Changes in Travel Behavior/Demand Associated with Managed Lanes

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Disclaimer

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1. SUMMARY

This project was primarily aimed at discovering relationships between the implementation of managed lanes and travel behavior, or traveler response.

There is a wealth of published work on both HOV and HOT lane implementations, most of which has to do with implementation and operation, rather than traveler response. We were able, however, to find both descriptive studies and econometric model–based studies that shed considerable light on behavioral response, particularly on the implementation of variable-lane pricing schemes that are of considerable interest to policy makers and their advisors. These econometric models use advanced forms of logit regression and the papers are academically oriented. While some of the logit techniques described have been in the literature for some time (10 years or so), they have not been utilized by practitioners because they are not easily available in commonly used statistics packages and because the source papers are mainly written by econometricians and are technically demanding for many of the engineers and planners who carry out everyday model application tasks. An objective in this report is to try to make these techniques a little more transparent to practitioners.

When considering HOV (carpooling) facilities, there are clearly a number of quite different operating environments. There are unique implementations, such as the Shirley Highway (Virginia) lanes leading into Washington DC and the San Francisco–Oakland Bay Bridge, both of which generate so-called “slugs,” or casual carpools, of unrelated individuals. There are cities that have systems of HOV lanes of significant length (10 to 20 miles), such as Houston or Seattle, which generate some carpools of unrelated individuals. There are also many implementations of short 5- to 10-mile HOV lanes, not part of a system, which have most of the users drawn from household-based shared rides. We can think of this last group as opportunistic HOV lane users. We attempt in this study to disentangle the somewhat scant information on user behavior (which can only be studied by a disaggregate analysis of user/non-user surveys) to determine predictors of HOV use. We also describe briefly why the truly unique systems work the way they do and why those experiences cannot be generalized to be useful for applications elsewhere.

When considering HOT (priced) lane implementations there are two linked, but different objectives. The public sector is concerned about travel demand management, maintenance of efficient flows to maximize throughput, recovery of some or all of the costs of implementation, and possible private sector funding, and hence the ability to forecast use under various pricing schemes. The private financing sector is concerned about risk analysis (worst case scenarios from exogenous inputs such as the performance of the economy over time, or land use assumptions not realized), as well as the performance of forecasting models currently used. This last element is common to both sectors—the ability to forecast use under various pricing schemes. This is the area of focus of this report.

1.1 HOV Lanes

From the studies considered here (I-15 and SR 91 in Southern California, and Houston, Texas), the primary predictors of carpooling are trip length, in terms of distance or time, and household composition; travel time saving is also mentioned in the context of Houston. One model developed in California also includes travel time-savings (Steimetz and Brownstone, 2005). In the California studies, distances of 20 to 30 miles are positively associated with carpools. Household composition, particularly larger households with multiple workers, is also positively associated with carpooling, implying ridesharing by household members. This result is also borne out in the Maryland study of HOV user composition.

There is concern that the implementation of HOT lanes might convert or reduce HOV use by converting HOV participants to SOV-pay. The implications from I-15 (Golob, 2001) and SR 91 (Parkany, 1999) are that there is little such effect. It is probable that the motivation for each of these modes is quite different. Carpools are formed from the need for cost savings (long distance or high parking costs), and with a long distance, the time costs of carpool formation are dissipated or amortized over the long total travel time. The motivation for paying for express travel has to do with time-savings at a cost, whether because of higher income, or because of situational effects (e.g., the need to be at work at a fixed time, or the need to retrieve a child from daycare).

1.2 HOT/Priced Lanes

There are myriad papers derived from the five waves of the I-15 project survey and the five surveys of the SR 91 project in Southern California. The I-15 project in San Diego was implemented in a very high-income corridor, while the SR 91 project between Riverside and Orange Counties was implemented in a slightly lower (for California) income corridor. These papers reveal values of time-savings (VoTS) that are very much higher than previously accepted as established wisdom. These values are in the range of $15 to $40 per hour, but mostly $20 to $30. Brownstone and Small (2005), when normalizing the I-15 model to reflect the income levels of commuters on SR 91, find that VoTS in both corridors are about $20 per hour. The VoTS in the California studies are offset by a separate value of reliability time (VoRT) having the effect, on average, of about one-third of the VoTS. In essence, there is a preference for HOT and HOV lanes that has to do with perceived reduction in the variability of travel time, and very likely, a perceived value of safety.

Many of the studies reveal a consistent over-estimate of time-savings by the user, as compared with actual time-savings measured on the ground, of approximately double the actual savings. This, in part might explain the very high values of time from these Revealed Preference (RP) studies. The values of time reported here are also approximately twice those estimated from Stated Preference (SP) surveys. For the SR 91 study, a sample of respondents who answered the revealed preference survey (actual behavior) were also given an SP survey (hypothetical behavior). Interestingly, the VoTS from the SP survey was half of that derived from the RP survey (Brownstone and Small, 2005).

From a non-quantitative basis, it is evident that variable pricing can be used to achieve policy goals, such as maintenance of free flow by increasing pricing to control demand. This can be carried out on a real-time basis and does not require forecasting capability. The consideration of maximizing income can similarly be carried out experimentally in real time. The issue of forecasting income in order to justify the investment in a highway or HOT lane, however, does require the ability to forecast behavioral response to pricing and associated time-savings.

1.3 Modeling and Behavior Analysis

Constructing models that are statistically sound is usually thought of as a tool for policy analysis and for forecasting. There is another dimension that is extremely important—the understanding and explanation of behavior that correlates with the variables needed and used in the model.

Experience with toll and pricing forecasts in practice has been extremely variable and somewhat unreliable. This is true both in the USA and elsewhere. While the three major firms that are certified to do so-called “Bond Quality” or “Investment Quality” forecasts in the US do not publish their methodologies, treating them as proprietary, it appears that the methods are primarily post-processing of existing trip-based 4-step model output through the use of diversion curves or assumed elasticities using empirical data or experience gained by the firm. As such they are effectively using the equivalent of point estimates and mean values of the value of time.

Current model practice is (mostly) a trip-based, aggregate application with mean point estimates of the coefficients for time and cost and, hence, value of time. This implies homogeneity for fairly broad groups of users. These coefficients and values of time are, in fact extremely heterogeneous and probably non-linear. Here, the mean, or average value, can be misleading. Heterogeneity in response of potential users, both observable and non-observed (situational), needs distributions of response rather than a point estimate of either mean or median. In practice, this will require household or traveler microsimulation (sometimes called sample enumeration). The models could be trip-based, tour-based, or activity-based, although all the current models that use traveler microsimulation are, in fact activity- or tour-based.

Critical elements are the value of time saved (VoTS) and the value of reliability (VoR), which together translate into willingness-to-pay. Several of the most recent analyses have, in fact, developed effective methods to separate the VoTS and VoR.

1.4 Survey and Data Needs

In order to properly evaluate heterogeneity of response, either indirectly through random parameter logit modeling or directly, it is necessary to have both stated preference (SP) and revealed preference (RP) data for one or more managed lane implementations. SP data are needed to avoid multicollinearity problems inherent in RP data, and to allow for a separate value of time to be estimated for each respondent, giving heterogeneity. RP data are needed to provide scale to the SP response in a model that can be jointly estimated and can be calibrated to observed (revealed) choices.

2. INTRODUCTION

2.1 Research Problem Statement

Background

Understanding what happens to travel behavior when managed lanes are implemented or expanded has been a challenge faced by state DOTs during highway corridor and systems planning. Current modeling and state of the practice do not fully capture the extent to which HOV facility expansion changes travel behavior/demand on both the managed lanes and the general-purpose lanes, and do not delineate the resulting impacts on mode splits, travel times, and travel patterns. Given the availability of data, a nationwide analysis of travel behavior at locations where HOV and other managed lanes have been built or expanded would give planners a better idea of the range of travel behavior/demand changes that can be expected. Research into this topic would also support future research on HOT lanes and freeway Bus Rapid Transit (BRT).

Objective

The objective of this study was to evaluate and describe how expanding HOV or HOT facilities and other managed lane approaches (as distinct from services) influence corridor mode choice, travel times, and patterns. The results of this study will support better evaluations of needs and demand during highway system planning and corridor alternatives analyses. The original research plan involved the following tasks:

1. Performing a literature search to identify documented research on changes to travel behavior when managed lanes are implemented or expanded;
2. Determining which states and metropolitan areas have established new or expanded HOV, HOT, or other managed lanes;
3. Interviewing officials in each area that has added managed lane capacity, gathering studies that have been done, and obtaining any available data on travel behavior changes;
4. Identifying up to five case study locations to examine travel behavior changes due to managed lanes;
5. Conducting the case studies and summarizing their results and the findings derived from each; and
6. Completing a final report outlining findings, conclusions, and currently available approaches for analyzing managed lane impacts on travel behavior, and recommending future research needs.

3. LITERATURE REVIEW

The purpose of the literature review was to discover what was known and documented with respect to managed lanes and travel behavior at the beginning of this study.

In general, more information about individual traveler behavior was found for variably priced HOT lanes than for HOV lanes. Consequently, it was decided that aggregate outcome effects would be reported for HOV lanes and that the review would be separated into an HOV lane section and a HOT lane section. Where both carpooling and payment for access are addressed in the literature, the information is covered either in the HOT lane section or as part of the corresponding case study.

3.1 HOV Implementations

Several studies of HOV systems were identified that evaluate travel patterns and operations, with particular attention to total vehicle throughput, person throughput, and average vehicle occupancy (AVO). The most useful of these for the purposes of this review present data from both before and after the HOV lane implementation. Only limited information was found pertaining to carpool composition in HOV vehicles. Most user data focused on general demographics and trip characteristics, with some consideration of factors affecting mode choice.

General

HOV facilities are intended to provide an incentive for people to choose higher occupancy vehicles due to improved travel time and travel time predictability. As such, one essential measure of effectiveness of an HOV program is average vehicle occupancy (AVO). The review of research indicates that in all but a few exceptions, improved AVO has been achieved after implementation of HOV programs. Table 1 provides a summary of such data regarding average vehicle occupancy (AVO) for select facilities, as summarized by Pratt et al. (2000).

Table 1 Changes in Average Vehicle Occupancy After HOV Implementation

Facility	Before Date	Before AVO	After AVO	After Date
Dallas				
East Rl Thornton	1991	1.35	1.33	1992
California				
SR 55, Orange County	1985	1.18	1.28	1992
Houston, Texas				
I-45N (North)	1978	1.28	1.41	1996
I-45S (Gulf)	1988	1.29	1.26	1996
I-10W (Katy)	1983	1.26	1.52	1996
US 290 (Northwest)	1987	1.14	1.36	1996
US 59W (Southwest)	1992	1.16	1.29	1996
Los Angeles, California				
San Bernardino Transitway	1972	1.29	1.69	1992
Minneapolis, Minnesota				
I-394	1984	1.42	1.51	1998
Seattle				
I-5 North	1982	1.24	1.69	1992

SOURCE: Pratt et al. (2000)
AVO: Average vehicle occupancy

Table 1 shows a general increase in AVO after the HOV facilities were implemented. One exception was in Dallas, where the AVO showed a slight decrease after HOV implementation. The Dallas after-implementation study was conducted in the year following implementation, and no indication was given regarding potential improvements over time. The other exception was on one of the Houston facilities (I-45S), which had a slight decrease in AVO after HOV implementation. Notwithstanding these exceptions, the general indication from the data is that facilities realize an overall increase in AVO after implementation of HOV facilities.

Other relevant studies of traffic operations and user characteristics included in this review are for the following facilities:

- Shirley Highway (I-395 in Virginia);
- San Francisco–Oakland Bay Bridge;
- Houston, Texas (various facilities);
- Seattle, Washington (various facilities); and
- Maryland (I-270).

The Shirley Highway and the San Francisco–Oakland Bay Bridge facilities have been in place for more than 35 years and are generally regarded as successful in terms of increased person travel per lane. The cities of Houston and Seattle both have fairly extensive "networks" of HOV facilities among multiple highways. Findings from the relatively short and somewhat isolated I-270 facility in Maryland are also provided. In addition, key findings related to other facilities, as summarized by Pratt et al. (2000), are also provided, including survey responses of travel modes used by carpoolers prior to HOV implementation.

Shirley Highway, Virginia (I-95/I-395)

The Shirley Highway HOV lanes were the first major freeway HOV facility in the country. The facility was originally implemented in 1969 as bus-only lanes. Facility expansion began in the mid-1970s and the system currently consists of 27 miles of barrier-separated HOV lanes connecting the District of Columbia to Prince William County, Virginia. Initially, only carpools with four or more persons were allowed (HOV4+). This was later changed to allow HOV3+ carpools as well. The HOV restrictions are in place during weekday peak periods in the peak travel direction. Table 2 shows average vehicle occupancy for the HOV and GP (general purpose) lanes on the Shirley Highway over time as key facility features (number of lanes and user restrictions) were modified, as reported by Pratt et al. (2000).

