What Drives Decisions of Single-Occupant Travelers in High-Occupancy Vehicle Lanes?

Investigation Using Archived Traffic and Tolling Data from MnPASS Express Lanes

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High-occupancy toll (HOT) lanes are in operation, under construction, and planned in several major metropolitan areas. The premise behind HOT lanes is to allow single-occupant vehicles (SOVs) to access high-occupancy vehicle lanes (and a higher level of service) if they are willing to pay a toll. To maintain a high level of service in the HOT lanes, the toll rate is set dynamically to restrict the number of SOVs that access the facility lanes as they near capacity. Thus, HOT facilities provide operators of transportation systems with an additional tool: pricing. To use pricing effectively, it is critical for those operators to understand how drivers behave when faced with a set of traffic conditions and toll levels. This paper presents the results of an empirical investigation into the relationship between toll rate, traffic conditions, and SOV driver behavior, on the basis of data from the dynamically tolled I-394 HOT facility in Minneapolis, Minnesota. Analysis of the empirical data indicated that a large percentage of SOV drivers used the HOT lanes at different, yet predictable, rates throughout the morning peak period, even when there was no clear travel time advantage. After these users were accounted for, it was determined that the remaining SOV drivers used the HOT lanes at greater rates when the cost per hour of commute time saved was lowest. A model was developed that incorporates both of these findings, predicting HOT lane usage rates based on time savings, time of day, and toll rates, with an R^2 value of .684.

High-occupancy toll (HOT) lanes are a form of managed lanes that offer free or reduced-toll travel to high-occupancy vehicles (HOVs), while allowing single-occupant vehicles (SOVs) that pay a toll (*1*). Some HOT lanes employ dynamic pricing strategies to control congestion and maintain high speeds by changing toll rates in response to congestion. HOT facilities that use dynamic tolling are examples of the emerging approach known as active traffic management (ATM), in which infrastructure providers seek to manage recurrent and nonrecurrent congestion on the basis of real-time traffic conditions (*2*). Currently, HOT lanes exist in several U.S. cities, and more are under construction or planned.

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The HOT lanes concept relies on the assumption that SOVs will be discouraged from entering HOT lanes as toll rates increase, thus preventing HOT lanes from becoming congested. Most willingness-to-pay research has either focused on stated preference (SP) surveys (*3*) or investigated the median cost per hour of commute time saved (*4*). Although SP studies have been shown to be inaccurate in determining real-world HOT lane behavior (*4*), little research has been conducted to analyze and model actual drivers' responses to minute-to-minute changes in toll rates and traffic conditions by using empirical data from an operational HOT lane system. This paper attempts to understand and model the impact of toll rates and traffic conditions on the behavior of drivers of SOVs in a HOT lane system through analysis of data from an operating HOT lane facility in Minneapolis, Minnesota. This is necessary to make maximum use of this ATM strategy: allowing road operators full understanding of the impact of toll increases on traffic assignment.

HOT lane usage is measured from a combination of toll transaction records and detector data from the I-394 MnPASS express lane system. The study period was the morning peak between November 7, 2006, and March 31, 2008, along the 2.7-mi, barrier-separated, reversible section of I-394 near downtown Minneapolis. The study ignores the possibility of SOVs using the system illegally on the basis of the low 3% noncompliance rate found for the section in a 2006 study (*5*).

MnPASS FACILITY

The I-394 MnPASS is an 11-mi HOT lane facility in Minneapolis, Minnesota, operated by the Minnesota Department of Transportation (DOT). The facility, in operation since May 2005, is one of the few HOT lanes that dynamically adjusts toll rates in response to traffic conditions. Between Central Avenue and TH-100, the HOT lanes are former HOV lanes in both directions, separated from general-purpose (GP) lanes over 8-mi by double white lines. The double-striped lanes, often referred to as diamond lanes, operate Monday through Friday from 6 to 10 a.m. in the eastbound direction and from 2 to 7 p.m. in the westbound direction. From TH-100 to I-94, the facility operates as a two-lane reversible facility 2.7 mi long. The reversible HOT lanes are barrier separated from the GP lanes. The reversible section is operational at all times, including weekends, except when the lanes' directions are being switched. The HOT lanes are operated in the eastbound direction from 6 a.m. to 1 p.m. and in the westbound direction from 2 p.m. to 5 a.m. Figure 1 is a map of the facility (*6*).

