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16. Abstract
With the evolution of high-occupancy vehicle (HOV) facilities to managed lanes, and the increasing level of activity in the development of managed lanes in Texas and nationally, research and guidance defining the role of carpools in priced managed lanes is needed, especially a better understanding of the tradeoffs between carpool exemptions and other project objectives. Increasingly, project objectives reflect not only mobility concerns but funding deficiencies and the need to generate revenue. As a result, allowing exempt users such as carpools requires an evaluation of revenue impacts as well as mobility interests such as person movement, operations, and emissions. This study utilizes a state-of-the-practice review, a 4600-respondent survey of freeway users in Houston and Dallas, and simulation modeling of six alternative HOV scenarios at varying toll rates to identify the tradeoffs associated with carpool toll discounts in new managed lanes.

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THE ROLE OF PREFERENTIAL TREATMENT FOR CARPOOLS IN MANAGED LANES

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CHAPTER 1. INTRODUCTION

High-occupancy vehicle (HOV) facilities are an important element of the transportation systems in Houston and Dallas, and are being considered in other metropolitan areas in the state. The Texas Department of Transportation (TxDOT) and partnering agencies have learned a great deal about the design, operation, and enforcement of HOV lanes over the past three decades. With the evolution of HOV facilities to managed lanes, and the increasing level of activity in the development of managed lanes in Texas and nationally, there is a need for research and guidance defining the role of carpools in priced managed lanes and the tradeoffs between carpool exemptions and other project objectives. Increasingly, project objectives are reflecting not only mobility concerns but funding deficiencies and the need to generate revenue. As a result, allowing exempt users such as carpools requires an evaluation of revenue impacts as well as mobility interests such as person movement, operations, and emissions.

The underlying premise of free or discounted passage for HOVs is the belief that such incentives have a causal relationship with carpool formation. As a result, the investment in such incentives would be offset by community benefits in improved person movement in the corridor(s) and air quality. However, as with any investment the opportunity cost for this investment must be evaluated against the loss of revenue and its inherent limitations on transportation improvement. In order to properly evaluate this opportunity cost, the foundation of the causal relationship must be properly defined and verified.

The purpose of this research study is to identify the benefits, drawbacks, and tradeoffs of providing preferential treatment for carpools in managed lane facilities, through toll exemptions or discounts, by:

- examining the causal relationship between ridesharing incentives—particularly pricing incentives—and the propensity to carpool;
- assessing the state of the practice in carpool preferences for managed lanes in order to identify the basis for decisions made by agencies regarding pricing incentives; and
- evaluating the tradeoffs associated with preferential treatment from the perspectives of person movement, revenue, operations, and air quality using original data collected through surveys of travelers.

Figure 1 illustrates the methodology for conducting this research study and the major elements in the process. A Project Advisory Committee comprised of TxDOT and partner agency representatives from across the state provided input to the two significant components of the study: the traveler survey and the impact analysis modeling. The state-of-the-practice review also informed those two major components.

An extensive survey of travelers in Houston and Dallas was used to obtain information on travel behavior and interest in managed lanes. From the results researchers developed descriptive statistics that produced some observations about carpooling behavior, as well as derived models that were incorporated into the impact analysis tool. The results from all of the different elements of the research formed the basis of a decision matrix to guide policy development for managed lanes.

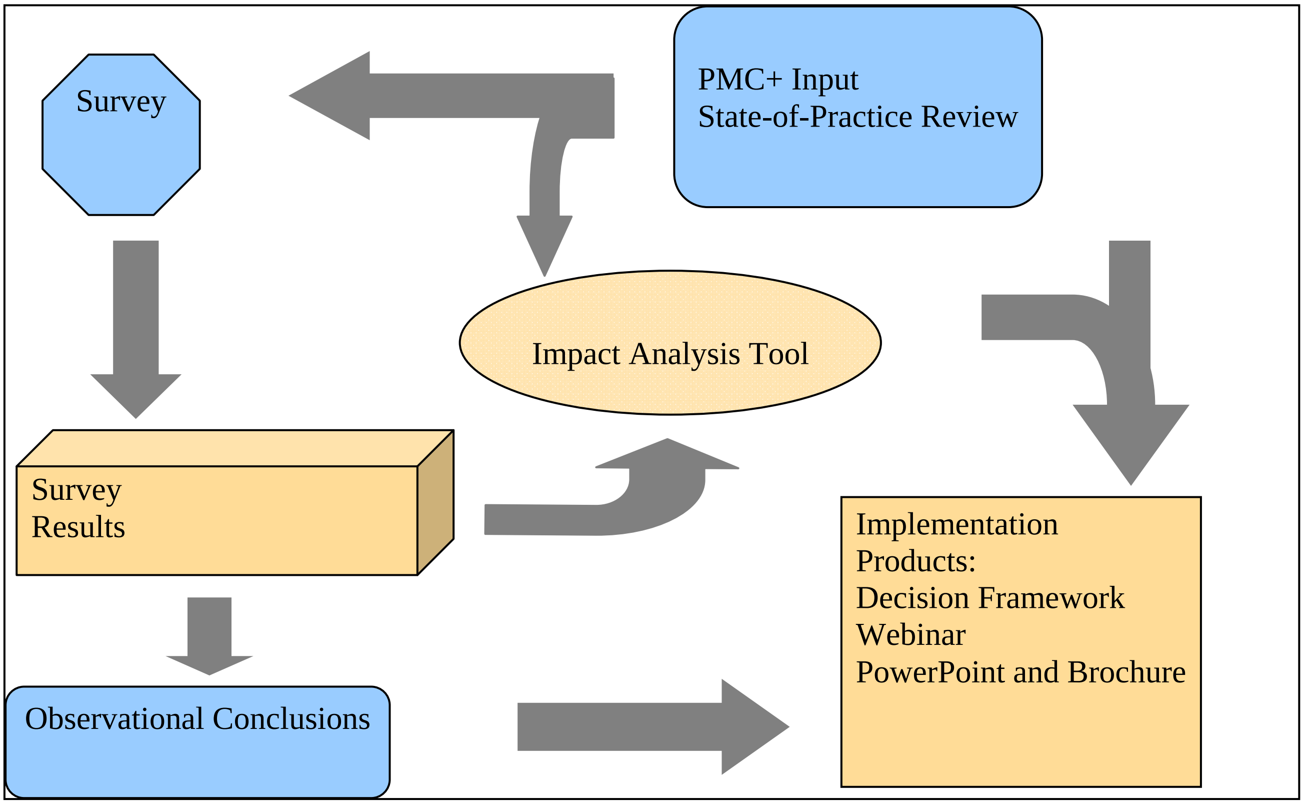


Figure 1. Research Process.

CHAPTER 2. STATE-OF-THE-PRACTICE REVIEW

The concept of tolling on managed lanes (ML) has evolved since the first iterations in the early 1990s. Initially conceived in Texas as the allowance of previously prohibited vehicles on HOV lanes in exchange for the payment of a fee, otherwise known as high-occupancy/toll (HOT) lanes, managed lanes have expanded in scope to include a variety of implementations, without any inherent policy regarding HOVs. The official definition of managed lanes, as established by the TxDOT Project Monitoring Committee and reported in TxDOT Report 0-4160-3, is as follows *(1)*:

> A managed lane is a facility that increases freeway efficiency by packaging various operational and design actions. Lane management operations may be adjusted at any time to better match regional goals.

Of particular interest in Texas and various other states are those implementations that feature the collection of toll revenue in return for use of the managed lane facility. Originally perceived under one of two applications—HOT lanes or express toll lanes (ETL)—managed lanes are studied and implemented with many operational variants. The broad definition of managed lanes not only includes these variants, but any application that involves system-management techniques such as time-of-day restrictions, vehicle-type restrictions, and value pricing. In addition to HOT lanes and ETL facilities, common types of managed lanes in the United States are HOV lanes, truck-only lanes, and limited-access express lanes.

Of these, HOV lanes have a longer history of operations in Texas and North America than HOT lanes and ETL facilities. First implemented on Virginia's Shirley Highway (I-395) in 1969 as an exclusive busway, the concept of HOV lanes was born when four-or-more person carpools and vanpools were permitted access to the facility in 1973. Initiated during a time of high fuel costs, fuel shortages throughout the United States, and public concerns regarding mobility, HOV lanes provided yet another incentive to carpool or vanpool. Although the magnitude of travel time savings offered by HOV lanes has been studied, the role of HOV-lane related incentives relative to other incentives to carpool has rarely received the same attention. Nationally, since 1993, vehicle miles traveled have increased 25 percent, while the percentage use and absolute number of carpools and vanpools for commute trips has declined to a 30-year low—10,057,000 trips in 2003, down from 11,852,000 in 1993 *(2)*. In the same 10-year time frame, HOV lane miles have more than doubled, from approximately 1300 lane miles in 1995 to over 2500 in 2000, and forecasted to be 3100 in 2005. The majority of these HOV lane miles are located in California (1000), Georgia (400), and Texas (300) *(3)*.

In order to use the HOV facilities, users must adhere to the facility's particular occupancy and use policies. Most freeway-based HOV lanes apply a two-person-or-more (HOV-2+) occupancy policy, generating a level of demand that justifies the HOV lane without it becoming overloaded or congested *(3)*. These policies may cause an inconvenience to the user, such as traveling additional mileage in order to pick up a carpool partner. As a result, the user must weigh the value of time gained from the HOV lane versus the cost of time as a result of inconvenience.

In many ways, HOV lanes are selling the possibility of recurring congestion in adjacent general purpose lanes in return for an uncongested carpool trip in the HOV facility. The expectation, in return for accepting the inconvenience associated with the trip, is that the use of the HOV lane will provide some travel time savings. As a result, carpooling rates have increased significantly within HOV corridors (over 100 percent) even as carpool rates nationwide have declined (30 percent) during the past two decades *(4)*. However, severe congestion in the general purpose lanes have tended to cause animosity on the part of the general public toward HOV lanes if they are underutilized *(3)*. As a means of mitigating the "empty lane syndrome," HOT lanes have been promoted as an effective way of utilizing the excess capacity without yielding the HOV lanes' travel time advantages *(5)*.

In addition to HOT lanes, which imply maintenance of HOV operations, ETL concepts have also been promoted as a means of enhancing mobility within congested corridors and regions. First implemented in Orange County, California, as the privately built and operated State Route 91 (SR-91) express toll corridor, ETL facilities provide the same benefits of HOT lanes (exclusive right-of-way with congestion-free trips along the length of the corridor), but they do not carry the same implied benefit to carpools and vanpools. The SR-91 express toll facility has, at times, provided free use by three-people-or-more (HOV-3+) users, but has also at other times required partial toll payment by these users in the past eight years of operations. Although SR-91 is the only ETL facility currently in operation, ETL concepts are more attractive than HOT lanes for those transportation agencies seeking enhanced sources of revenue and ease of enforcement.

As managed lanes are considered throughout Texas' congested metropolitan areas, as well as more than 25 cities throughout North America, there is a need for research and guidance defining the role of carpools in tolled managed lanes and the tradeoffs between carpool exemptions and other project objectives. Increasingly, project objectives are reflecting not only mobility concerns but funding deficiencies and the need to generate revenue. As a result, allowing exempt users such as carpools requires an evaluation of revenue impacts as well as mobility interests such as person movement, operations, and emissions.

CARPOOLING AND HOV LANES

HOV lanes and carpooling have an overlapping purpose: encourage greater person throughput through greater vehicle occupancies. By encouraging people to rideshare, particularly during peak periods, person throughput on congested corridors can increase without a corresponding significant increase in capacity. Since the 1970s, HOV lanes have been implemented with the explicit purpose of encouraging the formation of new carpools through a significant travel time incentive. This section identifies the formation of carpools, incentives that contribute to carpool formation, and the history of HOV lanes in Texas.

Carpool Formation

Carpooling as a strategy for transportation investment dates back to World War II, when the federal government enacted a marketing program for citizens to share rides with one another in order to conserve energy for the war effort. As illustrated in Figure 2, the famous marketing program declared, "When you ride alone, you ride with Hitler" *(6)*.

Figure 2. First Known Carpool Marketing Campaign *(6)*.

Although distinction is made between *regular* carpools (recurring, scheduled carpools) and occasional carpools (situational carpools only), the basics of carpooling remains the same 60 years later—a minimum of two people with common commute patterns share one vehicle for their trip. Carpooling itself requires no public investment because the decision to carpool remains a private one. However, advocates for governmental and commercial encouragements to carpool rationalize that "Every person added to a carpool means another congestion- and pollution-causing car is taken off the road" *(7)*. As practice holds, if commuters are presented a large enough incentive to switch from driving alone to carpooling, they may form a carpool either formally (through a matching service and/or agreement) or casually (through situational agreement, as noted below).

Ridematching serves as the basis for formal carpooling and has been actively conducted for 30 years. Deployed at either regional or employer levels, formal programs may be administered by employers, transit organizations, or rideshare agencies, with overlap being common. For example, a regional rideshare program may offer promotional activities and incentives through participating employers. Commuters provide information to the rideshare agency that assists in matching riders together, such as work hours, vehicle availability, location of residence, and location of employment in the case of a non-employer rideshare program. Typically, successful formal carpooling depends upon a similar employment destination, so areas with high employment densities are more aptly suited to carpool promotions than those areas with dispersed employment *(8, 9, 10)*. Successful ridesharing occurs only when a variety of factors are met. Potential riders should:

1. live near each other,
2. travel a sufficient distance to work so that the time required for pickup and drop-off does not significantly add to the total commute time,
3. either work together or within a short distance of one another,
4. have agreeable working hours to carpool schedules, and
5. consistently use carpools *(8, 9)*.

Casual or "slugging" carpool formations began in the late 1970s and have since emerged in Virginia, California, and Texas. Not officially administered or sanctioned by governmental entities, slugging involves drivers picking up a random carpool partner to access HOV lanes at pre-identified locations *(11, 12)*. Casual carpooling avoids pre-arrangement and fixed-schedule hassles of formal carpooling, but does add a layer of uncertainty and risk for drivers and riders alike *(13)*.

Studies have shown there are three main reasons commuters switch from driving alone to ridesharing (either carpools or vanpools):

- Travel time. Research has shown that commuters are likely to alter their commute choice if it reduces their commute time. Since driving alone is typically the quickest means from home to work (or the reverse), total travel time is one factor that makes driving alone attractive to drivers *(8, 14, 15, 16)*. HOV lanes have been shown to reduce travel time, thereby making carpooling more appealing and counteracting the disposition toward driving alone *(16, 17, 18)*.
- Convenience. Studies have also confirmed convenience is a factor in determining mode choice. Driving alone is seen as the most convenient mode for most commuters. However, this can change if employers or municipalities have carpooling incentives in place making carpooling more suitable for their needs, such as conveniently located parking spaces reserved for carpoolers *(8, 14, 15, 16, 19, 20)*.
- Cost. Although many commuters do not use the most cost-effective commute choice, it is an influential factor. Cost savings can be realized simply through the sharing of costs between driver and passenger(s), although additional financial incentives and subsidies may be offered by governmental and/or employer entities. This is especially true with vanpool programs *(16, 19, 20)*. Researchers note that free or low-cost parking tends to influence a greater use of single-occupant vehicles *(19)*.

Applications of HOV Incentives

Since the federal government's marketing efforts in the 1940s to encourage carpooling, governmental entities at all levels have provided incentives and promotions to support the use of carpooling. Carpool incentives are offered in forms of subsidies, parking management, reward programs, and guarantees and are funded using a combination of public, private, and non-profit sector sources. Although these incentives have a varying degree of effectiveness independently, research has shown all of these incentives are enhanced with the presence of HOV lanes *(10)*.

Subsidies

Subsidies for carpool use may take many forms. In the late 1990s, Congress endorsed a new tax incentive designed to encourage the commuter use of vanpools and transit, deployed through participating employers. Currently, the federal tax code offers a $105 per month tax-free spending account for transit or vanpool costs ($200 for parking). For regular vanpoolers and transit riders, the tax-free spending account provides an additional positive effect on disposable income and serves to subsidize the cost of using these options *(21, 22)*.

Additional subsidies depend upon mode of travel. Many regions, such as Atlanta, Austin, and Houston, subsidize the cost of vanpools, dramatically reducing the out-of-pocket cost for commuters. For example, in the Atlanta region, a $50 per month flat rate fee is charged for vanpoolers (which may, in turn, be paid out of tax-free spending accounts, extending the subsidy further). The total average cost of the vanpool service per person yields a 70 percent subsidy paid for by federal, regional, and local sources of funding *(23)*.

Other communities provide direct subsidies to commuter travel by any alternative mode, including carpooling. For example, Aspen (Colorado) and Riverside County (California) have provided "commuter club" programs, where a small payment (such as $0.50) was paid to the commuter per day for carpooling. Employers around the United States have often participated in similar programs, particularly in parking-constrained areas or in communities with mandated employer participation (such as the states of Washington, Oregon, and California) (*24*).

Parking Management

Parking management applied at the employer level may positively affect carpool formation. The cost, availability, and location of parking have a considerable effect on commuters' travel choices *(25, 26, 27)*. When parking is expensive or located far from an employee's work site, transit and rideshare may be a more attractive alternative.

A variety of techniques are included under the broad heading of parking management, including strategies most likely to influence carpool formation: pricing strategies (such as eliminating parking subsidies, parking cash-out, and transportation allowances) and providing preferential parking spaces for carpools. Parking management strategies work best when used in connection with other rideshare incentives *(8, 24, 28)*. Eliminating parking subsidies altogether is another method employers may use as a parking incentive against driving alone *(24)*.

Gifts/Awards

In some instances, gifts or awards are given to commuters who use an alternative mode of transportation to get to work. This gift or award may be part of a drawing, or participating commuters may accumulate points every time they carpool. The employer's transportation coordinator or agency in charge of establishing carpools designates the type of program used to distribute the prizes *(24)*. Some employers offer time off with pay to those employees who carpool to work. The amount of time off differs, depending on the number of times the employee carpooled within a certain time frame *(24)*.

Guarantees

A critical barrier to commuter use of ridesharing is the perceived dependence on a vehicle during work hours. Commuters desire having a vehicle ready for use in order to run an errand, have an off-site meeting, or just in case an emergency occurs. Employers have provided services to alleviate these concerns by locating on-site amenities for common errands (such as restaurants, dry cleaners, and daycare centers), providing company or subscription-based vehicles for daily use (including bicycles, scooters, and automobiles), and offering guaranteed ride home programs for emergencies or unexpected working hours (such as a late meeting). The specific combination of services and amenities will influence the amount of trip reduction that can be achieved *(24)*.

HOV Lanes

HOV lanes reserve highway capacity (typically) for vehicles with more than one occupant. HOV lane users can save substantial time over comparable trips in congested general purpose lanes and provide more predictable travel times to buses, carpools, and vanpools. Carpool programs are likely to be more successful where carpool lanes exist because they reward commuters with travel time savings, in addition to monetary incentives as identified above *(8, 10)*.

History of HOV Lanes in Texas

For three decades, TxDOT and its partnering agencies have been planning, designing, and building HOV lanes. Beginning with the I-45 Contraflow Demonstration Project in Houston, HOV facilities in Texas have proven to be an effective mobility strategy by offering a high-speed option with travel time savings for bus riders, carpoolers, or vanpoolers. From that early I-45 contraflow project, it became clear that commuters would shift from single-occupant travel to bus or vanpooling when offered a time-saving alternative. Data from the demonstration showed that 35 to 40 percent of bus riders and vanpoolers on the contraflow lane previously drove alone *(29)*. As the HOV systems in Houston and Dallas developed, similar shifts in mode have been observed, and corridor average vehicle occupancy (AVO) measures have reached levels that are consistently higher than non-HOV corridors *(30)*.

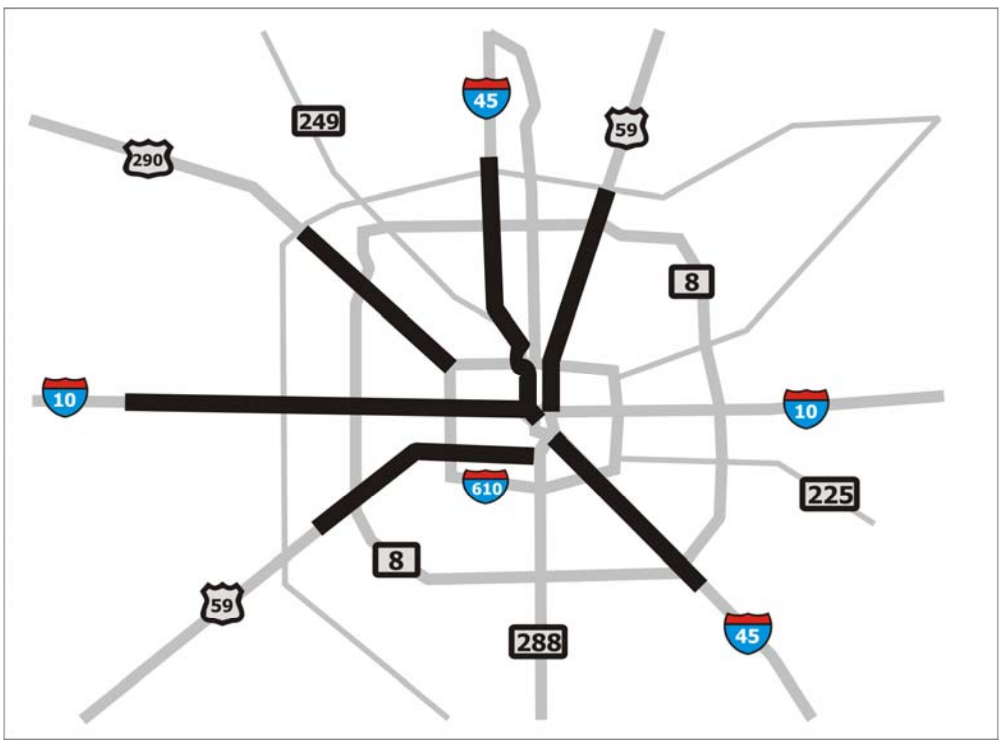
Texas has also had unique experience in addressing operational concerns by modifying vehicle eligibility requirements in HOV lanes and evaluating the impacts, particularly on the Katy HOV lane in Houston. When the Katy HOV lane was opened in 1984, only buses and vanpools were allowed. Gradually between 1984 and 1987, 4+ carpools, then 3+ carpools, and then 2+ carpools were allowed, and with each step the change was evaluated from an operational standpoint. As is the case with all Texas HOV facilities, the majority of users of the HOV lanes have been two-person carpools *(30)*.

By 1988, morning peak-hour vehicle volumes on the Katy Freeway were frequently approaching or exceeding free-flow capacity, thus degrading travel time savings and trip reliability. A policy decision was made in 1988 to increase vehicle occupancy to 3+ during the morning peak hours. By eliminating two-person carpools during the morning peak hours, carpool volumes dropped 65 percent and peak-hour person volumes declined by 33 percent *(29)*. The QuickRide program, initiated in January 1998 as Texas' first HOT lane operation, allows two-person carpools back into the HOV lane during the restricted time periods at a flat toll rate of $2 per trip. The program is an effort to recover the person-movement benefits of the lost two-person carpools, better utilize HOV lane capacity, and yet maintain high-speed operation to preserve the travel time savings for buses and other users. The program was expanded to the Northwest HOV lane in 2000.

Currently, there are over 155 HOV lane miles in Texas in Houston and Dallas. Many more have been planned in those cities as well as other Texas metropolitan areas. However, within the last several years TxDOT has recognized that the growing cost of highway construction coupled with the declining buying power of the gas tax requires a new way of looking at project implementation. There is interest in adapting existing HOV lanes to managed lanes with a tolling component, expanding existing HOV corridors into managed lane corridors, or developing new managed lanes in corridors where HOV facilities were once planned.

HOUSTON AREA HOV LANES

The Metropolitan Transit Authority of Harris County (METRO) manages the area's 112.9-mile HOV lane system *(31)*. Figure 3 shows the Houston area HOV lanes, and Table 1 summarizes the current status of the lanes.



Source: Metropolitan Transit Authority of Harris County *(31)*

Figure 3. Houston HOV System Map, 2006.

Table 1. Houston HOV System, 2006.

HOV Facility	Year First Phase Opened	Miles in Operation (Planned)	Vehicles Allowed to Use HOV Lane	Hours of Weekday Operation
Katy (I-10W)	1984	13.1 (15.3)	3+ vehicles from 6:45 a.m. to 8 a.m., 5 p.m. to 6 p.m.; 2+ vehicles during other operating hours	5 a.m. to 12 p.m. inbound, 1 p.m. to 8 p.m. outbound
North (I-45N)	1984	19.3 (19.9)	2+ vehicles	5 a.m. to 11 a.m. inbound, 2 p.m. to 8 p.m. outbound
Gulf (I-45S)	1988	15.0 (17.7)	2+ vehicles	5 a.m. to 11 a.m. inbound, 2 p.m. to 8 p.m. outbound
Northwest (US 290)	1988	15.5 (15.5)	3+ vehicles from 6:45 a.m. to 8 a.m.; 2+ vehicles during other operating hours	5 a.m. to 11 a.m. inbound, 2 p.m. to 8 p.m. outbound
Southwest (US 59S)	1993	13.5 (15.6)	2+ vehicles	5 a.m. to 11 a.m. inbound, 2 p.m. to 8 p.m. outbound
Eastex (US 59N)	1998	14.8 (21.8)	2+ vehicles	5 a.m. to 11 a.m. inbound, 2 p.m. to 8 p.m. outbound

Source: Metropolitan Transit Authority of Harris County *(31)*

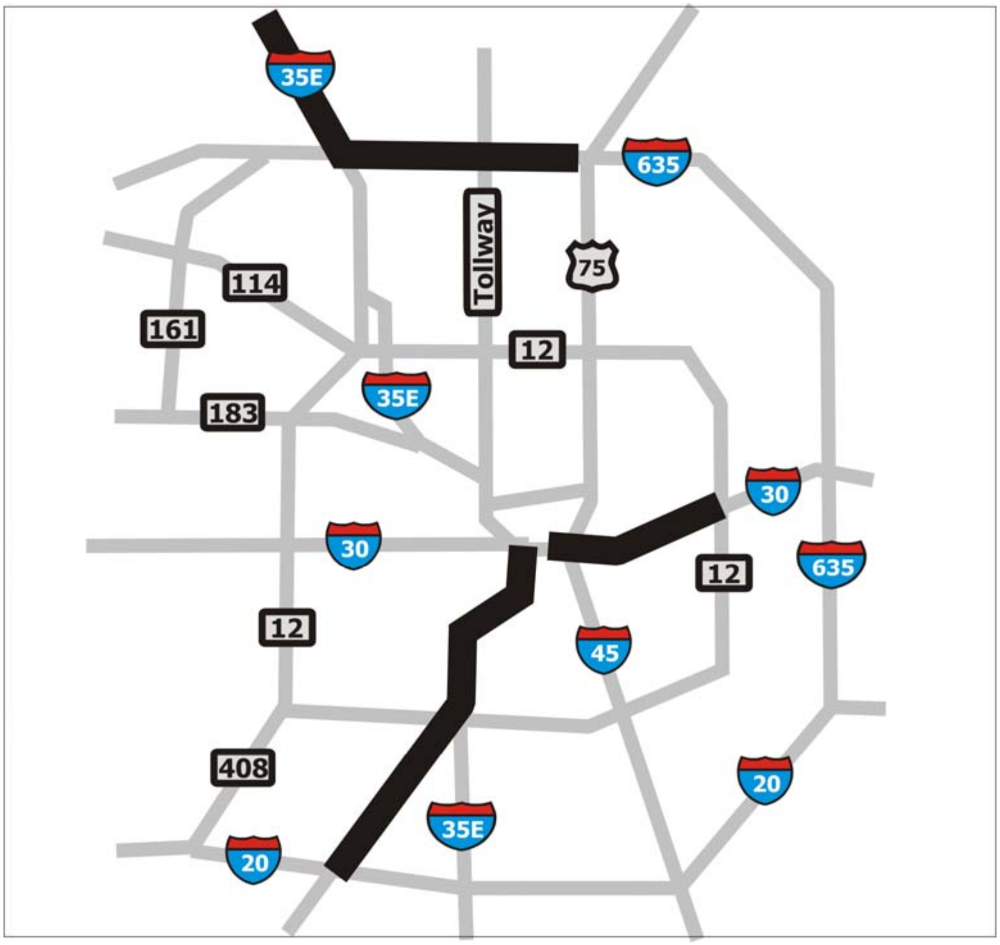
The system facilitates approximately 118,000 person trips each weekday, which corresponds to about 36,400 vehicle trips. The average operating speed is approximately 50 to 55 miles per hour (mph), which saves the average commuter 12 to 22 minutes per trip. The Houston area HOV lanes move morning rush-hour traffic toward downtown, Monday through Friday. The lanes reverse and move rush-hour traffic away from downtown during the evening rush hours *(4, 31)*.

The Houston area HOV lanes have been the focus of many studies and overall have been found to successfully meet project goals. The I-10 (Katy Freeway) and US 290 (Northwest Freeway) lanes have already been designated an HOV-3+ occupancy facility during peak periods and has allowed HOV-2 users to access the facility under the QuickRide program, a variation of HOT lane concepts.

DALLAS AREA HOV LANES

Dallas Area Rapid Transit (DART) manages the area's HOV lane system. Currently, the system consists of 29 lane miles on four facilities *(32)*.

Figure 4 shows the Dallas area HOV lanes, and Table 2 summarizes the current status of the lanes. The system currently facilitates approximately 100,000 person trips each weekday *(3,32)*.



Source: Dallas Area Rapid Transit *(32)*

Figure 4. Dallas HOV System Map, 2006.

Table 2. Dallas HOV System, 2006.

HOV Facility	Year First Phase Opened	Miles in Operation	Vehicles Allowed to Use HOV Lane	Hours of Weekday Operation
I-35E	1996	7.3	2+ vehicles	24 hours
I-635	1997	6.8	2+ vehicles	24 hours
I-30E	1991	5.2	2+ vehicles	6 a.m. to 9 a.m. inbound, 3:30 p.m. to 7 p.m. outbound
I-35E/US 67	1995	15.0	2+ vehicles	US 67 south of Loop 12 is 24 hours; the rest is 6 a.m. to 9 a.m. inbound, 3:30 p.m. to 7 p.m. outbound

Source: Dallas Area Rapid Transit *(32)*

The HOV lanes in the Dallas area have been evaluated and found to perform well. TxDOT Project 7-4961 looked at the HOV lanes in Dallas during the years of 1997 to 1999 with a goal of investigating the operational effectiveness of the lanes. Researchers found that all HOV lane projects in the Dallas area were cost-effective and had attained, or were projected to attain, a benefit/cost ratio of greater than 1.0 within the first six years of operation. Additionally, each HOV lane generated a substantial number of carpools, increased the person movement in the corridor, and increased the occupancy rate in the corridor—without negatively influencing the operation of the adjacent freeway main lanes *(33)*.

EFFECTIVENESS OF HOV INCENTIVES

Benefits

Benefits from carpooling, which HOV lanes endeavor to encourage, can be articulated for both users and society.