When buses are removed from the equation, the HOV lanes had an AVO of 3.1 and 3.4 during the a.m. and p.m. peak hours, respectively, in 1997. This compares to 1.14 and 1.18 AVO in the adjacent GP lanes. The overall AVO of 4.1 for the Shirley Highway HOV lanes during the a.m. peak hour corresponds to approximately 5,600 persons per lane, compared to 2,000 persons per lane in the GP lanes. Travel time savings for the entire 27-mile HOV lanes are estimated to be 34 to 39 minutes.

Table 2
Average Vehicle Occupancy on Shirley Hwy HOV Lanes (AM Peak Hour)

Lane Types	1969 Bus only	1973 Bus Only	1988 Bus & HOV 4+	1989 Bus & HOV 3+	1997 Bus & HOV 3+
Number of Lanes HOV/GP	1/2	2/4	2/4	2/4	2/4
Bus AVO	49.2	40.6	35.5	34.9	26.1
Vanpool & Carpool AVO	----	---	4.3	4.1	3.1
Total AVO	49.2	40.6	6.9	6.1	4.1

SOURCE: Pratt et al. (2000)

San Francisco-Oakland Bay Bridge

A peak-period toll plaza “queue jump” was implemented in 1970 for morning inbound traffic on the San Francisco-Oakland Bay Bridge. The facility is open for use by buses, vanpools, and 3+ carpools. Users benefit not only from travel time savings, but also gain free passage across the toll bridge.

Pratt et al. (2000) summarized findings related to average vehicle occupancy after the facility was developed. The morning peak period AVO increased from 1.33 to 1.83 following implementation. Between 7 and 8 a.m., the HOV lanes carried 57% of the people in one-quarter of the vehicles.

After the HOV lanes were implemented, peak-direction carpool volumes increased from 1,200 to 2,200 in the three-hour morning peak period, and increased further to 3,100 carpools in 1978. In 1982, the number of HOV lanes was doubled to 4 lanes and carpool volumes reached 5,300 vehicles during the three-hour a.m. peak period. These carpool volumes were generally maintained through 1993, when documented.

Houston

There are several barrier-separated HOV facilities connecting Houston to the surrounding area. The first was opened in 1979 (I-45 North); the success of this project led to construction of similar facilities on the Katy Freeway (I-10), I-45 South, US 59 North and South, and US 290 (Northwest Freeway). All of the facilities are connected to park-and-ride lots and have significant transit usage.

In 1991, Diane Bullard produced a significant study of the impacts of carpools on the Katy Freeway starting in 1985. The study included traffic operations data as well as surveys of HOV users and non-users from before and after program implementation in March 1985. Surveys were also conducted pertaining to other HOV facilities in Houston.

Among the topics addressed in the Bullard study was the previous travel mode of HOV users. There had been concern that allowing carpools to use the HOV lanes would cause bus and vanpools travelers to switch to lower AVO carpools. The survey data indicated that only a small fraction of HOV lane carpoolers had switched from buses or vanpools; the vast majority of travelers switched from drive-alone to higher AVO travel modes. Overall, between 36 and 45 percent of carpoolers formerly drove alone, while 38 to 46 percent of bus riders previously drove alone. The increased carpool and bus mode shares resulted in considerably higher vehicle occupancies in the HOV lanes when compared to the adjacent general-purpose lanes.

Table 3 shows the AVO from 2003 for six managed lane facilities in Houston, as reported by Turnbull (2003). The table does not show before-and-after AVO, but does provide comparisons between HOV and general purpose lanes. The table shows a significantly higher AVO on the HOV lanes, with and without inclusion of bus occupancies.

Table 3
2003 Average Vehicle Occupancy on Houston HOV Lanes (AM Peak Hour)

Lane Types	Katy (I-10 W)	North (I-45 N)	Gulf (I-45 S)	Northwest (US 290)	Southwest (US 59 S)	Eastex (US 59 N)
Lanes HOV/General Purpose	1 / 3	1 / 4	1 / 4	1 / 3	1 / 5	No Data
Bus AVO	42	53	53	47	52	48
Vanpool & Carpool AVO	2.30	2.30	2.20	2.24	2.19	2.18
Total HOV Lane AVO	**3.22**	**4.08**	**3.30**	**3.20**	**3.44**	**2.95**
GP Lanes AVO	**1.12**	**1.02**	**1.07**	**1.05**	**1.07**	**1.05**

SOURCE: Turnbull (2003)

In 1998, carpool requirements for the Katy Freeway HOV lanes were loosened to allow HOV2 carpools with payment of a toll (the QuickRide program). Stockton et al. (2000) evaluated the pricing conversion of the facility from general HOV to HOT during the first year of the QuickRide program. The study included a review of overall usage patterns using automatic vehicle identification (AVI) data from QuickRide participants. Operational data were also used to calculate travel times in both the HOV and mainlines. In addition, a mail-back survey was sent to QuickRide users to obtain demographic data and travel patterns.

The Stockton study determined that among QuickRide program participants, the number of two-person carpools on the Katy Freeway nearly doubled and that, generally, usage of the Katy HOV lane increased during the peak hours. Still, the study concluded that, at least in the first year, the data did not indicate a significant overall increase in person travel, nor a significant improvement in travel speeds on the mainlines. There was generally low demand and infrequent use of the QuickRide project, perhaps due to the burden of forming a two-person carpool. This is consistent with the finding that the majority of QuickRide participants carpooled with a family member, which would reduce (remove) the travel time for carpool formation. It was determined that larger households (three or more persons) were more likely to use the program than households of one or two persons. This is reflected in the findings of carpool make-up shown in Table 4, as determined through user surveys.

Table 4
Carpool Partners in QuickRide Program

Carpool Partner	Percent
Adult Family Member	37%
Child	12%
Co-Worker	41%
Neighbor	6%
Other	4%
Total	100%

SOURCE: Stockton et al (2000)

Other aspects of the Katy Freeway QuickRide program are discussed in the section on HOT facilities.

Seattle

Washington State has numerous HOV facilities linking the major freeway network serving the Seattle area. Development of the facilities began in 1982. Table 5 provides an overview of key facility characteristics.

Table 5
Overview of Seattle Area HOV Facilities

<table>
<tr><th>Corridor</th><th>Occupancy Requirement</th><th>Lanes</th><th>Direction</th><th>Geometric</th></tr>
<tr><td rowspan="2">I-5</td><td rowspan="2">HOV 2+</td><td rowspan="2">1 each direction</td><td>NB, SB</td><td>Concurrent flow</td></tr>
<tr><td>SB (AM only)</td><td>Barrier-separated
Express lane
Reversible flow</td></tr>
<tr><td>I-405</td><td>HOV 2+</td><td>1 each direction</td><td>NB, SB</td><td>Concurrent flow</td></tr>
<tr><td rowspan="2">I-90</td><td rowspan="2">HOV 2+</td><td>1 each direction</td><td>WB, EB</td><td>Concurrent flow</td></tr>
<tr><td>2 reversible</td><td>WB (AM only)
EB (PM only)</td><td>Barrier-separated
Reversible flow</td></tr>
<tr><td>SR 520</td><td>HOV 2+ (EB)
HOV 3+ (WB)</td><td>1 each direction</td><td>WB, EB</td><td>Concurrent flow</td></tr>
<tr><td>SR 167</td><td>HOV 2+</td><td>1 each direction</td><td>NB, SB</td><td>Concurrent flow</td></tr>
</table>

The state determined the following objectives for the HOV program.

- Improve the capability of congested freeway corridors to move more people by increasing the number of people per vehicle;
- Provide travel time-savings and a more reliable trip time to high occupancy vehicles that use the facilities; and

- Provide safe travel options for high occupancy vehicles without unduly affecting the safety of freeway general purpose mainlines.

The state established speed and reliability standards to monitor the effectiveness of the HOV program, including specific average speed requirements for peak hour operations, and regular reporting of person-carrying capability, travel time savings, and reliability.

A study by Nee et al. (2004) evaluated the system's performance using both traffic volume data and a survey of HOV and SOV travelers in the study corridors. The study focused on a comparison of HOV and GP lanes, and did not provide "before implementation" data to evaluate changes in behavior. The research included peak-period vehicle and person volumes in the HOV and adjacent GP lanes.

Nee consistently found that AVOs in the HOV lanes were typically double or even triple that of the GP lanes. In corridors with high transit volumes, AVO in the HOV lanes was as high as 9.2 passengers per vehicle. These findings are consistent with findings from studies conducted in the 1980s and early 1990s for the I-5 HOV lanes, as summarized by Pratt et al, 2000 (see Table 6).

Table 6
Average Vehicle Occupancy on Seattle I-5 HOV lanes (AM Peak Hour)

	1985 HOV3+	**1989 HOV3+**	**1991 HOV 2+**
Lanes HOV/General Purpose	1 / 4	1 / 4	1 / 4
HOV Lane Vehicle Volumes			
Buses	35	64	64
Carpools/Vanpools	385	466	1169
Total Vehicles	420	530	1233
HOV Lane Person Volume			
Buses	1,480	2,605	2,605
Carpools/Vanpools	1,250	1,398	3,039
Total Person Volume	2,730	4,003	5,644
Average Vehicle Occupancy			
Bus AVO	42	41	41
Vanpool & Carpool AVO	3.2	3.0	2.6
Overall HOV AVO	6.5	7.6	4.6
General Purpose Lane AVO	1.2	1.23	Not available

SOURCE: Pratt (2000)

In addition to the traffic operations data, Nee conducted a mail-out survey to vehicles identified in the HOV or adjacent SOV lanes; additional surveys were handed out at park-and-ride lots. The survey included questions regarding mode choice, the decision of eligible vehicles to use the HOV facilities, and general attitudes about the HOV program.

Peak Period Mode Choice

In survey questions regarding mode choice, it was determined that the largest group of survey respondents usually drives alone. The findings are summarized in Table 7. However, more than half occasionally used some type of HOV mode to get to work, mostly typically carpools (89%). The author concluded that there is a high degree of "periodic" carpool users.

Table 7
Peak Period Mode Choice

Mode Choice	Usual Mode Choice	Mode When Using HOV Lane
Drive Alone	45%	3%
Carpool 2	11%	67%
Carpool 3+	3%	22%
Vanpool	1%	3%
Bus	37%	38%
Bicycle, walk	1%	n/a

SOURCE: Nee (2004)

Reasons for Not Using HOV Lanes

In the survey, 40% of respondents indicated that they did not always use the HOV lane even when they knew they were in an eligible vehicle. The most prevalent reason given for not using the HOV lanes was that traffic was already fast enough in the GP lane. Other reasons included having trouble changing lanes, and slower travel speeds in the HOV lanes compared to the GP lanes.

Attitudes about HOV Facilities

Responses to questions regarding general attitudes toward HOV facilities are summarized in Table 8. Overall, support for HOV lanes continues to be high among all survey respondents, including support for continued construction of HOV facilities. Predictably, support is higher among HOV users. Concern about under-utilization of HOV lanes was generally consistent among both groups, and both groups tended to believe that HOV lanes should be open to all vehicles during non-peak periods. HOV users were somewhat more likely to indicate that carpooling would increase with more HOV facilities, with 42% stating agreement or strong agreement with the statement, compared to 27% among SOV respondents.

Maryland

The northbound HOV lane on I-270 in Montgomery County, Maryland opened in September 1993, followed by the southbound lane in July 1994. Expansions followed, and by December 1996, the State Highway Administration (SHA) had a continuous 19-mile HOV lane along northbound I-270 between I-495 and MD 121, and a continuous 12-mile southbound HOV lane linking I-370 to I-495. The HOV lanes operate during peak periods in the peak directions. At other times, the lanes are open to all traffic.

Table 8
General Attitudes about HOV Facilities

Survey Statement	Respondent*	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
HOV Lanes are a good idea	SOV	8%	2%	9%	30%	48%
	HOV	0	2	2	20	75
HOV lanes are convenient to use	SOV	6	11	14	50	18
	HOV	0	7	10	56	27
Existing HOV lanes are being adequately used	SOV	11	28	22	33	5
	HOV	5	23	21	40	10
HOV Lanes should be opened to all traffic	SOV	28	31	13	12	14
	HOV	52	31	6	5	6
HOV Lane should be opened to all traffic during non-commute hours	SOV	11	13	11	25	39
	HOV	16	24	17	25	17
HOV Lane construction should continue	SOV	9	9	11	52	17
	HOV	1	3	5	51	39
Constructing HOV lanes is unfair to taxpayers who choose to drive alone	SOV	25	38	14	9	12
	HOV	49	31	10	6	4
More people would carpool if HOV lanes were more widespread	SOV	11	27	33	21	6
	HOV	4	21	32	31	11

* Respondents were grouped according to their “usual” mode of travel during the peak periods.