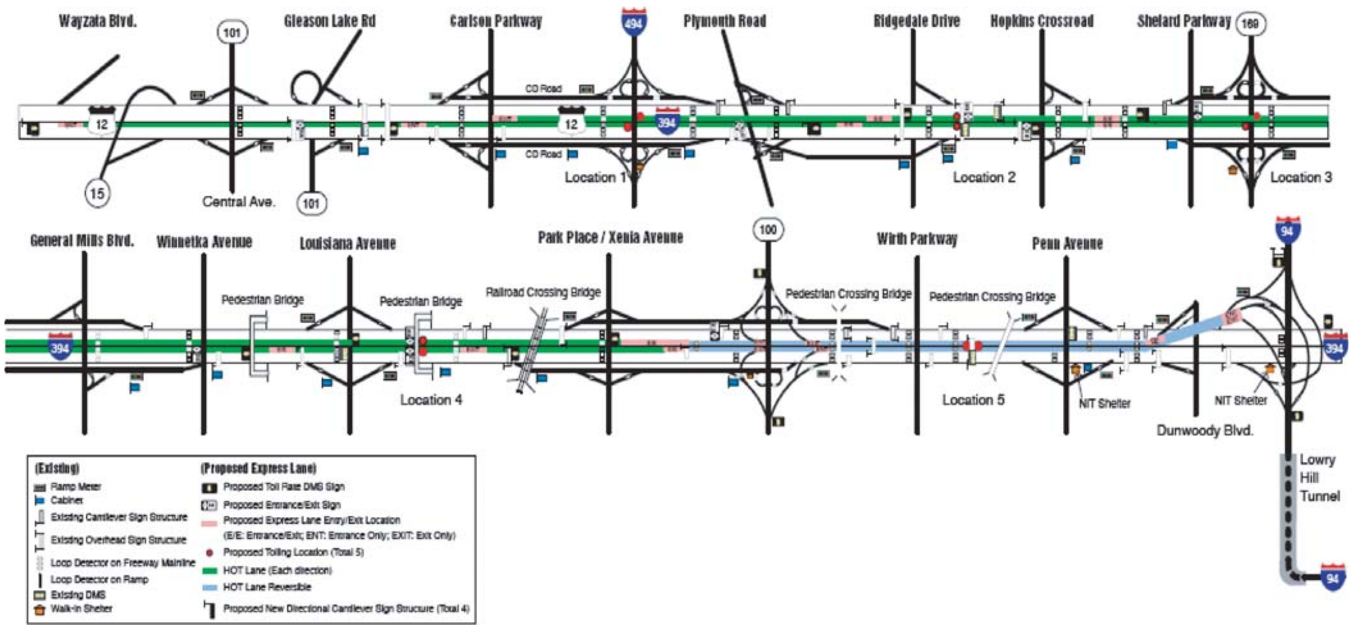

FIGURE 1 I-394 MnPASS HOT lanes (*6*).

Tolls for SOVs are collected electronically at five locations. SOVs using the HOT lanes must be equipped with MnPASS transponders, which can be leased for $1.50/month. The diamond and reversible sections have separate toll rates. Rates are automatically adjusted every 3 min to maintain high speeds in the HOT lanes. The total toll for a vehicle using the entire system ranges between $0.50 and $8.00 per trip.

The corridor regularly experiences congestion during the peak period, with tolls typically reaching just under $2.00, speeds in the HOT lanes reaching 70 mph, and speeds in the GP lanes falling to 45 mph. Figure 2 shows average speeds of the HOT and GP lanes over the study period. Figure 3 shows the average percentage of SOVs using the HOT lanes over the study period.