User benefits include personal cost savings and perceived quality of life enhancements. Many commuters underestimate the true cost of driving alone to and from work. The potential savings of carpooling or vanpooling are shown in Table 3. The table indicates an estimated monthly cost savings of $129 for a 30-mile round trip commute if a drive-alone person rideshares with two other people. If a person has a round trip commute of 80 miles, the estimated savings increases dramatically to $343 a month in a three-person carpool. The monthly savings more than doubles if a commuter switches modes from a three-person carpool to a 10-rider vanpool. As shown in Table 3, the cost of commuting may be significantly reduced when carpoolers or vanpoolers share the costs. This is especially true in situations with added costs, such as parking fees *(34, 35)*. Commutes are increasingly becoming too congested and stressful, which can be carried over into professional and social situations. Carpooling enables the riders to relax and allows them to arrive at their destination stress free *(34, 36)*.

Table 3. Estimated Monthly Commuting Costs.

Round Trip Miles	Drive Alone	3-Rider Carpool	10-Rider Vanpool
30	$193	$64	$31
40	$257	$86	$37
50	$321	$107	$43
60	$386	$129	$50
70	$450	$150	$56
80	$514	$171	$63

Source: Todd Littman *(35)*

Societal benefits are most typically associated with reduction in vehicular use (and corresponding reduction in vehicle miles traveled) and a resulting improvement in air quality. In areas of serious air quality concerns, carpooling and HOV lanes together constitute important elements in achieving conformity with air quality targets *(37)*. Coupled with the perception of HOV lanes and carpooling as enabling broader environmental objectives (including favorable land use and fuel consumption goals), a significant stakeholder community has been formed around their continued use and promotion *(3)*.

Effectiveness of Incentives

Although air quality benefits are the primary reason for regional and statewide financial investment in rideshare incentive programs (most notably, through the Congestion Mitigation and Air Quality [CMAQ] program), the benefits estimation for conformity purposes lacks consistent application throughout the United States. Communities may directly model the benefits of trip reduction and vehicle miles traveled (VMT) reduction for ridesharing and HOV lanes, produce estimates off-model, or directly measure the results of implemented programs *(37)*. Altogether, the variety of estimation methodologies yields a noticeable lack of measurement of the direct benefits of ridesharing upon air quality. Various research efforts have attempted to evaluate the pollutant and travel reduction effectiveness of HOV incentives (including HOV lanes), but this research has yet to provide solid evidence of the longitudinal impacts of these incentives either on a regional or site-wide scale—a factor that may be important in the consideration of HOV benefits for managed lanes.

As evaluated within the literature, the effectiveness of rideshare incentives varies greatly upon the following factors:

1. the type and degree of incentive,
2. the affected area, and
3. the extent of concurrent supporting strategies.

The first factor pertains to what strategy is deployed and how many resources are applied to that strategy. For the second factor, the effectiveness of a strategy will differ depending upon the comparative scale—an extremely successful employer-based vehicular-reduction program may not even be measurable within a half-mile radius of the employer. As evaluated in the literature, almost all programs have less than a 1 percent effect upon regional trip making *(38, 39)*. Third, the effects of HOV incentive programs are not mutually exclusive of one another. Often, a combination of strategies is present when modal use is measured, complicating the isolation of strategies for effectiveness.

Two cross-cutting efforts serve as the principal body of knowledge regarding HOV incentive effectiveness—one in 1994 and the other in 2002 *(37, 40)*.

The former study involved a bounty of data primarily accumulated by the State of California during a period of mandated trip reduction efforts. The results of this data analysis were used to create a post-process model for the Federal Highway Administration (FHWA), known as the Transportation Demand Management (TDM) model. To this day, the TDM model remains the only official model capable of evaluating the regional impacts of various rideshare promotion and incentive activities, including HOV lanes. However, since the early 1990s, all states with the exception of Washington have eliminated the use of mandated commute trip reduction programs. As a result, the effectiveness of ridesharing programs has diminished with solely voluntary adoption.

Evaluating worksite-based and regional travel data, the 1994 study concluded rideshare incentives could potentially eliminate up to 2 percent of regional VMT and 1 percent of regional trips (if applied regionally) or up to 3 percent of VMT and 4 percent of trips when promoted at employment sites, as shown in Table 4. HOV lanes alone can provide up to 1 percent of regional VMT reduction and 0.5 percent of regional trip reduction *(40)*. At first glance, it appears that rideshare incentives are more effective than HOV lanes; however, it should be noted that:

1. HOV lanes' regional impact is affected primarily within particular corridors (unlike rideshare programs, which have a regional scope); and
2. additional studies have identified a synergistic relationship between rideshare programs and HOV lanes, in so much that the likelihood of carpooling as a result of an HOV incentive program increases with the availability of HOV lanes *(35, 39, 41)*.

Table 4. Travel Impact Estimates: Range of Daily Regional Reductions (Percent).

Transportation Control Method (TCM)	VMT (Percent)	Trips (Percent)
Employer trip reduction	0.2 - 3.3	0.1 - 4.1
Area-wide rideshare	0.1 - 2.0	0.5 - 1.1
Transit improvements	0.0 - 2.6	0.6 - 2.5
HOV lanes	0.2 - 1.4	0.5 - 0.6
Park-and-ride lots	0.1 - 0.5	0.0
Parking pricing		
Work	0.5 - 4.0	0.4 - 4.0
Non-work	3.1 - 4.2	3.9 - 5.4
Congestion pricing	0.2 - 5.7	0.4 - 4.2
Compressed work week	0.0 - 0.6	0.0 - 2.8
Telecommuting	0.0 - 3.4	0.0 - 0.5

Source: Apogee Research, Inc. *(40)*

The latter study pertained to a review of data submitted by regional and statewide entities currently participating in the CMAQ improvement program. For most very large and large metropolitan areas, and some medium-sized areas, CMAQ provides a significant amount of funding for rideshare programs. Additionally, to the extent that local and regional transportation service providers use their funding to leverage CMAQ funding, local and regional funds are also reported under CMAQ performance reviews. According to the Committee for the CMAQ Improvement Program, "Few retrospective analyses of projects are conducted to determine whether estimated changes in travel behavior and emission benefits have actually occurred. Local agency staff members cite the small size and large numbers of projects as a deterrent to conducting such evaluations cost-effectively. Nor is it easy to conduct such evaluations in a methodologically sound way" *(37)*. This has made the evaluation of the effectiveness of HOV incentive programs problematic.

Examining evaluation studies of CMAQ programs where the methodology of evaluation was considered sufficiently robust, the 2002 Transportation Research Board (TRB) study yielded the following illustrative summary of cost-effectiveness from CMAQ projects *(37)*. As seen in Table 5, rideshare and TDM programs (which provide the bulk of incentives for HOV use) tend to be among the more cost-effective of CMAQ projects, yet the extent of effectiveness is cautiously positioned as indicated.

In a parallel assessment of CMAQ projects using data provided in the 2002 TRB report, an Arizona Department of Transportation report identifies the comparative relationship between HOV facilities and other strategies for the cost of air quality improvement. In this analysis, carpool and vanpool promotion programs, including cost subsidies and other incentives, are shown in Table 6 to be far more cost-effective in reducing pounds of volatile organic compounds (pollutants) than HOV facilities. However, as noted in the report, the effectiveness of those rideshare and TDM programs is enhanced with the availability of HOV facilities *(41)*.

For HOV lanes in particular, a comprehensive evaluation of HOV lanes in Texas found three factors that impact the level of utilization of an HOV lane by carpools:

1. the length of time the priority lane has been operating,
2. the vehicle group allowed to use the HOV lane (either HOV-2+ or HOV-3+), and
3. the travel time savings and trip time reliability provided by the HOV lane (*41*).

As would be expected, the third factor is perhaps the most important single factor influencing HOV-lane use. Unless the HOV lane offers (on a recurring basis) a peak-hour travel time savings of at least five minutes, relative to the general purpose lanes, utilization of the HOV facility will be marginal, thereby exacerbating the net vehicles reduced, the pounds of pollutants reduced, and by extension the cost per pound reduced. It is of interest to note that previous research has shown that the time savings perceived by the users (as determined in surveys of HOV lane users) is much greater than the actual time savings *(42)*.

Table 5. Summary of Cost-Effectiveness of CMAQ-Eligible Projects.

CMAQ Project Sponsored Category	No. of Projects	Cost-per-Ton Range (2000$)		1992-1999 CMAQ Outlay (Percent)
		Low	High	
Traffic flow improvements				33.1
Traffic signalization	5	6,000	128,000	8.5
Freeway/incident management	4	2,300	544,000	8.1
HOV facilities	2	15,700	337,000	4.6
Intersections, traveler info., other	0	NA	NA	11.9
Ridesharing				3.8
Regional rideshare	5	1,200	16,000	2.4
Vanpool programs	6	5,200	89,000	
Park-and-ride lots	4	8,600	70,700	1.4
Travel demand management				2.9
Regional TDM	8	2,300	33,200	2.1
Employer trip reduction programs	7	5,800	176,000	0.8
Telework	10	13,300	8,230,000	0
Bicycle/pedestrian	14	4,200	345,000	3.2
Transit improvements				28.3
Shuttles, feeders, and paratransit	15	12,300	1,970,000	7.4
New capital systems/vehicles	6	8,500	471,000	12
Conventional service upgrades	10	3,800	120,000	7.4
Park-and-ride lots	15	6,000	56,000	1.5
Fuels and technology				20.6
Conventional-fuel bus replacements	5	11,000	39,900	12.7
Alternative-fuel buses	11	6,700	569,000	3.1
Alternative-fuel vehicles	2	4,000	31,600	0.6
Inspection and maintenance	5	1,800	5,800	4.2
Other/Surface Transportation Program (STP)				8.2
Total				100

Source: Committee for the Congestion Mitigation and Air Quality Improvement Program *(37)*

Table 6. Cost-Effectiveness of CMAQ Programs.

CMAQ Strategy	Cost per Pound of Emissions Reduced
Inspection and maintenance	$0.95/lb.
Regional rideshare programs	$3.70/lb.
Charges and fees (parking pricing, tolls)	$5.15/lb.
Vanpool programs	$5.25/lb.
Miscellaneous TDM	$6.25/lb.
Conventional-fuel bus replacement	$8.05/lb.
Alternative-fuel vehicles	$8.09/lb.
Traffic signalization	$10.05/lb.
Employer trip reduction	$11.35/lb.
Conventional transit service upgrades	$12.30/lb.
Park-and-ride lots (rideshare and transit)	$21.50/lb.
Modal subsidies and vouchers	$23.30/lb.
New transit capital systems/vehicles	$33.20/lb.
Bicycle and pedestrian programs	$42.05/lb.
Shuttles, feeders, and paratransit	$43.75/lb.
Freeway/incident management	$51.20/lb.
Alternative-fuel buses	$63.20/lb.
HOV facilities	$88.10/lb.
Telework	$125.90/lb.

Source: E. Schreffler *(41)*

Survey data have previously shown that the HOV lanes are attracting younger, educated white-collar professionals to transit and ridesharing. They are using the HOV lane for a long-distance commute trip. Over 60 percent of the carpools are made up of family members, an issue that will be discussed in the "Challenges" section, below. Surveys of carpoolers and vanpoolers showed that their occupational characteristics and motivation to use the HOV lanes are fueled by travel time savings and congestion avoidance. Control surveys of non-HOV lane users showed that their trip characteristics were more dispersed than carpoolers, providing some indication of their limited ability to take advantage of HOV lanes *(42)*.

Challenges

Since the 1980s, when earnest planning for HOV lanes was taking place throughout the country, carpooling itself has declined significantly, both in absolute numbers of commuters as well as percentage of overall population *(2)*. As shown in Table 7, declines have occurred consistently as measured by the Bureau of Transportation Statistics.

Table 7. National Principal Means of Transportation to Work (Thousands [Percent]).

	1985	1989	1993	1997	1999	2001	2003
Drive alone	72,137 (72.4)	81,322 (76.3)	79,449 (76.6)	90,207 (77.5)	92,363 (78.2)	93,942 (78.2)	91,607 (79.4)
HOV-2	10,381 (10.4)	9,708 (9.1)	9,105 (8.8)	9,294 (8.0)	8,705 (7.4)	9,036 (7.5)	7,866 (6.8)
HOV-3	2,024 (2.0)	1,748 (1.6)	1,684 (1.6)	1,526 (1.3)	1,454 (1.2)	1,635 (1.4)	1,351 (1.2)
HOV-4+	1,606 (1.6)	1,165 (1.1)	1,063 (1.0)	881 (0.8)	945 (0.8)	973 (0.8)	840 (0.7)

Source: Bureau of Transportation Statistics *(2)*

Critics of HOV lanes claim carpooling as a choice of mode of travel for work peaked at the time when HOV lane planning hit its stride, thereby exacerbating the rationale for continuing to offer HOV lane incentives to carpools. Potential reasons for the decline in carpooling may include an increase in disposable income, increase in car ownership, dispersed employment locations, trip chaining, and availability of in-car entertainment *(6)*.

This criticism is valid from the perspective of home-based work (HBW) trips, which are the type of data provided by the Census. In a comprehensive side-by-side analysis of journey to work (Census) and National Household Travel Survey (NTHS) data, however, one author identifies distinctions between HBW trips and what was called "work tour" trips, a term that attempts to aggregate trip chaining into one consolidated work trip (as the primary purpose). Using NHTS data, the authors found a robust measurement of "passenger drop off" trips in the trip chaining, as evident in the increase in carpool trips shown in the work tours as compared to the home-based work trips, shown in Table 8 *(43)*. Hence, when accounting for trip chaining in the work trip, there is a greater percentage of the population that uses carpool modes for the work trip (meaning that these are not home-based work trips because the trip involves a pickup or drop-off at some point between home and work). What this research does not indicate, however, is what proportion of the work trip involves a carpool.

Table 8. Mode of Travel to Work, 1990 and 2001 (Percent).

	1990 HBW	2001 HBW	2001 Work Tours
Drove alone	74.9	79.7	72.6
Carpool	16.3	12.3	20.1

Source: Nancy McGuckin and Nandu Srinivasan *(43)*

Further investigation into current carpooling trends indicates that the majority of carpools are family oriented, a type of carpooling termed "fampools" *(6)*. Only 26 percent of all 2001 work tour carpools involved a non-household member, as shown in Table 9 *(43)*.

Table 9. Carpools by Participant Type (Percent).

	Carpool	Fampool
1990 HBW	24.5	75.5
2001 HBW	17.0	83.0
2001 work tours	26.3	73.7

Source: Nancy McGuckin and Nandu Srinivasan *(43)*

Critics have argued that the extensive amount of household-member-only carpooling for work trips belies the premise behind investments in HOV lanes—that it will encourage the formation of carpools between two drivers, explicitly to take advantage of the travel time savings in the HOV lanes *(6)*:

> That fampooling does not take cars off the street is particularly evident when HOV lanes are used by drivers whose passenger is someone who, for a variety of reasons, would not be driving anyhow. For example, it is certainly convenient for a parent driving with a son or daughter to use the carpool lane, but as long as the son or daughter is under the legal driving age, this sort of carpool does not spare the road from an extra car.

Regions with significant HOV facility investments have not been immune to declines in carpool rates. In Southern California, representing the greater Los Angeles metropolitan region, carpooling *as a share of work trips* has declined from 14.3 percent to 11.4 percent since 2000, despite the availability of over 350 route miles of HOV lanes *(44, 45)*. Similarly, the San Francisco Bay Area, with over 150 route miles of HOV lanes, declined from a peak of 19 percent of commuters by carpool in 1995 to 14 percent in 2005 *(45, 46, 47)*. It should also be noted that in the San Francisco Bay Area, the trend for fampooling is belied by strong colleague-based carpooling, as shown in Table 10.

Table 10. Composition of Carpools, San Francisco Bay Area (Percent).

Relationship	2003	2004	2005
Co-workers	42	39	45
Household members	33	40	34
Friends/neighbors	6	11	11
Casual carpool	8	4	5
Non-household relative	7	5	4
Other	4	2	0

Source: RIDES Associates *(47)*

APPLYING CARPOOL INCENTIVES TO MANAGED LANES

The term *managed lanes* evokes different meanings and connotations depending on the public agency or individual project. FHWA defines managed lanes as "highway facilities or a set of lanes in which operational strategies are implemented and managed (in real time) in response to changing conditions. Managed lanes are distinguished from other traditional forms of lane management strategies in that they are proactively implemented, managed, and may involve using more than one operational strategy" *(48)*. Prior to the establishment of the FHWA definition, TxDOT developed its own definition for managed lanes as part of its managed lanes research program, and it serves as the official definition of the concept for TxDOT *(49)*:

> A managed lane facility is one that increases freeway efficiency by packaging various operational and design actions. Lane management operations may be adjusted at any time to better match regional goals.

HOV lanes are only one of many managed lane approaches that currently exist, or are proposed to exist, on preferential roadway facilities. Under the philosophy espoused by both FHWA and TxDOT, the operating agency proactively manages demand and available capacity on the facility by management strategies such as variable pricing, vehicle eligibility restrictions, or access control *(50)*. Variable and dynamic pricing have been demonstrated in practice as the principal strategy to manage demand on a consistent basis in HOV facilities.

Impacts of Choosing between HOV and ML

As noted previously, the underlying premise of free or discounted passage for HOVs is the belief that such incentives have a causal relationship with carpool formation. As a result, the investment in such incentives would be offset by community benefits in improved person movement in the corridor(s) and air quality. However, as with any investment, the opportunity cost for this investment must be evaluated against the loss of revenue and its inherent limitations on transportation improvement. In order to properly evaluate this opportunity cost, the foundation of the causal relationship must be properly defined and verified.

Travelers generally choose their route, mode of travel, and time of travel in an effort to maximize the utility (or, more accurately, minimize the disutility) associated with their trips *(51, 52, 53, 54, 55)*. Many factors influence the utility of each option for each traveler. These factors include characteristics of the trip being made; characteristics of alternatives to the mode, route, and time of the current trip; and characteristics of the traveler. Although there are dozens of potential factors in each of these three categories that could influence travel decisions, many studies *(56, 57, 58, 59, 60)* have found the following factors to have the most influence over mode and route choice:

- direct monetary cost of the trip (tolls, fares, and parking);
- travel time; and
- travel time reliability.

In this research, the focus is on the impact of charging HOV travelers for use of a managed lane instead of allowing them to travel for free on an HOV lane. The factors above, combined with available alternative modal and route choices, will dictate the number of commuters who would pay a toll to use the managed lanes versus those that would not. For those who choose not to use the managed lane, estimating the percentage of former commuters choosing each alternative option is necessary. These alternatives are likely to include:

- use an HOV on the general purpose lanes,
- use an HOV on alternative routes,

- use a single-occupancy vehicle (SOV) on the general purpose lanes,
- use an SOV on managed lanes,
- use an SOV on alternative routes,
- use transit,
- abandon the trip, and
- alter the time of travel.

In specific cases, when the managed lane has variable toll rates or a variable toll based on occupancy levels, other alternatives exist including:

- continue to use the HOV lane but at a less expensive time and
- increase the number of vehicle occupants to a less expensive occupancy level.

Travelers select from this long list of alternatives based on which alternative offers the least disutility (overall cost) to that traveler. How this group of travelers chooses between alternatives will then impact the performance of the general purpose lanes, HOV lanes, and alternative routes and modes. For example, if many of the HOV travelers switch to SOV travel on the general purpose lanes, then the level of service will deteriorate on the general purpose lanes. Assuming the HOV lane already operated at free-flow conditions, there would be no impact on travel speeds on the HOV/managed lane. In the case of a congested HOV lane, this scenario could have a positive impact on travel speeds in the lane.

Value of Travel Time

Statistical analysis of State Route 91 Express Lanes users (discussed below) indicated that commuters in high-income groups were found to be twice as likely as commuters in low-income groups to frequently use the facility (23 percent to 10 percent). Although there was clear correlation between the frequency of use and income, 50 percent of the highest-income travelers (>$100,000 annual income) reported they never or infrequently used toll roads while 25 percent of lower-income groups (<$25,000 annual household income) reported that they use toll roads on a frequent basis (50 percent or more of the time) *(61)*.

These findings indicate that users' value of time spent in traffic is not related to income. It also shows that people value travel time differently day to day, depending on daily commitments such as daycare, second jobs, or other appointments. The creation of a suitable pricing scheme requires an understanding of the value that travelers place on travel time savings. The value of travel time savings is measured by estimating drivers' value of time. Value of time describes how much monetary value drivers place on their travel time. This value is typically estimated in dollars per hour. It can be measured by a revealed or stated preference survey, or by observing travelers' route choices *(59)*. For instance, if a driver pays a $1 toll to use a toll facility rather than an adjacent route and saves 10 minutes on his trip, then that traveler had a travel time value of at least $6 per hour. By analyzing values of time, toll authorities can increase or reduce the toll amount to manage demand for the toll road. Research estimates the value of time in the range of 20 to 50 percent of the driver's wage rate *(58, 62)*. However, drivers also place a value on travel time reliability. Research indicates that confidence in trip length and arrival time is valued highly by travelers *(56, 60)*.

Applications of Managed Lanes and HOV Incentives

As of the writing of this report, only five managed lane facilities have been implemented. Four of the facilities have had extensive evaluation research conducted at some point in the facilities' lifetime, reported below. These are SR-91 in Orange County (California), I-15 in San Diego (California), and I-10 and US 290 in Houston (Texas). The fifth facility, I-394 in Minnesota, has been open for less than a year and does not yet have substantive evaluation ready for review.

Orange County, California (SR-91 Express Lanes)

The oldest operational managed lane facility, the SR-91 Express Lanes project has had significant operational changes directly affecting the use of HOV benefits in a tolled facility. Constructed and opened in late 1995 as a four-lane, concurrent-flow, channelizer-separated managed lane facility in eastern Orange County, the SR-91 project involved a unique partnership between the California Private Transportation Corporation (CPTC) (an investment consortium developed exclusively for the facility), the California Department of Transportation (CalTrans), the Orange County Transportation Authority (OCTA), and the Southern California Association of Governments (SCAG). Since opening, SR-91 has provided a free-flow alternative in one of the most heavily congested corridors in California while satisfying the repayment of construction bonds and operational funding obligations.

Originally conceived as an HOV lane facility by a Memorandum of Understanding (MOU) between OCTA and the Riverside County Transportation Commission (RCTC), a sales tax referendum to finance Orange County's portion of the HOV lanes failed at the ballot. This financing dilemma created the nexus by which Orange County pursued replacing the planned HOV facility with the SR-91 Express Lanes concept. Through negotiation, a Memorandum of Agreement (MOA) was signed in January 1992 among OCTA, CPTC, and RCTC. An independent analysis of the MOA and its effects on the construction of the SR-91 project found *(63)*:

> Over the life of the concession agreement, only carpools with three or more occupants would ride for free on the private SR-91 median lanes… If CPTC was unable to maintain a debt service coverage ratio of 1:2, HOV-3s would pay a discounted toll. Under the concession agreement… CPTC agreed to spend half of its possible 6 percent incentive return on transportation projects selected by OCTA and RCTC, such as park-and-ride lots, bus systems, and potential commuter rails.

Essentially, this agreement allowed CPTC to enjoy a possible 23 percent rate of return (instead of its 17 percent profit limitation) on the project if it achieved the average vehicle occupancy objectives through HOV incentives *(64)*.

After the formative years of SR-91's operations, public opposition to private operation of the facility grew in the late 1990s, primarily due to the facility's non-compete clause for adjacent facility traffic improvement. In early 2003, OCTA purchased the facility from CPTC, eliminating the non-compete clause and establishing a formal policy of demand management as the principal concern for the SR-91 Express Lanes *(65, 66)*:

> The goals of the toll policy are as follows: (a) provide a safe, reliable, predictable commute for customer; (b) optimize vehicle throughput at free flow speeds; (c) pay debt service and maintain debt service coverage; (d) increase average vehicle occupancy; (e) balance capacity and demand to serve customers who pay tolls as well as carpoolers with three or more persons who are offered discounted tolls; (f) generate sufficient revenue to sustain the financial viability of the 91 Express Lanes; (g) ensure all bond covenants are met; and (h) repay OCTA's internal borrowing and provide net revenues for the Riverside Freeway and the 91 Express Lanes improvements.

This policy change brought about a renewed focus on providing incentives and promotions to HOV users of the SR-91 Express Lanes. Throughout the history of the SR-91 project, a variety of policies had been used relative to HOV users. The following identifies the general history *(67, 68, 69, 70):*

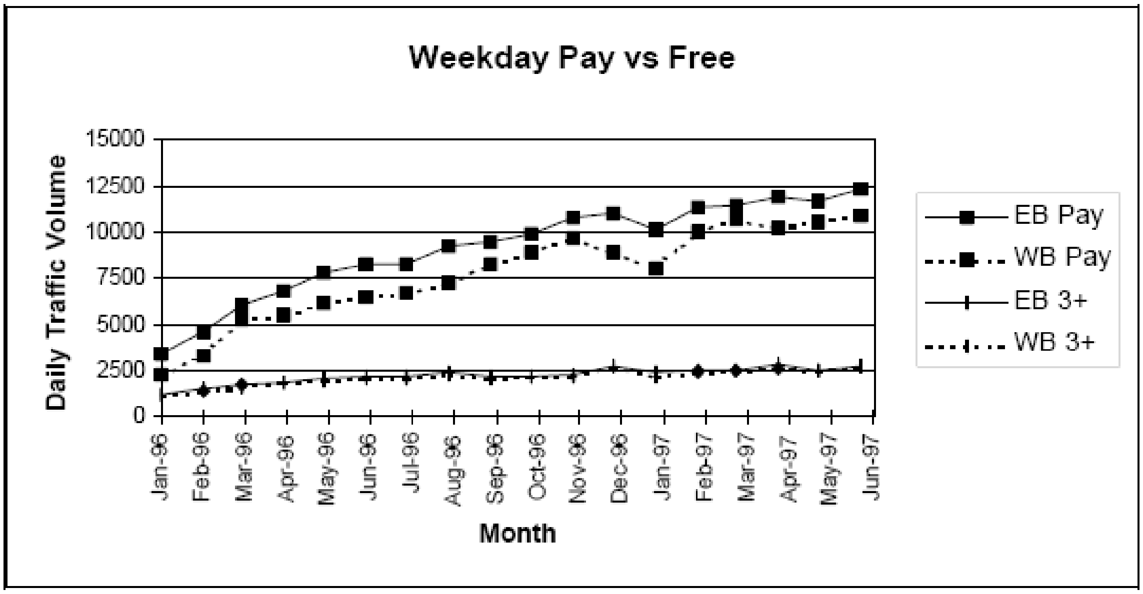
- December 1995 to December 1997: HOV-3+ has free use of the facility (CPTC ownership);
- January 1998 to April 2003: HOV-3+ has half-toll use of the facility (CPTC ownership); and
- May 2003 to present day: HOV-3+ has half-toll use in the PM peak direction (4 p.m. to 6 p.m.), and HOV-3+ has free use all other times (OCTA ownership).

Comprehensive evaluations of the facility's operations and demographic market were conducted by the California Polytechnic State University between 1995 and 2000. Particular attention was paid to the effect of the express lanes upon the use of carpooling in the corridor since the SR-91 project was built in lieu of planned HOV lanes and Riverside County had constructed HOV lanes at the terminus of the facility itself.

HOV-Related Findings for the Free Use Period (December 1995 to December 1997). Initial findings during the period of free use by HOV-3+ users included *(61):*

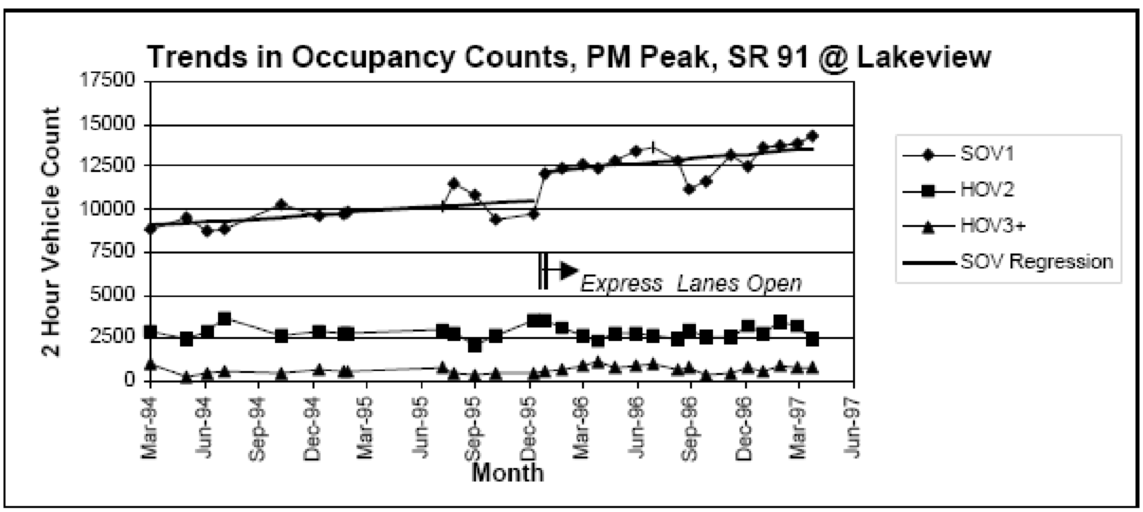
- 46 percent growth in HOV-3+ vehicles on the corridor, as compared to the year prior to the opening of the facility;
- significant growth in SOV and HOV-2 (toll-paying) vehicles, derived from three sources:
    - traffic returning from parallel city streets,
    - new induced travel for non-work purposes which had previously avoided the corridor, and
    - continuation of overall SOV growth trends;
- induced traffic including a high percentage of HOV-3+ users (12.7 percent); and
- overall effect of SOV growth greater than HOV-3+ growth, yielding an overall decrease in average vehicle occupancy (1.2 AVO in 1994 to 1.1 in 1997, not including vans or buses).

Figure 5 and Figure 6 show the growth of HOV-3+ traffic on the SR-91 Express Lanes relative to SOV and HOV-2 users during the first two years of operation and the growth by vehicle occupancy for the entire corridor (both Express Lanes and general purpose lanes), respectively *(61)*.



Source: Edward Sullivan *(61)*

Figure 5. Comparison of Express Lanes Traffic Growth in Toll and HOV-3+ Lanes.

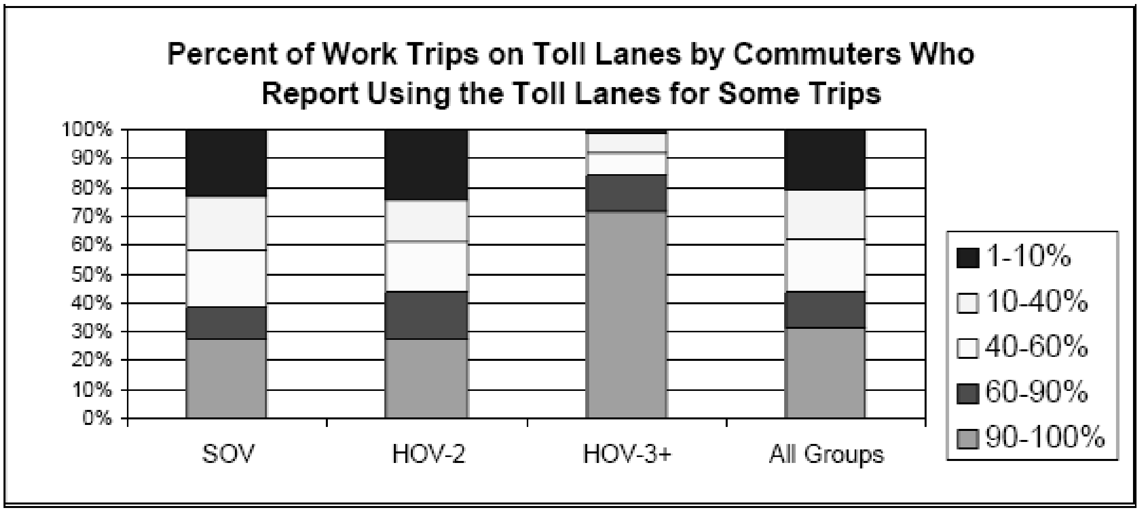


Source: Edward Sullivan *(61)*

Figure 6. PM Peak Traffic Growth on SR-91 (All Lanes Eastbound) by Vehicle Occupancy.