SOURCE: Nee (2004)

An early review of the program found better-than-expected results, with an average of 700 HOVs per hour. A study of a.m. peak hour conditions showed that the HOV lane was carrying 30% of the people in 15% of the cars, with an average time savings of approximately four minutes.

The improved operational conditions generally did not correspond with public perceptions, as reported in a 2002 SHA survey of HOV and SOV travelers on I-270 (Hoffman, 2002). A license plate survey was conducted at three locations over five days during peak hours. More than 20,000 license plates identified for both HOV and non-HOV lane users. Questionnaires were sent to a random sample of 7,000; approximately 16% responded (1,028 responses).

Generally, people didn’t think the HOV lanes were effective (80% of non-users). Some people felt it had increased trip time on the GP lanes (55% of non-users and 39% of HOV users, with a median increase of 15 minutes), although the author points out that some of this perception could be due to an overall increase in traffic in the corridor at the time. More than a third of HOV lane users felt their trip time had decreased by a median of 15 minutes.

The survey determined that income had virtually no determining effect between HOV and non-HOV users. The most effective incentives to carpooling were guaranteed ride home programs and improved trip time reliability. These were the only proposed motivators that would appear to have much impact.

No distinction in the carpooling respondents was identified based on age, education, or gender. There was a slightly higher tendency for federal employees to carpool, but this would likely be associated with the large concentration of federal employees providing relatively convenient carpool opportunities. The cost of parking was not revealed to have any impact on the decision to carpool, although nearly half of the respondents indicated an expectation to have free parking indefinitely. More than one-third said they would not use carpools no matter how much parking costs.

There was some indication that trip length has some effect on the choice to carpool; longer trips showed some increased tendency to carpool. This might be directly tied to the likely time-savings; slightly more than half indicated they would consider carpooling for trip time-savings ranging from 6 to 30 minutes.

In the end, the authors concluded that there were virtually no significant distinctions between HOV and SOV lane users.

3.2 HOT and Pricing Implementations.

Most of the HOT lane research identified to date has addressed user demographics and equity considerations, probably to address political and public acceptance concerns for implementation. More recently, some researchers have begun to address value-of-time (VoT) issues. Earlier VoT estimates have compared auto to transit travel time, which may be biased as a result of factors not captured in transportation models, such as the level of crowding on transit vehicles (Brownstone et al., 2002). Hensher (2001) concludes that earlier studies did not adequately accommodate unobserved influences on users' choices resulting in a tendency to *underestimate* the value of travel time-savings. On the other hand, Hensher and Goodwin (2003) posit that past estimates have tended to make simplifying generalizations regarding the distribution of users' value of travel time-savings that have resulted in a tendency to *overestimate* VoT. As a consequence, these simplifying generalizations result in overly optimistic revenue projections that are then used in making transportation investment decisions.

Pertinent research findings were identified for the following HOT facilities:

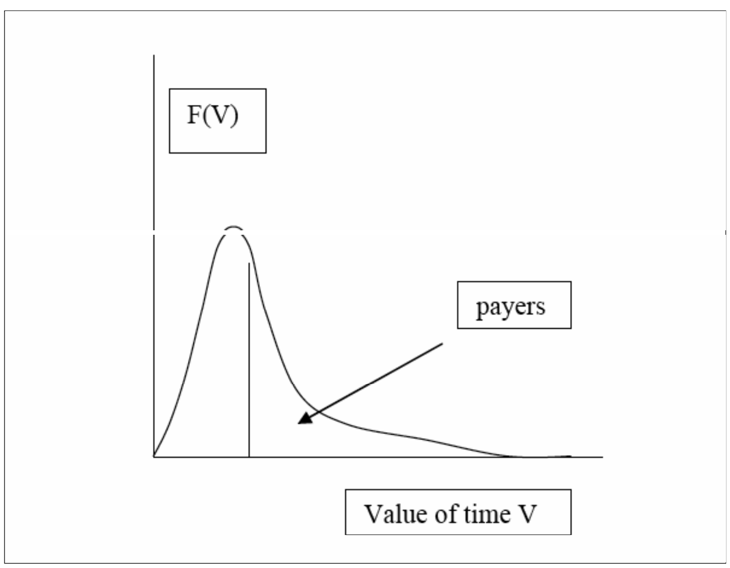
- San Diego (I-15);
- Southern California (SR 91 Express);
- Houston (Katy and Northwest Freeways); and
- Lee County, Florida.

Research reports addressing willingness-to-pay and value-of-time estimates were reviewed for Southern California's SR 91 and San Diego's I-15 projects. Houston has conducted several surveys in the past, which have focused primarily on equity issues. More recent work in Houston by Burris and Appiah (2004) addressed willingness to pay; however, the authors found relative inelasticity, with little usage at very low levels of tolling ($1 to $3). The probable reason for this result was that the pricing option was for 2-person carpools (3-person carpools used the lanes for free). This still leaves the effort and time to create a carpool, which confounds the analysis of willingness to pay. Similarly, a study of Minnesota's MnPASS system ((Mark Bradley, Unpublished reports, 2005 and 2006) references surveys that address toll acceptability; this study is addressed in detail in the Case Study later in this report. Other studies reviewed tended to focus on general demographics, driver or other public perceptions, and other user characteristics; these have not been not summarized in detail.

General

The need to move away from average values of time obtained from aggregate analyses, for the purpose of estimating the use of priced facilities and the income to be derived, was the focus of papers by Hensher (2001) and Hensher and Goodwin (2003). The first paper posits the need to use distributions of VoT response, recommends the use of median values from disaggregate analysis as being better than the use of mean values, and stresses the importance of including methods to measure unobserved effects. The second paper is more applicable to practitioners. It concludes that neither the mean nor the median is the correct choice; instead, the percentile for which the VoT is equal to the time saved at a given cost for each traveler. Only those who exceed this value will pay. Hensher argues that the distribution is left-skewed, with a long tail, meaning that the mean (and probably the median) will overestimate the number of drivers who will pay. Yet, while pointing to growing evidence for a skewed distribution, Hensher and Goodwin caution that it is unknown empirically whether the effects on actual revenue projections are big or small.

Figure 1 Theoretical Distribution of VoT



SOURCE: Hensher and Goodwin (2003).

Hensher and Goodwin's concept is utilized in some of the Southern California studies described later, and is given empirical validation in the MnPASS project surveys, described in the Case Studies section.

San Diego I-15 HOT Lanes

San Diego's I-15 HOV lanes opened in 1988. Due to concerns about low lane utilization, the HOV lanes were converted to HOT lanes in late 1996, allowing SOVs to use the lanes for a fee. In the initial phase, called Express Pass, drivers purchased monthly passes for unlimited use. At the beginning of program, 500 passes were sold for $50/month. This was gradually increased to 1,000 passes for $70 per month. In May 1998, the program was modified and the current FasTrak™ program was initiated. Subscribers are now issued transponders and accounts are automatically debited. The program uses dynamic toll changes to maintain free- flow traffic; tolls usually range from $0.50 to $4.00, but sometimes go as high as $8.00 for the eight-mile distance.

Relevant Research Findings

A five-wave panel survey was implemented to track changes in travel choice behavior and attitudes concerning the project. A panel study refers to repeatedly interviewing the same individual on a number of occasions. Due to an average attrition of approximately 30% per wave, random refreshment was used to maintain the survey population size of 1,500. The survey included HOT subscribers, users of the I-15 freeway mainline, and a control group of users of another freeway (I-8) in the San Diego area. The panel survey was initiated in fall 1997 with successive waves every 6 months. Waves 1 and 2 of the survey were under Express Pass while waves 3, 4, and 5 were under FasTrak.

Supernak et al. (1998) conducted an extensive study of the ExpressPass phase of the HOT program. The study included an analysis of the first wave of the panel study, addressing mode choice, user characteristics, attitudes toward the new ExpressPass program, and impacts on users' travel times. The study did not deal specifically with willingness to pay. However, on the general question of price sensitivity, the study determined that the majority of ExpressPass users thought that the $70 monthly fee was too high. At the same time, most of the I-15 users felt that the price should increase if the HOV lanes became too congested. Increasing the price was favored over raising the vehicle occupancy requirement from two to three persons. The authors conclude that this finding is an indication of support for the principle of pricing SOVs to use the HOV facility. In addition to the survey data, the study addressed numerous conditions before and after HOT implementation, including traffic volumes, cost of delay, air quality, park-and-ride use, truck use, and bus ridership.

Brownstone et al. (2002) used data from all five waves of the survey to estimate that the median willingness to pay is roughly $30 per hour for morning commuters. The upper quartile was $43 per hour and the lower quartile was $23 per hour. The report does not provide an estimate for the afternoon peak or off-peak times of day. There also tended to be increased use of FasTrak when the tolls, which are posted prior to the entry point, were higher than average. The authors deduced that the higher tolls signaled drivers of higher-than-average congestion ahead, leading them to pay the toll for access to the HOT facility. This suggests that drivers are most concerned with unexpected delays in their morning commutes. Higher tolls were associated with reduced FasTrak use if the reduction in variability in time-savings is less than 7.21 minutes. However, higher reduction in variability is associated with increased FasTrak use only when the toll is above $1.41.

The authors point out that some drivers may perceive the HOT facilities to be safer than the mainline due to the separation from the other lanes of travel. This could result in a positive bias of willingness to pay. However, they note that separation from mainline travel lanes would be consistent among all HOT facilities and thereby conclude that such a bias would carry over to similar toll facilities.

Brownstone et al. note that their estimate of willingness to pay is considerably higher than estimates of $3.50 to $5.00 per hour from past studies. They attribute the difference to the use of revealed preference, rather than stated preference data, and point to a study by Wardman (2001) that found that stated preference studies generally yield lower values than revealed preference studies.

The authors also point out that while most estimates of willingness to pay are reported as a percentage of hourly wage rate, the direct relationship between value of time and income "has not been borne out by recent surveys." Further, the panel survey does not provide information on respondent's income. For the sake of comparison, based on estimated household income in the corridor, it is estimated the value of travel time is approximately 88% of hourly wages, compared to other studies that estimated 15% to 25% (Calfee and Winston, 1998) to 50% (Small, 1992).

The findings of the Brownstone analysis are closer in scale to the findings of the SR 91 study by Lam and Small (2001), which identified the value of time to be between $19 and $24. The main difference between the SR 91 study and the I-15 study is that the SR 91 facility uses time-of-day pricing instead of dynamic congestion pricing.

Using data from the same San Diego panel survey, Ghosh et al. (2000) estimated the value of time and the value of variability. This study found that the mean value of travel time in the morning was $22 per hour, or 75% of the wage rate. The afternoon value of travel time was much lower; the median rate was $15 per hour, approximately 55% of the wage rate. (As in the Brownstone study, the wage rate is estimated, rather than taken directly from the survey.)

Table 9
Value of Time Estimates ($/Hr) for Morning and Afternoon Commute

Percentile	Morning		Afternoon	
	Model	Bootstrap	Model	Bootstrap
	22.36			
5th percentile	--	15.15	9.35	8.75
25th percentile	--	18.45	11.00	11.06
50th percentile	--	22.75	13.74	14.06
75th percentile	--	28.41	19.21	17.14
90th percentile	--	33.89	22.36	20.70
Mean	--	24.01	14.83	14.46
Standard deviation	--	9.01	4.75	4.95

Note: Model = estimates from the coefficients of the model
Bootstrap = Bootstrapping the coefficients for 1000 draws and the median value summarized
Source: Ghosh et al. (2000)

Table 10
Value of Variability for Morning Commute Before 7:30 AM

Percentiles	Model	Bootstrap
	58.07	
10%	--	40.51
25%	--	48.25
50%	--	58.19
75%	--	71.68
90%	--	87.67
Mean		62.35
Standard deviation		21.65

Source: Ghosh et al. (2000)

In terms of general user characteristics, Ghosh et al. (2000) concluded that high-income, female commuters are more likely to own a pass, and that middle age also influences its use. Larger households and females with children are more likely to carpool. Also, use of FasTrak was more likely for commute trips and longer-distance trips.

Morning commuters are more sensitive to variability than afternoon commuters. As in the Brownstone study, the toll level was found to signal commuters of congestion ahead, with a positive relationship to FasTrak use. Value-of-variability estimates indicate that commuters are willing to pay for a reduction in uncertainty as well as a reduction in travel time.

Several studies reported findings related to user demographics, commute characteristics, and other mode choice factors. Golob and Golob (2001) evaluated the frequency of various mode choices among FasTrak users. I-15 travelers have three travel choices: solo on the mainline, solo using FasTrak, and carpool. Travelers who carpool the majority of the time may still drive alone one or two days a week. Table 11 summarizes the findings related to travel modes used over the course of a week. The table starts with the travel mode used on the most recent morning commute, and then shows the percentage of those respondents who also used one of the other travel modes in the previous week.