ANALYSIS

To focus on the periods of highest congestion and toll rates (when SOVs are most likely motivated to use HOT lanes), the study concentrated on the reversible section during the morning peak period

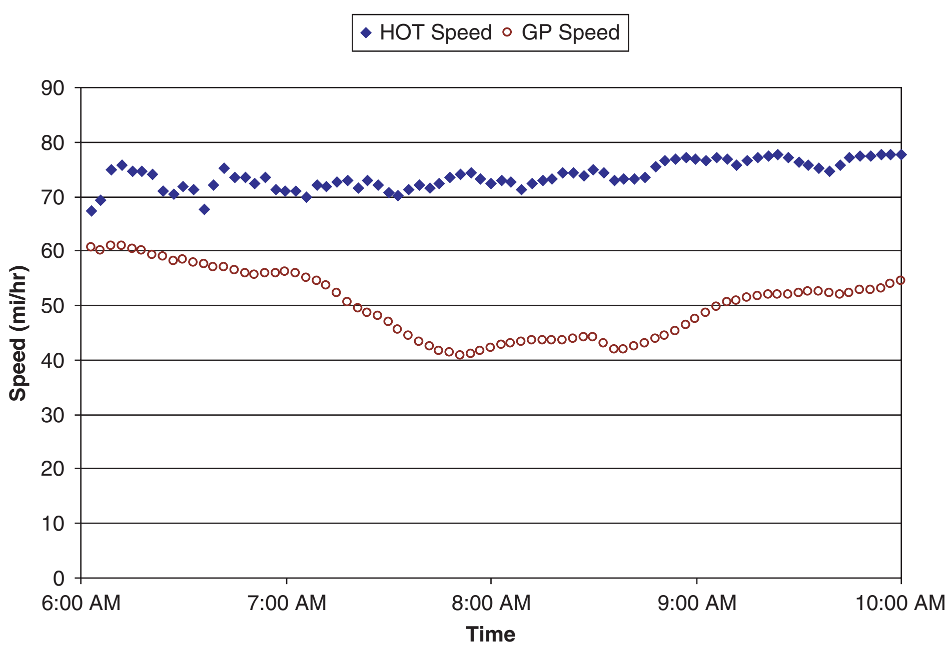

FIGURE 2 Average speeds during study period.

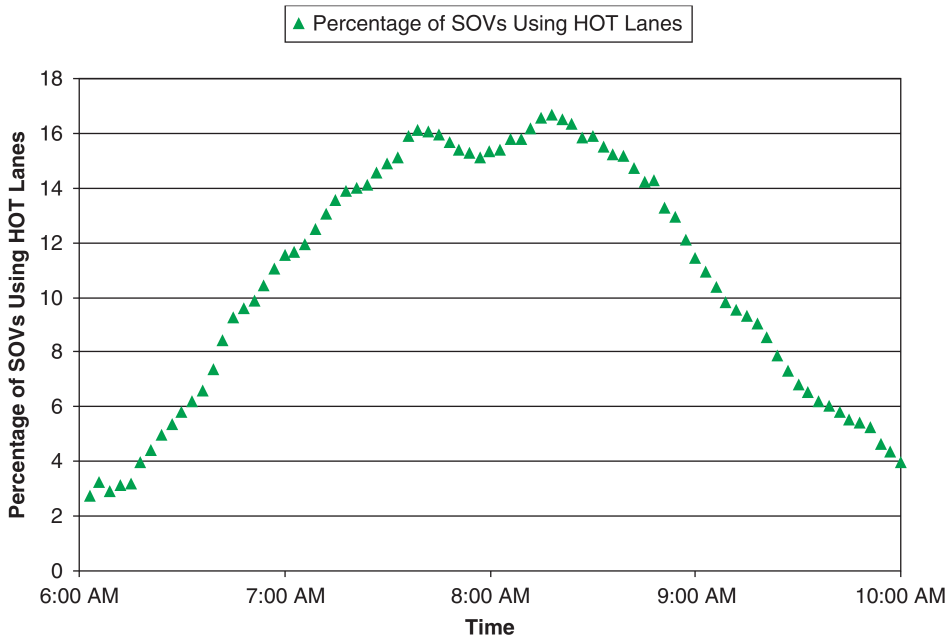

FIGURE 3 Average percentage of SOVs using HOT lanes during study period.