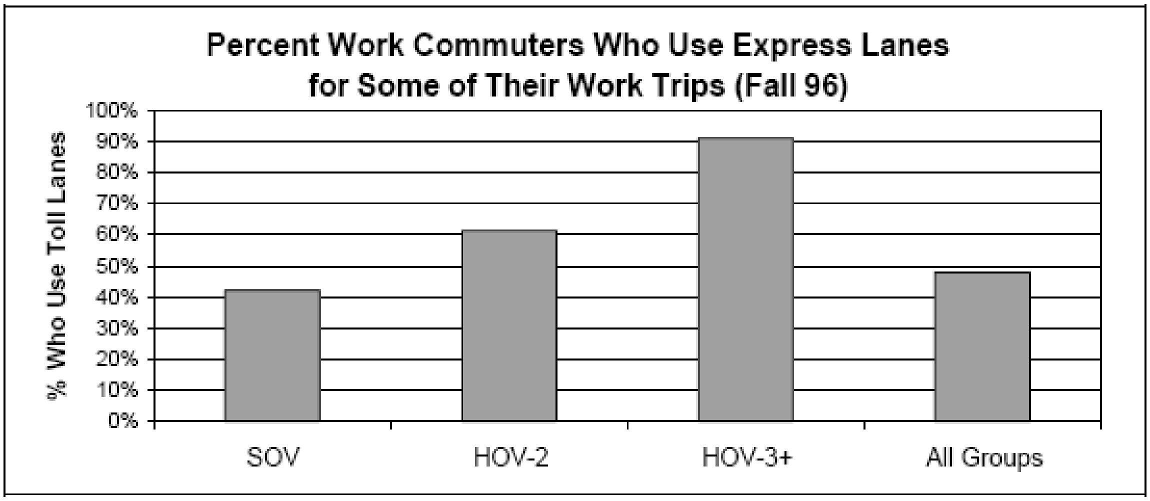
The initial findings further conclude that the opening of the SR-91 Express Lanes did little to encourage or discourage the use of HOV-2 carpools (who are charged the full toll rate). As noted by Edward Sullivan, the principal researcher for the study, "On average, about 30 percent of the HOV-2 vehicles using the SR-91 corridor choose to travel in the toll lanes, which is significantly less than the proportion of HOV-2s who use conventional HOV lanes when they are available, typically about 60 percent. The 30 percent estimate for peak period HOV-2s choosing to use the express lanes is approximately equal to the percentage of all traffic (predominantly SOVs) choosing to use the express lanes during the peak 2-hour travel period." By comparison, approximately 50 percent of HOV-3+ traffic uses the facility, more comparable to typical HOV facility findings *(61)*. This seems to imply that toll-charge sharing between HOV-2 partners does not occur; however, the effects of this upon fampools may be less pronounced.

Analyzing HOV market behavior, as reported by users of the corridor, the study found that HOV-3+ users were more likely to be frequent SR-91 Express Lanes users than SOV and HOV-2 users (75 percent, 16 percent, and 26 percent, respectively). This finding is depicted in Figures 7 and 8, with attention to work trips.



Source: Edward Sullivan *(61)*

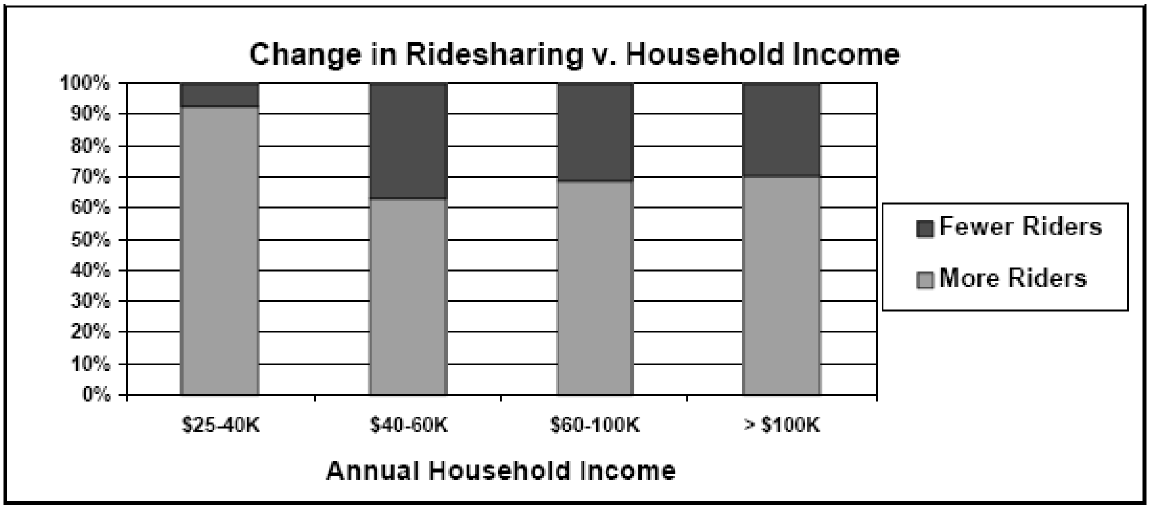
Figure 7. Comparison of Toll Lane Use Frequency by Vehicle Occupancy.



Source: Edward Sullivan *(61)*

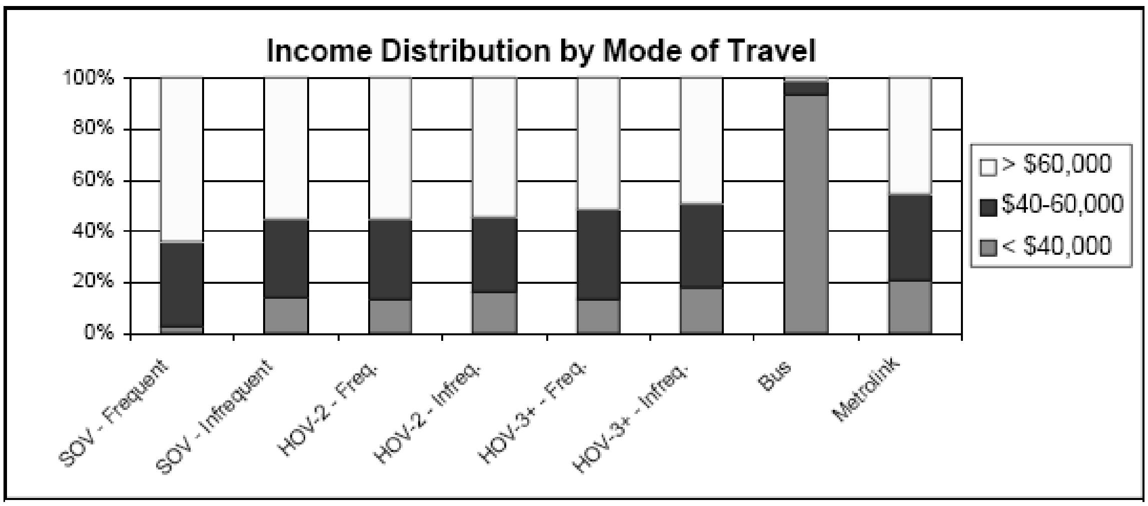
Figure 8. Percent of Express Lane Users for Work Trips by Vehicle Occupancy.

Addressing the issue of lower-income household benefit from HOV discounts, the study found that lower-income commuters were more likely to use the SR-91 Express Lanes as a carpooler (although this correlation was significant only at the 85 percent confidence level), seen in Figure 9 and Figure 10.



Source: Edward Sullivan *(61)*

Figure 9. Changes in Occupancy Relative to Household Income.

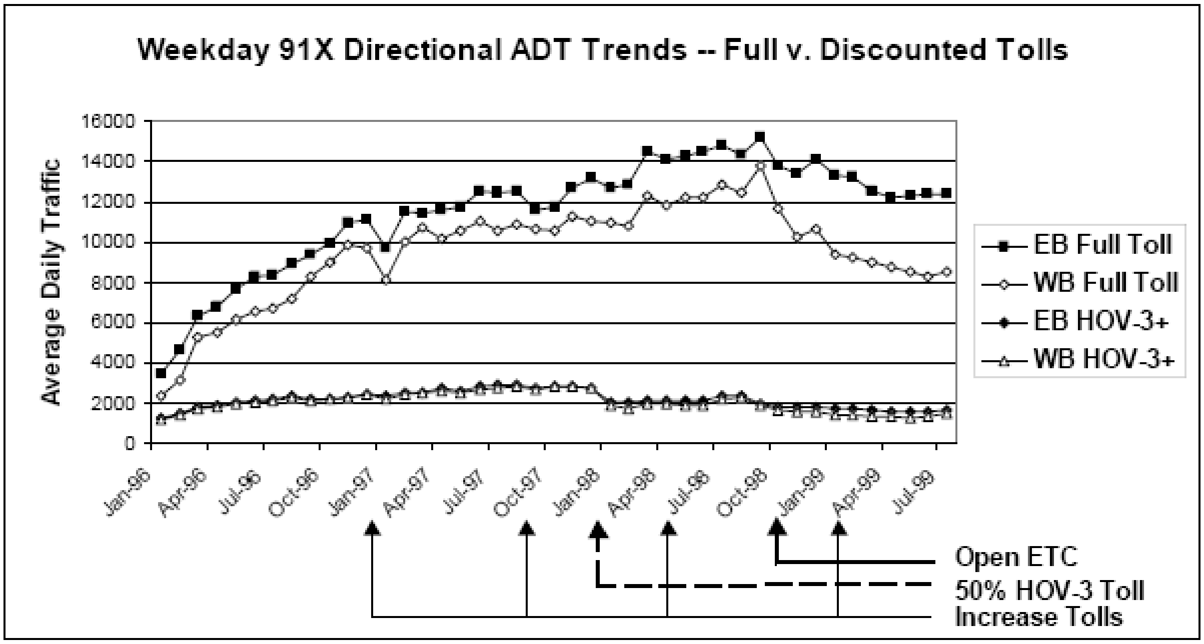


Source: Edward Sullivan *(61)*

Figure 10. Peak-Period Income by SR-91 Express Lane Vehicle Occupancy.

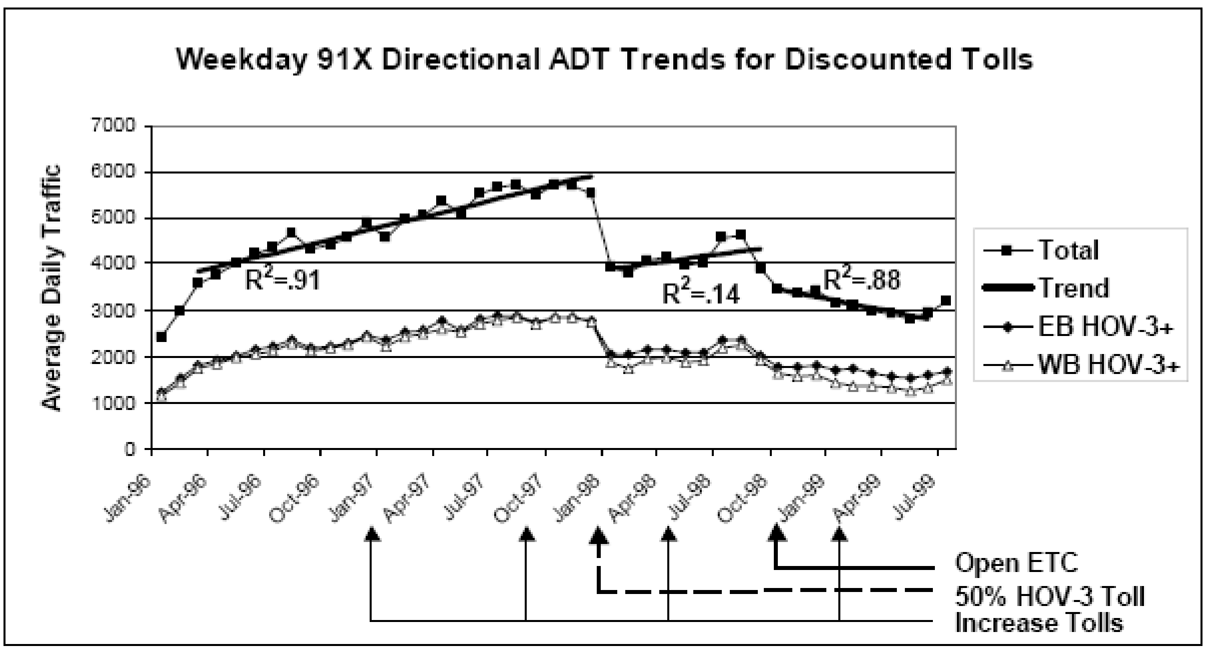
HOV-Related Findings for the Discount Use Period (January 1998 to April 2003). Although findings from the latter end of the discount use period are limited (2000 to 2003), the earlier portion was analyzed as a part of the comprehensive SR-91 evaluation (1998 to 2000). These findings during the discount use period included *(67):*

A significant decline in use of the SR-91 Express Lanes (2100 vehicles per day) by HOV 3+ vehicles occurred immediately following the imposition of the 50 percent toll fee (as opposed to toll-free use). Overall use of the SR-91 facility also declined, but SOV and HOV-2 users rebounded to previous levels whereas HOV-3+ users did not, as shown in Figure 11 and Figure 12.



Source: Edward Sullivan *(67)*

Figure 11. Trends in SR-91 Toll Lanes Weekday Traffic by Vehicle Occupancy.

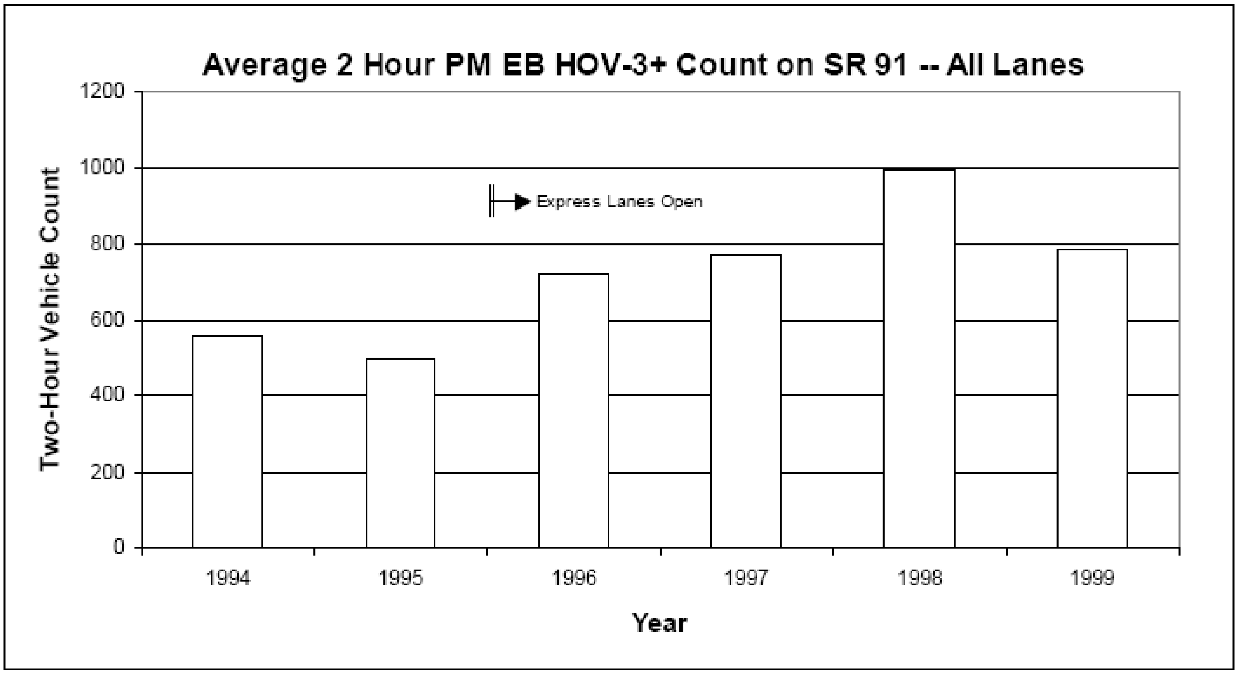


Source: Edward Sullivan *(67)*

Figure 12. Regression Lines Fit to HOV-3+ Trends on SR-91 Toll Lanes.

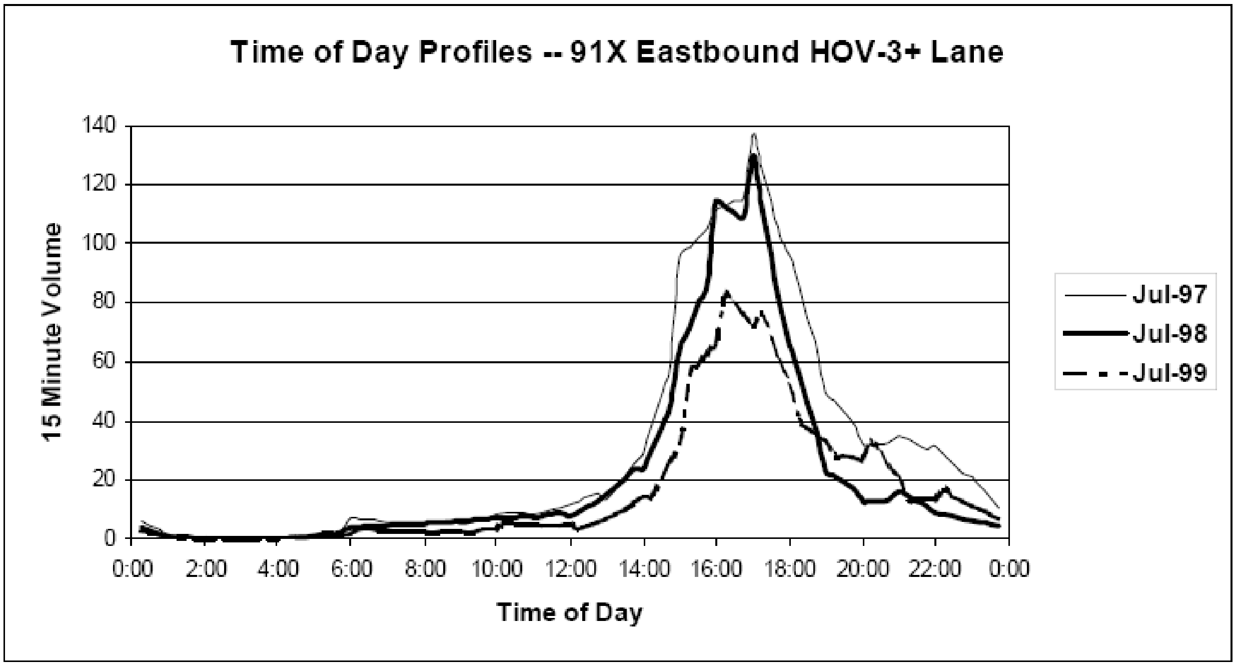
However, the majority of HOV-3+ users who diverted from the facility remained in 3+ carpools; they simply used the general purpose lanes typically in the shoulders of the peak period. The average daily use of HOV-3+ users across all lanes of traffic on SR-91 (including the Express Lanes) actually increased after the 50 percent toll was imposed, as shown below. Overall, "starting to charge 50 percent tolls for HOV-3+ groups coincided with a significant increase in

HOV-3+ trips in the adjacent free lanes, with no net decrease in corridor ridesharing," seen in Figures 13, 14, and 15.



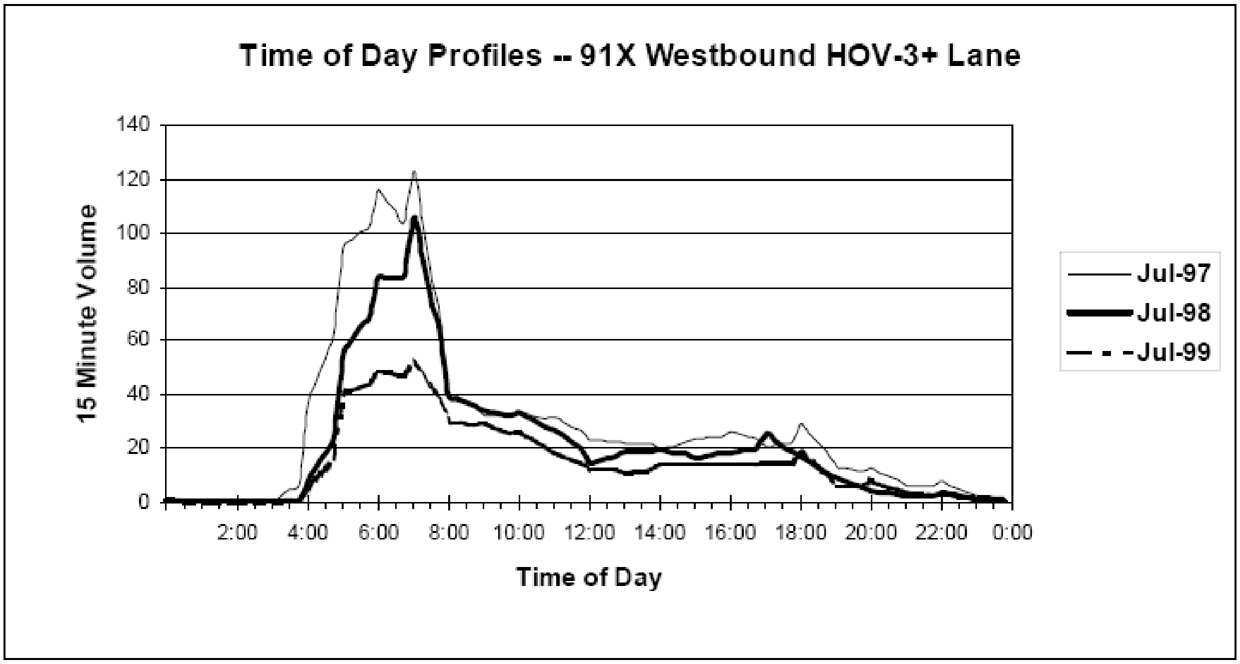
Source: Edward Sullivan *(67)*

Figure 13. Observed PM Peak HOV-3+ Traffic across All SR-91 Lanes.



Source: Edward Sullivan *(67)*

Figure 14. HOV-3+ Use of the Toll Lanes by Time of Day, Eastbound.



Source: Edward Sullivan *(67)*

Figure 15. HOV-3+ Use of the Toll Lanes by Time of Day, Westbound.

SOV growth outpaces HOV-2 use (flat growth) and HOV-3+ use (slight growth) for the corridor. As such, HOV vehicular counts remain stable over time, but SOV growth in the corridor creates a declining percentage of use, shown in Table 11.

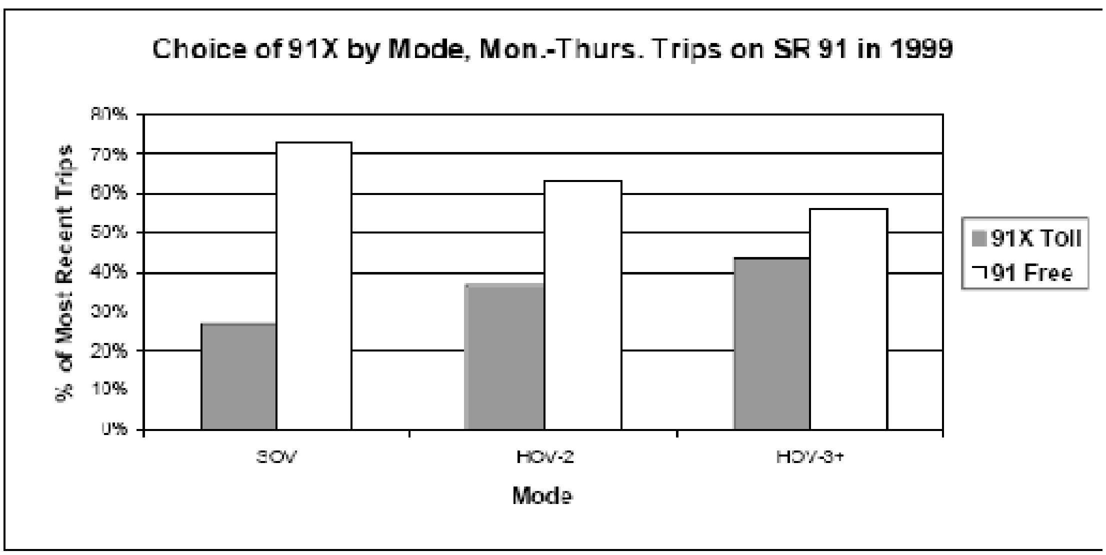
Table 11. Changes in Observed Commuter Mode Share.

Mode	1994 - 1995	1996 - 1999	Difference Significant at α=
SOV	74.3 percent	78.3 percent	1 percent
HOV-2	21.7 percent	17.3 percent	1 percent
HOV-3+	4.0 percent	4.5 percent	25 percent

Source: Edward Sullivan *(67)*

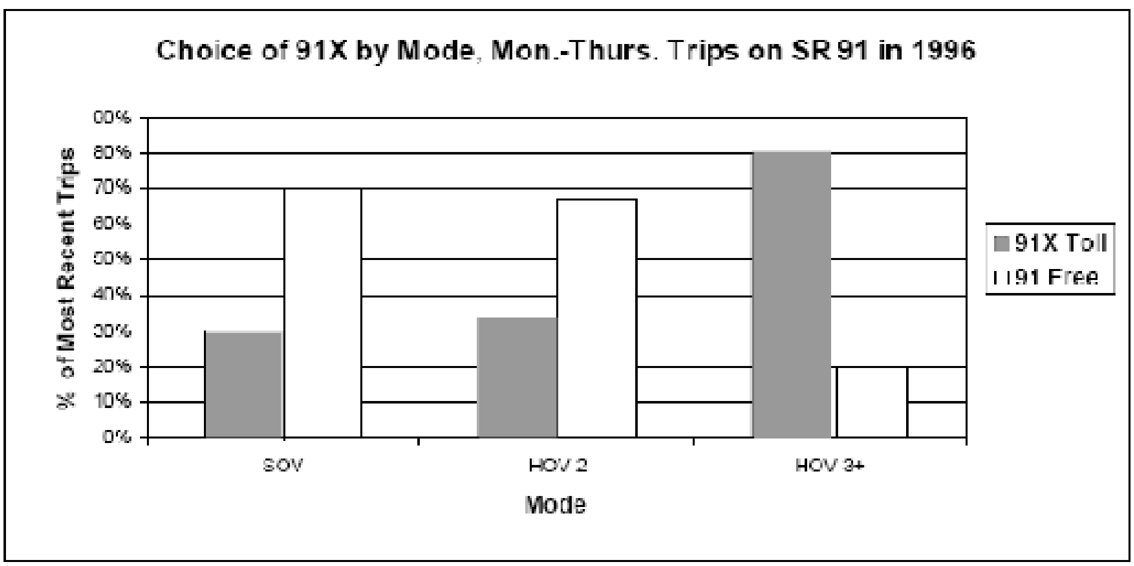
Using a longitudinal panel of SR-91 corridor users, surveyed in 1996 and 1999, researchers also found no significant shifts in mode use. Although a 3 percent shift from SOV to HOV modes was measured in the panel, the standard deviation was 4 percent, indicating the shift is not statistically significant.

Based upon the panel, HOV-2 and HOV-3+ commuters are more likely than SOV commuters to use the SR-91 Express Lanes, as seen in Figure 16 (1999), Figure 17 (1996), and Figure 18 (Longitudinal, 96 – 99). Researchers suggested this may indicate a desire to split the toll among passengers. It should be noted that this finding tends to counter the findings based upon vehicular counts.



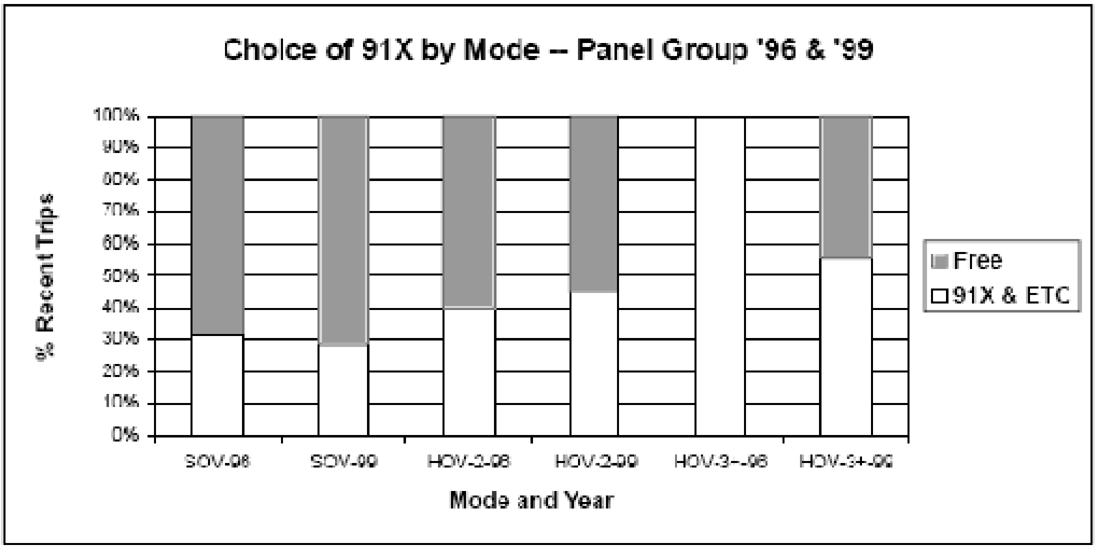
Source: Edward Sullivan *(67)*

Figure 16. Use of Toll Lanes for Recent Commute Trips by Vehicle Occupancy, 1999.



Source: Edward Sullivan *(67)*

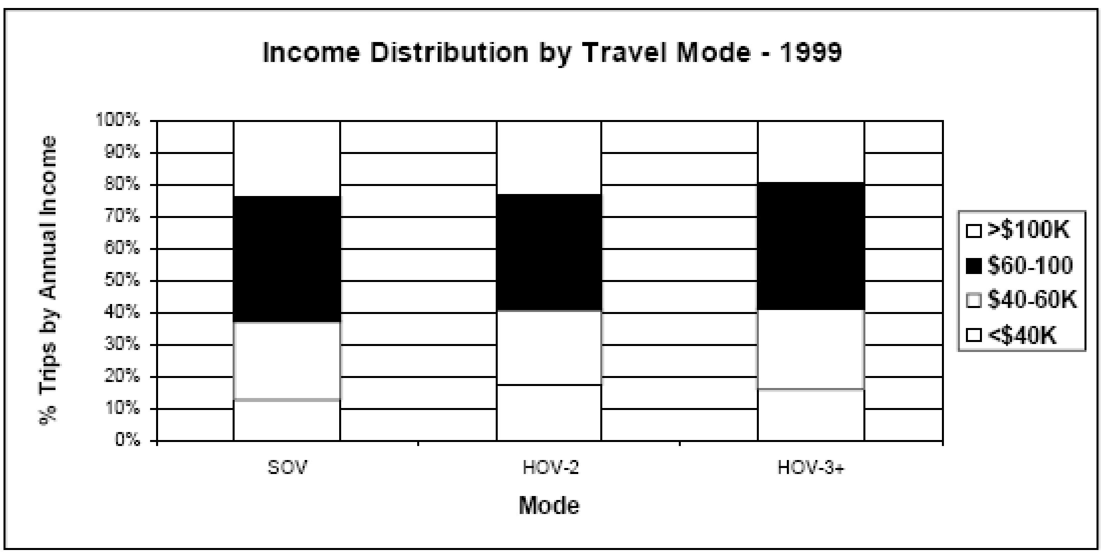
Figure 17. Use of Toll Lanes for Recent Commute Trips by Vehicle Occupancy, 1996.