Table 11
Frequency of Alternative Commute Mode Choices

Other Modes Used in Last Week	For Most Recent Mode for Morning Commute		
	Carpool	Solo on Main Line	Solo on FasTrak
Carpool	n/a	16.7%	7.9%
Drove Solo on Mainline	22.5%	n/a	16.9%
Drove Solo using FasTrak	10.6%	7.6%	n/a

Source: Golob and Golob (2001)

California – SR 91 Express

The 91 Express Lanes in Orange County, California were the first congestion-priced roadway in the United States. The express lanes are located within a ten-mile corridor between the Riverside county line and the SR 55/SR 91 interchange in Orange County. The facility was free to carpools of three or more people, while SOVs and two-person carpools (HOV 2) vehicles were allowed for a $2.75 toll during the peak period for travel in the peak direction. In 1998, the toll increased to $3.20. Typically, travelers save up to 12 minutes each way by using the express lanes. Starting in January 1998, due to insufficient revenue, HOV 3+ vehicles were charged half the toll charged other vehicles.

Several studies were identified that analyzed survey data aimed at determining general impacts to traffic, commute patterns, and the socioeconomic characteristics of the primary users (Parkany, 1998; Sullivan et al., 1998; and Mastako et al., 1998). In a later study, Lam and Small (2001) used revealed preference data to estimate that users' value of time was between $19 and $24 per hour.

A dissertation by Kimberly Mastako (2003), revisited the SR 91 data. Sets of models were estimated generically, assuming that all respondents faced the same choice set, and then re-estimated after an analysis of choice availability to generate constrained choice sets. These data included household income of respondents so that differential responses by income could also be evaluated. Values of time assuming a common all-inclusive choice set were implied at $9.60 to $19.35 at a $80,000 income level, and $7.86 to $13.14 at a $40,000 level. The highest values of time were for women between the ages of 30 and 49. The main thrust of this dissertation, however, was to identify the real choice sets being considered and then to use these choice sets in model estimation. This work yielded values of time of between $1.72 and $15.22 for market segments for various choice sets.

Brownstone and Small (2004) compared the pricing estimates from the various studies of Route 91 in Orange County and I-15 in San Diego. Estimates using revealed preference data obtained values of time from $20 (Route 91) to $40 (I-15) per hour. When the I-15 sample is weighted to match the income and commute distance distributions of the SR 91 sample, all of the studies find a value of travel time of approximately $20. The evaluation also determined that stated preference surveys underestimate the value of time, compared to revealed preference surveys. The study makes the distinction between estimates of travel time value and travel time reliability value. While noting recent improvements in the estimation of the value of travel time reliability, the authors identify this issue as a top priority for further research.

Small, Winston, and Yan (2005) used mixed logit (introduction of random parameters in the model estimation) on combined RP and SP data to obtain measures for both observed and unobserved heterogeneity. This work gave a distribution of motorists' preferences (and values) for travel time-savings and reliability of travel time, as recommended by Hensher (2001) and Hensher and Goodwin (2003). The researchers had an unexpected result in that the model estimation obtained the best fit with an assumption of a normal distribution, whereas a left-biased distribution (such as log-normal) was expected. They obtained a median hourly value of travel time-savings (RP values from the joint estimation) of $21.46. Reliability was represented by the time difference between the median time saved and the 80th-percentile time saved over a series of measurements of facility travel time (11 days) at each point in time through the morning peak. The value of reliability was $19.56. Because of the lower value of reliability time, compared to travel time-savings, it turns out that willingness to pay can be attributed as two-thirds to savings in travel time and one-third to reliability of travel (the reliability has a lower weight because it applies to only a portion of trip time). In this study (as in others) the value of time from a pure SP estimate was roughly 50% of that from the RP. This might have resulted from a perception of time saved by respondents in the RP survey being about double the measured time saved, which was used in this RP estimate.

In a study that addressed the policy issues and trade-offs between HOV and HOT lanes, Small, Winston, and Yan (2006) compared GP, HOV, HOT and express toll lanes. In terms of lane capacity, their study determined that HOV lanes are inefficient policies when congestion is light because they result in underutilized lane capacity. However, they found that HOV lanes are highly effective when congestion is heavy because they pose a strong incentive for carpooling, resulting in reduced overall vehicle volumes. They determined that HOT lanes provider fewer benefits directly to travelers than HOV lanes, but that in terms of social welfare, they outperform HOV lanes due to the revenue generated. The fully priced toll lane is inferior to HOT lanes when congestion is heavy because HOT lanes have some carpool incentives, which can reduce travel times. They further caution that consideration of converting HOV lanes to HOT lanes should consider the spillover effects on congestion elsewhere.

Houston

In 1984, a grade-separated, reversible HOV lane was opened on the Katy Freeway. Initially, the facility was intended for transit and vanpools only. Due to low utilization, the facility was later changed to allow HOV 2 vehicles. However, this action resulted in congestion. In response, eligibility was restricted to HOV 3+ vehicles, but low utilization again resulted. Concerns about excess capacity led to the implementation of the QuickRide program in January 1998. Under the QuickRide program, HOV 2 vehicles are given the opportunity to use the HOV lane for a fee.

An early study conducted in 1998 (Hickman et al., 2000) was aimed at assessing the facility's user characteristics, including changes in user travel behavior and factors affecting the frequency of use. The study included usage data obtained through the transponders given to QuickRide participants, travel time information in both the HOV lanes and the mainline, and responses from a mail-back survey of program participants. Although the focus of this study was not to estimate value-of-time or willingness-to-pay, it uses the fee of $2 and the average time-savings of 20 minutes to deduce an average value of time of $6 per hour per vehicle. However, the disutility of having to form a carpool may reduce the monetary value paid for the travel time-savings.

Subsequent studies of the QuickRide program focused on factors that determine usage of the facility. Burris and Haney (2003) examined equity considerations using data obtained from a survey of QuickRide enrollees. This study determined that income was not an indicator of the amount of QuickRide use among enrollees; however, it appeared to be a significant factor of whether an individual enrolls. Later, Burris and Appiah (2004) used data collected in a 2003 survey to evaluate factors that affect the frequency of QuickRide usage. The study concluded that carpool formation times have a larger impact on QuickRide participation than minor changes in the $2 toll. The focus of the analysis was in identifying socioeconomic and commute characteristics that impact frequency of use.

Lee County Florida

Lee County, Florida has a population of approximately 400,000, the majority of whom live in either Cape Coral or Fort Myers. The Caloosahatchee River separates the two cities. There is considerable commuter travel between the cities via four bridges. The newest of the bridges was opened in 1998. At that time, Lee County instituted variable toll collection on two of the bridges: the Cape Coral and the Midpoint. Tolls are discounted by 50% during the shoulders of the a.m. and p.m. peak commuter periods. Several studies have been conducted regarding the impacts of the variable tolls on traffic. However, these have focused on user demographics, changes in traffic patterns, and general public perceptions of HOT facilities (Yelds and Burris, 2000; Burris et al., 2000; and FDOT, 2000). No studies were identified that address willingness-to-pay and/or value of travel time-savings for these bridges.

3.3. Common Threads—What Can We Learn?

HOV

There are not a lot of pure behavioral data for this group, but this is because few user-use surveys have been attempted. In addition, poor detail on supply-side data during the implementation of most HOV facilities limits information on behavioral response related to travel time saved. The lone standout for data analysis is the model estimation exercise for the Houston system. This work gave unexpectedly high values of time saved for both toll-payers and carpools. However, more work of this kind is needed. There is no doubt that the HOV lanes on the Katy (I-10) and Northwest (US 290) freeways are very highly valued, so much so that at an HOV 2+ operation the lanes became oversubscribed. A switch to HOV 3 left the lanes underutilized; this was re-balanced by allowing 2-person carpools with a toll payment. Houston has lanes of a length that allow significant time-savings over the GP lanes or alternative routes.

Both the Houston studies and the user/non-user opinion surveys from the Seattle region show significant use of express transit on these lanes. There is a reported preference among transit users for the independence and privacy afforded by transit compared to carpools. The Seattle surveys reinforce the need to be aware of the real perception of congestion and time-savings with many non-users reporting non-use of carpool lanes because of too little benefit for the effort of accessing them. This suggests that the lanes are not competing with congested GP lanes for significant time periods, or for some locations.

There are many clues from the priced-lane analyses which lead us to suspect that a concerted effort to collect user and non-user travel data, along with realistic estimates of journey length, journey travel time, and travel time saved by using the lane, and using a small enough time period to capture the real duration of time-savings at various levels, would yield similar results in response to travel time-savings for priced lanes. This would be a more useful policy analysis tool than simple distance measures that occur in the literature. It is also important to include the composition of any carpools captured, and to capture information on inter-household traveler and household characteristics.

The data retrieved for isolated lanes shows a significant number of intra-household (family) carpools (almost to the exclusion of inter-household pools). While this suggests that these lanes do not affect behavior, it does not mean that such a lane cannot have larger user benefits than conversion of such a lane to a GP lane. Once more, both accurate counts and accurate values of travel time need to be obtained, estimated, or forecast for such a decision.

There is very little that can be transferred from the two very successful implementations, Shirley Highway and the San-Francisco–Oakland Bay Bridge that are the result of unique local situations.

Priced Lanes

The two priced-lane studies in California have given us a wealth of information that show very different behavioral response from what would be assumed using values of time derived from a traditional regional mode choice model. The values of time obtained are very much higher than reported from mode choice model estimation ($20 to $30 per hour instead of $5 to $11 per hour).

Heterogeneity of Behavioral Response

More recent studies of pricing have gradually brought out the importance of considering the heterogeneity of travelers, affecting their response, and the fact that this response is non-linear. According to Hensher and Goodwin (2003), this response goes a long way to explaining the historically poor performance of toll-road income forecasts, which essentially use aggregate travel groups and average values of time. This factor has serious implications, both for data collection to uncover behavioral distributions, and for efforts to forecast behavior.

There are two kinds of heterogeneity: (1) that which is observed, or can be observed, and (2) that which is unobserved or unobservable. Observable heterogeneity has mostly to do with the household composition, the activities for which travel is undertaken and the actual difference of levels of service between the alternative routes that can be observed at the time of travel. Unobservable heterogeneity has to do with the preferences or situation of the traveler. For example, Hess et al. (2004) report research that indicates that over a range of travel times, some users may have a positive preference for travel time, in which case the value of travel time-savings would be negative (Hess et al., 2005). The ability to engage in other tasks, such as planning the days' activities, following the news, or being entertained may explain such preferences.[1] Travelers' idiosyncratic situations may be a source of unobserved heterogeneity. For example, Brownstone and Small (2005) suggest that differences between SP and RP responses may be due to a time inconsistency in which the user intends to use the less-expensive alternative but does not allow sufficient time and is thereby forced by scheduling constraints to take the more-expensive express lanes. This kind of heterogeneity can also be expected in the same traveler at different times, which is why many travelers with transponders use the service intermittently. Given the information collected in a survey, some of the observable data may not be collected; it is then joined with the unobservable to form the unobserved heterogeneity in any particular study. We also saw the effect of heterogeneity of response by travel direction (or time of day) where, in the one study that considered the afternoon as well as the morning travel, the values of time for the homeward journey were a half of those for the morning inbound journey.

These two kinds of heterogeneity can have different solutions in practice. The first kind (observed) requires much more information about the traveler than is used current trip-based

[1] Indeed, National Public Radio has advertised its programming as providing "driveway moments" in which a commuter stays in his or her vehicle at the end of trip to finish listening to a story on the radio.

models and requires trips to be built using household microsimulation, where each individual traveler is stochastically modeled from a generated synthetic household. This is practice in existing activity- and tour-based models; therefore, for regions that have such models in place, there is not much extra effort or complexity as long as the household survey has captured the required information.

The second kind of heterogeneity (unobserved) cannot be solved in a forecasting sense, as we cannot ask the question "are you late this morning," for example. This problem requires the estimation of a model using random coefficients to get the distribution of this unobserved response—this is the "mixed logit" which is now incorporated in most of the commercial statistical packages that are used by transport analysts. However, this model form cannot be estimated from a single cross-sectional RP survey, as variation in individual response is needed; a panel (repeated surveys of the same individual in situations where conditions are changed) could be used. This model can also be estimated from an SP survey (one person's response to several hypothetical situations in a carefully designed experiment). However, evidence from the studies we have referenced shows a consistent underestimation of the value of time from stated preference. The technique used by Small, Winston, and Yan (2005) to estimate a model using random coefficients for SR 91 used the technique of combining a cross-sectional revealed preference study with a stated preference study. They found substantial unobserved heterogeneity in their data and that the combination of RP and SP data provides additional power to identify heterogeneity without biasing results for the rest of the model.