from 6 to 10 a.m. Monday through Friday. The reversible section was selected because, unlike the diamond section, drivers in the reversible section pay a single toll for a predetermined distance and because the section acts as a pipeline with no exits along the corridor. This makes volume comparisons between the HOT and GP lanes relatively simple. Data were obtained from the Minnesota DOT for the period from November 2006 to March 2008 at 3-min intervals. The following data were collected from the Minnesota DOT:

- Toll rates and their start times;
- Individual toll transactions by vehicle, time stamped and identified by each electronic toll reader passed;
- Data from five detectors in the HOT lanes and five detectors in the GP lanes, with speeds, volumes, and occupancies recorded at 3-min intervals. Detector data were validated through data quality standards developed by the Texas Transportation Institute (*7*).

Those data, in conjunction with the following table, were used to determine the cost per hour of travel time saved:

Hot-Lane Speed (speed limit, 65 mph)	*GP-Lane Speed (speed limit, 55 mph)*	*Equation Used*
≥65 mph	≥55 mph	No advantage, value null
≥65 mph	<55 mph	$c = \dfrac{T}{\dfrac{D}{S_{GP}} - \dfrac{D}{L_{HOT}}}$
<65 mph	≥55 mph	No advantage, value null
<65 mph	<55 mph	$c = \dfrac{T}{\dfrac{D}{S_{GP}} - \dfrac{D}{S_{HOT}}}$

where

c = cost per hour of travel time saved ($/h);
T = toll rate ($);
D = distance of the highway segment (mi), in this case 2.7 mi;
S = speed of the HOT or GP lanes (mi/h); and
L = speed limit of the HOT or GP lanes, 65 and 55 respectively (mph).

RESULTS

When one first examines the data, it appears that the cost per hour of travel time saved has little influence on SOV behavior. Figure 4, which summarizes the data over all time intervals in the a.m. peak, shows that, regardless of the cost per hour of travel time saved, roughly 14% to 15% of SOVs choose to travel in the HOT lanes.

However, when plotting the time series of the percentage of SOVs using the HOT lanes during the morning peak period, one notices a clear fluctuation in HOT lane use, regardless of traffic conditions or toll rate. For example, Figure 5 shows the average HOT lane use when GP speeds are above 55 mph, the speed limit on this facility. Even in these conditions, with little apparent incentive to use the HOT lanes, drivers are almost six times as likely to use the HOT lanes at midpeak than during early peak.

Several possible explanations exist for this phenomenon. First, because the Minnesota DOT was careful not to overmarket MnPASS transponders (*8*), it is likely that most MnPASS users are drivers who routinely experience heavier-than-average congestion. It is possible that a greater percentage of drivers during the midpeak period have transponders, which thus explains their greater proportion in the HOT lanes. Small et al. (*9*) have suggested that travel time reliability is also an important factor in driver behavior. In their analysis of the I-15 dynamically priced HOT lanes in San Diego, California, Brownstone et al. assumed travel time reliability to be

