{ri} is the required travel time for a given time of day

This reliability measure converts the reliability to a 0-1 scale, where 1 indicates most reliable and 0 least reliable. Note that all travel times used in this study are estimated with the Piecewise Linear Speed Based (PLSB) model *(19).* This PLSB method reconstructs mean travel times based on time series of speed measurement at consecutive detector locations along a route. This method is almost unbiased given dense enough detector spacing *(20).*

RESULTS AND ANALYSIS

VOT Distribution Analysis for Infrequent Users and Frequent Users

To examine whether infrequent users and frequent users have different VOT distributions, the transponder records were extracted from database for the northbound commute during the morning peak period between 5:00 A.M. to 10:00 A.M. The transponder data covers in total 21 days in February and March, 2009, Tuesday through Thursday. Figure 2 shows the histogram of SOV usage on HOT lane based on transponder record. In this study, 14 days is chosen as a threshold to distinguish the two groups of users. That is to say, within these 21 days, the transponders shown up fewer than 14 days are considered to be infrequent users, and transponders that show up more than 14 days are considered frequent users. The users chosen here for the VOT study are those who traveled the whole northbound corridor for the morning peak period. The reason is that individuals may have differential sensitivities to times spent in different travel distances and time periods. They may not be willing to pay as much for saving a minute of travel time from a longer-distance trip as opposed to saving a minute from a shorter-distance trip. Therefore, by restricting to users that travel the same distance under the same study period, the VOT distribution can be better studied and reasonably interpreted. There are in total 5,247 transponder samples collected across the span of the sampling period.