In a random utility model of the discrete choice family of models, the analyst assumes that a sampled individual faces a choice among several alternatives in each of several choice situations and chooses the alternative that yields the highest utility. The individual's utility is a function of observed explanatory variables (e.g., time of day or expressway toll) and an error term. In addition to observed variables, it is possible that unobserved information relevant to making a choice may induce correlation across the alternatives in each choice situation and/or induce correlation across choice situations. Mixed logit takes this into account by partitioning the stochastic component into two additive (i.e., uncorrelated) parts. One part is correlated over alternatives and heteroskedastic, and another part is independently, identically distributed over alternatives and individuals. Different substitution patterns are obtained by appropriate specification of the distribution of the first part.

The mixed logit model recognizes the role of the information provided by specifying a distribution and handling it in two ways. The first way, known as *random parameter specification,* involves specifying a coefficient for each individual associated with an attribute of an alternative as having both a mean and a standard deviation. In other words, the coefficient is treated as a random parameter that varies across individuals and/or situations instead of a fixed parameter shared across all individuals and situations. The second way in which mixed logit recognizes the role of different substitution patterns is known as the *error components approach.* It treats the unobserved information as a separate error component in the random component. Since the standard deviation of a random parameter is essentially an additional error component, the estimation outcome is identical. Both the random parameter specification and the error components specification lead to the same model only when the random parameter model has a non-zero mean.

4. SURVEY OF RECENT AND IMMINENT IMPLEMENTATIONS

4.1 Description

The project team conducted an Internet survey to identify changes in travel behavior and demand associated with managed lanes facility system expansion. The purpose of the survey was to identify and locate potential data sources, ongoing studies, and unpublished work that deal with the effect of expansion of lanes on travel behavior. Specifically, the survey was designed to help identify studies and projects that identified the users of HOV and HOT lanes and contained information on willingness to pay tolls, the value of time, and the value of reduced variability of travel time.

A sample of the flyer that was created to solicit survey participants is provided in Appendix A.

The flyer also contained a link to the survey website and was sent via the e-mail lists of various committees, such as the Travel Model Improvement Program (TMIP), the Portland State University Center for Transportation Studies, the American Association of State Highway Transportation Officials (AASHTO) Standing Committee on Planning, and the Transportation Research Board (TRB) Committee on High Occupancy Vehicle Systems (AHB35), as well as through the Value Pricing Program listserve. The survey was not designed to be implemented scientifically or with statistical reliability. Additionally, several hundred e-mails were sent to individual researchers and agency staff across the nation who was likely to have knowledge about ongoing studies within their state or region. The flyer was also distributed at the 2006 TRB Annual Meeting.

Survey respondents were asked to identify and provide information about all completed and ongoing HOV or HOT lane studies carried out in their state or region. The respondents were requested to provide information on whether before-and-after studies were conducted as a part of their HOV/HOT projects. The web survey consisted of four pages; images from the survey are also presented in Appendix A.

The survey had the capability of allowing the respondents to list a maximum of three HOV/HOT projects. In addition to the set of questions that they were asked to answer, space for additional comments was also provided for at the end of the survey. This enabled the respondents to list additional projects and also provided an opportunity for them to provide any other information that was relevant to the survey.

For each project that they listed, the respondents were asked to provide contact information, such as name, email address, and phone numbers of people associated with the projects. This information was gathered with the purpose of contacting the people associated with the projects directly to gather more information if required. In addition to providing contact information for each listed project, the respondents were also asked if before-and-after surveys were carried out.

Since the aim of the survey was to identify changes in travel behavior and demand associated with managed lanes, the respondents were asked if post-implementation surveys of users and use of the HOV/HOT lane facility were conducted for each project that they listed. The respondents were also asked if locally prepared analyses or reports were available for each listed project. The survey was fairly short and did not require a large amount of time to complete, thereby not imposing a large burden on the respondents. Completed surveys could be submitted easily by clicking a button. The completed surveys were downloaded from the server and processed for further analysis.

4.2 Results

The Internet-based survey was administered in July 2005. A total of 21 responses were received. A review of the responses found some duplicate entries for individual facilities. This resulted when different sets of people filled out the survey for the same facility. These duplicates were filtered out and the remaining entries are summarized in Table 12. The raw survey results are provided in Appendix A. Sixteen facilities or studies emerged from the survey, but not all had information on whether post-implementation surveys of users and use of facility were conducted. In most cases, respondents went beyond the basic survey questions by including additional comments; these are provided in the appendix. In many cases, it was observed that the respondents answered affirmatively to the availability of post-implementation surveys. However, it was determined from the additional comments that the surveys were still being planned in most cases. The respondents were subsequently contacted to gather more information about the facilities in their region.

4.3 Conduct Interviews

Based on the literature reviews, several major project locations and researchers were identified. The two areas with the most promise for data availability were Houston, Texas and SR 91 and I-15 in California.

A teleconference was conducted with Professor Mark Burris of Texas A&M University regarding as-yet unpublished work in Houston. He provided additional research reports from his graduate students.

Teleconferences or e-mail discussions were held with Professor Tom Golob of the University of California at Irvine, Professor Ed Sullivan of the California Polytechnic State University, and Professor Ken Small of the University of California at Irvine. These discussions revealed little new unpublished data or findings and we were re-directed to the published work, which has some excellent information on behavioral responses to the implementation of managed lanes on SR 91 and I-15 in southern California. In this process we discovered the excellent dissertation by Kimberly Mastako.

Later in the study, a teleconference and subsequent email communications with researchers involved in the MnPASS implementation did obtain some late-breaking information. The persons contacted included Dr. Johanna Zmud of NuStats; Dr. Frank Douma and Dr David Levinson of the University of Minnesota; Nick Thompson and John Doan of the Minnesota Department of Transportation; and Mark Bradley, an independent consultant..

Table 12
Processed Survey Results

PROJECT	CONTACT PERSON	BEFORE/ AFTER SURVEY	POST IMPLEMENTATION SURVEY OF USERS	POST IMPLEMENTATION SURVEY OF USE OF FACILITY	REPORT
MN Pass -Twin Cities	Frank Douma	Yes	Yes	Yes	Yes
	Kevin Gutknecht				
	Nick Thompson				
Atlanta HOT/TOT Study	Guy Rousseau	No	No	No	Yes
I-75 Atlanta	Andrew Smith	No	No	No	No
	Guy Rousseau				
I-77, North of Charlotte, NC	SteveDeWitt	No	No	No	No
I-15 High Occupancy Toll Lanes	Derek Toups	Yes	Yes	Yes	Yes
Maryland Cross Connector	Neil Pedersen	No	No	No	No
	Raja Veeramachaneni				
I95 / 395 HOV Lane Use Study	Frank Spielberg	No	No	Yes	Yes
	Phil Shapiro				
Long Island Expressway	Wayne Ugolik	Yes	Yes	Yes	Yes
I-40 Research Triangle Area, NC	Mike Bruff	Yes	No	No	Yes
Vancouver, WA HOV	Chad Hancock	Yes	Yes	Yes	Yes
I-405 HOV Project, Bothell to Interstate	Mark Bandy	Yes	Yes	Yes	Yes
Katy (I-10) HOV Lane	Hameed Merchant	Yes	Yes	Yes	Yes
I-5, Pierce County Line to Tukwila Stage	Stanley Eng	Yes	Yes	Yes	Yes
Northwest (US-290) HOV Lane	Michelle Hoelscher	Yes	Yes	Yes	Yes
SR 167 HOV to HOT Lanes Pilot Project	Nytasha Sowers	Yes	Yes	Yes	Yes
I-30 E HOV Lane	Stephen Ranft	Yes			

4.4 Identify Case Studies

Despite our inability to discover many new useful behavioral studies through the survey, there were useful elements discovered through the literature review that are worth showcasing as case studies—particularly the subject of priced or HOT lanes, with some coverage of behavioral aspects of HOV lanes. The specific issue for study here is the data collection methods which, while not perfect, point the way to future data collection methods needed to shed further light on this complex behavior.

We identified the following case studies:

- SR 91;
- I-15; and
- Minneapolis-St Paul.

The first two had well-designed surveys and generated a wealth of both published and unpublished studies discussing models that have a behavioral interpretation. This information needs to be summarized and made more accessible to the forecasting practitioners. Minneapolis-St. Paul has completed before-and-after surveys completed; its case study primarily relates to survey and study design, but also analyzes the stated preference portion of the surveys.

5. CASE STUDIES

5.1 Southern California: I-15 and SR 91

There are many similarities between these two projects in terms of length, operating characteristics, and being the subjects of many research papers. Both have had significant surveys of users and non-users, and both have loop detectors for measuring operating flows, traffic density and lane speeds. Both also had supplemental floating car speed and delay surveys. However, the two projects were different in their final pricing structure in ways that affect the analysis. I-15 has active sensing of both GP and express lane speeds with a response every six minutes to set (and display) a toll that varies with demand to maintain free-flow speeds (LOS C) in the express lane. Because price and time savings are strongly correlated, it makes it more difficult to account for heterogeneity in response; it also means that the prices displayed (which could change every six minutes) are also a signal to prospective users about the level of congestion and probable delay in the GP lanes. Therefore, the toll level is a signal to those with a very high value of time to use the lanes. SR 91 had broad pricing which varied by hour and which was changed four times between 1996 and 2000. Its prices were advertised for months at a time. SR 91 was priced highest during the peak two hours in the a.m. and p.m., with shoulders of one hour at a lower price, and multiple mid-day hours at a lower price yet. The flow and speed varied within these pricing windows so that there was not a strict correlation of price and time saved; this gives a much richer variance of time saved relative to price.

I-15

This project was carried out as a demonstration project by SANDAG, the San Diego MPO, with FHWA and Caltrans funding. It was implemented with carefully thought-out before-and-after panel surveys, which led to a large number of high-quality research projects and papers carried out by independent academics. As such, the I-15 project is a good example to emulate (with improvements) when any new HOV or pricing projects are due for implementation.

It was initially implemented as an 8-mile-long, two-lane reversible carpool (HOV) lane project. After it had been in operation for a few years it became obvious that the carpool lanes were underutilized, and that it was ripe for conversion, initially to a fixed monthly price and, later, to a variably priced HOT lane project. Pricing was set to maintain free flow, and the price could be changed every six minutes.

Surveys

There were two periods of longitudinal panel survey implementation. The first, 1988 to 1990, was a three-wave study prior to and following the implementation of reversible lanes to be used by HOVs of 2 or more persons. The waves were approximately 12 months apart: before opening the lanes, immediately after lane opening, and 12 months after the lane opening. Golob, Kitamura, and Supernak (1997) provide a description of these panel surveys. The second period, 1997 to 1999, was a five-wave survey which followed the conversion of the HOV lanes to lanes that could be used by HOVs (free) and by SOVs that were prepared to pay for the access, i.e., HOT lane operation (Golob and Golob, 2001). HOT use occurred in two phases: 1996 to March 1998, when users could buy a monthly fixed-price pass to use the lanes; and April 1998 on, when potential users could purchase a vehicle-mounted transponder that enabled the user to be charged for actual use at differential rates that depended on levels of demand and congestion (also known as variable pricing). The first wave was in October of 1997, after the fixed price implementation, while the other four waves were: May-June 1998, immediately after variable price implementation; October-November 1998; May-June 1999; and October-November 1999. The panel sample of about 1,500 individuals, which was refreshed at each wave, was broken down into approximately one-third ExpressPass subscribers, former subscribers, and persons on the waiting list; one-third other I-15 commuters; and one-third commuters in another freeway corridor in the San Diego area, used as a control group (Golob, 1999).

The definition of a longitudinal panel is a panel of respondents who are repeatedly surveyed, that is, the same people are surveyed at several points in time. This method enables the researcher to isolate intra-person variation in response to change from variation among respondents as obtained in a more usual cross-sectional survey. This is a more powerful way of considering behavioral effects. The methods are more complex as respondents leave the panel (attrition) between waves and have to be replaced. The data obtained can also be used more simply as cross-sectional data.

The data were enriched by the addition of monitored speed and flow data and network-derived data for the HOT-lane implementation.

Survey and Analysis Issues

The way in which the surveys were drawn—from separate samples of users and non-users—results in a choice-based sample (this was also true for SR 91). This means that while an unweighted model estimation should reveal the correct coefficients for variables such as time saved, travel time variability, cost, household composition, and socio-economic factors, and hence value of time saved (VoTS), it will not reveal the mode-specific constants, and hence correct share. Although most of the analytical reports have not attempted to use external data to calculate real shares (necessary to weight the surveys), there is at least one exception, a study to compare the results from I-15 and SR 91 (Brownstone and Small, 2005). These constants can be thought of as the price of admission, or the level of bias against paying, that must be overcome by the benefits perceived for a particular traveler (time saved) at a particular price.