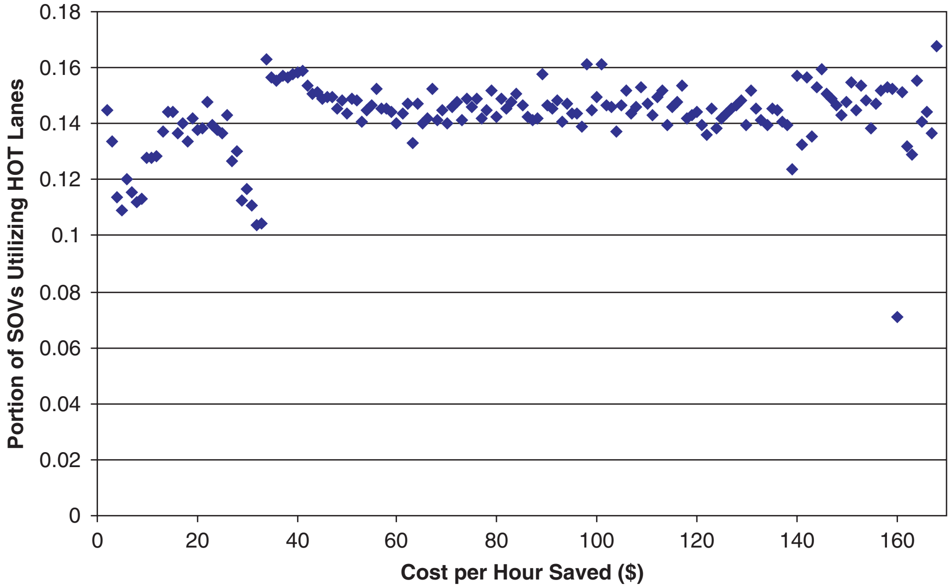

FIGURE 4 Average portion of SOVs using HOT lanes versus cost per hour saved.

a major decision factor for drivers (*4*). Because the GP lane speeds are less reliable during midpeak, drivers may be using the HOT lanes as insurance against congestion, regardless of the evidence of any congestion upstream.

If one assumes that the drivers who use the HOT lanes even when there is no apparent benefit in travel time are insensitive to price, these drivers can be considered to be everyday HOT lane users. In other words, these SOV users will choose the HOT lanes largely for their reliability rather than as an improvement to current conditions. Therefore, it is reasonable to "remove" these SOVs from the data in an attempt to model behavior for the set of drivers who are sensitive to costs associated with real-time travel time savings.

By removing the average portion of everyday drivers from each individual record on the basis of its time of day, one can directly consider drivers who are more sensitive to travel time savings and conditions. Figure 6 shows the average portion of SOVs using the HOT lanes at various prices for travel time savings, with the everyday drivers removed from the data. The relationship here is much clearer, as SOV drivers use the HOT lanes at greater rates when the relative cost is lowest.

The research team chose to model the relationship illustrated in Figure 6, with an exponential model, as shown below:

$$P(c) = \alpha \ln(c) + \beta$$

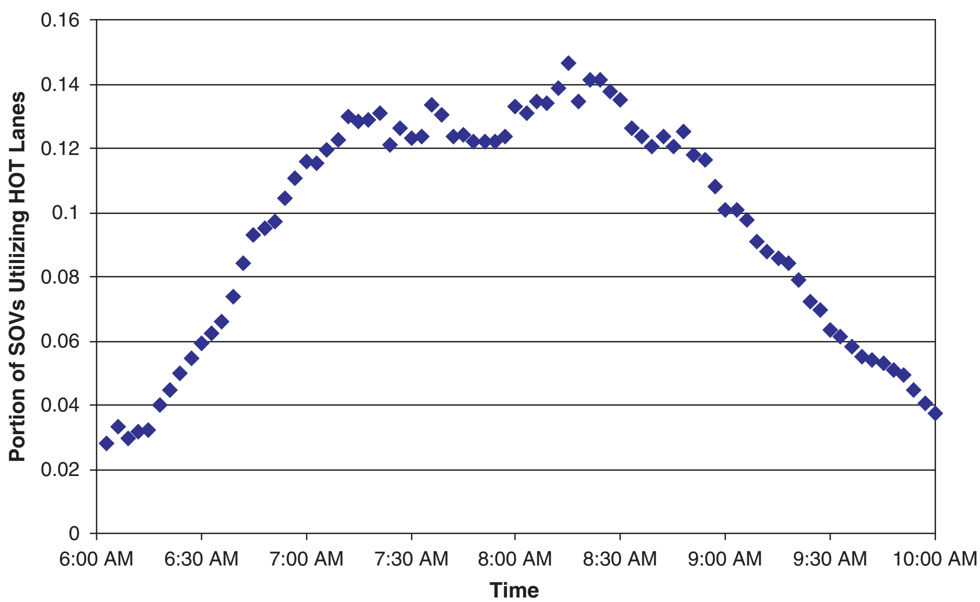

FIGURE 5 Time series of average portion of SOVs using HOT lanes when GP speeds are greater than 55 mph.