Source: Edward Sullivan *(67)*

Figure 18. Use of SR-91 Toll Lanes by Vehicle Occupancy for Longitudinal Panel.

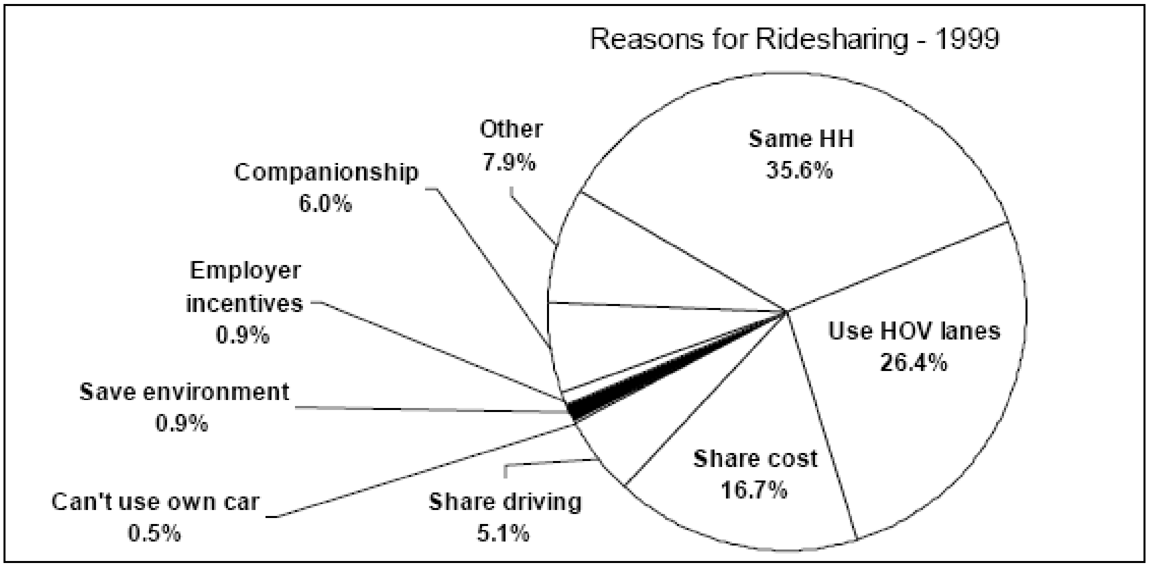
The relationship between income and use of the facility for each vehicle occupancy level (SOV, HOV-2, and HOV-3+) is not significantly different from each other, as seen in Figure19.



Source: Edward Sullivan *(67)*

Figure 19. Comparison of Traveler Income by Vehicle Occupancy, 1999.

Cost sharing only accounts for a small percentage of reasons for carpooling—69 percent of carpoolers indicated they did not share costs of travel, with higher rates of cost sharing among HOV-3+ (46 percent) than HOV-2 (26 percent) users. Researchers found the highest reasons given by carpoolers included being from the same household and use of HOV lanes to reduce travel time, shown in Figure 20.



Source: Edward Sullivan *(67)*

Figure 20. Primary Reason for Carpooling (HOV-2 and HOV-3+), 1999.

The presence of an employer-based rideshare program significantly increases the likelihood of using HOV-3+ alternatives (from 5 percent to 13 percent mode share, with no measurable effect upon HOV-2 use, 18 percent in both cases).

Study researchers concluded, "Opening the SR-91 Express Lanes had a generally positive or neutral effect on ridesharing. PM peak HOV-3+ use increased and was not adversely affected by the 50 percent toll imposed in January 1998. Although HOV-3+ use of the SR-91 Express Lanes significantly decreased, overall HOV-3+ ridership in the corridor did not decrease. HOV-2 counts remained stable throughout the period. The measured reduction in AVO presents a mixed picture, and probably as much reflects time-of-day shifts in response to increased peak capacity (from adding two more lanes) as actual shifts in mode" *(67)*.

HOV-Related Findings for the Combination Discount and Free Use Period (May 2003 to Present Day). In comparison to the comprehensive evaluation conducted between 1996 and 2000, only summary information is available regarding the period of OCTA ownership, including the conversion to the "three-ride-free" policy. After implementation of the policy change, findings include (2003 versus 2004) *(69)*:

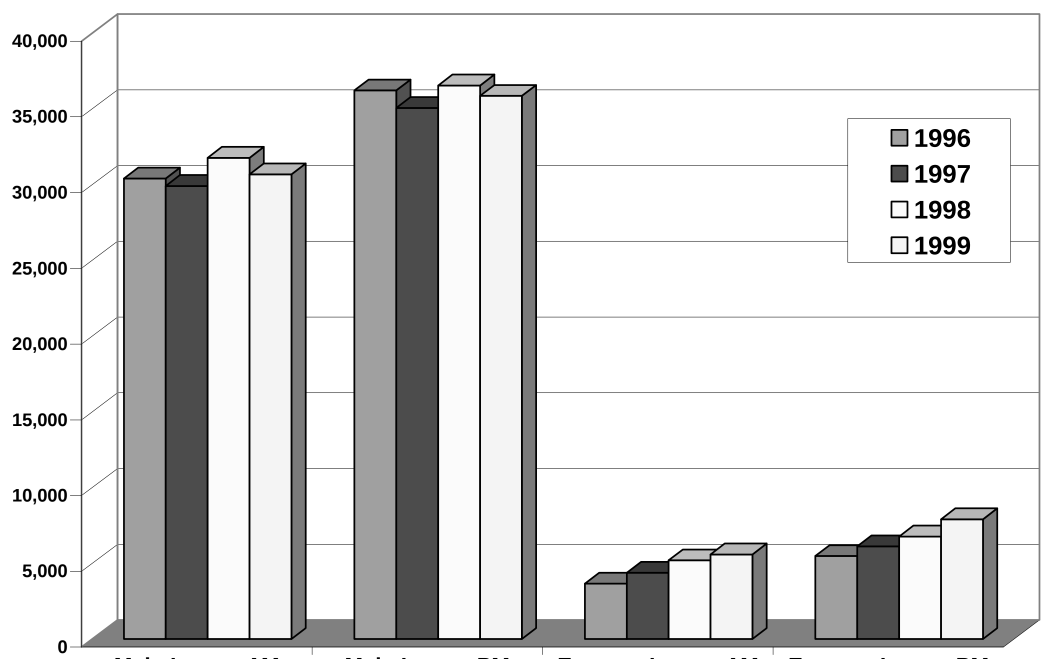
- HOV-3+ trips increased 41 percent over the same month in the previous year, adding 112,000 new HOV-3+ trips on the SR-91 Express Lanes. Overall toll lane use grew 3.9 percent in the same time period.
- Average vehicle occupancy in the SR-91 corridor increased from 1.36 to 1.49 in the AM peak period and 1.38 to 1.42 in the PM peak period.
- Lost revenue from the three-ride-free policy averaged $26,000 per week ($1.4 million per year).

San Diego, California (I-15 FasTrak HOT Lanes)

Unlike the SR-91 Express Lanes, the I-15 facility opened as two barrier-separated, reversible HOV lanes in the fall of 1988. Initially adapted to include a prepaid monthly pass to the HOV lanes, the I-15 HOT lanes currently feature dynamic pricing of single-occupant vehicles. HOV-2+ users remain free, as do motorcycles and zero emission vehicles. The monthly pass program, called ExpressPass, existed from December 1996 through March 1998. The dynamic pricing program, called FasTrak, was implemented in April 1998 and continues to the present day.

San Diego State University researchers conducted an evaluation of the HOT lanes' performance over the first three years of the project. Principal findings from this effort include the following *(71)*.

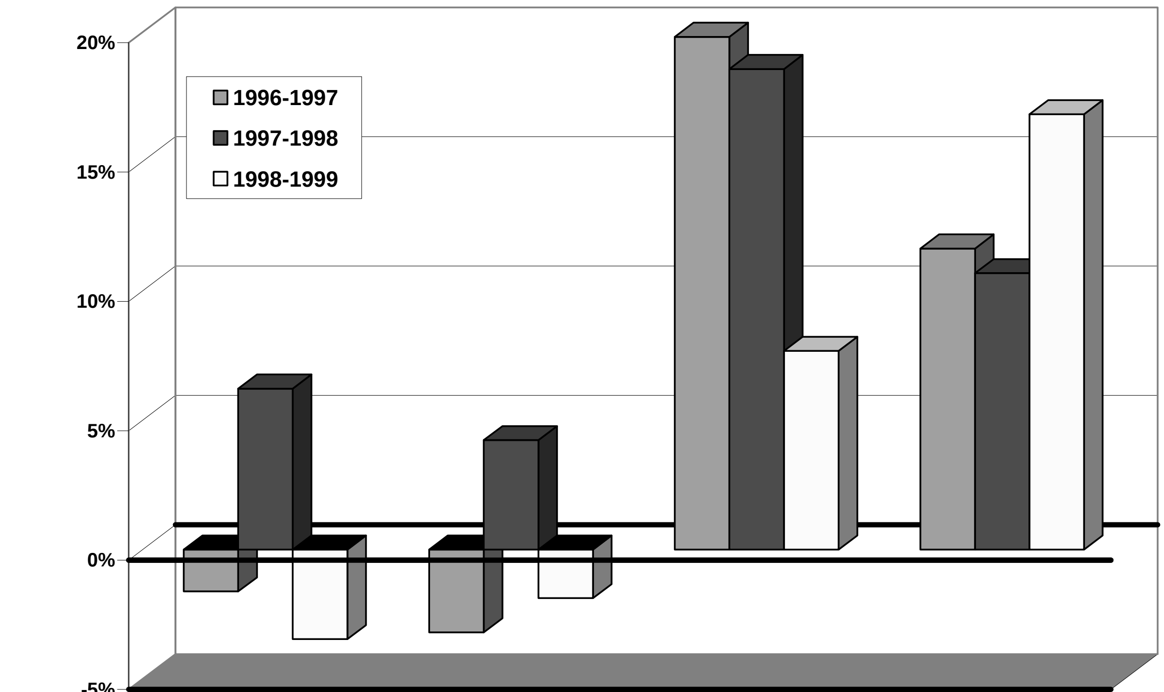
Use of the I-15 Express Lanes increased significantly following the implementation of tolls for single-occupant vehicles, shown in Figure 21 and Figure 22. Researchers concluded that "the I-15 pricing project alleviated congestion on the I-15 main lanes by redirecting an increasing share of volume onto the I-15 Express Lanes" *(71)*. This is an important finding, relative to a decline in carpooling to be discussed later in this section.



	Main Lanes, AM	Main Lanes, PM	Express Lanes, AM	Express Lanes, PM
1996	30397	36214	3650	5476
1997	29905	35055	4373	6113
1998	31765	36537	5185	6766
1999	30666	35850	5583	7904

Source: Janusz Supernak *(71)*

Figure 21. I-15 HOT Lane Vehicular Volumes, 1996-1999.

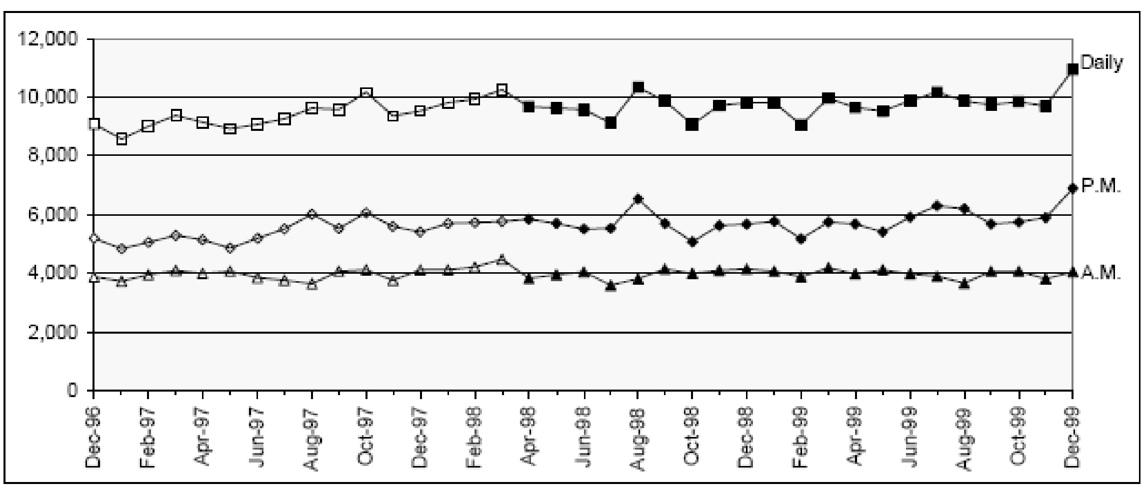


	Main Lanes, AM	Main Lanes, PM	Express Lanes, AM	Express Lanes, PM
1996-1997	-1.6%	-3.2%	19.8%	11.6%
1997-1998	6.2%	4.2%	18.6%	10.7%
1998-1999	-3.5%	-1.9%	7.7%	16.8%

Source: Janusz Supernak *(71)*

Figure 22. I-15 HOT Lanes Percentage Growth in Volumes, 1996-1999.

Whereas total I-15 HOT lanes' vehicular volume increased overall, HOV-2+ growth was limited in the afternoon peak period (less than 1 percent growth) and flat in the morning peak period, as seen in Figure 23.



Source: Janusz Supernak *(71)*

Figure 23. HOV-2+ Volume on the I-15 HOT Lanes.

Carpool volumes in the I-15 corridor have been unpredictable during the timeline of the I-15 HOT lanes. From 1988 to 1997, HOV-2+ volumes almost doubled in the AM peak period (2688 vehicles in 1988 to 7323 in 1997) and again increased by 7 percent in the ExpressPass (monthly pass) program (6831 to 7311 vehicles). However, during the FasTrak (dynamic pricing) program, average HOV-2+ counts in the I-15 corridor decreased by 15 percent in the fall of 1998 and another 32 percent in the fall of 1999 (to 4205). This decline occurred in both the HOT lanes (2 percent decline from 3732 to 3675 and another 25 percent to 2937 for the same time periods) and the general purpose lanes (29 percent from 3579 to 2535 and another 50 percent to 1268 vehicles). A hypothesis for this decline was suggested by the researchers *(71)*:

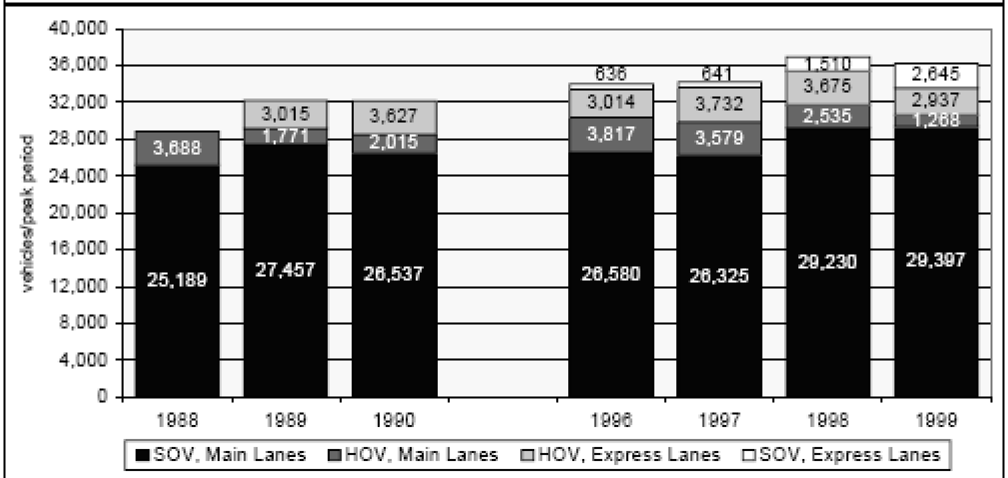
> It is not clear what caused the decrease in carpool volumes in the I-15 corridor during the a.m. peak period in 1998 and 1999. It could be a reaction to the slight traffic relief observed on the I-15 main lanes, creating some disincentive to carpooling on the main lanes. One could notice that there are two different groups of carpoolers in the studied section of the I-15 corridor. The first group consisted of the "rewarded" carpoolers who can travel on the Express Lanes and experience tangible rewards that include (a) substantial timesavings (compared to the main lane travelers) and (b) cost savings (compared to ExpressPass / FasTrak program participants).
>
> The second group consists of the "unrewarded" carpoolers who cannot use the Express Lanes primarily because of the location of their residences and employment sites in relation to the entrance to and exit from the I-15 Express Lanes facility. Thus, "unrewarded" carpoolers have to share the inconvenience of congestion on the I-15 main lanes with SOV main lane users.
>
> With the introduction of FasTrak, the gap between those two groups may have been perceived to be widening; the cost savings realized by carpooling (and using the Express Lanes for free) versus paying a toll to use the Express Lanes are greater under the FasTrak program than under the ExpressPass program for travelers in the middle of the peak period. This perception of greater savings combined with the uncongested travel conditions in the Express Lanes may have created extra incentive for carpooling on the Express Lanes for the "rewarded" carpooler, and perhaps a disincentive for the "unrewarded" carpooler.
>
> This in turn could have caused some main lane carpoolers to either (a) add some travel distance to enter the Express Lanes and become "rewarded" carpoolers using the free flowing Express Lanes or (b) abandon "unrewarded" carpooling and become solo drivers, trading off the cost savings of carpooling for the improved flexibility and convenience associated with solo driving.

> This shift may represent a gradual phenomenon of switching selectively between carpooling and FasTrak use. Particularly during a booming economy, switching travel modes would constitute an acceptable trade off for spending extra cost for more convenience by using FasTrak instead of carpooling when most needed, without losing the privilege to use the I-15 Express Lanes. Thus, the economic boom of the late 1990s also could have contributed largely to the substantial overall decrease of HOV volumes in the I-15 corridor.

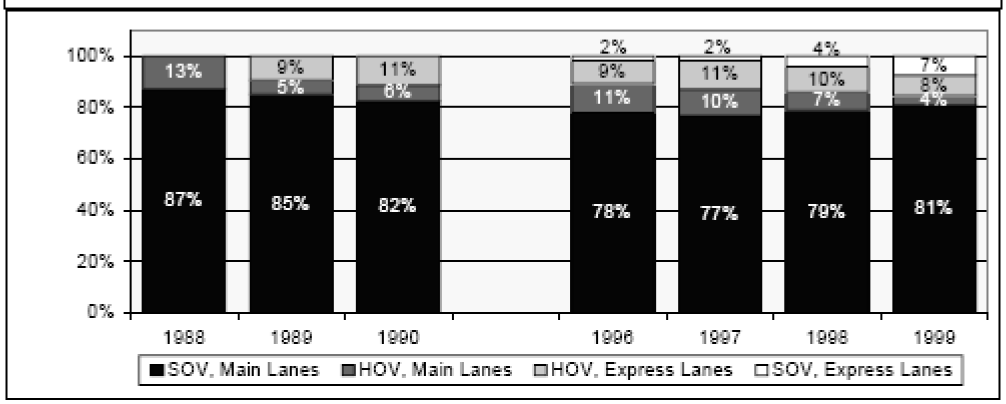
Interestingly, the SOV mode share in the I-15 corridor reached its lowest point just prior to the implementation of tolling on the I-15 HOV lanes. In 1988, SOV use constituted 87 percent of AM peak-period vehicles; by 1997 SOV use was 77 percent of vehicles. SOV mode share increased, though, with the implementation of pricing—reaching 79 percent in 1998 and 81 percent in 1999. When examined as a percent of mode by total persons (instead of vehicles), SOV travelers decreased from a high of 77 percent in 1988 to 61 percent in 1997. However, SOV travelers increased to 66 percent in 1998 and 72 percent in 1999. These declines in HOV mode share contrast with an observed *rise* in HOV volume along a control corridor during the same study period. Figures 24 and 25 show the vehicular and person volume metrics, respectively *(71)*.

Project researchers concluded their analysis: "The project clearly seems to have affected the SOV share of total Express Lane volume, which increased commensurately with the number of FasTrak subscribers, however. There is no obvious and compelling reason why the project would have had an indirect role in the rise in SOV shares on the I-15 main lanes. Other demographic and socioeconomic factors, such as the economic boom in the late 1990s affecting the affluent I-15 residents more than the less-affluent I-8 residents, are more likely responsible for this trend" *(71)*.

Southbound I-15	1988	1989	1990	1996	1997	1998	1999
SOV, Main Lanes	25,189	27,457	26,537	26,580	26,325	29,230	29,397
HOV, Main Lanes	3,688	1,771	2,015	3,817	3,579	2,535	1,268
HOV, Express Lanes		3,015	3,627	3,014	3,732	3,675	2,937
SOV, Express Lanes				636	641	1,510	2,645
Totals	**28,877**	**32,243**	**32,179**	**34,048**	**34,278**	**36,950**	**36,248**



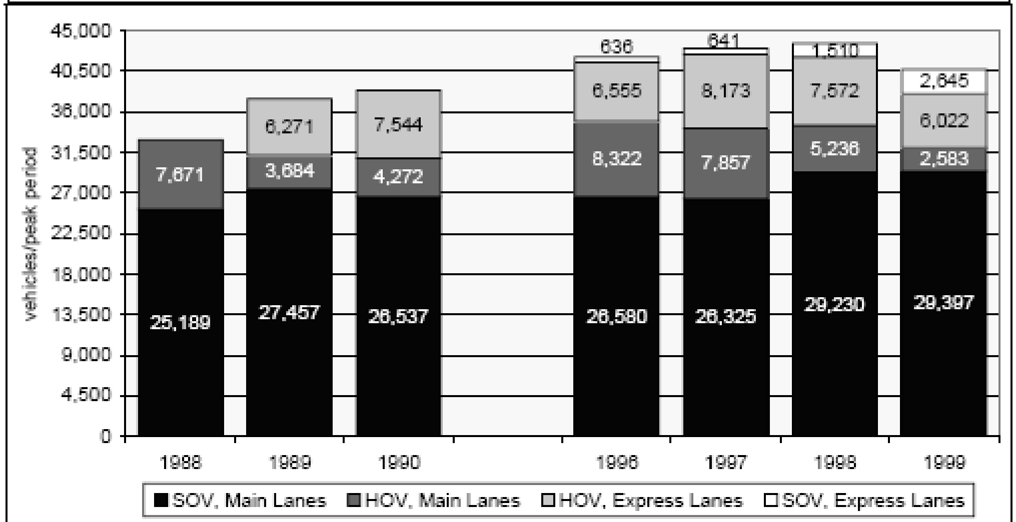
Southbound I-15	1988	1989	1990	1996	1997	1998	1999
SOV, Main Lanes	87.2%	85.2%	82.5%	78.1%	76.8%	79.1%	81.1%
HOV, Main Lanes	12.8%	5.5%	6.3%	11.2%	10.4%	6.9%	3.5%
HOV, Express Lanes		9.4%	11.3%	8.9%	10.9%	9.9%	8.1%
SOV, Express Lanes				1.9%	1.9%	4.1%	7.3%



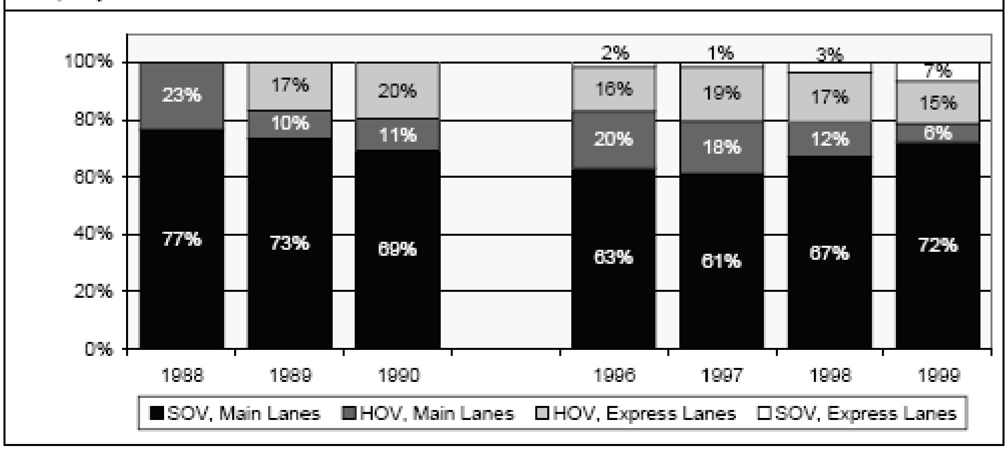
Source: Janusz Supernak *(71)*

Figure 24. Summary of I-15 Corridor Vehicle Volume, Totals, and Percentages.

Southbound I-15	1988	1989	1990	1996	1997	1998	1999
SOV, Main Lanes	25,189	27,457	26,537	26,580	26,325	29,230	29,397
HOV, Main Lanes	7,671	3,684	4,272	8,322	7,857	5,236	2,583
HOV, Express Lanes		6,271	7,544	6,555	8,173	7,572	6,022
SOV, Express Lanes				636	641	1,510	2,645
Totals	**32,860**	**37,412**	**38,353**	**42,093**	**42,997**	**43,548**	**40,648**



Southbound I-15	1988	1989	1990	1996	1997	1998	1999
SOV, Main Lanes	76.7%	73.4%	69.2%	63.1%	61.2%	67.1%	72.3%
HOV, Main Lanes	23.3%	9.8%	11.1%	19.8%	18.3%	12.0%	6.4%
HOV, Express Lanes		16.8%	19.7%	15.6%	19.0%	17.4%	14.8%
SOV, Express Lanes				1.5%	1.5%	3.5%	6.5%



Source: Janusz Supernak *(71)*

Figure 25. Summary of I-15 Corridor Person Volume, Totals, and Percentages.

Houston, Texas (I-10 and US 290 QuickRide)

The Katy (I-10) and Northwest (US 290) Freeway HOV lanes in Houston have adapted eligibility twice in their history. Peak-period occupancy restrictions changed from HOV-2+ to HOV-3+, and finally to HOV-3+ free with HOV-2 paying a $2 toll under the QuickRide program. Traffic volumes on these lanes, and studies of those data *(72, 73, 74, 75)*, illustrate how these changes impact traffic.

For example, when the Northwest Freeway underwent this change in the morning peak period (6:45 a.m. to 8:00 a.m.) in July 1999, there was a dramatic shift in the time of travel of HOV-2s (see Figure 26—the change from June 1999 to June 2000). QuickRide began on this facility in late 2000, and some HOV-2 vehicles came back to the peak period for the $2 toll (see Figure 26—the change from June 2000 to June 2001). This provides an initial indication of how HOV vehicles will react when an HOV facility changes from free of charge to one that charges for peak-period use.

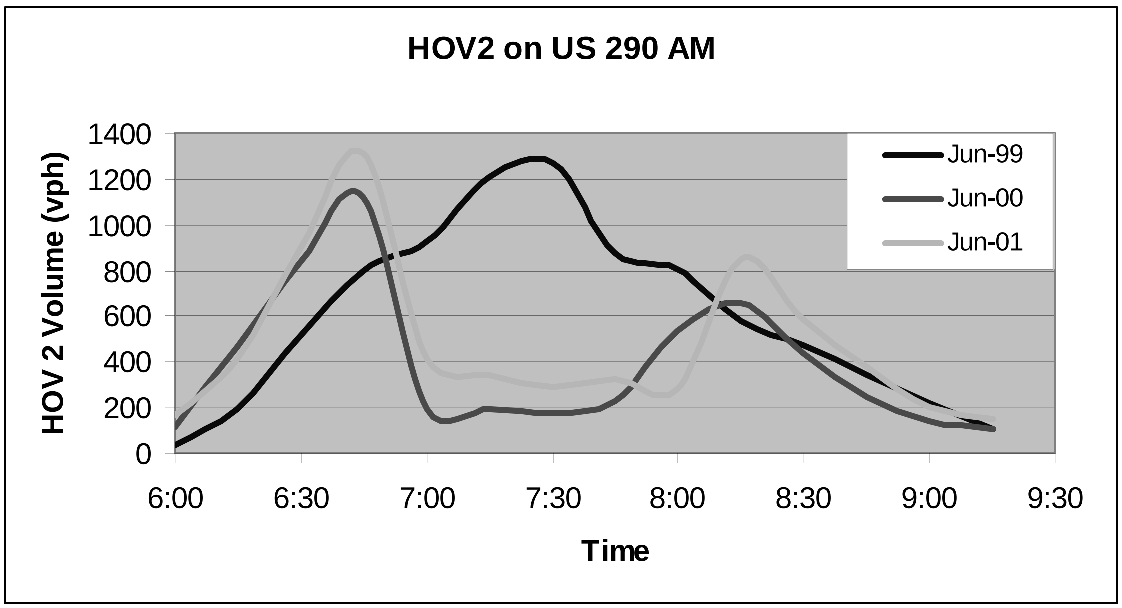


Figure 26. HOV-2 Volume on US 290, 1999-2001.

The QuickRide program has seen a steady increase in daily usage (see Figure 27). This indicates that HOV travelers are willing to pay a toll for premium service. Of course, many peak-period HOV-2 travelers had to alter their route, mode, or time of travel when the HOV-3+ restrictions were added to these lanes in the peak periods (as shown in Figure 27). Next, when QuickRide was initiated on the Katy Freeway, those selecting this new travel option were previously using many other mode and travel choices (see Table 12). These changes made by travelers in the Katy corridor provide a base of understanding upon which to build models of traveler behavior.

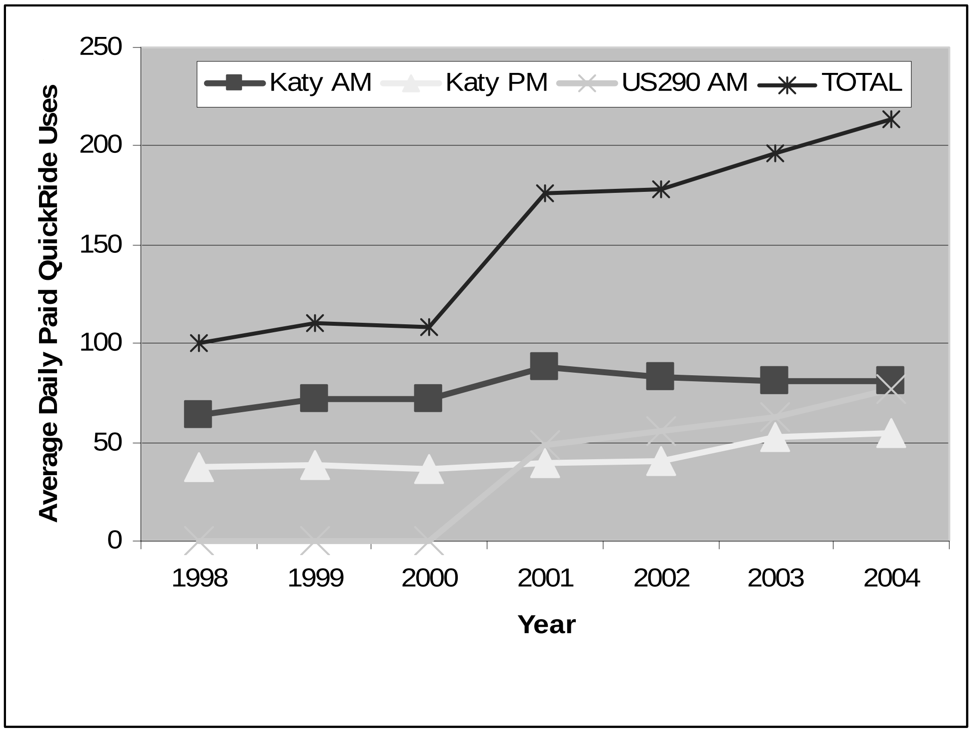


Figure 27. Growth in QuickRide Usage.