LOS or Time-Saved Data Estimates

The most serious problem with the I-15 time-savings estimates is that for most of the early analyses, the source of data for potential travel time-savings for both users and non-users was single-loop detectors embedded in the GP lanes and a probably correct estimate of near 70 mph for the priced lanes. Potential issues include the following: there is more than one algorithm for converting flow and density data to speeds, at very high densities there are errors in density and flow measurement, and loops may not have been working consistently.

Because the estimate of time saved for respondents at the times of day they reported using the facility directly affects the coefficient estimated for travel time saved (TTS), it also affects the estimate of VoTS or willingness to pay.

Dr. David Brownstone of the University of California at Irvine arranged for students to conduct 5 days of floating car runs, where they found that the reported travel times (speeds) were very poorly related to measurements from the loop detector data. Steimetz and Brownstone (2005) reported a multiple-imputation method to estimate missing data and essentially calibrate the loop-derived data to give speeds matching the floating car data. This method was used to condition the speed/time data from the loop detectors for the traveler surveys used in VoTS analysis (reported in the same paper).

Findings

HOV Response to HOV Lanes

Traveler behavior was studied based on three waves of a longitudinal panel survey (Golob, Kitamura, and Supernak, 1997). This is the only empirical study of HOV participant behavior prior to and during the implementation of HOV lanes that we found.

Besides the usual questions on the starting and ending points of the trips, time of travel and mode used (shared-ride or solo-driving), the survey also asked for perceptions of traffic flows in the GP and HOV lanes (10-point scale), attitudes towards the HOV lanes (5-point scale), perceptions of GP (and after-implementation HOV) lane traffic quality (10 point scale), travel time (continuous), and ride share behavior (dichotomous). The methodology used descriptive statistical analysis, descriptive dynamic analysis, and the modeling of interrelationships between these four factors using a structural (simultaneous) equations approach.

Carpooling increased from 17% in the first wave (before implementation) to 22% in the second wave and 25% in the third wave. Perceptions of traffic quality reduced over the waves, despite the reported improvement in travel times after HOV implementation. Also, attitudes towards the HOV lanes became slightly less positive over time. Carpoolers in the HOV lanes also had a more negative perception of traffic flow in the GP lanes than users of the GP lanes. The use of panel data gave unusual insight into the formation and dissolution of carpools: the process is dynamic, with about 10% of drive-alones switching to carpool and 25% of carpoolers switching to drive-alone over each of the two inter-wave periods of about 12 months. The net growth in carpools comes from the much larger base of drive-alones during the study.

Following the HOV lane implementation, travel times initially decreased by 15% for carpoolers and 10% for drive-alones. However perceptions of GP lane traffic conditions were worse for both groups, ride-sharers more so than drive-alones. This may reflect the fact that a free-flowing HOV lane in sight of congested GP lanes provides a reference speed for roadway users—they have a more visible and ongoing reminder of how slowly the GP lanes are moving. The largely positive attitude to carpool lanes stayed relatively constant.

The structural equation modeling showed that although there were causal linkages among attitudes to carpool lanes, perception of GP lane speed/traffic, travel time, and choice between carpool and drive-alone, the choice of mode (behavior) was affected only by travel time in waves 1 and 3. However, in wave two, immediately after implementation, behavior was affected by travel time, perceptions of traffic, and attitude towards the HOV lanes. Behavior (choice) affected both attitude towards the HOV lanes and traffic perception. This is of importance as it means length of trip (in time) is the real driver of shared-ride behavior. As time and distance are strongly correlated, this also means that distance is important to rideshare.

Response to Variable Pricing

The numerous papers covered in the literature review section showed quite varied values of time, or willingness to pay, in the range of $20 to $40 per hour.

There are essentially two steps in response: (1) to become a FasTrak™ customer (purchase the responder and maintain a credit account), and then (2) to decide whether or not to use the HOT lanes as a paying solo driver. Golob (1999), using a logit model, shows that customers are more likely to be female, be between 35 and 64 years of age, have a higher income, and come from a household with one or two workers. A non-linear distance function minimizes FasTrak purchase at 23 miles (maximum for carpools), everything else being equal.

The application of variable pricing has proved to fit the theory of marginal pricing as the use and the operational speed maintenance objectives have been met.

Much of the variation in the reported value of time among the various studies of this project appears to be the result of poor recording/estimation of operating speeds on the GP lanes from the single loop detectors (i.e., measurement error).

Steimetz and Brownstone (2005) used a floating car method to record speeds in 15-minute increments over 5 days, and a method of multiple imputation to “calibrate” the loop detector speed estimates. They observed heterogeneity of response with respect to distance, income, trip purpose (work or non-work), and worker status (full or part time). While not dealing with unobserved heterogeneity, their report does point out the need to address the different value of time curves for different market segments or observed heterogeneity. Table 13 shows the resulting VoT estimates, followed by Figure 2 which shows a set of curves relating work-trip VoT to travel distance; both were taken from the Steimetz and Brownstone paper. These values of time were developed from a conditional multinomial logit model that was used to estimate mode choice among three modes: drive alone in the GP lanes, drive alone and pay (FasTrak), and carpool.

In Steimetz and Brownstone’s model, the reference mode was set to drive-alone in the GP lanes. The independent variables used for each of the other modes represent the direction of change relative to the reference mode. Positive independent variables for FasTrak were: income > $80,000 x toll, income not reported x toll, median time-savings x distance, time-savings variability x distance, home owner, and college degree or higher. Negative variables for FasTrak were: mode-specific constant, work trip x toll, non-work trip x toll, part-time worker x toll, median time savings x distance squared, “low toll” signal, free-lane traffic rating, and flexible arrival time. Positive independent variables for carpool were: median time-savings and number of people per vehicle in the household, while negative variables were: mode-specific constant, free-lane traffic rating, single worker household, dual-worker household, and mobile phone available for personal use. *Low toll signal* is an indicator variable, set to one if the posted toll is lower than the average for that time period. The *free-lane traffic rating* was a rating from 1 to 10, with 1 being bumper-to-bumper traffic in the GP lane and 10 being free-flow, as reported by the respondent. This study, unlike the others for I-15 and SR 91, did not find a significant effect for females, and did not include a “middle-age” effect, as this variable was collinear with home ownership and income.

Table 13
Value o f Time Estimates and Estimation Uncertainty

	Multiple Imputations				Single Imputation			
	Median Estimate	Boostrap Median[a]	75%-ile 25%-ile[b]	Interquartile Range[c]	Median Estimate	Boostrap Median[a]	75%-ile 25%-ile[b]	Interquartile Range[c]
Full Sample	45.47	29.68	45.69, 18.81	26.88	17.39	18.36	25.01, 14.56	10.45
Full Sample at Mean Distance	67.18	38.77	60.88, 21.93	38.95	26.68	24.91	36.94, 16.29	20.65
Work Trips								
Income>$80K	71.93	64.90	111.78, 41.48	70.30	39.69	39.69	55.91, 29.91	26.00
Income<$80K	21.95	21.52	28.79, 16.21	12.58	15.87	15.74	19.85, 12.62	7.23
Income Not Reported	69.78	45.29	88.91, 20.62	68.29	32.38	31.70	50.12, 20.59	29.53
Full-time Workers	58.33	44.12	70.36, 25.81	44.55	25.77	25.08	36.31, 16.17	20.14
Part-Time Workers	15.89	15.65	21.50, 11.58	9.92	13.76	12.97	17.07, 9.86	7.21
Non-Work Trips								
Income>$80K	14.37	14.35	21.35, 10.37	10.98	12.26	12.64	12.64, 9.70	2.94
Income<$80K	9.63	9.60	12.92, 7.16	5.76	8.14	8.31	10.38, 6.51	3.87
Income Not Reported	14.88	14.87	22.34, 10.23	12.11	11.65	12.03	16.94, 9.07	7.87
Full-time Workers	10.45	10.83	14.43, 7.97	6.46	8.72	9.08	11.40, 7.22	4.18
Part-time Workers	7.28	7.25	9.57, 5.53	4.04	6.51	6.47	8.27, 5.15	3.12

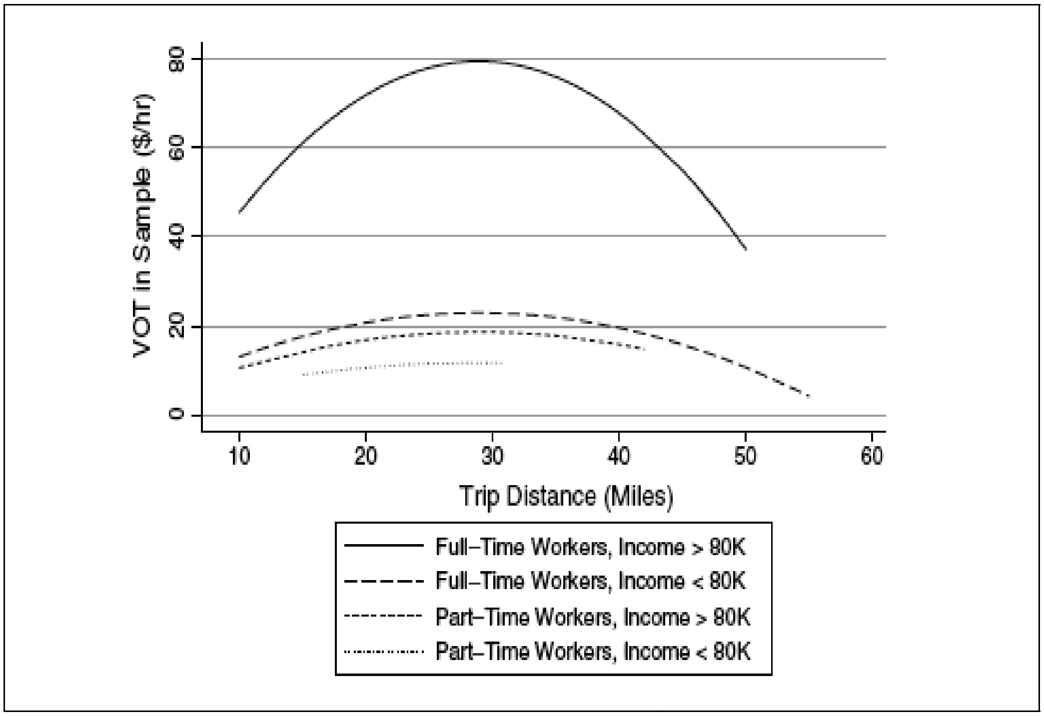
[a] These estimates are expected values of median VoT taken over the sampling distribution of their underlying parameters.

[b] These figures reflect characteristics of the estimated distributions of the parameter estimates, not the distribution of VoT within the sample. The interquartile ranges reported here characterize the degree of uncertainty in estimating VoT due to statistical error in estimating its underlying parameters. They are determined by Monte Carlo draws from the sampling distributions of the parameter estimates, i.e., they are "bootstrapped."

[c]These figures are differences between the 75th and 25th percentiles reported in the proceeding column—not to be confused with VoT heterogeneity within the estimation sample.

SOURCE: Steimetz and Brownstone (2005)

Figure 2
Work-trip VoT vs. Trip Distance



Source: Steimetz and Brownstone (2005)

While at first sight the VoTs shown here seem high, the median VoT of $30 matches closely with other median estimates based on I-15 users. The corridor serves high-income travelers: 36% are under $80,000, while 56% are over $80,000. Of the group with incomes over $80,000, 40% of those are at over $120,000.

A look at the above table and the figure showing distance effects gives a clear indication why the use of one (usually average) value of time is inappropriate. The argument given by the authors of this paper for the concave shape of the VoT with distance is that those travelers whose distance is beyond 30 minutes are composed of people who have chosen long-distance travel and thus are a self-selected group with low VoT.

The authors note that the information on the interquartile ranges and other distributional measures do not reflect the VoT distributions, but rather the sampling distribution of the parameter estimates in the “bootstrapping” technique used.

SR 91

This is a 10-mile section of SR 91 in the Los Angeles region that consists of four regular freeway lanes and two express lanes in each direction. The express lanes are priced according to a fixed price by time of day schedule, with the highest pricing during the peak hour(s). Carpools are also priced, with 3+ person carpools paying half the regular toll. The express lanes were initially privately built and operated, but were purchased in January 2003 by the Orange County Transportation Authority (OCTA), which now operates them. While the project was covering its costs prior to the sale, the profits were less than forecast for the private investor.

Surveys

Four waves of a partial-panel survey of commuters were conducted by Dr. Edward Sullivan of California Polytechnic State University, San Luis Obispo, including both priced lane and non-priced lane users. These waves were fielded in fall 1995, spring and fall 1996, and spring 1997. There was also a larger cross-sectional commuter survey in fall 1999. These surveys gave a wide range of variability in terms of time saved and for different levels of pricing—as such, giving fairly robust data for model estimation. The Brookings Center on Urban and Metropolitan Policy fielded a cross-sectional survey and a linked Stated Preference survey of users and non-users in 2000.