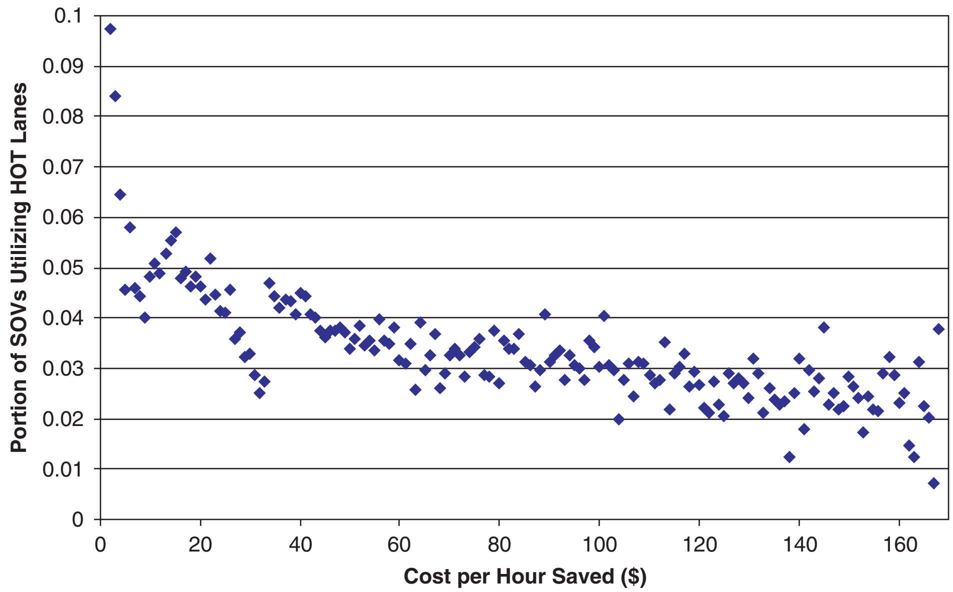

FIGURE 6 Average portion of SOVs using HOT lanes versus cost per hour saved after removing the everyday HOT lane SOVs.

where $P(c)$ is the average percentage of SOVs using the HOT lanes at the cost per hour of travel time saved c. On the basis of a regression of average HOT lane users, values of the coefficients α and β were found to be −0.0107 and 0.078, respectively. The model had an R^2 value of .7265.

DEVELOPMENT OF SOV HOT LANE MODEL

On the basis of the results presented in the previous section, the research team proposed the following two-component model of SOV behavior to account for the everyday and price-sensitive drivers:

$$U(t,c) = E(t) + P(c)$$

where

$U(t, c)$ = percentage of SOVs using HOT lanes in time interval t at cost per hour of travel time saved c,

$E(t)$ = average percentage of SOVs using HOT lanes in time interval t when speed in GP lanes exceeds 55 mph (speed limit), and

$P(c)$ = average percentage of SOVs using HOT lanes at cost per hour of travel time saved c.

When the model was applied to the entire MnPASS data set, the multicomponent model had an R^2 value of .684. Figure 7 provides an example of the model as applied to a typical day.

The performance of the multicomponent model is driven largely by the everyday user component, $E(t)$. Of the SOVs using the HOT