Table 12. Previous Mode and Time of Travel of QuickRide Participants.

Mode	AM Shoulders[A] Percent	AM Peak[B] Percent	Total Percent	PM Shoulders[A] Percent	PM Peak[B] Percent	Total Percent
Drive alone	12.7	38.0	50.7	24.5	33.2	57.7
Two-person HOV, HOV lane	7.0	---	7.0	6.8	---	6.8
Two-person HOV, freeway	10.7	12.0	22.7	3.6	25.7	29.3
HOV-3+	2.3	2.4	4.7	–2.4[C]	–3.7[C]	–6.1[C]
Vanpool	0.0	2.0	2.0	0.0	2.3	2.3
Bus	0.6	10.0	10.6	1.6	3.7	5.3
Other	0.0	2.4	2.4	0.0	4.7	4.7
Total	33.2	66.8	100.0	34.1	65.9	100.0

Notes: A—periods before and after the peaks
B—peak periods defined as 6:45 a.m. to 8:00 a.m. and 5 p.m. to 6 p.m.
C—a negative value indicates increased trips by QuickRide participants

In March 2003, a survey analyzed the socio-economic and trip characteristics of QuickRide users. Surveys were sent to 1366 QuickRide enrollees, and 525 were returned for a response rate of 38.4 percent. In November 2003, a similar survey was conducted to analyze non-users.

Cameras were used to capture license plate numbers of vehicles traveling on the Katy and Northwest Freeway main lanes and HOV lanes during both the peak and off-peak periods. Surveys were mailed to the registration addresses of the license plates. Additionally, surveys were manually handed out to transit users and casual carpool passengers. A total of 15,240 surveys were distributed, and 3505 were returned for a response rate of 23.0 percent.

Analysis of the survey data revealed significant differences in the trip purpose and socio-economic characteristics of QuickRide users when compared to the other modes. QuickRide users were significantly more likely to make school trips than other modes. They were also more likely to have a postgraduate degree and have a household income greater than $100,000 per year. Additionally, they were significantly less likely to be male, be between the age of 25 and 34, or live alone.

The results gained from the survey seem to suggest that some of the primary users of the QuickRide program are parents taking their children to school. However, it is important to note the unique access requirements of the QuickRide program. SOVs are not allowed on the Houston HOV lanes for any toll amount. The admittance of SOVs would most likely change the socio-economic characteristics of QuickRide users significantly.

San Francisco Bay Area

Although not generally considered managed lanes, the San Francisco Bay Area Toll Authority combines toll discounts for carpools (HOV-3+) on toll bridges with HOV facilities on adjoining freeways (maintained by CalTrans). Together, this effect simulates a HOT lane—travel time savings and toll-cost savings by carpooling. However, it should be noted that the travel time penalty for a single-occupant vehicle or two-person carpool is coupled with the toll payment.

Toll-free lanes for HOV-3+ users are available on the Antioch, Benicia-Martinez, Carquinez, San Francisco-Oakland Bay, Richmond-San Rafael, Dumbarton, and San Mateo-Hayward bridges during peak periods, saving $3 for a round trip (tolls are generally collected in one direction only). Additionally, HOV lanes provide service adjoining three bridges reflected in Figure 28:

- San Francisco-Oakland Bay Bridge (A), with I-80 (1) and I-880 (2) HOV lanes;
- San Mateo-Hayward Bridge (B), with I-880 (3) HOV lanes; and
- Dumbarton Bridge (C), with I-880 (4) HOV lanes.

Figure 28. Toll Bridges and HOV Lanes in the San Francisco Bay Area.

Carpoolers enjoy significant time savings on the HOV lanes leading to these three bridges, as indicated in Table 13. Thus, the use of carpooling in these corridors yields a $1.50/trip cost savings and 10+ minute/trip time savings *(76)*.

Table 13. Minutes Saved on Select HOV Lanes by Year, San Francisco Bay Area.

HOV Lane		Minutes Saved				
		2000	2001	2002	2003	2004
1	I-80, westbound AM (4 lanes, 1.0 miles)	24	24	19	13	13
2	I-880, northbound AM (1.2 miles)	32	31	23	5	18
3	I-880, southbound AM (8.8 miles)	14	12	12	18	17
4	I-880/Route 84, southbound AM (11.5 miles)	25	40	40	20	19

Source: Metropolitan Transportation Commission *(76)*

Despite the significant travel time and moderate cost savings provided to carpoolers, actual peak-period carpool use has declined over time, despite an increase in freeway congestion levels during the same time period. For example, carpool vehicle counts on the I-80 HOV lane leading to the Bay Bridge declined 5 percent from 2000 to 2004 (3804 vehicles to 3628 vehicles) *(76)*.

Commuters in Alameda and Santa Clara Counties have the greatest likelihood of having access to a toll bridge and HOV lane on the same commute. An annual state of the commute survey conducted in the Bay Area found the following *(47)*:

- Approximately half of commuters have access to the HOV lane system (45 percent in Alameda and 57 percent in Santa Clara).
- Of those commuters, an average of 19 percent use the HOV lanes (21 percent in Alameda and 16 percent in Santa Clara).
- Of those commuters who use the HOV lanes, 61 percent (for both counties) report the presence of the HOV lanes influences their decision to carpool.

STATE OF THE PRACTICE IN EVALUATING CARPOOL INCENTIVES FOR MANAGED LANES

Given the evolution of HOV facilities to managed lanes over the last decade and the level of activity in development of managed lane projects in Texas and nationally, there is still very little in the way of research and guidance defining the role of carpools and the tradeoffs between carpool preference and other project objectives. A study of HOV treatments on toll facilities concluded that HOV pricing strategies and priority treatments are being utilized on a variety of toll facilities in the United States, although information on utilization levels and mode choice influences was very limited *(77)*. In examining the managed lane projects in operation today, decisions related to carpool preference have been based largely on policy decisions with little basis in quantitative analysis *(78)*.

In order to obtain a current picture of HOV policies on managed lane facilities—both active and pending implementation—state and regional agencies in eight metropolitan areas outside of Texas were contacted in January and February of 2006. Each responding entity, aggregated by region, compiled their communities' interests and pursuits regarding HOVs.

Overview of Metropolitan Areas

Table 14 illustrates various carpool preference options. The table shows different combinations of toll rates for HOV-2 and HOV-3+. Varying toll methods range from HOV lanes in the upper left corner (HOV-2 Free 24/7 and HOV-3+ Free 24/7) to express toll lanes in the lower right corner (HOV-2 Pay 24/7 and HOV-3+ Pay 24/7). Figure 29 provides an overview of the various regions' approaches toward the tolling of high-occupancy vehicles on managed lane facilities. It should be noted that the San Francisco Bay Area is different from the other implementations in that HOV discounts are applied on toll bridges, with HOV lanes feeding the bridges. As this proxies the effect of managed lanes, they are included in this analysis.

Table 14. Carpool Preference Combinations.

		HOV-3+				
		Free 24/7	Free Peak Period Only, Pay All Other Times	Discount 24/7	Discount Peak Period Only, Pay All Other Times	Pay 24/7
HOV-2	Free 24/7	HOV-to-HOT I-15 CA I-394 MN I-25 CO I-15 UT SR-167 WA				
	Free Peak Period Only, Pay All Other Times		I-10 Houston Expansion			
	Discount 24/7					
	Discount Peak Period Only, Pay All Other Times				DFW Policy	
	Pay 24/7	SR-91 CA, I-495 VA, I-95/395 VA				Express Toll Lanes

	San Francisco Bay	Houston	Orange County, CA	San Diego	Minneapolis	Denver	Seattle	D.C. (Virginia)	D.C. (Maryland)
	Active HOV Incentives on Managed Lane Facilities						Currently Considering HOV Incentives on ML Facilities		
TOLL POLICIES FOR HOVs									
SOV toll	☑	pending	☑	☑	☑	☑	☑	☑	☑
HOV-2 toll	-	☑	☑	-	-	☑	-	☑	☑
HOV-2 discount	-	-	-	-	-	-	-	-	-
HOV-2 free	☑	☑	-	☑	☑	☑	☑	-	-
HOV-3+ toll	-	-	-	-	-	☑	-	-	☑
HOV-3+ discount	-	-	☑	-	-	-	-	-	-
HOV-3+ free	☑	☑	☑	☑	☑	☑	☑	☑	-

Figure 29. State of the Practice—Toll Policies for HOVs, 2006.

As can be seen, a few patterns emerge from the responses:

- *All facilities toll or intend to toll single-occupant vehicles*, for reasons described elsewhere in this literature review.

- *Most facilities provide free access to HOV-3+*. The only exceptions to this policy are Orange County (where demand on the SR-91 Express Lanes is sufficiently high in the eastbound direction to require a discount toll instead of free passage); Denver's C-470 Express Lanes (for which HOV-3+ policies have not yet been finalized, but environmental documentation indicated all vehicles may be tolled regardless of occupancy); and Maryland (which intends to toll all vehicles on managed lanes statewide without regards to occupancy).
- *In general, either HOVs are tolled or not tolled*. Only one facility, the SR-91 Express Lanes, pursues a half-toll policy for HOVs. No other facility has adopted or intends to adopt a similar policy for either HOV-2 or HOV-3+.
- *Most communities have a standard HOV toll policy.* With the exception of the Denver area, where the I-25 and C-470 facilities provide differential rates and access to HOV-2 and HOV-3+, and the D.C. area, where Maryland and Virginia will have different HOV toll policies, all other communities generally have standardized their HOV toll policies across the region—either by intent or by default.

Figure 30 offers each region's responses to factors potentially impacting regional and/or corridor decisions for HOV-2 or HOV-3+ toll policies. These factors may be constituted in official transportation policy or may reflect prevailing concerns of agency stakeholders in the development of managed lane facilities per region. The scale for each factor is rated simply as "high importance," "moderate importance," and "low importance" in terms of its effects on decision making in the region.

Unlike the toll policies, these results do not lend themselves easily to overall trends. Two principal findings include:

- No factor uniformly rates as a high or low importance in regional decision making. This finding confirms that each region is different and has its own core issues to address in setting managed lane policies. Furthermore, the different importance values assigned to each factor suggest that nationally standardized criteria regarding HOV toll policies not only do not exist but are also inappropriate, relative to regional issues.
- Factors that rate consistently high or moderate across all corridors and/or regions include: enforcement of carpool vehicles, maximizing vehicular throughput, and uniformity/equity issues. The first two factors are invariably linked to one another. Ensuring adequate enforcement of carpool policies without cumbersome geometric solutions may help fulfill the objective of maximizing vehicular throughput since pricing can better respond to prevailing demand. The final factors, uniformity and equity, suggest a policy issue that is rarely quantified in HOV preference: offering an HOV incentive not for air quality or modal use purposes, but rather to provide a toll-free alternative for potentially disadvantaged communities that is still consistent with regional transportation objectives.

DECISION FACTORS	San Francisco - Oakland	Orange County, CA	San Diego	Minneapolis	Denver	Seattle	D.C. (Virginia)	D.C. (Maryland)
	Active HOV Incentives on Managed Lane Facilities					Currently Considering HOV Incentives on ML Facilities		
Separating toll vs. non-toll vehicles	●	●	●	○	●	○	●	●
Regional air quality goals/objectives	◉	●	●	◉	◉	○	●	◉
Technological concerns	●	●	●	○	◉	●	◉	○
Carpool enforcement concerns	●	◉	●	●	●	●	◉	●
Achieving mode use goals/objectives	●	◉	●	●	○	●	◉	○
Back office accounting concerns	○	○	○	○	●	●	○	●
Maximize person throughput	●	●	●	●	◉	●	◉	○
Maximize vehicular throughput	◉	●	●	◉	●	●	◉	●
Maximize revenue generation	◉	◉	○	○	◉	○	●	●
Uniformity and equity concerns	●	●	●	●	●	●	●	◉
Previous carpool operations consistency	◉	-	●	●	◉	◉	◉	○

Legend: ● = High ◉ = Moderate ○ = Low

Figure 30. State of the Practice—Decision Factors for HOV Toll Policies, 2006.

IMPLEMENTED REGIONAL CASE STUDIES

The following regional case studies provide context for the HOV toll policy decisions identified above for implemented managed lanes. Not all regions are represented in these case studies; rather, these case studies provide information for projects that have definitive data regarding HOV preference in managed lane facilities that are particularly illustrative for Texas.

SR-91 Express Lanes, Orange County, California

Orange County, California, is home to many HOV lane corridors and toll roads, including the San Joaquin Hills toll road (SR-73), Foothill toll road (SR-241), and Eastern toll road (SR-241/261/133). Within the context of this analysis, the SR-91 Express Lanes project, discussed previously in this literature review, is currently the only managed lane facility in Orange County with a pricing element. The SR-91 Express Lanes are newly constructed toll lanes built in the median of California's Riverside Freeway (SR-91) between the Orange/Riverside County line and the Costa Mesa Freeway (SR-55).

The SR-91 Express Lanes include two lanes in each direction, for four lanes in total, and operate 24 hours a day. The managed lanes are separated by a painted buffer with plastic channelizers. There are no midpoint access points for the facility. The operational capacity of the SR-91 Express Lanes is 1700 vehicles per hour per lane; however, sustained volumes above 1650 vehicles per hour per lane trigger a review of toll rates to ensure volumes are maintained lower than capacity limits. Speeds of 50 to 60 mph are maintained in the SR-91 Express Lanes during peak periods, whereas the adjacent general purpose lanes typically operate at less than 20 mph. This provides users of the 10-mile facility an average savings of 32 to 35 minutes.

Since construction, the SR-91 Express Lanes have used a preset, variable pricing scheme with differential toll rates by time of day. SOV and HOV-2 vehicles have always paid the prevailing full toll rate. However, at various times, and as discussed previously, HOV-3+ vehicles have either received toll-free use of the facility and/or paid a half-toll rate. Orange County Transportation Authority, the operator of the SR-91 Express Lanes since January 2003, instituted a “three-ride-free” policy on the SR-91 Express Lanes in May 2003, whereby HOV-3+ vehicles would receive free access to the facility for all times except 4:00 p.m. to 6:00 p.m., Monday through Friday, in the eastbound direction. At these times, HOV-3+ pay a half-price toll. In 2005, 34,000 paying vehicles per day accessed the facility, with an additional 4000 free vehicles. Included within the paying vehicles, however, are HOV-3+ paying the half-price toll rate during the afternoon peak period. The facility generates approximately $40 million annual gross revenue (2005). Principal costs include approximately $24 million in annual operations and maintenance, and repayment of $210 million in construction costs.

The history of the SR-91 Express Lanes, previously discussed in this literature review, involves a considerable amount of political consternation *(63, 64, 65)*. Ultimately, one of the driving interests has been the Southern California Association of Governments’ need to satisfy air quality conformity. Through a Memorandum of Agreement *(63)*, discussed previously, with SCAG, the SR-91 Express Lanes’ operators (now OCTA) are obligated to institute policies that achieve HOV mode use objectives in the corridor. OCTA’s adoption of the three-ride-free policy satisfied not only the terms of that agreement, but also helped satisfy the concerns of Orange and Riverside County residents regarding toll prices. As identified by OCTA staff in January 2006, the principal focus for the facility is person throughput, while maintaining the ability of OCTA to repay the cost of construction. This has led to the continuation of the HOV-3+ toll policy despite a decline in overall toll revenue *(79)*.

I-15 HOT Lanes and Managed Lanes Extension Project, San Diego, California

San Diego, California, like Orange County, features an extensive HOV lane system, as well as regional light rail and commuter rail transit. Regional toll roads also exist, including the new SR-125 toll road on the eastern half of the metropolitan area. Since 1998, the San Diego Association of Governments (SANDAG) has operated HOT lanes on the existing I-15 HOV lanes, in the median of I-15 between SR-56 and SR-163. Additionally, SANDAG finalized plans and initiated implementation of additional managed lanes to the north of the HOT lane facility, between SR-56 and SR-78.

The I-15 HOT lanes include two barrier-separated, reversible lanes in the median of I-15. The operational hours are: Monday through Friday (5:30 a.m. to 11:00 a.m. southbound); Monday through Thursday (12:00 p.m. to 7:00 p.m. northbound); Friday (12:00 p.m. to 11:59 p.m. northbound); and Saturday and Sunday (12:00 a.m. to 11:59 p.m. northbound). The managed lanes extension project would construct four new lanes, barrier separated to include a configuration that allows for operating three lanes in one direction and 1 lane in the opposite direction. This unconventional configuration will utilize a movable barrier to reverse the direction of the interior lanes of the facility as needed and feature bus rapid transit (BRT) as a modal alternative in the corridor. Whereas there are no midpoint access points for the I-15 HOT lanes, the managed lanes extension project will have five BRT direct-access ramps and six atgrade vehicular access points. The operational capacity of the I-15 lanes is 1520 vehicles per hour per lane.

The I-15 HOT lanes project was the first in the United States to feature dynamic pricing, whereby toll rates change with the level of prevailing volumes in the HOT lane facility itself (not the general purpose lanes, as is often confused). Dynamic price levels for SOVs only were initially set to maintain Level of Service C; however, SANDAG has also operated the facility without congestion at Level of Service D. The typical peak-period toll rate approaches $4 for use of the 8-mile facility, with a maximum toll rate of $8 in times of severe incidents. All HOV-2+, buses, motorcycles, low-emission vehicles, and emergency vehicles use the facility toll free. In 2004, 30,000 vehicles per day accessed the facility, with approximately 25 percent toll-paying SOVs. The facility generates approximately $2.0 million annual gross revenue (2004). Principal costs include approximately $500,000 for operations and maintenance and $1.0 million for the subsidy of transit service in the corridor, known as the Inland Breeze.

As noted, the I-15 HOT lanes project derived from the adaptation of existing HOV lanes on the I-15 corridor to HOT operations *(71)*. As a result, the principal factor determining the role of HOV preference in the corridor was the existing HOV operations. For the managed lane extension project, however, HOV lanes did not currently exist. The decision to continue HOV-2+ toll-free access maintains the consistency of policy for the HOT lane portion of the corridor. Thus, the operations of one facility partially predicated the provision of HOV benefits to the other facility.

I-394 MnPass (HOT) Lanes Project, Minneapolis, Minnesota

The Minnesota Department of Transportation (MnDOT) opened its HOT lane facility, the I-394 MnPass Lanes, in May 2005. Like I-15 in San Diego, the MnPass project constituted an adaptation of existing HOV lanes to HOT lane operations. However, unlike the California projects, the Twin Cities did not previously have toll facilities in the state. As a result, the MnPass project not only provided the first HOT lane project to Minnesota, but also the first application of electronic tolling.

The I-394 MnPass project has two sections. Between I-94 in downtown for 3 miles west to SH-100, the facility is a two-lane, barrier-separated, reversible facility in the median of I-394. Between SH-100 and the remaining 8 miles west to Wayzata Boulevard, the corridor features one concurrent, 2-foot buffer-separated lane in each direction. It should be noted that the latter section of I-394 constituted the first buffer-separated implementation of managed lanes with pricing in the United States. The barrier-separated section has no midpoint access; the buffer-separated section has six midpoint access locations, approximately 1 to 2 miles apart from one another.

The I-394 MnPass Lanes project was the second project in the United States to feature dynamic pricing. HOV-2+, buses, and motorcycles remain toll free on the facility. SOVs pay the dynamically set toll rate in the peak direction of the facility; in the off-peak direction on the buffer-separated section, SOVs may use the facility toll free. The typical peak period toll rate in the initial months of operation was around $2, with almost 80 percent of trips paying $0.50 or less *(80)*. Like I-15, I-394 has a maximum toll rate of $8 in times of severe incidents. In the first nine months of operations, the I-394 MnPass facility had a net loss of $450,000 and was $1.2 million short of projections *(81)*. MnDOT notes that two factors contributed to these disappointing results:

1. the off-peak toll-free use by SOVs was imposed upon MnDOT after the opening of the MnPass facility (and, hence, was not factored in revenue projections); and
2. dynamic pricing on a buffer-separated facility had never been attempted before, and the algorithms were not properly tuned.

Like I-15 in San Diego, I-394 involved the adaptation of existing HOV lanes to HOT lanes, and as a result, the principal factor determining the role of HOV preference in the corridor was the existing HOV operations. MnDOT clearly articulates that the MnPass program's principal focus is demand management and person throughput, not revenue generation. As a result, HOV preferences for future expansion of the MnPass program will likely be maintained in those corridors, as well.

CONCLUSIONS FROM STATE-OF-THE-PRACTICE REVIEW

From the information gathered through published literature and phone interviews, the carpool policies for existing and near-term managed lanes projects revealed consistencies in application. Most of the priced managed lanes in operation today either began as HOV lanes or were implemented in a planned HOV corridor, which influenced the method by which the policies were set.

The regional and state agencies interviewed for this research revealed the following:

- Most facilities provide free access to HOV-3+.
- Generally, HOV-2 either pay the full toll or travel toll free.
- Most communities have a standard HOV toll policy across all facilities.
- There is an intent to toll single-occupant vehicles on their managed lanes and related facilities, although the available capacity may limit the ability to allow SOVs during certain peak periods.

The agencies interviewed did not uniformly rate any particular factor as "high" or "low" importance in regional decision making for managed lane carpool incentives, indicating that local conditions play a strong role in the decision. The agencies were consistent, however, in rating "high" only a few factors that drive policies for carpool incentives:

- enforcement of carpool vehicles,
- maximizing vehicular throughput, and
- uniformity and equity considerations.

The three factors highlighted above that are of most concern to operating agencies are generally considered outside the realm of traditional TDM programs, where regional carpool incentives are typically set. TDM objectives usually address air quality, person mobility, and accessibility to employment. This implies that there is a disconnect between the expressed purpose of carpool programs on a regional basis and the application of carpool incentives on managed lane facilities. As regional planning processes consider the appropriate role of carpools on managed lanes, consideration should be made to directly connect the objectives of regional demand management programs with policies as applied on managed lanes.

The review also revealed that although a nexus is found between the use of incentives (including cost incentives and other TDM activities) and HOV lane usage, the evidence for priced managed lanes is less clear.

CHAPTER 3. TRAVELER SURVEY—HOUSTON AND DALLAS

A web-based survey was conducted from May to July of 2006 in both English and Spanish on separate Dallas and Houston websites, coupled with an on-the-ground paper survey at targeted locations to increase minority participation. The intent of focusing on Houston and Dallas was to capture traveler responses in regions that have both toll roads and HOV lanes. Various outreach efforts were made to increase public awareness of the survey and to encourage participation from low-income and minority groups. The survey generated over 4600 responses. The survey collected data on:

- personal travel patterns including reasons for choosing the current travel mode(s),
- managed lane opinions,
- stated preference on mode choice based on hypothetical travel and toll scenarios, and
- demographic information.

EXAMINATION OF THE GOALS AND OBJECTIVES OF MANAGED LANES

Researchers began by examining the overall goals and objectives of managed lanes. These were important since the goal of the project was to determine the role of preferential treatment of carpools in managed lanes. To fully understand the costs and benefits of preferential treatment for carpools, it was necessary to determine the goals and objectives of managed lanes and then examine how preferential treatment for carpools would impact those goals and objectives.

There are a number of potential measures of effectiveness (MOEs) upon which to judge the success of managed lanes in meeting their goals and objectives (see Table 15). Survey development focused on obtaining specific results for each of the MOEs. Estimating the vast majority of MOEs required the same information: *predicting how the travelers would alter their behavior given specific general purpose lane and managed lane options*. Therefore, the survey was designed with this goal in mind.

DETERMINATION OF REQUIRED DATA

Prior to developing the survey instrument it was important to examine the literature for information on how and why travelers choose different travel options. Special emphasis was on literature that examined traveler behavior on corridors with operational managed lanes or HOT lanes. With this information, plus a thorough understanding of managed lanes, survey questions were developed that would enable the research team to predict the use of managed lanes under various scenarios.

Table 15. Managed Lane Goals.

Goals	Objectives	Measures of Effectiveness
1. Improve operational efficiency of the transportation system	Reduce congestion	Reduce average travel time
		Compare average travel time of an HOV lane versus an ML
		Percentage time general purpose lane (GPL) is level of service (LOS) D or worse
		Percentage of time the HOV or ML is operating in LOS D or worse
		Average speeds
		Travel time index (TTI) (a ratio of travel time in the peak period versus travel time in the off-peak period)
	Improve travel time reliability	Percentage of vehicles' (ML and GPL) travel time is less than 1.2 times the free-flow travel time
		Difference between 95th percentile travel time and 50th percentile travel time
		Percentage of time vehicles achieve free-flow speeds
	Maximize throughput and person-carrying capacity	Number of vehicles per hour (ML and GPL)
		Number of persons per hour (ML and GPL)
		Increase in AVO and/or transit usage
2. Provide more travel options to the users	Provide additional travel options	Count number of travel options (count number of vehicles/persons selecting new options)
		Increase in AVO and/or transit usage
3. Generate revenue	Generate net revenues	Calculate difference between revenue and costs for conversion to managed lanes
4. Develop a sustainable transportation system	Reduce emissions	Calculate emissions (nitrous oxides [NOx], volatile organic compounds [VOCs], carbon monoxide [CO], and particulate matter) for both managed lanes and GPLs
	Reduce fuel usage	Calculate fuel usage for both managed lanes and GPLs
	Maximize use of existing infrastructure	Vehicle counts
		Increase in AVO and/or transit usage
	Pay for itself (operations and maintenance covered)	Revenue versus costs
		Acceleration of construction

Table 15. Managed Lane Goals (Continued).

Goals	Objectives	Measures of Effectiveness
5. Improve net societal benefits	Improve benefits to society	Calculate net societal benefits and costs. Costs include construction costs, operation and maintenance costs, and capital costs. Benefits include travel time savings, fuel savings, and emissions savings.
		Acceleration of construction
6. Enhance and support emergency management operations	Enhance and support emergency management operations	Reduced response time to emergencies
		Additional evacuation route

SELECTION OF SURVEY METHOD

The research team investigated a number of potential survey methods that could have been used to obtain the required data (see Table 16). After discussing the advantages and disadvantages of the possible survey methods with the project advisory team, the research team chose Internet surveys, with follow-up laptop/paper surveys to overcome the biased sample that could occur due to this method.

Table 16. Potential Survey Techniques.

Survey Technique	Advantages	Disadvantages
Personal interview	Fully explain options Longer surveys tolerated	Cost Skewed sample
Telephone	Fast Low cost	No answer/machine Very simplistic stated preference questions
Mail (with license plate capture)	Less intrusive, answer when convenient Lower cost	Take longer Lower response rate
Email	Fast Low cost	Unsolicited emails ignored Hard to get addresses Skewed sample
Computer (laptop) direct	No data entry cost Complex stated preference and skip patterns	Effort required for correct sample Must supply laptop and personnel
Internet	No data entry cost Complex stated preference and skip patterns Fast, low cost	Lack of control over who responds Lack of Internet access (skewed sample)

This method provided the greatest advantages for the questions that would need to be asked of respondents, particularly the complex stated preference questions that would be needed to better understand when and why travelers choose the ML option.

SURVEY QUESTIONS

The survey began by asking respondents to describe their typical trip on a major freeway in either Houston or Dallas. Questions included: freeway traveled, time of day, origin, destination, trip purpose, mode, toll, parking cost, trip length, and trip frequency. Then respondents were asked a couple of questions regarding the mode they do use and why they do not use other modes. Based on their travel mode response, they were asked questions about the reasons why they chose that mode or why they did not choose other modes. For example, if a respondent chose HOV as the travel mode for his/her typical trip, questions regarding why he/she travels by HOV were prompted. Additionally, HOV and vanpool users were asked to rank the importance of the factors that influenced their mode choice on a scale of 1 to 5, with 5 indicating a very important factor. Respondents were then introduced to the concept of managed lanes and asked several questions regarding their feelings toward managed lanes and various pricing options.

Next, each respondent was asked four stated preference questions regarding his/her potential use of a freeway with managed lanes. The options and factors were kept to a minimum to reduce respondent error. There were always six choices with factors and levels as shown in Table 17. Although these calculations were fairly complex, they were transparent to the respondent who observed a stated preference question like that in Figure 31.

Finally, the survey obtained socio-economic characteristics for the respondent, including age, gender, ethnicity, household type, household size, number of vehicles, occupation, education, and income. The complete survey can be found in Appendix A.

Table 17. Stated Preference Factors and Levels.

Passengers	ML or GPL	Travel Time Based On	Toll
0	ML	The travel distance was based on the respondent's answer to that question. However, if the distance was shorter than 3 miles or greater than 30 miles, then 15 miles was assumed for distance. The travel speed was randomly chosen between 60 to 70 mph.	Based on a realistic value of travel time savings. The range was $1/hr to $70/hr. Respondent would first see a mid-range ($10/hr to $20/hr) value. Subsequent questions would yield a higher toll rate if the respondent selected the toll option and vice versa.

Table 17. Stated Preference Factors and Levels (Continued).