Survey and Analysis Issues

As in the I-15 case, this was a choice-based sample, with the same issues as listed before.

LOS or Time Saved Data Estimates

The most serious problem here, as in the I-15 case, is that for most of the early analyses, the potential travel time-savings for both users and non-users was derived from the single-loop detectors embedded in the GP lanes and a probably correct estimate of near 70 mph for the priced lanes. This resulted in the same issues as I-15.

At the time of the Brookings surveys, an 11-day detailed floating car survey to determine speeds during the morning peak period was instituted using students from UC Irvine. The most important later studies utilized these data in place of the loop-detector data, as the floating-car data were seen to be more accurate and representative.

Response to Variable Pricing

Of particular interest in the surveys utilized here is the availability of both a stated-preference survey where each respondent considers several hypothetical scenarios in an exercise designed to force trade-offs between travel cost and time-savings, and revealed-preference surveys showing behavior by each respondent to one particular instance of a time and cost trade-off. The former method allows a calculation of the value of time for each respondent while the latter allows for a VoT for classes or market segments of groups of respondents. The stated-preference experiment depends on the understanding or “reality” of the hypothetical situations presented, and can give good information about response heterogeneity; it does not necessarily give the right shares and needs scaling to match real measured response. The model estimated from the RP data gives average values for response and VoT and will match the mode shares of the data from which it is estimated.

An exercise to uncover the heterogeneity of response or distribution of preferences using a combination of the SP and RP data is reported in Small, Winston, and Yan (2005) and its Econometrica Supplement. It is instructive to take a brief look at this paper in more detail.

The data were taken from three sources: (1) three surveys in a 10-month period of 1999 and 2000, (2) an RP survey by the Cal Poly and UC Irvine researchers in 1999 (Sullivan et al., 2000), and (3) a two-stage survey by UC Irvine collected by the Brookings Institution. The first stage of the Brookings study collected RP data that closely matched the Cal Poly survey, while the second stage was an eight-scenario SP survey. The surveys were designed to be merged for analysis and resulted in RP data for 522 individuals and 633 observations of SP responses from 81 individuals. Fifty-five of the Brookings sample responded to both RP and SP surveys.

Using a method of random parameter estimation (mixed logit) on either the combined SP-RP or the SP data for a binary choice between express (tolled) lanes and free (congested) lanes, the authors were able to estimate VoTs and VoRs for the sample, along with both observed and unobserved heterogeneity. This study tested both skewed distributions, such as log-normal for the distribution of the unobserved error term, and a normal distribution. In this case the only model form where the estimation converged was the normal distribution. This results suggests a different pattern than shown by the Minneapolis-St. Paul study described later. It also lessens the concerns expressed by Hensher and Goodwin (2003) about the need for a distribution to get accurate forecasts.

The variables used were similar to those in Steimetz and Brownstone (2005) in that interaction terms between travel time difference and distance of the overall trip were used (in this case, distance, distance squared, and distance cubed) to give the same U-shaped distribution for VoT showing heterogeneity with distance. The responses to time-savings (more likely to pay and use express lanes) and cost (less likely to use the express lanes and pay) are as expected. The income response is also similar, with higher income more likely to pay. Travel time unreliability, here expressed as the difference between the median and the 80th-percentile of travel time differences as measured over multiple days for the same 15-minute period, also increased the probability of using the express lanes. People between the ages of 30 to 50, women, and members of smaller households were also more likely to use the express lanes.

Values of Time and Reliability

Table 14 is taken from the referenced Small, Winston, and Yan paper (2005). Here, heterogeneity in VoT and VoR is defined as the measure of the inter-quartile range, the difference between the 25th- and 75th-percentile values across individuals.

The heterogeneity is substantial, with the unobserved being much higher than the observed for both RP and SP. This unobserved heterogeneity is probably mostly individual taste preferences. Based on the revealed preference data, the median VoT is $21.50, which is reported as being about 93% of the average gross wage rate for the counties of driver origin. This is considered to be high in comparison to the commonly quoted 50% of gross wage rate in the literature. Interestingly, the value for the SP survey is $11.90, or about 50% of the gross wage rate. As the authors state, there is evidence from SR 91 survey responses to suggest that travelers over-estimate (by about 100%) the time lost to congestion. This was also reported in Sullivan et al. (2000). Thus, if a traveler's perception is double (on average) the measured travel time-savings, this would have the effect of halving the coefficient on time saved (using measured time) and doubling the value of time. This would explain the discrepancy.

Table 14
Distributions of Values of Time and Reliability

	Base Model	Model with Time-of-Day Dummy	Model With Occupancy, Transponder Choices

	Median Estimate	90% Confidence Estimate [5%-ile, 95%-ile]	Median Estimate[a]	Median Estimate[a]
RP Estimates				
Value of time ($/hour)				
Median in sample	21.46	[11.47, 29.32]	27.44	23.64
Observed heterogeneity	4.04	[2.60, 8.34]	5.07	5.35
Unobserved heterogeneity	7.12	[3.15, 16.87]	7.34	8.64
Total heterogeneity in sample	10.47	[5.82, 24.11]	11.22	12.52
Value of reliability ($/hour)				
Median in sample	19.56	[6.26, 42.80]	24.31	24.59
Total heterogeneity in sample[b]	26.49	[8.60, 60.40]	29.76	28.49
SP estimates				
Value of time ($/hour)				
Median in sample	11.92	[7.09, 21.06]	11.99	10.88
Observed heterogeneity	2.60	[0.24, 8.86]	4.21	2.79
Unobserved heterogeneity	12.32	[6.90, 23.30]	14.50	12.39
Total heterogeneity in sample	13.31	[7.41, 23.88]	15.96	12.94
Value of reliability ($/incident)				
Median in sample	5.40	[3.26, 10.12]	5.54	5.23
Total heterogeneity in sample[b]	7.95	[4.65, 14.38]	7.75	6.52

[a] The 90% confidence intervals are not shown to save space; they are quite similar to the ones shown in column 2 and in no case does the confidence interval include zero.

[b] Total and unobserved heterogeneity of VoR, as defined here, are identical (i.e., there is no observed heterogeneity) despite the dependence of VoR on income. This is because observed heterogeneity in VoR arises only from variation in the dummy variable for income categories, and the 25th and 75th percentile values of VoR (across i) happen to come from the same income category (namely, the lowest).

Source: Small, Winston, and Yan (2005)

The ability to discover and model the distribution of response to cost and time means that the basic tools to understand the behavioral response are available. In a practical sense this means that variable pricing can be used to achieve various policy goals. For example, prices can be set to maximize income, to maximize throughput, or to set a level of service or speed.

5.2 Minneapolis-St. Paul

This project converted existing HOV lanes on I-394 to HOT lanes with single-occupant vehicles subjected to a toll and carpools traveling free. The project is 11 miles long, with 3 miles of barrier-separated reversible lane connecting to the pre-existing 8 miles of non-separated diamond lanes. The project's objective is to fully utilize the previously under-utilized HOV lanes by setting a toll that is continuously variable in 3-minute increments so as to maintain free flow speeds. The toll was envisaged to be in the $0.25 to $8 range, and currently reaches a maximum of about $4 in practice while maintaining speeds in excess of 50 mph. These tolls are very similar to those in use on I-15.

The facility opened in the spring of 2005 with a strong commitment to surveying and analyzing the response of users and non-users. There was a pre-implementation attitude and behavior survey (Wave 1) of travelers recruited from both the I-394 corridor and a control corridor (I-35W) in November-December of 2004, about six months before implementation. Post-implementation attitude and behavior surveys were carried out in November-December 2005 (Wave 2), 6 months after implementation, and in May 2006 (Wave 3), after a year of use. These surveys of corridor travelers collected information on travel, with self-reported start time, distance, and travel time, along with an in-depth set of questions on attitudes towards the conversion from HOV to HOT lanes and the concept of pricing.

Included in the analytical survey design was a stated preference survey. This survey had an experimental design to estimate the behavioral response to varying prices and hence the value of time. All 412 respondents who used I-394 in the main survey responded to this survey in the first wave. There were 367 respondents in the second wave.

Sample Size

The intent was to start with a sample of 1,000 respondents and to increase the sample size in waves 2 and 3 to 1,400 and 1,600 respectively. The initial survey had 750 respondents in the I-394 corridor and 250 in the I-35W corridor. The SP survey was administered to all respondents who indicated that they used I-394 and the reported trip from the attitude and behavior survey became the reference trip for the SP survey.

Between the first and second waves there was an attrition (loss) of 40% of the initial respondents. These were not replaced. A total of 150 travelers who had purchased the MnPASS and 250 travelers who used transit in the HOT lane were recruited to the survey for wave 2.

The two waves of the Attitude and Behavior survey are documented by the survey firm NuStats for the Humphrey Institute of Public Affairs, University of Minnesota, in two reports prepared for the Minnesota DOT. "Humphrey Institute… Wave 1(2): Final Report" (March 2005 and March 2006).

Information on the value of time distributions from the SP data is detailed in an unpublished document authored by Mark Bradley of Bradley Research and Consulting.

Key findings from the Wave 2, I-394 travelshed respondents are:

- "Support for the idea of letting single drivers to use the carpool lanes by paying a fee remained high after MnPASS implementation remained high (59% 'good idea' vs. 29% 'bad idea').
    - Approval was consistent across all income groups – 71% higher income, 60% middle income and 62% lower income.
    - Sixty-four percent of carpoolers were supportive of the MnPASS concept and 29% thought it was a 'bad idea,' and 45% of transit users were supportive, whereas 39% thought it was a 'bad idea.'
- MnPASS lane users represented a broad market – 87% used the MnPASS lanes as a carpooler, 7% as a single driver and 4% as a bus rider.
    - MnPASS usage was reported across all income levels – 66% higher income, 62% middle income and 54% lower income.

    - While transponder owners tend to be higher educated, higher income, middle-aged adults, transponder ownership cuts across all income levels, age groups, educational attainment levels and gender.

- Users, regardless of whether they are paying or not, were very satisfied with MnPASS operations.
    - The highest measures of satisfaction were with the speed of traffic flow in the MnPASS lane (85% satisfaction), and the lowest levels were with the enforcement of MnPASS usage (45%).
    - Safety did not surface as a major issue, with 76% reporting satisfaction with the ease of identifying the MnPASS entry points, and 66% satisfied with the safety of merging into the MnPASS lanes.
    - Thirteen percent of MnPASS users did experience difficulty merging into the MnPASS lane from the general traffic lane, but the majority placed the responsibility for the problem on congestion or rude drivers rather than operational aspects of the lanes.
    - Paying MnPASS subscribers were exceptionally satisfied with the details of having an MnPASS subscription as well as with MnPASS communications (i.e., Customer Service Center staff or the website).

- The implementation of MnPASS has not had a negative impact on carpooling on I-394 nor on traveling experiences on I-394.
    - The current mode share was comparable to pre-implementation distributions – 76% drive alone, 23% carpool, and 1% ride bus.
    - The percentage of I-394 panelists reporting a congestion delay fell from 38% in 2004 to 28% in 2005.
    - Satisfaction with the overall quality of travel on I-394 rose, from 36% being 100% satisfied in 2004 to 46% reporting 100% satisfaction in 2005 (among I-394 panelists).
    - The percentage that rated travel on I-394 'enjoyable' after MnPASS (61%) was higher than before MnPASS (50%).

- MnPASS lane users considered the MnPASS toll a good value.
    - Seventy-one percent said the toll was just right.
    - The mean value of travel time estimated for Wave 2 ($10.50 per hour) was higher than that captured in Wave 1 ($8.50 per hour), indicating that now that MnPASS is operating, people are more willing to pay a higher toll to avoid congestion."

Consideration of Stated Preference Results

The stated preference experiment fielded by NuStats was designed and analyzed by Bradley Consulting and Research using both a standard trade-off design and a "price meter" design, which is unusual. The two methods give consistent results (Mark Bradley, Unpublished reports, 2005 and 2006).

The following description of the survey methods is taken verbatim from the unpublished Bradley MnPASS report (March 2006):

> "Stated preference questions were used to measure respondents' likelihood of using the HOT lane as a function of the toll level and time-savings. The questions were asked of all 412 respondents whose reference trip was made as a solo driver on the I-394. The introduction and wording of the questions is shown below.
>
> **Now assume you're making the same trip in the future that you just told me about. It's a trip on the same day, at the same time of day, for the same purpose, and you're under the same**

time pressures. You enter the freeway, I-394, and find out that you can make this trip using a toll lane and paying via electronic toll collection if you want to.