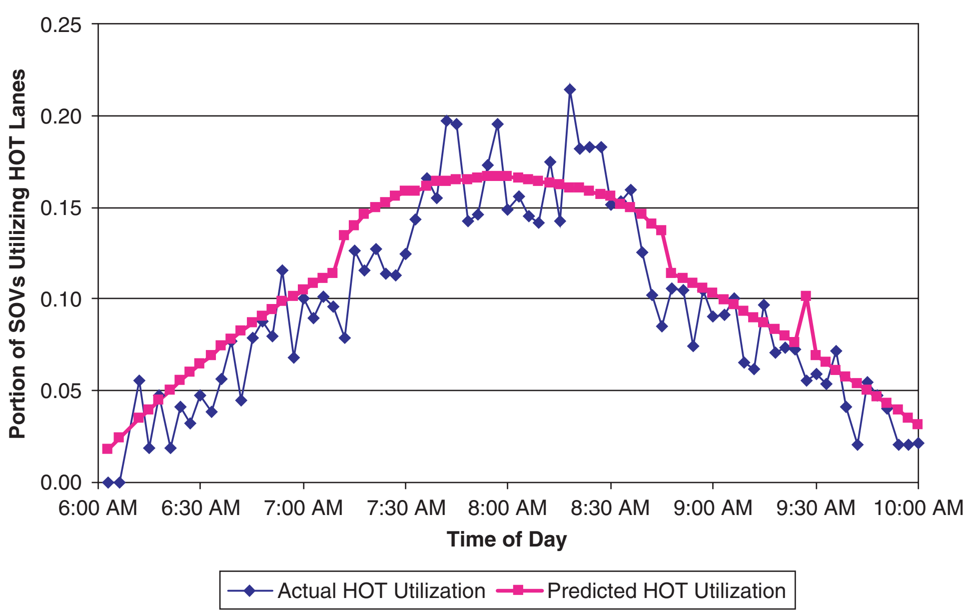

FIGURE 7 Comparison of predicted and actual HOT lane use on March 28, 2008.

lanes, the model predicts that 87.5% are everyday users. When only the historical average percentage of SOVs using HOT lanes, under any traffic conditions [i.e., $E(t)$ without the restriction of GP lanes operating at 55 mph or higher], is used to model U, an R^2 value of .675 results. Thus, the pricing has negligible influence. This is an extremely important finding in relation to future operation of HOT facilities. In this case, it is clear that the current pricing structure and population of eligible SOVs result in a situation in which pricing is ineffective in preventing SOVs from using the HOT lanes when such prevention is deemed necessary.

CONCLUSIONS

Based on an analysis of the data from the MnPASS HOT facility, SOVs use the HOT lanes at different rates throughout the morning peak period, even when GP lanes are operating above the speed limit and no strong advantage comes from using the HOT lanes. These drivers appear to place greater value on protection from possible future congestion than immediately visible travel time savings. If one assumes that these drivers use the HOT lanes as insurance against unanticipated congestion, this portion of vehicles can be ignored in the analysis of vehicles that are influenced by cost per hour of commute time saved. The remaining drivers show a clear relationship between value of travel time and usage of the HOT lanes. Accounting for both groups of drivers separately and then adding together their combined usage rates create a model that may be useful as DOTs attempt to predict traffic assignment in HOT facilities.

An equally important, if not more important, finding of this research is that much of the variation in HOT lane usage may be explained not by cost or current conditions but by expected traffic conditions. This is likely because most drivers do not typically have access to real-time travel time estimates and thus must estimate the traffic conditions on the basis of a combination of sporadic traffic reports, HOT lane toll rates, and historical congestion at that particular time of day. The HOT lanes experience an increase in usage during the middle of the morning peak period, even when little immediate advantage to using HOT lanes is apparent. Two possible explanations exist for this situation. First, drivers may be anticipating, on the basis of congestion in the past, greater congestion during the middle of the peak period and may be using HOT lanes to avoid potential rather than actual congestion. Second, there may be a greater proportion of drivers with HOT lane transponders during this period, as drivers using the facility during this period are the most likely to encounter congestion and therefore have the greatest incentive to participate in the MnPASS program.

Previous analysis of HOT lane usage assumed drivers had knowledge only of historic average travel times, not real-time traffic conditions (*4*). As traveler information becomes more widely available through 511 calls, IntelliDrive applications, smart phones, and in-vehicle navigation systems, drivers will be able to make more-informed decisions. As these devices and applications become more widely available and as travel time data become more accurate and sophisticated, drivers may begin to make decisions based more on real-time conditions than on perceived conditions or past experiences. This trend indicates the need for ongoing analysis of HOT usage data to allow for most effective operation of the facilities.

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