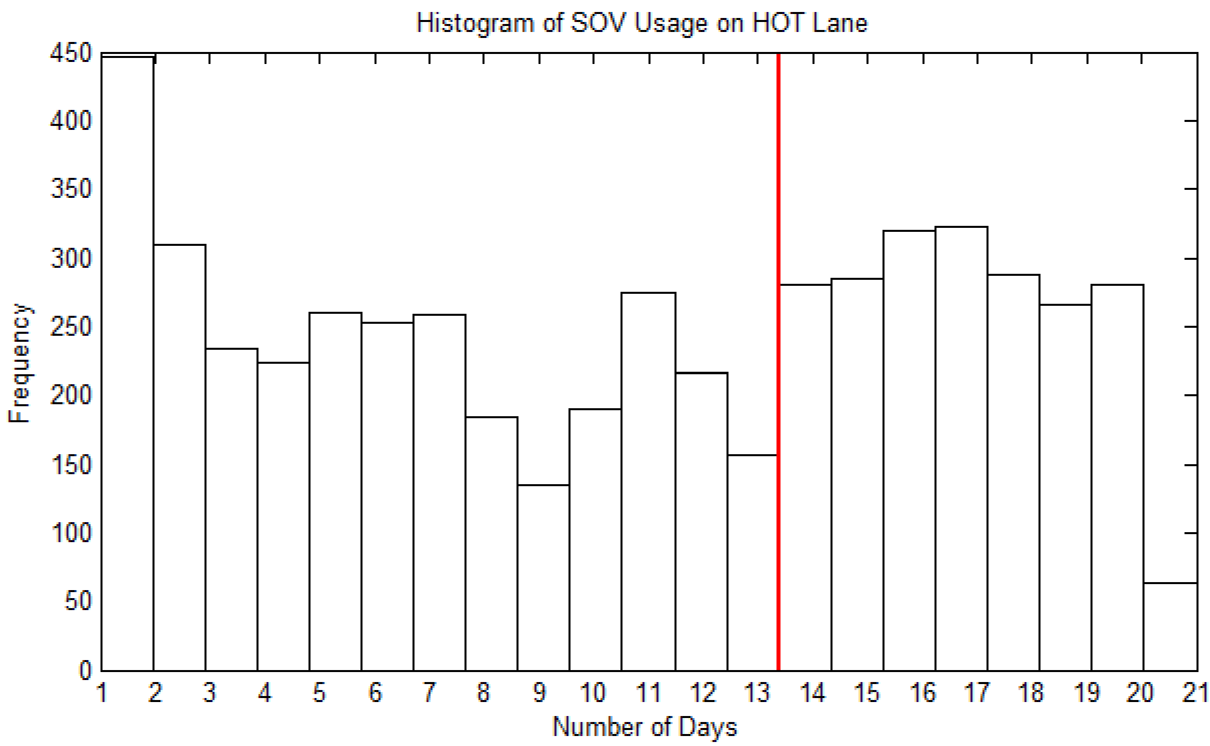
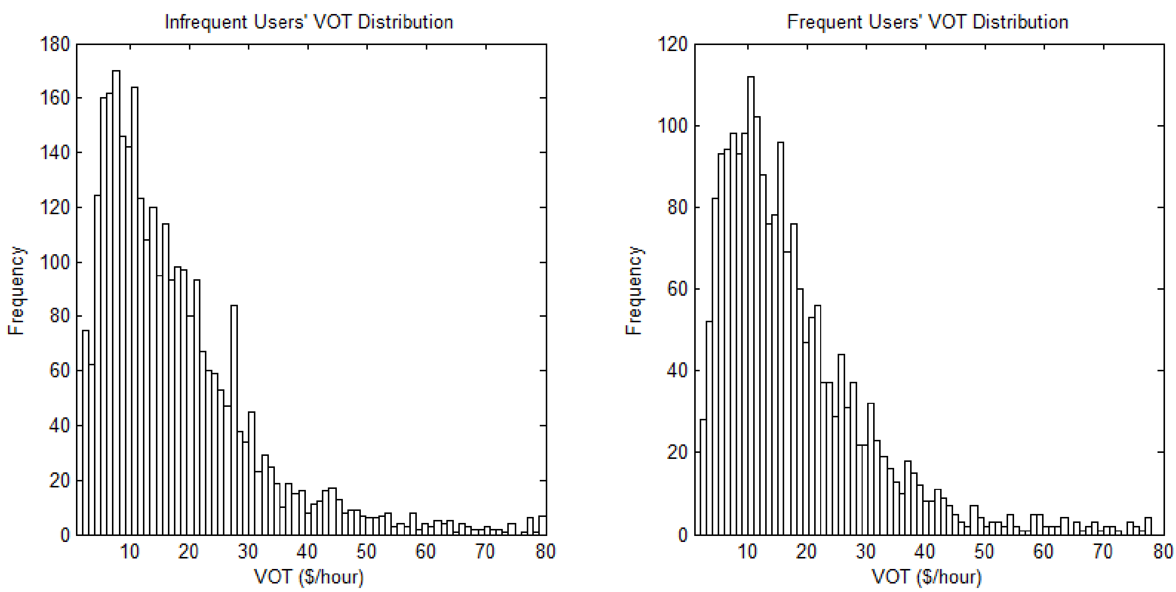
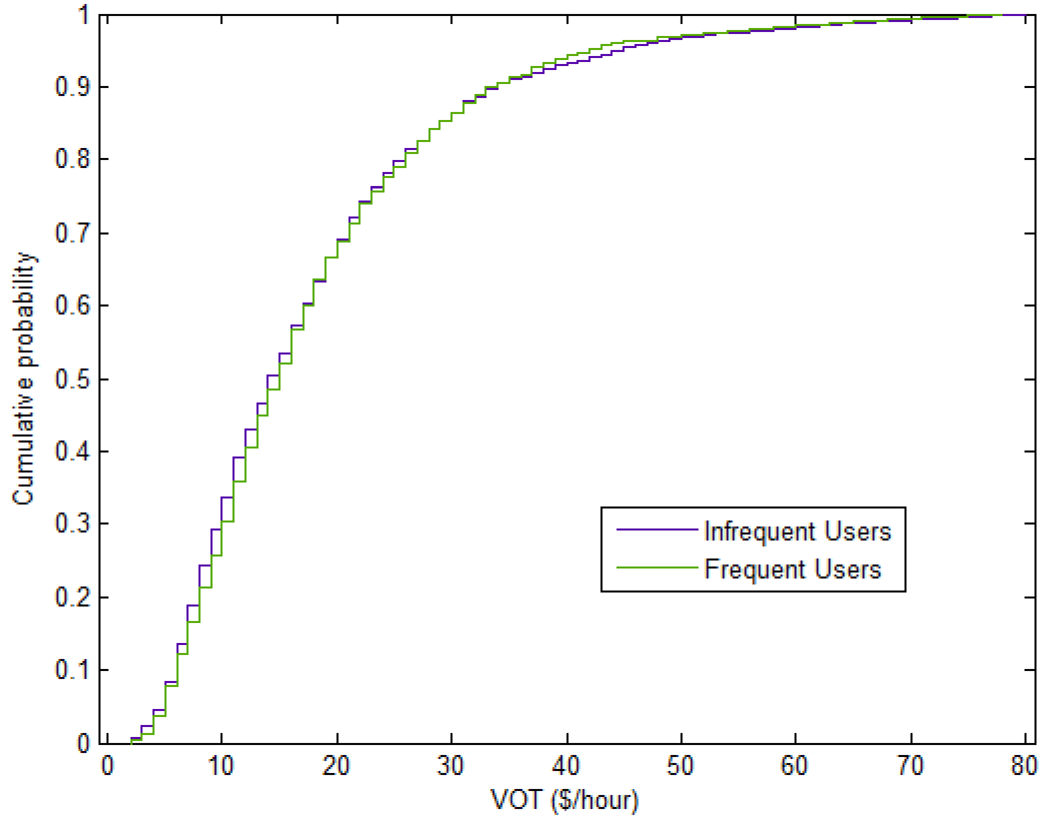