[Either VERSION 1]
If you were to use the general traffic lanes on I-394, your trip would take *TT+Y minutes* and be free. If you were to use the toll lane you would pay *$X* and your trip would take *TT minutes*, saving *Y minutes*. Now under these conditions, which would you choose to do?

Use the toll lane, pay $X and save Y minutes	001
Use the general lane for free	002

[or VERSION 2]
If you were to use the toll lane on I-394, you would pay *$X* and your trip would take *TT minutes.* If you were to use the general lanes, your trip would take *TT+Y minutes, Y minutes* longer than the toll lane, but it would be free. Now under these conditions, which would you choose to do?

Use the general lane for free	002
Use the toll lane, pay $X and save Y minutes	001

Method A
First, each person received 4 different scenarios, each with a different amount of time-savings (Y = 5, 10, 15 or 20 minutes) and toll (X = 50 cents, $1, $2, $3, $4, $5, $6 or $7). (The value TT used for the tolled lane was based on the respondent's estimate of their travel time with no congestion.) 9 different sets of 4 scenarios were used across the sample, with each respondent assigned 1 of the 9 sets at random. So, in total, 36 (9 x 4) different scenarios were used, each identifying a different time/cost tradeoff point.

Also, to avoid bias due to ordering effects, the questions were asked in two different ways. Versions 1 and 2 differ only in the order in which the toll and non-toll options are described to the respondent. Each respondent was assigned one of the two versions at random.

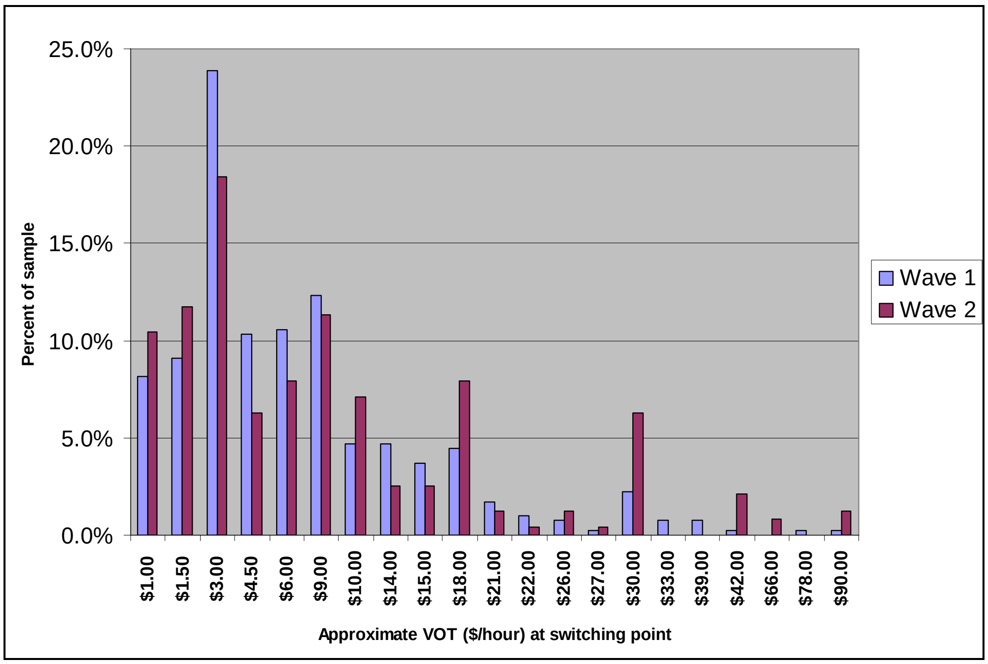
Method B (Price Meter)
Next, the same type question was asked again, but this time using the "price meter" approach. Each respondent was assigned a level of time-savings (S = 5, 10 or 15 minutes) at random. Then a random toll price point was chosen (P = 50 cents, $1, $2, $3, $4, $5, $6 or $7) and the same question from above was asked. If the person said that they would pay the toll, a higher price point was chosen at random, and if they said they would not pay the toll, a lower price point was chosen at random, and the question was asked again at the new toll level. This procedure was continued until the "switching point" was identified – e.g. the respondent would be willing to pay a toll of $2, but not $3. Note that from the respondents' perspective, there was no obvious difference between the Method A and Method B SP questions—both sets of questions used virtually identical wording."

The results from this procedure gave a value of time best described in a verbatim quote from the author:

"Just as we found for the Method A data, the Method B responses for Waves 1 and 2 are very similar, but with Wave 2 indicating a somewhat higher percentage of respondents with both very low VoT and very high VoT—i.e. a wider spread. The mode value is between $2 and $3 per hour for both Waves, but the median value is somewhat higher for Wave 2 (between $5 and $6 per hour) than for Wave 1 (between $4 and $ hour). The larger 'tail' of the Wave 2 distribution means a significantly higher average VoT in Wave 2. The mean VoT from Wave 1 was about $8.50 per hour, while the mean from Wave 2 is about $10.50/hour."

These values, which come from the "Price Meter" approach, are very instructive. As expected, the distribution is left skewed with a long tail, matching the concerns expressed in Hensher and Goodwin (2003). With this very simple, uncomplicated, empirical approach, the problem in using the mean value of time becomes apparent and visible; the median is very much lower than the mean, and the mode (most reported as acceptable) is lower yet. The following figure shows the distribution for both the first wave prior to implementation and the second, following implementation.

Figure 3
Distribution of Price Meter Outcomes



Source: Mark Bradley, Unpublished report: MnPASS Stated Preference Surveys

The same author has also completed identical surveys for both Atlanta and Dallas-Ft. Worth with very similar results: Atlanta with almost identical VoT estimates and Dallas somewhat higher.

It can be noted that after experience with priced lanes, the acceptance of willingness to pay has increased, as expressed by the mean VoT and as evidenced by the figure above with significantly more respondents in the tail of the distribution and fewer on the left.

The existence of a putative RP data set that needs only the addition of time saved at time of travel and cost of priced lanes for this study, along with the stated preference surveys, should allow for the scaling of the SP data by the "real" RP data to obtain the objective distribution of the value of time. These additional data have been archived (discussions with Nick Thompson of Minnesota DOT) and should be extracted and attached to enable comparison with the two very high income area data sets from California.

General Comments on the Case Studies

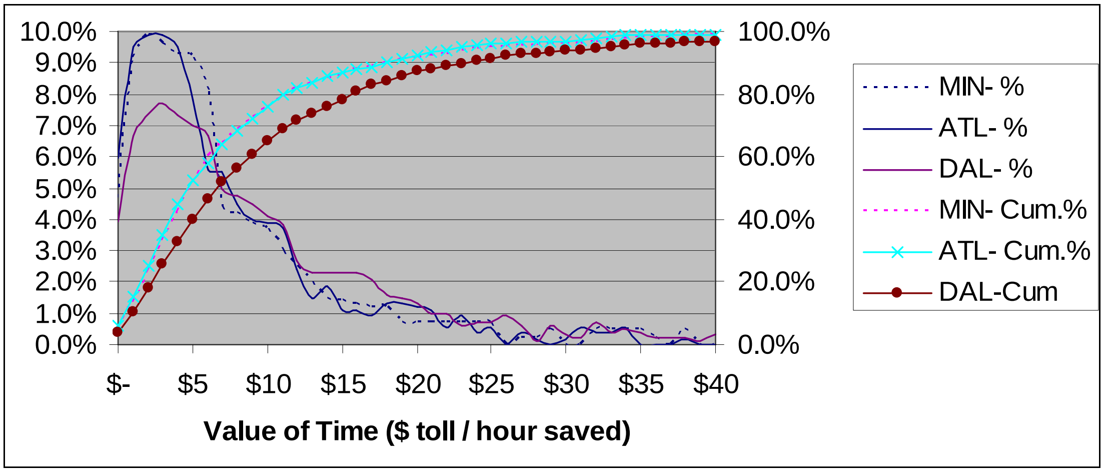
The three case studies covered have made serious attempts at surveys designed to uncover behavioral response, but it is clear that there are lessons that could be learned by talking to the analysts.

The two California studies have made an important assumption as to the respondent's awareness of actual travel time savings, that they can only use their perceptions from past experience and observation, although toll rates on rapidly responding systems (I-15 and I-394) are a signal of congestion on the free lanes. Their approach has been to measure actual travel times over a month(s)-long period by short time slices through the peak periods. Having done so, the data for a typical time period can be characterized by their statistical properties. A use of the median value of measured travel time for the time period has been accepted as the objective measured value from which actual time saved should be calculated. The value of reliability (VoR) has been shown to be weakly represented by values such as the standard deviation and strongly represented by the differences in time saved between the 50^{th}- and 90^{th}-percentiles. In the Small, Winston, and Yan (2005) study, the difference between the 50^{th}- and 80^{th}-percentiles was used (insufficient data at the 90^{th}-percentile).

It is clear (to these authors) that the distribution of response to time and cost can only be approached through a stated preference experiment, and that this was only attempted—on a very small scale—by the Brookings Institution survey on SR 91 in the California studies. In that case, in the construction of a mixed logit (random parameters) model, the model statistics were improved, but the error distribution used had to be a normal distribution (tests for non-symmetrical distributions such as log normal failed to converge). The empirical SP data from a relatively large sample in Minneapolis suggests (very strongly) otherwise. It is equally true that a concomitant RP survey is required in order to accurately scale the SP survey distribution results.

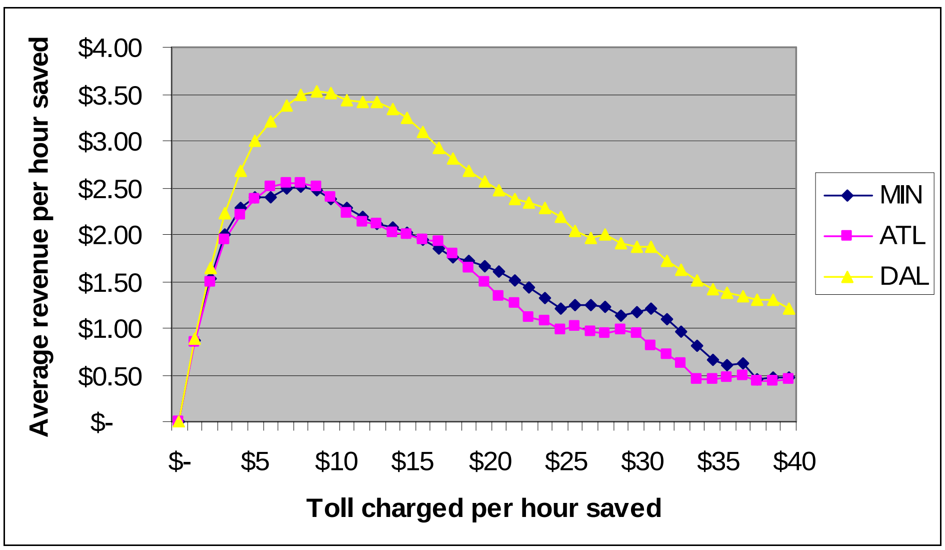
To reinforce the comment about the shape of the distribution of response, we include the following figures from an unpublished paper by Mark Bradley comparing the distributions from three cities (Minneapolis, Atlanta and Dallas) — a very consistent result. Also included is an analysis of the revenue forecast distribution at various toll levels with assumptions on speeds of alternate lanes or routes. It should be noted that the Dallas study is for a tolled freeway, not a HOT lane, and that Dallas drivers are familiar with tolled roads.

Figure 4
Sample Distribution of Imputed Value of Time



Source: Mark Bradley

Figure 5
Revenue as a Function of Toll Level



Source: Mark Bradley

6. NEEDS AND RESEARCH DIRECTIONS

6.1 Needs

To develop disaggregate forecasting and modeling techniques.

These techniques are well understood in the daily activity-modeling paradigm where individuals are modeled stochastically. While existing practice includes the capability to include household composition and person characteristics, it needs to be extended to include a sampling procedure for distribution of the value-of-time variables, to respond to non-normal distributions.

6.2 Needed Research - Recommendations

Empirical Studies

The primary need here is to be able to develop the probability density curves for the value of time. These need to be developed for market segments that include travel purpose, household composition and income.

To carry out surveys when instituting new variably priced lanes.

The best model at present is the procedure used for the MnPASS project, which consisted of before, during, and after implementation RP and SP surveys. The procedure used was fully described in the body of this report.

To develop and field surveys for HOV choice.

These are needed to measure the behavioral response to HOV provision by both user and characteristics of the HOV and non-HOV origin to destination paths. Surveys of users and non-users (similar to the HOT lane surveys developed for the MnPass project) should be undertaken. These will need to be both revealed and stated preference. The surveys need to follow the models laid out by the I-15, SR 91, and MnPass projects in terms of surveying both users and non-users. The inclusion of an extensive SP survey as used in the MnPASS project is essential to understanding the distribution of response, and to determine its shape.

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