Passengers	ML or GPL	Travel Time Based On	Toll
1	ML	The time above plus an additional time for picking up and dropping off a passenger. If the respondent was a carpooler, then the time he/she supplied in the survey was used. If not, 5 minutes was assumed.	25 percent of respondents had a $0.00 toll. 25 percent of respondents had the same toll as SOV on ML. 50 percent of respondents had a random toll between 25 percent and 75 percent of the SOV toll on ML.
2	ML	The time above plus another additional time for picking up and dropping off the second passenger. If the respondent was a carpooler, then the time he/she supplied in the survey was used. If not, another 5 minutes was assumed.	50 percent of respondents had a toll of $0.00. The other respondents had tolls between $0.25 to the full value of the ML with one passenger toll charge.
0	GPL	The travel distance was based on the respondent's answer to that question. However, if the distance was shorter than 3 miles or greater than 30 miles, then 15 miles was assumed for distance. The travel speed was randomly distributed as follows: 10 percent uniform distribution between 60 and 70 mph but always less than ML, 35 percent uniform distribution between 40 and 50 mph, and 55 percent uniform distribution between 20 and 30 mph.	$0.00
1	GPL	The time above plus an additional time for picking up and dropping off a passenger. If the respondent was a carpooler, then the time he/she supplied in the survey was used. If not, 5 minutes was assumed.	$0.00

Passengers	ML or GPL	Travel Time Based On	Toll
2	GPL	The time above plus another additional time for picking up and dropping off the second passenger. If the respondent was a carpooler, then the time he/she supplied in the survey was used. If not, another 5 minutes was assumed.	$0.00

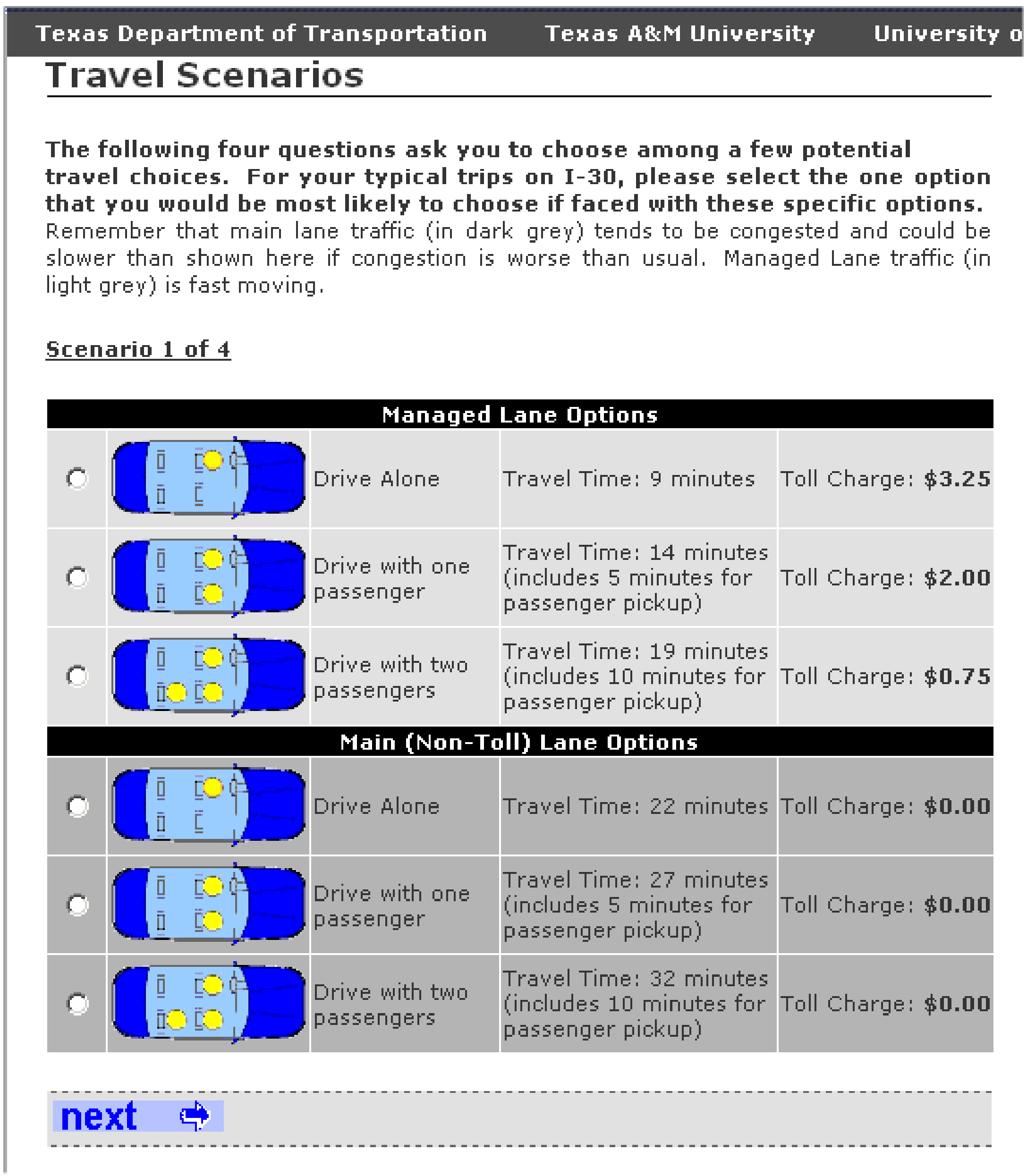


Figure 31. Sample Stated Preference Question.

STAKEHOLDER PARTNERS

Support and help from stakeholders was a critical aspect of disseminating the web address for the survey. The research team held meetings in person and via teleconference with various stakeholders in both Houston and Dallas (Table 18). The primary partners included metropolitan planning organizations (MPOs), department of transportation (DOT) district offices, toll agencies, transit agencies, transportation management agencies (TMAs), and newspapers. It was important to get their understanding and support early in the survey process since their involvement would be critical to placing the survey in view of a sufficient number of participants. After researchers discussed the project with the various agencies, all were willing to help provide traffic to the surveys, provided the researchers shared the survey results when it was complete. Once the major players were able to help, researchers contacted other organizations to increase the amount of outreach opportunities, including chambers of commerce, libraries, large employers, and transportation advocacy associations. A press release was also sent to media outlets in both cities explaining the project and survey.

Table 18. Stakeholders.

Organization	Dallas	Houston
Council of governments/ planning organizations	North Central Texas Council of Governments (NCTCOG)	Houston-Galveston Area Council (HGAC)
Transit agency	Dallas Area Rapid Transit	Metropolitan Transit Authority of Harris County
Toll agency	North Texas Toll Authority (NTTA)	Harris County Toll Road Authority (HCTRA)
TxDOT	Dallas District	Houston District
TMAs		TREK
Newspapers	The Dallas Morning News	The Houston Chronicle

PUBLIC AWARENESS

Not all stakeholders could help with outreach in the same format. Public awareness was done through different methods, ranging from simple (such as web link placements on homepages) to complex (handing out push cards at tollbooths). Outreach efforts were conducted for one month. Tables 19 and 20 identify all agencies contacted and their assistance in public awareness. The research team provided the organizations with all the material they needed to assist in reaching the public:

- **Brief write-ups**. The research team provided write-ups for newsletters and e-newsletters for agencies to send their members. A shorter write-up was provided with the survey web link for agencies to place on their homepages.
- **Push cards.** These cards were 5 inches by 3 ¾ inches and made of heavy paper, with English on one side and Spanish on the other side (Figure 32). Push cards were provided to agencies to hand out at customer service counters, agency events, and the Dallas toll booths.
- **Word of mouth.** Public awareness by word of mouth was used by organizations with meetings or functions during the survey. The research team provided a statement similar

to the write-ups provided to agencies sending out newsletters. One member of the organization read the statement and asked those in attendance to spread the word.

- **Email addresses.** The research team collected 96 email addresses from willing survey participants at the Houston-Galveston Area Council's Fresh Air Friday. This event, located in downtown Houston, attracted many employees from surrounding downtown businesses. Those who provided their email address were sent an email with the web address asking them to take the survey.
- **Press release.** The research team conducted a press release letting media outlets in Houston and Dallas know about the survey.

Table 19. Outreach Efforts by Dallas Stakeholders.

Primary Outreach	
NCTCOG	Newsletter Link on website Events—push cards
NTTA	Link on website E-newsletter—customers and political officials Events—push cards Customer service—push cards Toll booths—push cards
DART	Link on Park and Ride website
Dallas Regional Mobility Coalition (DRMC)	Placed in packets Mentioned at meeting
Newspaper	News article
Texas Section of the Institute of Transportation Engineers (TexITE)	Mentioned at meeting
Texas Transportation Institute Office	Push cards
Secondary Outreach	
City Council members	Emails
Hispanic community	Emails
Libraries	Flyers
Dallas Black Chamber of Commerce	Emails to members
Final Outreach	
Downtown driver licenses	Laptop
Southwest driver licenses	Laptop
Downtown driver licenses	Paper
Southwest driver licenses	Paper

Table 20. Outreach Efforts by Houston Stakeholders.

Primary Outreach	
HGAC Commute Solutions TMA meeting Fresh Air Friday Minipool	Link on website—Clean Cities E-newsletter Mentioned at meeting Emails E-newsletter
METRO	Newsletter E-newsletter Events—push cards
HCTRA	Link on website Link on website—EZ Tag Newsletter Customer service—push cards Printed on receipts
TREK	Events—push cards Link on website
TxDOT	Link on website—TranStar
Newspaper	News article
TexITE	Mentioned at meeting
Texas Transportation Institute Office	Push cards
Secondary Outreach	
State representative	Emails
Libraries	Push cards
Final Outreach	
Dover Street driver license	Laptop
Ripley House Neighborhood Center	Laptop
Dover Street driver license	Paper
Tidwell Road driver license	Paper

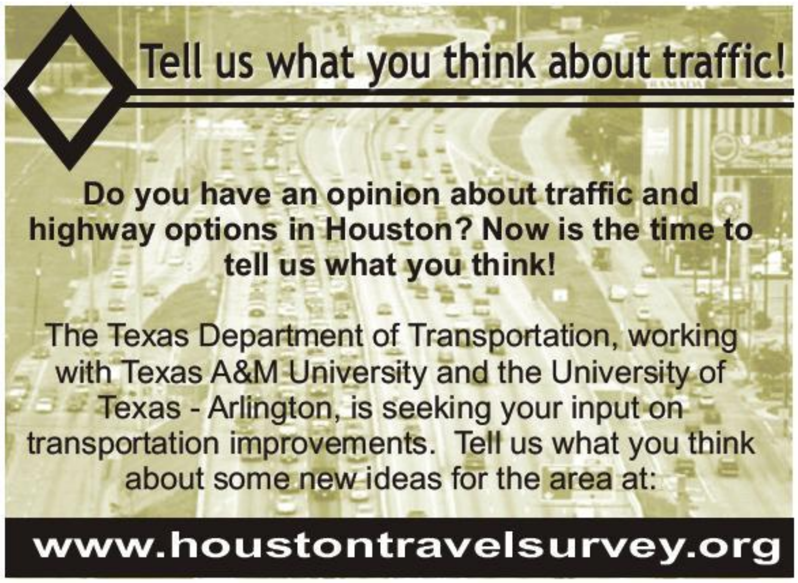


Figure 32. Houston Push Card.

WEB-BASED SURVEY

The survey was primarily conducted online using two websites (www.houstontravelsurvey.org and www.dallastravelsurvey.org) and was available in both English and Spanish. This facilitated customizing questions so that only relevant questions were asked to each respondent. For example, if the respondent indicated he/she never rode transit, then the only transit-related question he/she received was one asking why he/she chose not to ride transit. The web survey would also remind each respondent of the values he/she had indicated earlier so that the chances of confusion regarding questions would be minimized. Another advantage of the web-based survey was in the structure of the stated preference questions. It allowed questions associated with toll rate and travel time savings to be tailored based on the options selected in the previous question.

The primary advantage of using a web-based survey is that researchers can check real-time survey results throughout the duration of the survey. Before the web survey was activated, demographic data for both locations were collected from the U.S. Census. During the survey, the demographics of survey participants were examined to ensure the results matched the demographics of both metropolitan areas. This examination identified a lack of minorities—especially Hispanics and African Americans—and low-income households of $25,000 or less. Given the limitations of personal computer and Internet accessibility, this finding was expected and anticipated for further data collection efforts.

After the initial month of advertising for the survey, secondary outreach efforts were explored to capture the underrepresented populations. Communication with Dallas City Council members in minority and low-income districts, mapped by 2000 Census data, led to flyers being handed out at two City Council meetings. African American and Hispanic Chambers of Commerce were contacted in both Dallas and Houston. The Dallas Black Chamber of Commerce was the only organization to respond, which lead to emails to their membership list. Using the same demographic maps, libraries located in minority and low-income areas, in both cities, were sent push cards and flyers to post at reference desks or other locations permitted by the library. The City of Dallas public information officer agreed to establish links to the Spanish-language-only side of the City of Dallas website. Emails were also sent to a Dallas and Fort Worth list of active members of the Hispanic community. Houston's State Representative Garnet Coleman agreed to have his district director forward the email to an undefined list. Even with the secondary outreach efforts, more surveys completed by minorities and low-income individuals were needed.

Analysis of the survey respondents after these secondary outreach efforts indicated that the share of low-income respondents was not proportional to their share in overall population. This was perhaps due to unavailability of the Internet to low-income households.

MANUAL DATA COLLECTION

The research team decided that adding the in-field computer direct method at driver license office locations would be the best method for collecting additional responses from the underrepresented populations. Driver license office locations usually have long wait times (over an hour), which is ideal for allowing enough time to complete the 15-minute survey, and provides diverse demographics. Low-income and minority areas of Dallas and Houston were mapped in order to determine locations with the greatest possibility of providing the needed population. Once the locations were determined, visits were made in order to verify the demographics and assure the office layout would adequately suit the research team's needs for three to four laptops. Before surveys could be administered at the driver license office locations, permission from the Department of Public Safety's Driver License Division had to be granted. After a little persuasion, researchers were able to use three locations, two in Dallas and one in Houston. One disadvantage of this method is the need for multiple laptops. The research team was only able to acquire six laptops, requiring offsetting the days in Dallas and Houston to accommodate three laptops at each location. Each location had at least one researcher and one student assistant inviting those waiting to participate in the survey.

Incentives were offered to those who completed the survey, in hopes of increasing participation. The Travel Division of TxDOT provided Texas state maps, TxDOT's Texas Turnpike Division provided promotional pens, and the Texas Transportation Institute provided coloring books and crayons to those waiting with children or those adults who wanted to pass the time. In all, the costs of incentives were minimized, yielding an average $10 per day per location. Incentives provided to the survey participants seemed to attract more individuals for the computer survey versus the paper survey. People needed encouragement to leave their seats, or place in line, to take the survey, while the paper survey allowed them to say put while taking the survey.

Since only one location in Houston would allow laptop surveys, a neighborhood center located in the necessary demographic population provided another location to collect additional surveys. This community center offered an economically disadvantaged daycare and preschool program, yielding high traffic during the late afternoon. Since this time was after the main rush at the driver license office, using this location to intercept parents picking up their children was effective. The total number of surveys meeting the target demographic completed in two days in Houston was 85.

Surveys were conducted in two driver license office locations in Dallas. The Southwest Office had a shelf attached to the wall at chair height. This provided an ideal location to set up the laptops and not disturb the operations at this office. Although everyone waiting for service was invited to participate in the survey, only about 10 percent were willing upon invitation. The same process was used at the Downtown Office, except tables were needed to set up the laptops, and there were no power outlets to run the laptops. The surveys were conducted until the power in the laptops died. The total number of target surveys completed in Dallas in two days was 49—much less than in Houston, despite more favorable settings.

The total number of targeted surveys completed in both Houston and Dallas was 134—well short of the minimum target. A second trip to both cities was required. In order to increase participation in the survey (as attendees at the driver license office locations seemed hesitant to leave their place in line or chair to take the computer-based survey), the computer-based survey was adapted onto paper in English and Spanish. The paper-based survey maintained the same structured-random approach as the web-based survey (hence, every survey was different), but it lacked the adaptive response mechanism of the computer-based system.

In comparison to the computer-based survey, a paper survey allowed participants to remain in place while taking the survey. Initial results proved more effective in both Houston and Dallas, as percent participation noticeably increased. However, examination of the surveys after the first day revealed confusion about how to answer some of the questions. On the second day, while handing out the surveys, researchers explained how to answer the questions, yielding a better return of useful surveys.

OUTREACH RESULTS

In addition to typical web statistic tracking (including domain, referrer, and Internet provider tracking), there was also a question on the survey asking how they found out about the survey. Table 21 indicates the source of their knowledge about the survey. In Dallas, a majority of survey respondents found the survey on another website (50.6 percent), which is verified by viewing referral logs—most came from participating agencies, such as Dallas Area Rapid Transit, North Texas Turnpike Authority, and the City of Dallas. Almost a third responded with “other or no answer.” In Houston, the number one response (36.8 percent) was “news article” (also verified by referral logs from the Houston Chronicle and two television stations), followed closely by “website link” (35.0 percent). Only 10.7 percent of Houston respondents replied “other or no answer.”

Table 21. Outreach Results.

Source of Survey	Dallas	Houston
News article	4.4 percent	36.8 percent
TV article	0.1 percent	2.6 percent
Tollbooth card	2.4 percent	0.6 percent
Bus/train card	0.1 percent	0.1 percent
Traffic signal/road card	0.0 percent	0.0 percent
Employer email	7.8 percent	5.7 percent
Website link	50.6 percent	35.0 percent
Family/friend	5.1 percent	8.3 percent
Other/no answer	29.5 percent	10.7 percent

With various outreach efforts made to increase public awareness of the survey and to encourage participation from low-income and minority groups, the survey generated a total number of 4634 responses, with 2026 from the Dallas/Fort Worth (Dallas) area and 2608 from the Houston area.

CHAPTER 4. SURVEY DATA ANALYSIS

The survey responses were used for two primary analysis purposes: (1) descriptive statistics about the nature of carpools, carpoolers, and general interest in managed lanes; and (2) development of a mode choice model that predicts the decision-making behavior of drivers when presented with different managed lane options. In this chapter, we first describe the survey data and weighting procedures that are used for data refinement. We then present analysis results, including responses to carpool issues, interest in managed lanes, and mode choice propensity under hypothetical pricing and highway system conditions. We conclude the chapter with a summary of the findings and discussion of the implications.

SURVEY DATA

Table 22 presents race/ethnicity, income, and travel mode distributions of the survey sample. It also compares the sample with the 2005 American Community Survey (ACS) data representing the general population in the Tarrant, Denton, Collin and Dallas counties for the DFW area, and Harris, Montgomery and Fort Bend counties for the Houston area *(82)*.

The results show that the survey sample consists of a large proportion of white and high-income survey respondents as compared to the 2005 ACS population for the two areas. The travel mode distribution is close to the 2005 ACS, with a slightly high proportion for the non-single occupancy vehicle (SOV) groups. In addition, about 31 to 43 percent of the survey respondents are current toll road users.

WEIGHTING OF SURVEY DATA

In order to more accurately represent the general population in each metropolitan area, weights were developed to adjust the survey sample for analysis of interest in managed lanes. Procedures for weighting the survey data included three major steps:

1. create data weighting parameters according to census data;
2. adjust the percentage of interest in managed lanes based on the weighting parameters created at step 1; and
3. adjust scores for given reasons using the weighting parameters.

THE REPLICATE WEIGHTING PROCESS

The sampling design for this survey of ML travelers was simple random sampling (SRS) followed by post-stratification. Due to this data collection method, the statistical formulas and methods developed for survey analyses on SRS data were inappropriate. SRS would imply that for each stratum, the proportion of respondents in the sample was the same as the proportion in the population. The sample proportions for this survey were not equal to population proportions for each stratum, necessitating a weighting process using replicate weights.

Table 22. Comparison of Survey Sample and The 2005 ACS.

	Dallas		Houston	
	Survey	ACS2005	Survey	ACS2005
Race/Ethnicity				
White	78.0%	57.68%	75.0%	48.54%
African-American	8.1%	14.97%	7.2%	17.06%
Hispanic	6.9%	20.22%	10.6%	27.04%
Asian	2.9%	5.17%	3.8%	6.02%
Native American	1.3%	0.35%	0.8%	0.23%
Others	2.8%	1.62%	2.6%	1.10%
Total	100%	100%	100%	100%
Income				
Less than $15,000	4.4%	12.14%	3.8%	13.95%
$15,000 to $24,999	2.6%	11.20%	2.4%	12.32%
$25,000 to $34,999	4.6%	11.61%	5.4%	11.42%
$35,000 to $49,999	10.7%	15.43%	10.6%	14.80%
$50,000 to $74,999	17.2%	18.62%	19.4%	17.74%
$75,000 to $99,999	19.0%	11.93%	18.9%	10.80%
$100,000 to $199,999	34.4%	15.17%	33.2%	15.12%
$200,000 or more	7.1%	3.91%	6.2%	3.86%
Travel Mode *				
SOV	74.8%	80.2%	64.8%	78.0%
HOV2	12.4%	8.7%	14.1%	9.2%
HOV3+	3.4%	3.0%	5.3%	3.6%
Transit	7.0%	1.7%	10.0%	3.1%
Other	2.4%	6.5%	5.8%	6.2%

*Travel mode in the survey refers to a mode used for typical trips at the time of survey. ACS travel mode refers to commute mode for workers aged 16 and over.

In SRS, the sampling weights are fixed depending on the proportions of each stratum in the population. If the sampling plan is not SRS, the sampling weights (pweights) developed post-stratification depend on the given sample size. In other words, the sampling weights are random. They cannot be used like fixed weights to conduct tests of proportions or for testing other hypotheses. This is because a non-SRS methodology results in higher standard errors (SE) for the estimates. An assumption of fixed weights (with SRS) would imply lower SE. Thus, using fixed weights may lead to some results from non-SRS surveys being found statistically significant when in fact they are not.

To address this issue, replicate weights were calculated using post-stratification weights as the input. Income (four groups), ethnicity (four groups), and toll-road usage (two groups) were used as the criterion for computing the post-stratification weights (pweight). The formula for the pweight calculation is:

$$pweight = \% \, pop_i \, / \, \% \, sample_i \tag{1}$$

where:

$\% \, pop_i$ = percentage of the population in stratum *i* and

$\% \, sample_i$ = percentage in the survey sample in stratum *i*.

$strata_i$ = group (or strata) of the survey.

For example, one stratum could be Caucasians with annual household incomes less than $25,000 who traveled on a toll road. The post-stratification weights for the survey were computed using an iterative procedure. The final pweights were used to adjust the survey sample from each city (Houston and Dallas) to match that city's population (based on the 2005 American Community Survey data and average annual daily traffic volumes) in all 16 strata (four income groups by four ethnic groups) *(82)*.

Next, replicate weights were used to calculate a better approximation of the standard error of the full sample estimates. The method used to calculate replicate weights begins with dividing the sample into sub-samples. The same 16 sub-samples or strata (per city) were used with the replicate weights as were developed for the pweights. Next, the estimate of interest is calculated from the sub-sample and the full sample. The difference between the estimates of interest in the full sample and each of the sub-samples is used to get the standard error of the estimate.

For example, assume $\hat{\theta}$ is the full-sample estimate of some population parameter θ, for example, the mean. The variance estimation $\sigma^2(\hat{\theta})$, is given by:

$$\sigma^2(\hat{\theta}) = \frac{c \sum_{g=1}^{G} (\hat{\theta}_g - \hat{\theta})^2}{G-1} \tag{2}$$

where:

$\hat{\theta}_g$ = estimate of θ based on the observations included in the g^{th} replicate (sub-sample),

G = total number of sub-samples (or replicates formed), and

c = a constant depending on the replication method. For Jackknife-n, c = 1. *(83)*

Different methods of creating sub-samples yield different kinds of replicate weights. Since this survey of ML travelers had more than two primary sampling units per strata (Houston road, Dallas road, neither of the given roads in Houston or Dallas, or missing location), the Jackknife-n (JK-n) method was the only appropriate method. For the JK-n method, the formula for variance estimation is modified as shown in equation 3.

$$\sigma^2(\hat{\theta}) = \frac{c \sum_{g=1}^{G} f_g \, h_g \, (\hat{\theta}_g - \hat{\theta})^2}{G-1} \qquad \textbf{(3)}$$

where:

h_g = a factor specific to JK-n methodology,

f_g = finite population correction factor, and

g = replicate number.

The finite population correction factor (f_g) is estimated using equation 4 *(84)*. In both Houston and Dallas this value was extremely close to 1.

$$FPC \;=\; [\,(N-n)\,/\,(N-1)\,]^{1/2} \qquad \textbf{(4)}$$

where:

N is total population, and

n is total sample size.

The number of replicates, *G,* is equal to:

$$G = \sum_{h=1}^{L} n_h \qquad \textbf{(5)}$$

where:

L = number of strata (16 in our case), and

n_h (varies from 2 to 4) = number of primary sampling units (PSU) in the stratum *h.*

G totaled 39 for our survey.

The methodology for replicate weight creation is given in detail in WesVar Manual *(85)*:

> For computation of first replicate weight, the full sample of observations in the first stratum and first PSU are given a weight of zero and the weights associated with the other PSU in the same stratum are adjusted by $n_h / (n_h - 1)$ [in our case often 2] to account for reducing the sample. The weights for observations in all the other strata are not changed. The remaining replicates for the stratum (weights and θ_g) are formed in the same manner by systematically dropping each of the remaining PSUs for that stratum and computing the replicate weights in a manner similar to computation of the first replicate weight.

Then each stratum is done in a similar manner.

RESPONDENCE TO CARPOOL ISSUES

In the survey, respondents who identified themselves as carpool users were asked a number of questions regarding reasons for carpooling, types of carpooling, and carpool formation time. The analysis results of the responses are presented in this section. In addition, SOVs' responses to reasons for NOT carpooling are also presented to provide information about the SOVs' perspective. Note, data for carpool analysis were **not weighted** due to three reasons: (1) the sample size of carpoolers was too small to yield significant observations for carpool questions by race/ethnicity and income; (2) the carpool sample catches the population that is most likely to be affected by managed lane policies because middle- or high-income users are choice carpoolers; and (3) research on carpool decisions and formation of this specific population will provide useful information for managed lane policy-making.

Reasons for Carpooling

In the survey, respondents who identified themselves as carpool users were given a list of literature-based reasons that might affect decisions on carpool formation. They were asked to rate them on a scale of importance from 1 to 5, with 1 indicating the least important and 5 being the most important. SOV travelers were asked to identify their main reason for *not* carpooling.

Table 23 summarized HOV respondents' mean rankings of importance among the 14 potential options proposed. There were between 84 and 89 percent response rates on most of the potential factors in their decision. Access to HOV lanes and relaxation while traveling had the top two mean scores at 3.77 and 3.60, meaning these factors are between somewhat important to important in carpooling decision-making. Although relaxation was important to those who marked a response on it, almost 90 percent of HOV respondents did not care to rate its importance. Access to HOV lanes, however, was a strong factor with over half of carpoolers giving it a "very important" rating, and another 16 percent giving "somewhat to very important." Only 17.5 percent rated HOV lane access as not at all important in their decision to carpool. This finding was similar to that of the 2005 Bay Area annual commuter survey, where about 54 percent of commuters with a carpool lane available on their route to work reported the influence of a carpool lane on their decisions to use the HOV mode *(47)*.

The results also indicated that enjoying travel with others, environmental and social consideration, travel time saving, and vehicle cost sharing carried slightly more weight on average than "somewhat important." The distribution of importance given to enjoyment of traveling with others was relatively even with about one-fifth of HOV respondents rating it at no importance, and just 8 percent rating it less important, while 21 percent, 23 percent, and 27 percent, respectively, rated it from "somewhat important" to "very important."

Environmental and social considerations proved to be at least somewhat important 80 percent of the time, and not at all important to only 20 percent of HOV respondents. Those who ranked it with a 3, 4, or 5 were relatively evenly distributed at 22 percent, 23 percent, and 25 percent, respectively.

Table 23. Reasons for Carpooling.

Factors	Frequency Selected	Percent of Total (N = 789)	Mean Score	Std. Deviation
Access to HOV lanes	699	89 %	3.77	1.54
Relaxation while traveling	77	10 %	3.60	1.38
Enjoy travel with others	691	88 %	3.26	1.48
Help Environment and Society	684	87 %	3.23	1.45
Travel Time saving	690	87 %	3.16	1.68
Other	109	14 %	3.16	1.89
Sharing vehicle expenses	703	89 %	3.15	1.70
Reliability of arrival time	666	84 %	2.93	1.66
Splitting tolls on toll roads	159	20 %	2.38	1.61
Get work done while traveling	79	10 %	2.24	1.52
Drop off kids at school/day care	674	85 %	2.23	1.60
Carpool partner matching program	680	86 %	2.07	1.44
Encouraged by program at work	677	86 %	2.00	1.40
Preferred parking at work	687	87 %	1.94	1.40

Travel time-savings showed a bipolar importance distribution with 31 percent ranking it not important at all and 35 percent ranking it very important, and the remainder fall in between. Some carpoolers clearly perceived travel time-savings offered by HOV lanes while others did not. A further analysis of ranking by trip purpose shows that 45 percent of commute/work related trip makers gave the highest mark to the time saving factor, as compared to only 17 percent of other trip makers did so.

Splitting tolls on toll roads does not appear to be an important factor in carpool formation. Even lower were the influences of traditional TDM programs, such as carpool matching and employer-based incentives. Although there were small numbers of carpoolers who rated carpool matching programs, work programs, and preferred parking at work with some amount of importance, about 57 percent to 63 percent majorities expressed that these potential factors were "not at all important" to their decision to carpool. The mean scores of these factors were about 2.0 as shown in Table 22. This indicates that either such programs were not widespread enough to be effective, or that there were structural inhibitors that outweigh the incentives such programs offer, or that many of the carpools were comprised of family who did not require these incentives. Answers summarized in the section on why SOV users do not carpool would suggest that structural factors, such as difficulty in forming carpools and the need for flexibility are potential reasons.

To investigate variation among carpoolers in the rating of factors influencing their mode choice decisions, we further analyzed the reasons for carpooling by gender, trip purposes, and carpool composition. The results are summarized in Table 24 and discussed below.

Table 24. Differences in Reasons for Carpooling.

Factors	Gender		Trip Purpose		Fampool	
	Female	Male	Commute & Work	Other	Yes	No
Access to HOV lanes	3.88*	3.68*	4.06***	3.28***	3.64**	4.07**
Relaxation while traveling	3.69	3.50	3.46*	4.13*	3.57	3.65
Enjoy travel with others	3.44**	3.11**	3.17*	3.42*	3.29	3.20
Help Environment and Society	3.38**	3.09**	3.36**	2.99**	3.13**	3.45**
Travel Time saving	3.33**	3.01**	3.50***	2.58***	2.97***	3.58***
Other	3.45	2.98	3.07	3.21	3.23	2.97
Sharing vehicle expenses	3.33**	2.98**	3.53***	2.47***	2.89***	3.74***
Reliability of arrival time	3.19***	2.71***	3.27***	2.33***	2.75***	3.36***
Splitting tolls on toll roads	2.40	2.36	2.60**	1.95**	2.05***	3.17***
Get work done while traveling	2.34	2.05	2.04*	2.79*	2.32	2.04
Drop off kids at school/day care	2.61***	1.89***	2.21	2.26	2.43***	1.78***
Carpool partner matching program	2.14	1.99	2.18**	1.86**	1.97**	2.28**
Encouraged by program at work	2.08	1.93	2.10**	1.82**	1.88**	2.26**
Preferred parking at work	2.10**	1.79**	2.00	1.84	1.82**	2.21**

*** p < .000 ** p < .01 * p < .05

Gender Differences

Data showed that females consistently gave higher scores to all factors than males did, and that gender differences are statistically significant at the .05 level on most factors being studied. For instance, it is notable that 33 percent of females rated enjoyment as a very important reason as compared to 23 percent by males. On the other hand, only about 18 percent of the females rate the factor as not important at all as compared to 24 percent of the males. A similar, though more defined, pattern emerges regarding travel time-savings, where there is a 10 percent difference between females and males in rating this factor as very important, 40 percent of females versus 30 percent of males. In comparison, about 27 percent of females and 34 percent of males rated it as "not important at all." Environmental and societal considerations reveal roughly the same pattern but with a less bipolar distribution, and sharing vehicle expenses matches the pattern, too. Consistent with the overall rating, both males and females give the factor of access to HOV lanes the highest average rating scores among all the factors, as shown in Table 24. A chi-square test demonstrates that female and male are statistically different at rating on access to HOV lane at the .05 level.

While the average rating scores for dropping off kids at school/daycare by females and males were lower than many other factors, there was a significant gender difference in the ratings of this factor, with an average of 2.61 by females and 1.89 by males. For example, about 26 percent of females rated this factor very important, as compared to about 12 percent males. On the other hand, about 47 percent females considered this factor as "not at all important," as compared to 66 percent of males. These findings were consistent with previous findings in gender differences in family roles, travel patterns, and effects of travel demand management strategies.