FIGURE 2 Histogram of SOV usage on HOT lane based on transponder record.

Using the methodology proposed in Equation (1), the VOT distributions for the two groups of users are calculated separately. The VOT distribution results and cumulative probabilities are shown in Figures 3 (a) and (b), respectively. It is noted that for the two user groups, the VOT distribution follows a very similar pattern, with a close mean value (17.9 $/hr for infrequent users, and 18.1 $/hr for frequent users). The t-test indicates that the VOT difference between two data sets are statistically insignificant (t=0.37, P=0.35) at the 95% confidence interval. This indicates that the VOT distribution for frequent users is not statistically different from the infrequent users'. That is to say, frequent users care about travel time savings in a very similar fashion to infrequent users. Therefore, when modeling the SOVs response to tolling, it is not necessary to separate the two user groups as demonstrated in the following section.



(a) VOT Distribution Function for Infrequent Users and Frequent Users



(b) VOT Cumulative Probability for Infrequent Users and Frequent Users

FIGURE 3 VOT histogram and cumulative probability for infrequent users and frequent users.

Modeling SOVs' Response to Tolling and Traffic Conditions

To further model the SOVs response to the changing traffic conditions, the morning peak period is categorized into different traffic phases. A time series speed plot is shown in Figure 4. The period of GP lane breakdown is easily identifiable from Figure 4, where a sudden speed drop below 40 mph is observed. Before 6:30 A.M., the average speed across the GP lane is relatively high, remaining above 40 mph. However, at 6:30 A.M., the GP lane experiences a sharp speed drop to below 40 mph, and generally remains below that threshold until 8:30 A.M., and then speeds recover to the pre-congestion state. During the congested period, the speed of the HOT lane does not breakdown, although a slight speed drop to around 55 mph in average is observed. Therefore, when modeling SOVs response, the whole morning period is divided into three traffic phases: pre-congestion period (5:00 A.M. to 6:25 A.M.), congested period (6:30 A.M. to 8:30 A.M.) and post-congestion period (8:35 A.M to 10:00 A.M.).

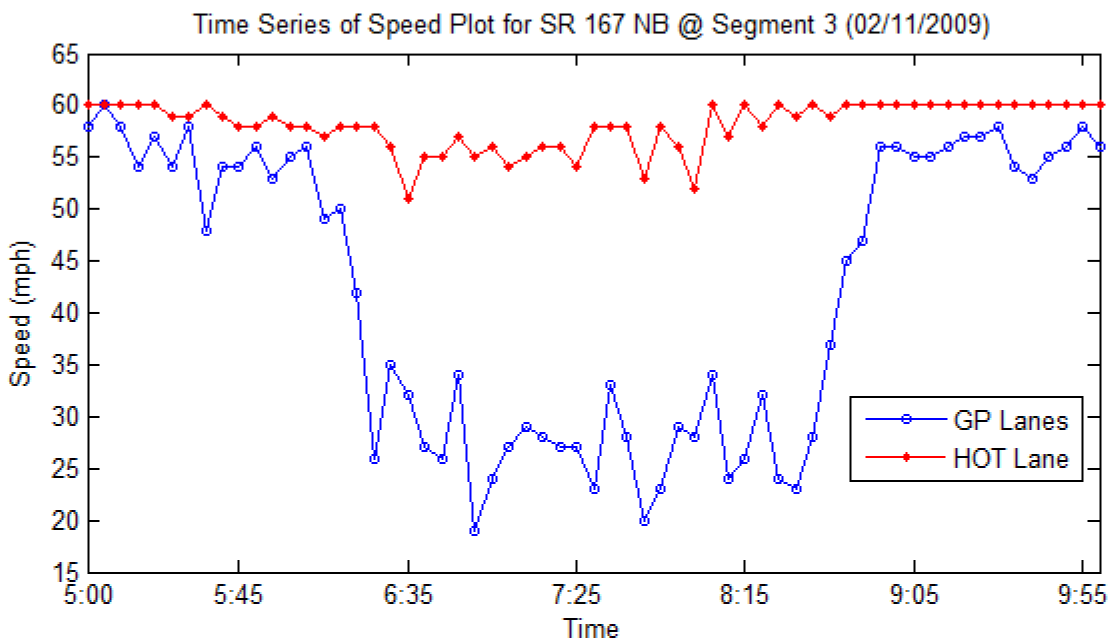


FIGURE 4 Time series of speed plot for SR 167 NB @ Segment 3.

An SOVs demand is therefore modeled following the methodology proposed in Equation (3) to (5) for the three different traffic phases. The probability that the approaching SOVs would choose to use the HOT lane is modeled in a logit-like format. By substituting Equations (3) and (4) into Equation (5), the model can be rewritten as:

$$\ln\left(\frac{1-p}{p}\right) = \partial * TR + \beta * (TT_{GP} - TT_{HOT}) + \omega * (R_{GP} - R_{HOT}) + C \quad (7)$$

The modeling results are shown in Table 1. All the models in the three phases yield reasonable estimation results, with R squared values ranging from 0.6 to 0.8. The left side of Equation (7) can be interpreted as the ratio between the SOV GP lane demand and the SOV HOT lane demand. Note that the toll rate in Phases 1 and 3, and the reliability in Phase 2 are not significant at 95% confidence level, therefore, they are eliminated from the final model. The final utility functions for the three traffic phases can be therefore written as:

Pre-Congestion:

$$\begin{aligned} U_{HOT} &= -0.012 * TT_{HOT} + 1.042 * R_{HOT} \\ U_{GP} &= -0.012 * TT_{GP} + 1.042 * R_{GP} + 2.511 \end{aligned} \quad (8)$$

Congested Period:

$$\begin{aligned} U_{HOT} &= -0.214 * TR - 0.005 * TT_{HOT} \\ U_{GP} &= -0.005 * TT_{GP} + 2.78 \end{aligned} \quad (9)$$

Post-Congestion:

$$\begin{aligned} U_{HOT} &= -0.003 * TT_{HOT} + 1.030 * R_{HOT} \\ U_{GP} &= -0.003 * TT_{GP} + 1.030 * R_{HOT} + 3.338 \end{aligned} \quad (10)$$