The genders are relatively united in their assessment of carpool programs, as both gave these factors the lowest average rating scores among all the factors. In fact, 50 ~ 67 percent of both females and males stated that all of these three reasons carried no importance for them. However, there was a gender difference in the average score of the factor of preferred parking at work.

Trip Purpose Differences

For this analysis, commute and work-related trips were combined into one category and all other recreational, social, and personal business into the other category (Table 24). There was a statistically significant difference between carpoolers making commute/work trips and those making non-commute/work trips in the ranking of most carpool enticing factors, except a few factors, such as dropping off kids at school/daycare, preferred parking at work, and other. Results of the analysis indicated that commute and work-related trip makers tended to rate certain factors, such as access to HOV lanes, travel time saving, sharing vehicle expenses, reliability of arrival time, help environment and society, etc. higher than other trip makers. For instance, access to HOV lanes was very important for 62 percent of commute/work carpoolers but only for 32 percent of non-work purpose carpoolers. For commute/work carpools, travel time savings were cited as very important 45 percent of the time, while for non-work they were rated that highly only 17 percent of the time. On the other hand, only 23 percent of commute/work carpools said time savings were not important at all while 43 percent of non-work carpoolers did not care about time savings. Similar patterns were also found in the reliability of arrival time factor, vehicle and toll cost sharing factors, as well as the factor of help environment and society.

As to be expected, non-work carpoolers gave higher ratings to such factors as enjoyment traveling with others and relaxation while traveling than commute/work carpoolers, as seen from the average rating scores of these factors shown in Table 24.

Mirroring what was seen with gender, carpoolers with different trip purposes were also united in their assessment of carpool incentive program factors. Both commute and non-commute trip makers gave low ratings in importance of these factors, ranging from 2.0 ~ 2.18 by commute and work trip makers and less than 2.0 by other trip makers. However, there is a statistically significant difference in the rating of carpool partner matching programs and carpool programs through work. This is expected because most carpool incentive programs have been provided to target commute trips.

Fampool Differences

Analysis of variation in decision factors by carpool composition indicates that fampoolers tend to rate a number of factors higher than non-fampoolers. These factors are "drop off kids at school/daycare" and "enjoy travel with others." On the other hand, non-fampool respondents on average rated other factors higher, especially travel time and cost related factors. For example, the average rating of the access to HOV lane factor was 4.07 by non-fampoolers, as compared to 3.64 by fampoolers. Similarly, the mean score for importance of the travel time saving factor was 3.58 by non-fampoolers, as compared to only 2.97 by fampoolers. Similar comparisons between non-fampoolers and fampoolers can be found in the average rating scores of such factors as vehicle cost sharing, travel time reliability, and toll cost sharing. Differences in mean scores are significant for most factors, except for such factors as relaxation, enjoy traveling with others, getting work done while traveling, and other (see Table 23).

Again, overall ratings for the three carpool incentive programs were low. But non-fampoolers on average tended to rate them higher than fampooler, with 2.21 ~ 2.28 by non-fampoolers as opposed to 1.82 ~ 1.97 by fampoolers. A Chi-square test demonstrates that these differences are statistically significant at the .01 level. These differences can be attributed to the observation that fampool trips are more social and recreation in nature than non-fampool trips. For example, about 79 percent of non-fampool trips were commute and work related, as compared to 51 percent of fampool trips were for the same purpose.

Reasons for Not Carpooling

The respondents who indicated SOV as their primary mode choice were later asked to judge their most important reasons for *not* carpooling, and were allowed to check all that apply from the list in Table 25.

The most important reasons cited were difficulty of finding someone with the same location and schedule, flexibility of driving alone, and needing vehicle during the day, with 55 percent, 45 percent, and 39 percent of SOV respondents, respectively, attributing them with primary importance in their decision-making (Table 25). The need for making chain trips was perhaps a little less important but still notable with 28 percent choosing it. Again, these findings are also factors cited more frequently by NPTS survey respondents and commuters in the Bay Area *(86, 87)*.

Table 25. Factors Associated with the Decision to NOT Carpool.

Main Reasons	Frequency	Percent of Total SOV Users
Location and schedule limitation	1682	55 %
Travel flexibility	1394	45 %
Need a vehicle during the day	1190	39 %
Need to make other stops during trip	862	28 %
Appreciate alone time	567	19 %
No program to encourage me	417	14 %
Like to listen to radio that others do not	175	6 %
Potential partners have disagreeable traits	125	4 %
Other	248	8 %

Who Is Carpooling Together?

In the survey, carpoolers were asked whom they traveled with on their most recent trip. The results of the responses by HOV2 and HOV3+ travelers are shown in Table 26. Results exceeded 100 percent as survey respondents could check more than one passenger type when appropriate. Overall, HOV users carpooled with their family members most of the time. When the rates of adult family member and child carpools are combined, 66 percent of responses included those two. The second most popular type of carpool was between co-workers and/or someone who worked in a nearby office building. The prevalence of this type of carpool was about 26 percent. Casual and neighbor carpools were both marked about three percent of the time, and examples of other types of carpools, which made up about three percent of the responses, include boy/girl friends, roommates or housemates, as well as significant others. One possible reason for a higher percentage of fampooling in our data is that our sample includes all types of trips, whereas most previous studies focused on commute trips only. It may also be an implication of location difference.

Table 26. Types of Carpools and Formation Frequencies.

	HOV2		HOV3+	
TYPE OF CARPOOLER*	Frequency	Percent of Valid Responses	Frequency	Percent of Valid Responses
Adult Family Member	308	54%	84	44%
Co-Worker/Nearby Office Building	141	25%	51	27%
Child	70	12%	41	21%
Casual Carpooler	14	2%	7	4%
Neighbor	10	2%	5	3%
Other	23	4%	3	2%

*Survey respondents were asked to check all that apply

Carpool Formation Time

Carpoolers were asked to enter in the amount of time, in minutes, it takes them to form their carpools. In other words, how much extra time they spent picking up and dropping off their passengers that they otherwise would have saved by traveling straight to work. In line with our findings about fampools, 55 percent of HOV2 and 42 percent of HOV3+ users reported they spent no extra time due to their carpools (Table 27). Another 21 percent of HOV2 and 23 percent of HOV3+ took five or fewer minutes to do so, indicating that either their passengers live very close to their routes to work, or they have made some special arrangement to minimize time for carpool formation. An additional 11 percent of HOV2 and 14 percent of HOV3+ spent six to 10 minutes, meaning that a full 86 percent of HOV2 respondents and 79 percent of HOV3+ respondents spent 10 minutes or less in carpool formation. The remaining spent 11 or more minutes doing so. The average time of carpool formation was about five minutes with a standard deviation of 8.3 for HOV2s, and 7.8 minutes with a standard deviation of 13.1 for HOV3+s. The short time for carpool formation is mainly attributed to fampool, as about 65 percent and 54 percent of HOV2 and HOV3+ fampools took no extra time for carpool formation. These results dovetailed with the reasons for carpooling given the importance attributed to travel time savings and access to HOV lanes, the latter of which probably contains at least some amount of time savings motivation. They also fit with the top two reasons SOV users gave for not carpooling, namely location or schedule limitations and travel flexibility.

Table 27. Carpool Formation Time.

EXTRA TIME FOR FORMING CARPOOL	HOV2		HOV3+	
	Frequency	Percent of Valid Responses	Frequency	Percent of Valid Responses
0 Minute	278	55 %	69	42 %
1 – 5 Minutes	100	20 %	37	23 %
6 – 10 Minutes	56	11 %	23	14 %
11 – 15 Minutes	41	8 %	17	10 %
16 – 30 Minutes	29	6 %	12	7 %
31 – 90 Minutes	5	1 %	6	4 %

Our data also supports evidence of a significant amount of “fampooling” or family-based carpools, with two thirds of carpools consisting of family members. Carpooling with adult family members and children was the most popular type of carpool formed by our survey respondents. “Acquaintance” carpools of casual carpool partners and neighbors were the least common in our sample, with carpools between co-worker and/or someone from nearby office building as the second most popular type of carpool.

Our results support earlier findings on fampooling. For example, in examining the 1977-1978 National Personal Transportation Survey (NPTS) data, Teal found that over 40 percent of carpoolers commuted with household members *(86)*. This notion of “fampooling” was supported by Pisarski and later studies *(88)*. As summarized by Poole and Balaker, commute surveys from 1998 and 2003 in the San Francisco bay area estimated fampools to make up 35 percent and 33 percent of carpools respectively, and a 1994 study in southeastern Wisconsin also estimated 33 percent fampools *(6)*. In southern California, fampooling increased from 49 percent to 55 percent from 1996 to 1999, while a recent Minneapolis/St. Paul study found it to be 67 percent *(6)*. In Houston, a previous study found that between 70 to 75 percent of carpools were fampools *(89)*. A nationwide estimate of all work commute carpools chronicled an increase of fampools from 75.5 percent to 83 percent for 1990 to 2001 *(43)*. Additionally, two of these studies estimated just two percent and eight percent of the type of work carpools between strangers that HOV policies supposedly encourage *(6)*.

Summary

In this section, an analysis was completed to investigate some of the reasons behind carpool formation along with how some carpools were formed. In addition, the research compared reasons for carpooling with those for driving alone using survey data from the DFW and Houston areas. Data indicated that the ability to use HOV lanes was rated by carpool users as the most important factor in their decision to form a carpool. Enjoying traveling with others was the second most popular factor for carpool formation. Other factors such as travel time-savings, helping the environment and society, and sharing vehicle cost were also highly ranked. Results of data analysis also indicated that among the 87 percent of carpoolers who gave ratings for travel demand management options, such as carpool partner matching program, encouraged by program at work, and preferred parking at work, as factors for consideration of carpooling, most of them ranked these the least important factor in mode choice decision-making.

Results of data analyses also showed that differences existed in rating of carpool mode choice factors by gender, trip purpose, and carpool composition. Female carpoolers gave higher scores to all reasons for carpooling than male carpoolers did. There was a significant gender difference in ranking of travel time- and family-related factors for carpooling. Commute/work related carpoolers and non-fampoolers tended to rank such factors as access to HOV lanes, travel time saving, and sharing vehicle cost higher. In comparison, non-commute carpool trip makers and fampoolers tended to rank such factors as enjoyment of travel with others and relaxation higher. Although travel demand management options were consistently ranked as less important factors, females, commute/work related trip makers, and non-fampoolers tended to rate them higher than their respective counterparts. The most commonly selected reasons for not carpooling given by SOV users were limited to location and schedule for carpooling, followed by flexibility of driving alone and needing vehicles during the day. By and large, our findings in gender, trip purpose, and carpool composition differences reflect previous findings.

Our data also conformed to the fampool findings by Teal, Pisarski, Poole and Balaker, and other regional studies *(6, 86, 88)*. Carpooling with adult family members and children was the most popular type of carpool formed by our survey respondents. Casual carpool partners and neighbors were the least common in our sample. In addition, the data showed that the average time taken to form a carpool was about 5 minutes for HOV2 and about 8 minutes for HOV3+. The short time for forming a carpool was due to large portion of fampools.

Our findings on carpool formation seem to support the arguments that many carpools are formed regardless of HOV policies and that taking away HOV preferential treatment may impact only a portion of carpoolers. However, our findings on *why* people carpool suggest that we should also be cautious about HOV preferential treatment and other carpool incentive policies. The finding of HOV lanes access as the most important reason for carpooling implies that giving HOVs certain preferential treatment does provide incentive to carpoolers, especially commute/work trip makers as evident in our findings on differences in rating of reasons between commute/work trip carpoolers and other carpoolers. Those specific policies related to HOV preferential treatment in managed lanes require further investigation after implementation because current attitudes are based on existing perceptions rather than actual experiences. As such, future HOV policies for managed lanes should be continuously reviewed for possible changes and improvements to meet any new opportunities. While arguably not the most efficient, HOT lanes can reduce the capacity penalty and congestion penalty of HOV lanes by introducing a pricing concept. The key is to set a price that can minimize the penalties. Furthermore, there may be social justice reasons for considering HOV preferential treatment, as evidenced in this paper and other studies that females, minority, and the economic disadvantaged make up a higher proportion of HOVs than their respective counterparts. Similarly, the notion of dominating fampools, along with findings of relatively higher rating of carpool incentive programs by females and commute/work trip makers suggest the need to search for effective policies that can address the needs of female and fampool commuters.

RESPONSES TO MANAGED LANES

This section focuses on the following questions related to managed lanes:

- Will travelers in different cities react to MLs differently?
- What reasons do travelers give for being interested in using MLs or not interested in using them? Also, do these reasons change based on current mode of travel?
- Will previous toll lane users be more likely than others to use MLs?
- Are there specific characteristics that may be common among ML supporters or opponents?

The section is divided into subsections that individually address these questions. All of the analyses are based on the weighted data using the replicate weights described above. The first consideration in the analysis is the level of interest in MLs by group. Comparisons between the different groups are made and the differences are tested for statistical significance using a t-test (with the means and variances developed using replicate weights). The p-values indicate the probability that the results from each group are statistically the same. For a level of confidence of 95 percent, a p-value of 0.05 or less indicates a significant difference between groups.

One of the main questions examined here is the respondent's initial reaction to ML concept and their interest in using it (See Figure 33 for the survey questions as taken). Overall, approximately 70 percent survey respondents expressed an interest in using managed lanes. Interest in MLs did not differ significantly by trip purpose.

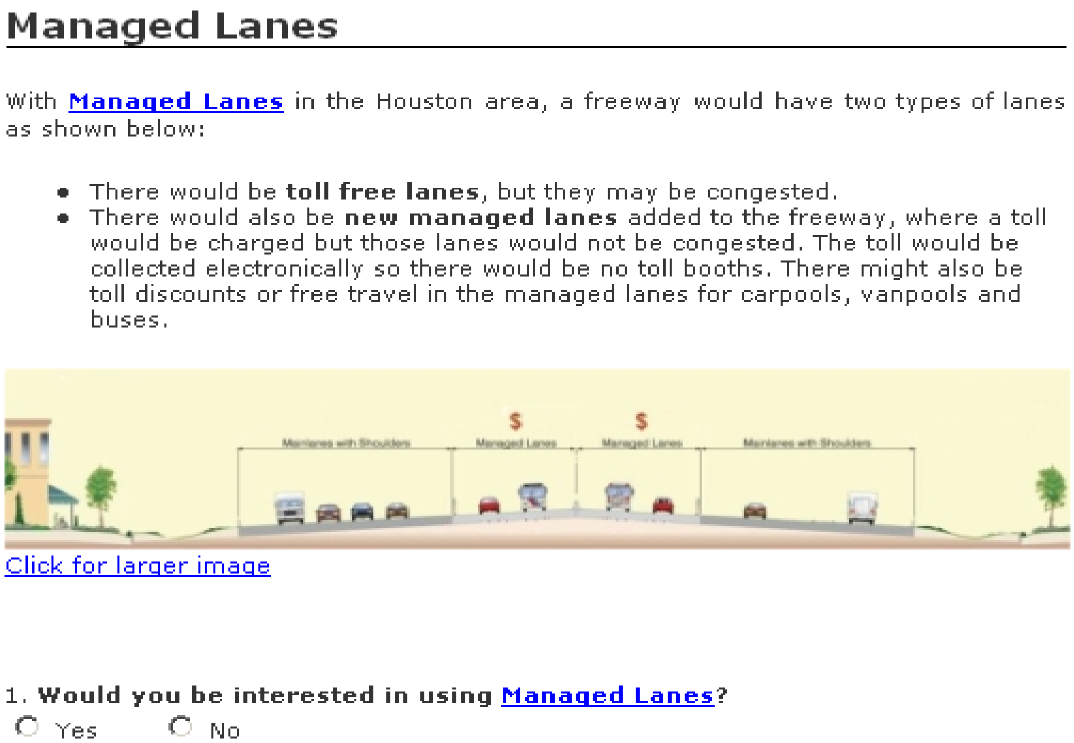


Figure 33. Survey Question on Managed Lanes.

Another critical issue is whether the respondent ever selected a managed lane option in any of the four stated preference questions. This is another gauge of the respondent's interest in managed lanes – and possibly more accurate than just asking them if they were interested. We have also split the data set into two groups using the answers to the four stated preference questions and analyzed the characteristics of respondents in these two categories:

- Those that never selected a managed lane option, and
- Those who selected a managed lane option at least once.

Descriptive Analysis of the Data

Next, descriptive statistics were developed using both the replicate weights and the fixed (or p) weights. This information was used to help determine what variables would most likely be included in the mode choice model (discussed below) and provide some insight into the impact of using replicate weights. The analysis divided the sample into two groups: (1) respondents who selected a managed lane option in at least one of the four stated preference questions (approximately 72 percent of respondents) and (2) respondents who never chose a ML option. The results of this analysis are provided in Table 28. Significant p-values indicate the respondents with that characteristic selected a ML option significantly more or less than respondents with the other characteristics. For example, travelers with a trip purpose of "other" were significantly less likely to choose a ML option than all other travelers combined.

As shown in Table 28, the means calculated using the replicate and fixed weights are the same; it is the standard deviations which change. In general, the standard deviations calculated by the replicate weighting method were larger, and therefore the probability (p-values) were also larger, indicating a lower likelihood that the differences observed were statistically significant. In the categories listed in Table 28, 13 were found to be significantly different using pweights, but the correct method, using replicate weights, found only 6 significant differences. The differences were not surprising, and respondents more likely to chose a ML option:

- were not on a trip purpose categorized as "other,"
- were younger than 65 years old,
- were traveling on a Dallas toll road,
- had one vehicle per household,
- had a household income between $35,000 and $49,999, and
- had a household income greater than $100,000

Table 28. Descriptive Statistics of Survey Respondents Choosing a ML Option.

Characteristics	N	Replicate Weights		P Weights	
		Choose ML (%)	p-value (%)	Choose ML (%)	p-value (%)
Trip Purpose					
Commute	2,364	71.6%	0.40	71.6%	0.40
Recreational	651	74.8%	0.26	74.8%	0.18
Work related	582	69.4%	0.33	69.4%	0.30
School	154	77.0%	0.31	77.0%	0.29
Other*	93	52.5%	0.01*	52.5%	0.04*
Road					
Houston: Beltway 8 (only Houston toll road in list)	106	79.3%	0.13	79.3%	0.03*
Houston: All other roads listed	2,178	72.2%	0.35	72.2%	0.32
Dallas: George Bush Turnpike and Dallas North Tollway (only Dallas toll roads in list)	219	80.0%	0.00*	80.0%	0.00*
Dallas: All other roads listed	1,203	67.1%	0.10	67.1%	0.01*
No road selected	182	78.7%	0.22	78.7%	0.16
Time of Travel (multiple answers allowed)					
Early a.m. (midnight – 6 a.m.)	513	68.8%	0.29	68.8%	0.26
Peak a.m. (6 a.m. - 9 a.m.)	2,190	72.1%	0.37	72.1%	0.36
Midday (9 a.m. - 4 p.m.)	1,080	71.9%	0.40	71.9%	0.40
Peak p.m. (4 p.m. - 6:30 p.m.)	1,929	73.2%	0.24	73.2%	0.16
Late p.m. (6:30 p.m. - midnight)	649	74.4%	0.29	74.4%	0.23

Table 28. Descriptive Statistics of Survey Respondents Choosing a ML Option. (cont.)

Characteristics	N	Replicate Weights		P Weights	
Typical Trip Length					
Short (0-3 miles)	140	65.4%	0.31	65.4%	0.24
Medium (4-9 miles)	582	70.4%	0.38	70.4%	0.34
Long (10-20 miles)	1,736	72.1%	0.39	72.1%	0.38
Very Long (more than 21miles)	1,206	72.7%	0.37	72.7%	0.34
Pay to Park at Destination					
Yes	599	68.1%	0.26	68.1%	0.17
No	3,266	72.4%	0.26	72.4%	0.17
Number of People in the Vehicle					
One	2,374	70.5%	0.27	70.5%	0.20
Two	515	76.3%	0.20	76.3%	0.08
Three or more	239	77.1%	0.30	77.1%	0.19
Vanpool, train, bus, or motorcycle	572	69.2%	0.26	69.2%	0.29
Number of Trips per Week					
1 or 2	311	72.7%	0.40	72.7%	0.39
From 3 to 5	1,183	72.1%	0.40	72.1%	0.40
From 6 to 9	490	68.4%	0.32	68.4%	0.25
10	1,205	72.5%	0.38	72.5%	0.37
more than 10	568	72.8%	0.39	72.8%	0.38
Travel Companion (only for carpoolers)					
Co-worker (nearby office)	164	78.4%	0.39	78.4%	0.37
Adult family member	338	72.9%	0.24	72.9%	0.13
Child	136	78.8%	0.38	78.8%	0.37
Other	87	86.1%	0.12	86.1%	0.11
Age					
From 16 to 24 years old	481	79.9%	0.12	79.9%	0.02*
From 25 to 34 years old	1,280	75.1%	0.15	75.1%	0.05*
From 35 to 44 years old	914	72.4%	0.39	72.4%	0.38
From 45 to 54 years old	784	64.6%	0.06	64.6%	0.00*
From 55 to 64 years old	361	68.8%	0.33	68.8%	0.25
More than 65 years old*	94	50.5%	0.03*	50.5%	0.00*

Table 28. Descriptive Statistics of Survey Respondents Choosing a ML Option. (cont.)

Characteristics	N	Replicate Weights		P Weights	
Gender					
Male	2,033	73.0%	0.24	73.0%	0.18
Female	1,873	70.0%	0.24	70.0%	0.18
Ethnicity					
Caucasian	1,908	73.6%	0.18	73.6%	0.10
Afro-American	602	72.7%	0.39	72.7%	0.37
Hispanic	860	71.1%	0.40	71.1%	0.39
Other	556	64.9%	0.08	64.9%	0.09
Household Type					
Single adult	1,160	70.9%	0.39	70.9%	0.37
Unrelated adults (e.g., roommates)	273	79.5%	0.15	79.5%	0.07
Married without child	704	73.9%	0.28	73.9%	0.21
Married with child(ren)	1,270	71.3%	0.40	71.3%	0.39
Other	468	66.0%	0.14	66.0%	0.13
Household Size					
One	776	66.8%	0.10	66.8%	0.04*
Two	1,169	73.2%	0.33	73.2%	0.30
Three	695	72.4%	0.39	72.4%	0.39
Four	652	75.0%	0.20	75.0%	0.18
Five or more	447	72.7%	0.39	72.7%	0.39
Number of Vehicles					
None	41	65.8%	0.35	65.8%	0.38
One	1,097	67.2%	0.03*	67.2%	0.02*
Two	1,692	74.0%	0.19	74.0%	0.09
Three or more	986	73.6%	0.30	73.6%	0.26
Occupation					
Professional	1,624	71.8%	0.40	71.8%	0.39
Technical	469	70.4%	0.37	70.4%	0.37
Administrative	602	68.7%	0.31	68.7%	0.24
Sales, service, manufacturing, student, and self-employed	755	76.7%	0.10	76.7%	0.05*

Table 28. Descriptive Statistics of Survey Respondents Choosing a ML Option. (cont.)

Characteristics	**N**	**Replicate Weights**		**P Weights**	
Stay-home, unemployed, retired, and others	**403**	**67.4%**	**0.30**	**67.4%**	**0.22**
Education					
High school graduate or less	**654**	**69.5%**	**0.31**	**69.5%**	**0.31**
Some college/Vocational	**1,245**	**70.5%**	**0.34**	**70.5%**	**0.33**
College graduate	**1,337**	**74.0%**	**0.18**	**74.0%**	**0.10**
Postgraduate degree	**675**	**70.9%**	**0.39**	**70.9%**	**0.38**
Income					
Less than $25,000	**978**	**74.3%**	**0.18**	**74.4%**	**0.23**
From $25,000 to $49,999	**1,099**	**66.4%**	**0.01***	**66.4%**	**0.01***
From $50,000 to $99,999	**1150**	**71.7%**	**0.40**	**71.7%**	**0.40**
More than $100,000*	**700**	**76.0%**	**0.01***	**76.0%**	**0.01***

*Statistically significant at 95%

Dallas and Houston Responses to ML

Many respondents selected at least one managed lane option in the stated preference questions in both Houston and Dallas. However, more Houston residents (72.9 percent) selected a managed lanes option than did Dallas residents (69.5 percent) (see Table 29). Selection of MLs in each city was also examined by mode. There were no statistically significant differences in ML interest between Dallas and Houston travelers regardless of mode (see Table 29).

Table 29. ML Choice Selection in Houston and Dallas by User Characteristic.

Characteristic	**Percentage Choosing a Managed Lane Option**				
Household Income	**Dallas**		**Houston**		**p-value**
Less than $25,000	75.3%	7.9%	73.9%	2.7%	0.39
From $25,000 - $49,999	64.2%	3.8%	67.7%	2.5%	0.30
From $50,000 - $99,999	66.9%	9.2%	74.9%	4.3%	0.29
More than $100,000	75.6%	2.5%	76.5%	1.1%	0.38
Ethnicity					
Caucasians	73.4%	3.1%	73.6%	2.7%	0.40
Afro-American	64.9%	6.9%	76.7%	2.4%	0.11
Hispanic	68.7%	7.7%	71.9%	5.6%	0.38
Others	58.2%	4.9%	68.3%	2.9%	0.08

Table 29. ML Choice Selection in Houston and Dallas by User Characteristic. (cont.)

Characteristic	**Percentage Choosing a Managed Lane Option**				
Trip Purpose	**Dallas**		**Houston**		**p-value**
Commute	70.3%	3.2%	72.4%	2.8%	0.35
Recreational	71.7%	6.8%	77.8%	3.2%	0.29
Work	67.1%	6.7%	70.6%	5.1%	0.37
School	59.1%	16.3%	82.4%	6.4%	0.16
Other	46.0%	25.6%	56.0%	13.9%	0.38
Mode					
SOV	69.7%	3.6%	71.0%	2.5%	0.38
HOV-2	72.1%	5.0%	78.8%	5.4%	0.26
HOV-3+	80.6%	16.4%	75.8%	8.5%	0.39
Transit	62.2%	6.3%	72.0%	5.8%	0.21
Motorcycle	65.3%	27.3%	64.0%	16.4%	0.40
Vanpool	68.9%	31.5%	78.3%	5.9%	0.38
Total	69.5%	3.0%	72.9%	1.9%	0.25

As shown in Table 29, selection of a managed lanes option was fairly consistent between the two cities in most strata. There was no significant difference in attitude toward MLs between the two cities, and therefore little need for calibration of separate behavioral models for these two cities.

Comparison of Overall Modal Selection of MLs

Given so many respondents selected a ML option, differences by travel mode were further examined. As shown in Table 30, a lower proportion of transit travelers selected ML options (68 percent) than any other group. However, this was not a statistically significant difference. It was still important to note this potential issue as transit systems may experience the least perceived improvement in their travel time since they mainly operate on fixed routes and have a fixed schedule.

Table 30. Selecting of a ML Option by Mode.

MODE	Number	Number Choosing ML		P-VALUE					
				SOV	HOV-2	HOV-3+	Transit	Motor-cycle	Vanpool
SOV	2374	1674	70.5%	-	0.18	0.29	0.37	0.38	0.23
HOV-2	515	393	76.3%	0.18	-	0.40	0.19	0.32	0.40
HOV-3+	239	184	77.1%	0.29	0.40	-	0.25	0.32	0.40
Transit	410	280	68.4%	0.37	0.19	0.25	-	0.39	0.21
Motorcycle	78	50	64.9%	0.38	0.32	0.32	0.39	-	0.32
Vanpool	85	65	76.5%	0.23	0.40	0.40	0.21	0.32	-

Reasons Why Respondents Were and Were Not Interested in MLs

The next tables (31, 32 and 33) use the respondents answer to the "interest in managed lanes" question to separate respondents into those who indicated an interest in using MLs and those who did not. Each respondent who expressed an interest in using MLs was given a chance to rank different reasons why they were interested in using the MLs (see Table 32). The ranking was on a 1 to 5 scale, 5 being the most important. Those respondents who were not interested in MLs were directed to a different set of questions to rank why they were not interested in MLs (see Table 33). The scores shown in both tables are average scores computed for each reason given by different mode users.

Table 31. Respondents Interest in Managed Lanes.

Characteristic	**Percentage Interested in Managed Lanes**				
Household Income	**Dallas**		**Houston**		**p-value**
Less than $25,000	68.0%	5.0%	66.5%	5.3%	0.39
From $25,000 - $50,000	71.9%	7.0%	65.2%	5.6%	0.30
From $50,000 - $100,000	69.9%	3.9%	66.6%	5.0%	0.35
More than $100,000	79.1%	1.2%	78.4%	2.8%	0.39
Ethnicity					
Caucasians	72.8%	3.1%	72.5%	3.5%	0.40
Afro-American	69.2%	6.3%	70.3%	4.5%	0.40
Hispanic	76.7%	8.4%	69.1%	3.3%	0.28
Others	63.9%	2.4%	52.1%	3.4%	0.01
Trip Purpose					
Commute	73.7%	2.7%	69.8%	2.9%	0.25
Recreational	66.8%	5.5%	68.3%	4.6%	0.39
Work	70.8%	6.4%	62.4%	7.8%	0.28
School	67.3%	15.0%	62.1%	9.3%	0.38
Other	77.6%	17.0%	72.6%	14.5%	0.39
Mode					
SOV	73.5%	3.1%	68.6%	3.8%	0.24
HOV-2	73.5%	6.6%	67.6%	8.0%	0.34
HOV-3+	72.6%	10.2%	67.7%	11.1%	0.38
Transit	61.2%	7.4%	59.1%	7.4%	0.39
Motorcycle	89.0%	9.0%	77.1%	12.9%	0.30
Vanpool	84.2%	14.7%	81.7%	9.2%	0.39
Total	71.8%	2.4%	68.2%	2.9%	0.25

Table 32. Average Scores Given for Interest in Managed Lanes.

Reason	SOV		HOV2		HOV3+		Transit		Motorcycle		Vanpool		Total	
	Number of observations (# obs.)	Score	# obs.	Score	# obs.	Score	# obs.	Score	# obs.	Score	# obs.	Score	# obs.	Score
Able to travel alone and still use ML	1799	4.3	395	4.0	170	3.9	268	4.0	67	3.3	77	4.1	2775	4.2
Able to use transit on the ML	92	3.2	16	4.2	17	3.6	269	4.1	0	0.0	3	5.0	397	3.9
Able to travel faster than GP	1800	4.6	390	4.6	174	4.3	277	4.4	67	4.4	77	4.6	2785	4.6
Travel time reliability	1790	4.6	394	4.7	167	4.5	276	4.5	67	4.5	77	4.5	2772	4.6
Able to use carpool / vanpool on ML	1754	2.4	381	4.0	170	4.2	263	3.7	66	2.2	77	4.2	2710	2.9
ML not have large trucks	1789	4.1	394	4.4	173	4.7	266	4.4	67	3.9	77	4.4	2765	4.2
ML less stressful	1796	4.2	399	4.4	166	4.6	271	4.4	67	3.6	77	4.5	2775	4.2
Other factor	194	4.4	67	4.5	30	4.5	49	4.3	25	4.9	17	4.1	382	4.4

Table 33. Average Scores Given for Disinterest in Managed Lanes.