It is confirmed from the models above, that for different traffic phases, the SOV demand is adjusted based on different user concerns. For the pre- and post-congestion period, SOVs care more about travel time savings and travel time reliability, which play a significant role in the models. This is reasonable because for those two periods, the toll rate is normally fluctuating between $0.5 and $1. Due to this relatively lower rate, the lane choice may not be determined by the fee, but rather by travel time savings or a reliable trip. During the congested period, however, toll rate has a significant impact to the SOV demand. During that period, the SOV HOT lane demand would increases as the toll rate goes up. This seems counterintuitive at first glance, but is easily explainable under the dynamic tolling context since it captures the signaling effect of the congestion pricing scheme. The toll is adjusting based on the real time volume and speed measurements on both HOT lane and GP lanes. Since the SR 167 HOT lane seldom experiences any congestion, the toll rate is functioning as a signal indicating the traffic condition on both downstream HOT lane and GP lanes (normally fluctuating between $1.00 to $2.75). For the majority of HOT lane users, when the toll rate goes up during the congested hours, it indicates that the downstream traffic in the GP lane is fairly congested. Therefore, people would rather pay more to use the HOT lane to avoid the traffic. Also, it is noted that travel time is significant in all the three phases, indicating the fact that the priority for people choosing the HOT lane is for an immediate benefit of travel time savings.

Table 1: Statistic Result for Modeling SOVs Demand to Tolling and Traffic Conditions

Traffic Phase	Variables	Coefficients	t Value	p Value
1. Pre Congestion	**Toll Rate**	0.239	1.973	0.049
	Travel Time	-0.012	-8.070	0.000
	Reliability	1.042	6.863	0.000
	Constant	2.511	16.125	0.000
2. Congestion	**Toll Rate**	0.214	3.206	0.001
	Travel Time	-0.005	-5.205	0.000
	Reliability	0.017	0.182	0.855
	Constant	2.78	23.192	0.000
3. Post Congestion	**Toll Rate**	0.600	1.540	0.124
	Travel Time	-0.003	-10.574	0.000
	Reliability	1.030	-4.429	0.000
	Constant	3.338	12.135	0.000

CONCLUSION

The HOT lane concept has been developed to help alleviate congestion while gathering revenue. A lot of research has been done to examine the effectiveness of HOT lanes from a transportation policy perspective. However, few efforts have been made to investigate how the SOVs utilize the HOT lanes under various scenarios from an operational perspective.

This paper focused on the necessity of assessing HOT lane traffic operations, especially for travel pattern changes of SOVs under various conditions. The SOVs on HOT lane were classified into two user groups (infrequent users and frequent users) according to the frequency of their transponder IDs occurring in the database. The VOT distribution of the two user groups were further estimated at an individual level. It is determined that the two user groups have a similar pattern in VOT, which indicates that frequent users value travel time savings as much as the infrequent users. Then the reason that some people (frequent users) use the HOT lanes more than the others may lie in the socioeconomic differences, such as income, lifestyle, educational level, etc. This study further investigated, at a macroscopic level, how the SOV demand on HOT lane changes with toll rate and various traffic conditions. A logit-like model is applied in this study to simulate the effect. It is found that SOV demand would mostly be affected by three factors: toll rate, travel time difference and travel time reliability. A travel time reliability index is developed to measure the system reliability using a probabilistic approach, which is defined as the probability that a trip can be made successfully within a specified interval of time as a function of time of day. The model is applied to three different traffic phases: pre-congestion, during congestion, and post-congestion. From the model results, it is determined that for the pre-congestion and post-congestion periods, the SOV demand is more affected by the system reliability and travel time savings. While during the congested period, tolling is functioning as a signal to attract more traffic into HOT lane in an effort to avoid downstream congestion.

The results of this research are important as analysts are developing methods to better understand the effectiveness of HOT lane performance and the heterogeneity among the SOV users. The finding of this paper suggests that, under different traffic conditions, the SOVs lane choices may be affected by different attributes. This is important in the consideration for an optimal tolling policy setting, which oftentimes overlooks variation in users' concerns under different traffic conditions.

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