Reason	SOV		HOV2		HOV3+		Transit		Motorcycle		Vanpool		Total	
	Number of observations (# obs.)	Score	# obs.	Score	# obs.	Score	# obs.	Score	# obs.	Score	# obs.	Score	# obs.	Score
Do not have a credit card to establish account	694	1.6	168	2.1	238	2.0	159	1.9	14	2.6	16	2.1	1290	1.8
Use bus or train, and will not change	22	1.4	8	2.7	16	2.1	163	3.6	0	0.0	0	0.0	210	3.2
Do not want a toll transponder in my car	713	1.8	164	2.1	235	2.2	157	2.4	14	1.7	16	2.3	1299	2.0
ML is complicated or confusing	693	2.2	164	2.3	235	2.4	151	2.8	14	2.2	17	2.3	1274	2.3
I have flexibility to travel at less congested times	720	3.0	164	2.7	235	2.8	155	2.9	15	2.0	16	2.6	1305	2.9
Do not want to pay the toll cost	744	4.4	169	4.3	246	4.3	168	3.8	15	4.6	18	4.6	1361	4.3
Carpool. Will not switch to drive alone	0	0.0	158	3.3	223	3.2	0	0.0	0		0	0.0	381	3.2
Travel on uncongested roads. Will not switch to ML	23	4.2	4	3.1	7	2.6	2	2.5	0	0.0	0	0.0	37	3.6
Other factor	37	.5	5	3.6	70	3.8	50	4.4	9	5.0	7	5.0	423	4.3

Results for Respondents who were Interested in Using MLs

Travel time savings (4.6) and increased travel time reliability (4.6) ranked as the strongest contributing factors for interest in ML use where the scores for both questions indicated that all user groups tend to rank these reasons as very important. Furthermore, for both of these reasons, over 95 percent of survey respondents who indicated they were interested in using MLs answered those questions, which indicated their applicability to all travelers. Not surprisingly, SOV traveler's ranked being able to use the ML while driving alone quite high (4.3), higher than did travelers in other modes. SOV traveler's also ranked the ability to use a carpool/vanpool in the managed lane very low (2.4), lower than other modes except motorcycle.

Surprisingly, current carpool users, HOV 2 and HOV3+, also indicated that the ability to use the MLs while driving alone (4.0 and 3.9) was nearly as important as the ability to use the ML while carpooling (4.0 and 4.2). This finding was important because without additional incentives to remain in a carpool, at least some current carpools are likely to revert to SOVs.

Texas travelers supported the idea of prohibiting large trucks from using MLs and will want to use MLs because they provide superior operational performance to the GPLs. Some care needs to be taken to ensure that the overall system vehicle occupancy rate does not decrease as a result of implementing MLs.

Results for Respondents who were Not Interested in MLs

The primary reason travelers were not interested in using MLs appears to be an opposition to the tolls required for their use with an average score of 4.3. This is not surprising as tolls are generally unpopular with the public. A recent survey found over 58 percent of respondents unsupportive of tolls to build new roadways and reduce congestion *(90)*. Unlisted or "other" reasons may also play a critical role in the opposition to MLs; the average score was 4.3, which was significantly higher than the toll cost, and 26.8 percent of the respondents indicated another reason impacts their opinion. The other reason cited most often was that taxes already paid for the road. This reason was similar to that of ranking the toll as a major impediment to manage lane use. Current carpoolers, HOV2 (49.9 percent) and HOV3+ (62.5 percent),[1] indicated that their loyalty to their carpool makes the ML concept undesirable, likely because they would no longer have exclusive access to HOV lanes.

The low scores given to reasons involved with some operational or technical issue are also interesting. These results show that the main opposition to the concept of MLs does not rise from the fact that users may need to have credit card or install a transponder in their vehicles in order to be able to access these lanes. Nor was it a result of the expected higher perceived complexity of these facilities compared to GPLs. This does not necessarily indicate that these issues are completely unimportant; however, they were at most secondary concerns.

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[1] These are the number of users who indicated 1, 2, or 3 in the choice for "Carpool. Will not switch to driving alone."

Comparison Based on Toll Payment

Previous exposure or acceptance of tolls significantly increased the likelihood of selecting a ML option (see Table 34). Of the toll payers who participated in this survey, about 80 percent selected a ML option at least once; in contrast, this ratio falls to 70 percent among participants who were not paying any tolls. This finding suggests that support for MLs will likely be higher in regions where toll roads already exist and get numerous users. This finding further supports the argument that the primary opposition to MLs stems from the tolls.

Table 34. Effect of Toll Payment on Selection of Managed Lane Options.

Already pay a toll?	Number of Respondents		Selected a ML Option				
			Number		Percentage		
	Dallas	Houston	Dallas	Houston	Dallas	Houston	p-value
Yes	219	106	176	84	80.0%	79.3%	0.39
No	1292	2270	875	1,648	67.7%	72.6%	0.18
Total	1512	2376	1,051	1,732	69.5%	72.9%	0.25

Comparison of ML Proponents

This section summarizes the analyses performed on a variety of socio-demographic attributes that may affect ML use. The goal was to identify those attributes which may increase or decrease the level of use of MLs. The socio-demographic attributes of interest in this study included the respondent's age, gender, income, ethnicity, household type and size, vehicle ownership, type of occupation and level of education.

Those Attributes With No Significant Effect on Interest in MLs

There was little or no significant difference in selection of MLs among many different socio-demographic groups. This section briefly discusses these results related to these attributes.

There was little or no significant difference in selecting a ML option based on age, household type, or occupation of the respondent. The one exception was respondents older than 65 were less likely to select a ML option. There was no significant difference in selection of ML options by different sized households. ML selection ranged from a low of 72.7 percent for households with five individuals to 75 percent for households with four people. There was no significant difference in ML selection based on the educational level of the respondent.

Approximately 73 percent of males and 70 percent of females were interested in using MLs. The difference was not statistically significant.

Comparisons Based on Income

A majority of respondents from all income groups selected at least one ML option (see Table 35). However, the level of income did appear to affect the proportion of respondents selecting MLs. The likelihood of selecting a ML option generally increased as household income increased. Approximately 74.3 percent of respondents with household incomes less than $25,000 selected a ML option, while 76 percent of respondents with household incomes greater than $100,000 selected a ML option. Selection of a ML option was not significantly higher when annual household incomes exceed $100,000.

Table 35. Effect and Significance of Household Income Level on Selected Managed Lane Option.

Household Income Group	Weighted Number of Respondents	Selected a ML Option		P-VALUE			
		Number	Percent	<$25,000	$25,000-$50,000	$50,000-$100,000	>$100,000
<$25,000	978	727	74.3%	-	0.01	0.34	0.30
$25,000 - $50,000	1099	730	66.4%	0.01	-	0.20	0.00
$50,000 - $100,000	1150	825	71.7%	0.34	0.20	-	0.23
>$100,000	700	532	76.0%	0.30	0.00	0.23	-

Comparison Based on Ethnicity

There were no significant differences in the likelihood of selecting a ML option based on a group's ethnicity. However, 73.6 percent of Caucasians selected a ML option whereas around 65 percent of other ethnicities chose a ML option. At a 5 percent level of significance this is not a significant difference, but would be significantly different at a 10 percent level of significance. This indicates a potential issue that might require further investigation.

Summary

This analysis found that interest in the ML concept was high among Texas residents in metropolitan regions with 70 percent of travelers interested in using ML. Current mode choice appears to have a minimal affect on interest in MLs because all mode choices showed high interest in using MLs. Similarly, approximately 70 percent of respondents selected a ML option in at least one of the four stated preference questions.

All of the reasons for interest in use of MLs provided in the survey received high importance ratings on average, with the lowest being the ability to carpool/vanpool. Every mode user group identified travel time savings and increased travel time reliability as the strongest contributing factors for ML use. Current carpoolers identified the ability to drive alone as more important than the ability to carpool/vanpool. Texas travelers definitely support the idea of prohibiting large trucks from using MLs and favor the use of MLs because they provide superior operational performance to GPLs.

Those individuals who had no interest in using MLs identified tolls and "other" as the most important reasons impacting this decision. Additionally, prior exposure or acceptance of tolls significantly increased the potential use of MLs. Many current carpoolers viewed the ML concept undesirable because they will have to share their current facility, an HOV lane, with SOVs or pay a toll. This is not surprising in the event an HOV lane is adapted to be a HOT lane, but is somewhat surprising in this survey where it was stated that these MLs were new capacity. Respondents indicated that the technical and operational reasons for no interest in MLs were of secondary concern at most. Clearly, the presence of tolls served as a barrier to use for most individuals that were not interested in MLs.

While all income groups selected a ML option, income level had a significant impact on respondent interest. A household income of approximately $100,000 appears to be the level at which ML selection increases to its highest level. It is important to note that even in the lowest income group over 74 percent of respondents selected MLs.

RESPONSES TO HOV POLICIES

In addition to questions regarding carpooling and interest in managed lanes, the survey used a stated preference (SP) experiment to assess the potential decision-making behaviors of drivers when choosing between using the managed lanes (MLs) or general purpose lanes (GPs). A total of four stated preference questions on mode choice based on hypothetical travel time and toll scenarios were asked. Each respondent was asked to choose one of the three variable mode choices for traveling on MLs or GPs. As previously described, a total of six alternatives were presented for each stated preference question that was randomized based on the previous response.

In the stated preference question, a travel time saving was calculated depending on the input travel distance and randomly given speeds on GP and ML lanes. For SOV, tolls were random, based on given value of time between 10 and 20 dollars per hour. This SOV toll was used for calculating the HOV tolls. HOV2 tolls were separated into three groups with 25 percent free, 25 percent same as SOV toll and 50 percent randomly set at 25 percent to 75 percent of SOV toll. In the HOV3+ case, tolls were divided into two groups with 50 percent free and 50 percent set at 1 percent to 100 percent of HOV2 toll. Responses to these questions are analyzed and the results are presented in this section.

Table 36 and corresponding Figure 34 show the percentage changes in total SOV usage under different HOV policy conditions. The modal share of the SOV travelers at the free condition, where HOV2 and HOV3+ are not charged, is 73.8 percent. In the case where HOV2 is charged the same toll as the SOV, the total percentage of SOV usage increases. This is due to HOV2 users switching to the SOV mode. Decreasing HOV tolls seems to have no impact on SOV users. However, this may be the result of survey questions that confused the respondents. In the stated preference questions, policy scenarios were not specifically controlled.

Table 36. Change in SOV Share under HOV Policy Conditions.

HOV3+ Toll	HOV2 Toll			
	Free	25-50% of SOV	50-75% of SOV	Same as SOV
Free	0.00% (3173)	2.44%*** (1576)	2.15%*** (1608)	4.14%* (1661)
1-25% of HOV2	N/A	3.09%*** (446)	-1.74%*** (320)	0.28%*** (326)
25-50% of HOV2	N/A	5.09%*** (359)	-1.87%*** (364)	11.57%* (467)
50-75% of HOV2	N/A	-2.38%*** (375)	1.66%*** (446)	6.00%** (415)
75-100% of HOV2	N/A	-0.09%*** (404)	5.25%** (487)	6.63%* (403)

* *p < .000* ** *p < .01* *** *p < .05*
Numbers in parentheses are number of cases.

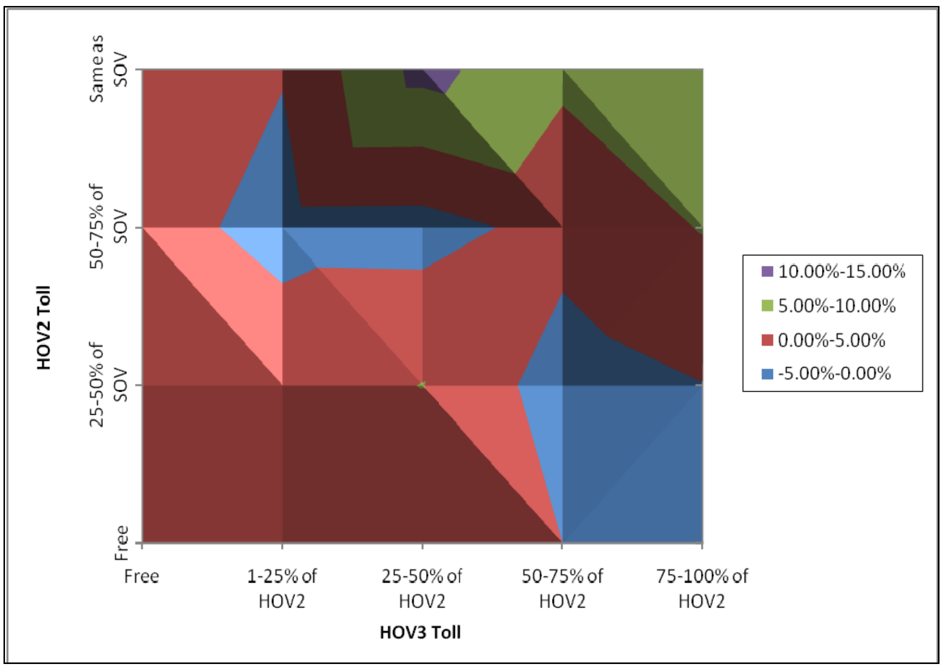

Figure 34. Distribution of Percentage Changes in SOV Share in Response to HOV Toll Policies.

Table 37 and corresponding Figure 35 show results of percentage changes on HOV2 under HOV policy conditions. Under the free condition, 22.1 percent of travelers are HOV2. As seen from the table, increasing HOV2 tolls results in decreases in HOV2 users. A t-test indicates that the percentage changes in HOV2, where HOV2 tolls are charged the same as SOV, are significant at the .000 level. When HOV2 is charged the same toll as SOV, HOV2 travelers will be greatly reduced in the system.

Table 37. Change in HOV2 Share under HOV Policy Conditions.

HOV3+ Toll	HOV2 Toll			
	Free	25-50% of SOV	50-75% of SOV	Same as SOV
Free	0.00% (948)	-4.68%* (359)	-5.71%* (346)	-9.15%* (275)
1-25% of HOV2	N/A	-7.40%* (85)	-3.36%*** (83)	-7.73%* (63)
25-50% of HOV2	N/A	-6.67%* (70)	-2.29%*** (100)	-11.81%* (56)
50-75% of HOV2	N/A	-0.15%*** (115)	-4.45%*** (104)	-8.40%* (71)
75-100% of HOV2	N/A	-1.07%*** (115)	-6.63%* (95)	-11.27%* (54)

* $p < .000$ ** $p < .01$ *** $p < .05$
Numbers in parentheses are number of cases.

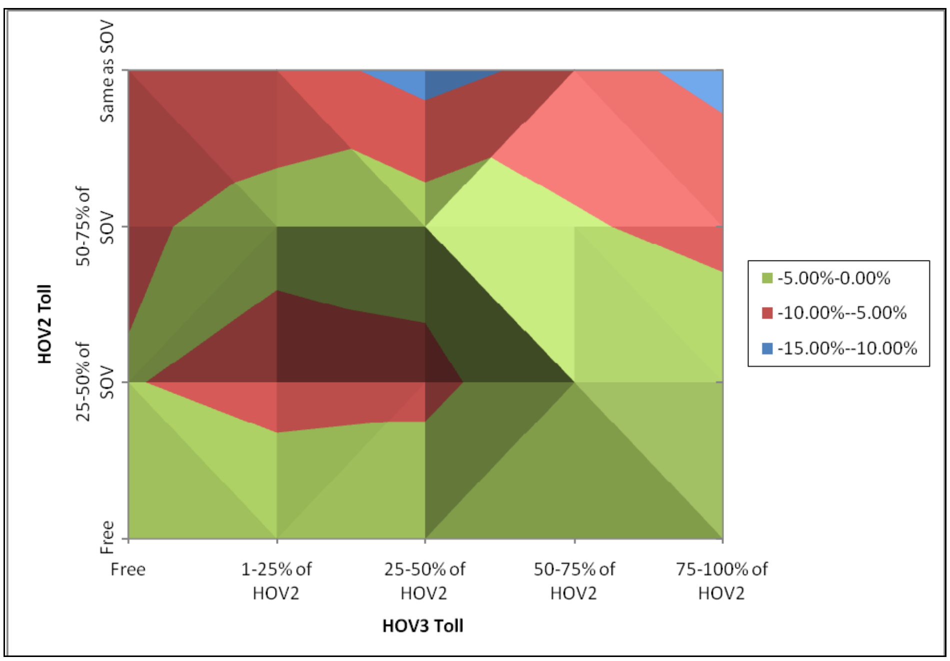

Figure 35. Distribution of Percentage Changes for HOV2 in Response to HOV Toll Policies.

The percentage changes in HOV3+ under various policy conditions are shown in Table 38 and corresponding Figure 36. At the free condition, 4.1 percent of travelers are HOV3+. As mentioned previously, the higher HOV2 toll will decrease the HOV2 mode. Table 38 indicates that when HOV2 tolls are increased, HOV3+ travelers also increase, indicating that those travelers may become HOV3+. However, a definitive conclusion cannot be made from this table due to the small sample size in many cells.

Table 38. HOV3+ Percentage Changes under HOV Policy Conditions.

HOV3+ Toll	HOV2 Toll			
	Free	25-50% of SOV	50-75% of SOV	Same as SOV
Free	0.00% (178)	2.25%* (132)	3.56%* (163)	5.01%* (195)
1-25% of HOV2	N/A	4.31%* (49)	5.09%* (41)	7.45%* (51)
25-50% of HOV2	N/A	1.57%*** (26)	4.16%* (42)	0.25%*** (24)
50-75% of HOV2	N/A	2.53%** (35)	2.80%** (41)	2.40%*** (34)
75-100% of HOV2	N/A	1.15%*** (29)	1.38%*** (34)	4.64%* (44)

* $p < .000$ ** $p < .01$ *** $p < .05$

Numbers in parentheses are number of cases.

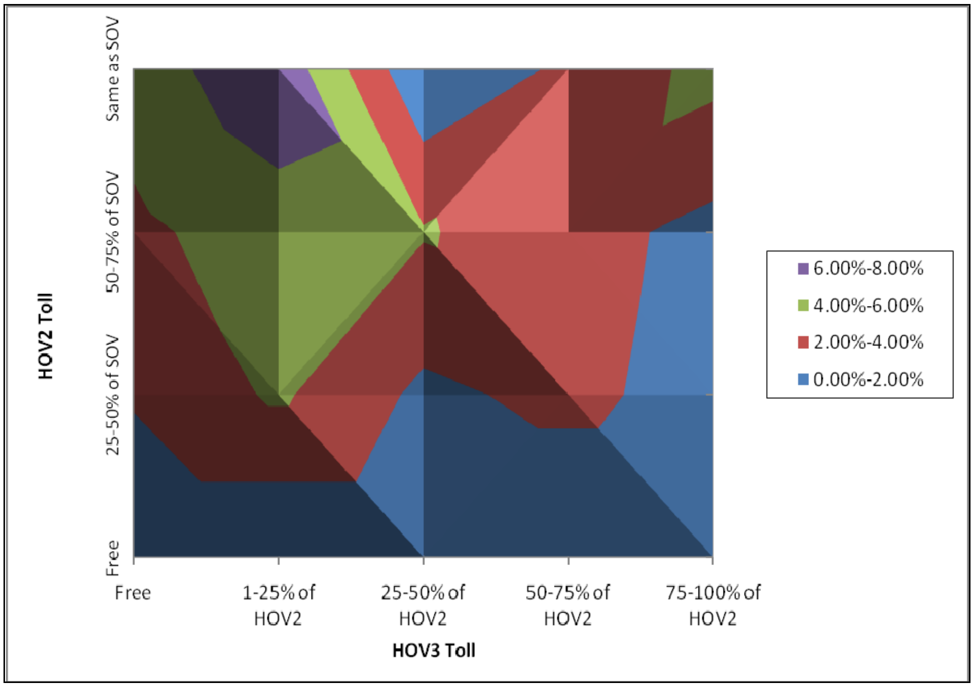

Figure 36. Distribution of Percentage Changes for HOV3+ in Response to HOV Toll Policies.

Summary

This section provides some initial guidance on potential impacts associated with different HOV tolling policies. Some HOV2 users appear to convert to SOV when they are charged a toll; however, decreasing the HOV tolls appears to have limited effect on SOV users. On the other hand, tolling HOV2 users also increases the number of HOV3+ users. Overall, about 10 percent of HOV2 users appear to convert to SOV and HOV3+ combined. Adding a toll to HOV3+ appear to have a limited effect on their share, which means the user group may be relatively unaffected by higher toll rates because their carpool may not be based exclusively on access to the HOV lane. Due to the limited conclusions that can be drawn from this analysis, mode-changing behavior is not accounted for in any of the impact analysis in Chapter 5. Identification of specific candidate policies prior to future surveys will increase the utility of future analyses.

CHAPTER 5. IMPACT ANALYSIS

The main purpose of the impact analysis is to provide quantitative estimates of HOV preferential treatment impacts on toll revenue, air quality, and system performance on managed and general purpose lanes. The Toll Pricing Model (TPM) 3.1, a computer model developed under TxDOT Project 0-4818, was used as a tool to estimate impacts of the 24 pricing policy scenarios developed by the research team. To ensure the validity of the pricing evaluation tool, model estimates were compared with estimates from a study by Wilbur Smith Associates, as well as field observations from the I-394 MnPass program, operated by the Minnesota Department of Transportation *(91, 92)*. The model validation process and results are provided in Appendix B.

The next section briefly introduces the TPM-3.1. Following the model description, methods for deriving price sensitivities were described and logit model estimations of mode choice for impact analysis were presented. The final two sections present and summarize results of the impact analysis.

TOLL PRICING MODEL 3.1: A TOLL FOR IMPACT ANALYSIS

Model Theory

The TPM-3.1 model was developed based on the concepts of price elasticity and the speed-flow-concentration model originally proposed by Greenshields *(93)*. TPM-3.1 sets the default values for the percentage of SOV users willing to pay a certain toll value based on data collected from the stated preference surveys in Houston and the DFW areas. In the survey questionnaires, respondents were asked a number of questions including toll value they were willing to pay for an expected travel time savings. Survey results were analyzed, and the resulting relations between the percent of SOV, HOV-2, and HOV-3+ users willing to pay a specified toll amount to use the managed lanes for a given travel time savings are summarized in the price sensitivity parameter table in the TPM-3.1 model (see Figure 1.2 in *User Guide to Toll Pricing Model V3.1* by Ardekani et al., 2007) *(94)*. Currently, the model linearly extrapolates for the cases with tolls higher than \$0.5/mile or less than \$0.1/mile or when travel time savings exceed 2 minutes/mile or are less than 0.5 minutes/mile. Otherwise, the model will linearly interpolate to find the appropriate toll value to achieve a desired operational objective.

The values in the price sensitivity parameter table are utilized to find the proper toll for the SOV, HOV, and HOV-3+ users of the MLs. Naturally, the drivers' choice between GPLs or MLs directly impacts the speeds, concentrations, and levels of service on each facility. Speeds, in turn, will dictate the magnitude of the travel time savings. The Greenshields model is utilized to characterize the relationship between speed, flow, and concentration. Equation 1 is utilized to calibrate the Greenshields model by estimating the values of the model parameters, k_j and u_f *(94)*. The Greenshields model also yields Equation 2 to estimate the flow as a function of speed and concentration.

$$u = u_f (1 - k/k_j) \quad (1)$$

$$q = u_f k (1 - k/k_j) \quad (2)$$

where:

u = speed (mph),
u_f = free-flow speed (mph),
q = flow (vehicles per hour [vph]),
k = concentration (vehicles per mile [vpm]), and
k_j = jam concentration (vpm).

The theoretical maximum flow per lane (saturation flow per lane) implied by Equation 2 is determined to be $q_{max} = u_f . k_j/4$. In conditions where demand exceeds capacity, the speeds are expected to vacillate between $u = 0.5u_f$ (at $q = q_{max}$) and $u = 0$ (at $q = 2q_{max}$). In such cases, the TPM-3.1 model linearly interpolates the speed between $0.5u_f$ and zero for demands between q_{max} and $2q_{max}$. For demands higher than $2q_{max}$, speed is considered to be zero (jam condition).

Emissions estimates are largely based on a series of regression models, which predict the emissions amounts as a function of the average speeds *(95)*. These models are summarized in Table 39. The regression models for CO, VOC, and NOx are calibrated for data from a series of U.S. Environmental Protection Agency (EPA) MOBILE 6.2 simulation runs *(96)*. The regression model for CO_2 was developed based on tailpipe field data *(95)*. The SO_2 estimates are based on rates provided by vehicle manufacturers and built into the MOBILE 6.2 simulation model.

All emissions estimates, except for CO_2, are based on MOBILE 6.2 simulation runs for the following conditions: a projected 2010 vehicle mix, freeway cruise speeds, exhaust emissions, the month of July, 7 a.m. sunrise, 8 p.m. sunset, a temperature range of 74°F to 90°F, a relative humidity range of 51 to 88, a barometric pressure of 29.4, a fuel program of 4, oxygenated fuels with a fuel Reid vapor pressure (RVP) of 6.8, diesel sulfur of 15.0, and particulate size of 2.5. The CO_2 estimates are based on field measurements of tailpipe exhaust emissions for a 2007 Dodge Charger passenger car under average freeway non-cruise speeds with comparable ambient conditions as in MOBILE 6.2 runs. The CO_2 emissions for other vehicle types were estimated by adjusting the passenger car rates from field measurements proportional to the CO_2 constant rates in MOBILE 6.2 for passenger cars versus other vehicle types.

Model Inputs and Outputs

Several inputs are required in order to use the model for impact analysis of pricing policies for a specific managed lane facility. First, the model requires information on the facility being investigated. Facility information includes number of lanes, maximum speed (mph), maximum density (passenger car per lane mile - pcplm), density at maximum flow (pcplm), and saturation flow per lane (passenger car per hour per lane - pcphpl) for both managed and general purpose lanes, as well as corridor length (miles).

Table 39. Regression Models for Emissions (Grams/Mile) versus Average Speed, V (mph).

Vehicle Type	Regression Model
SOV/HOV-2/HOV-3+ (LDGV)	$HC = 0.0267 + 1.184\ (1/V) + 1.11815E\text{-}05\ V^2$
	$CO = 1.6915 + 30.0587(1/V) + 0.0008483\ V^2$
	$NOx = 0.1579 + 2.229\ (1/V) + 3.0664E\text{-}05\ V^2$
	$CO_2 = 94.416 + 3384.6\ (1/V) + 0.0026\ V^2$
Buses (HDGB)	$HC = 0.4632 + 21.510\ (1/V) – 0.00014\ V^2$
	$CO = 70.8397 – 2.80546V + 0.033\ V^2$
	$NOx = 5.4089 + 0.04593V + 0.000144\ V^2$
	$CO_2 = 360.375 + 12918.7\ (1/V) + 0.0099\ V^2$
Paratransit (GVWR-LDGT1)	$HC = 0.0326 + 1.6\ (1/V) + 1.3754E\text{-}05\ V^2$
	$CO = 1.9579 + 29.850\ (1/V) + 0.000942\ V^2$
	$NOx = 0.1827 + 1.9855\ (1/V) + 3.747E\text{-}05\ V^2$
	$CO_2 = 122.476 + 4309.5\ (1/V) + 0.0034\ V^2$
Vanpool (GVWR-LDGT1)	$HC = 0.0326 + 1.6\ (1/V) + 1.3754E\text{-}05\ V^2$
	$CO = 1.9579 + 29.850\ (1/V) + 0.000942\ V^2$
	$NOx = 0.1827 + 1.9855\ (1/V) + 3.747E\text{-}05\ V^2$
	$CO_2 = 122.476 + 4309.5\ (1/V) + 0.0034\ V^2$
Motorcycles (MC)	$HC = 0.2572 + 25.029\ (1/V) – 0.00015\ V^2$
	$CO = –5 + 333.14\ (1/V) + 0.003256\ V^2$
	$NOx = 0.5123 – 0.00454V + 0.0002082V^2$
	$CO_2 = 45.502 + 1631.2\ (1/V) + 0.0013\ V^2$
Light Freight (GVWR-LDGT4)	$HC = 0.0274 + 1.880\ (1/V) + 1.7849E\text{-}05\ V^2$
	$CO = 1.5321 + 24.5034\ (1/V) + 0.0007499\ V^2$
	$NOx = 0.3422 + 2.878\ (1/V) + 4.9308E\text{-}05\ V^2$
	$CO_2 = 159.924 + 5732.9\ (1/V) + 0.0044\ V^2$
Heavy Freight (Single Trailer) (HDGV6)	$HC = 0.1027 + 5.482\ (1/V) – 3.453E\text{-}05\ V^2$
	$CO = 32.050 – 1.3199V + 0.01567\ V^2$
	$NOx = 1.8958 + 0.01606V + 5.1098E\text{-}05\ V^2$
	$CO_2 = 281.246 + 10082.1\ (1/V) + 0.0077\ V^2$
Heavy Freight (Double Trailer) (HDGV8a)	$HC = 0.2258 + 10.451\ (1/V) – 7.2833E\text{-}05\ V^2$
	$CO = 40.570 – 1.671V + 0.01983\ V^2$
	$NOx = 4.0646 + 0.0344V + 0.000109\ V^2$
	$CO_2 = 324.389 + 11628.6\ (1/V) + 0.0089\ V^2$

Second, information about user composition in the investigated facility is needed. This comprises information about total corridor demand, percentage of various vehicle types, and corresponding equivalents to passenger cars (PCE). Vehicle types included in the model are SOV, HOV-2, HOV-3+, paratransit, vanpool, bus, motorcycle, light freight vehicles, heavy freight vehicles with a single trailer, and heavy freight vehicles with a double trailer. Definitions of vehicle types are specified in the help menu embedded in the model.

The last input required for using the model is price sensitivity parameters of various users. The parameters are percentages of users' willingness to pay at a price increment of $0.10/mile for time savings of 0.50 minutes/mile, 1 minute/mile, and 2 minutes/mile.

The TPM-3.1 model outputs include estimates of peak-hour volumes and average speeds on managed lanes and general purpose lanes, estimates of corridor toll revenue, and estimates of CO, VOC, NOx, CO_2, and SO_2 emissions (kilograms/mile).[2]

METHODS FOR DERIVING USERS' PRICE SENSITIVITIES

Logit models were used to predict the value of a binary dependent variable from a set of independent utility variables. The probability of an event is the predicted probability that an event occurs. The managed lane model estimates the probability that a driver makes a decision to travel on MLs under a given price and level of service scenario. The dependent variables in this model are the lane choice (ML or GPL). The independent variables consist of socio-demographic variables, freeway performance, and policy. The structure of the binary logit model is based on the travelers' facility choice given two options. The model structure is shown in Figure 37.

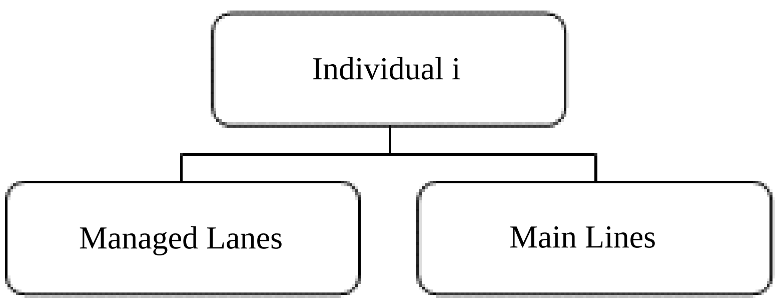

Figure 37. Binary Logit Model Structure.

The independent variables can be selected for inclusion in the model based on their level of significance. For a case with many independent variables, the logistic regression model probability is calculated using Equations 3 and 4.

[2] For more details about the model and model usage, see *User Guide to Toll Pricing Model v3.1: TPM-3.1* by Ardekani et al. (2007) *(94)*.

$$\text{Probability of event } (P) = \left(\frac{1}{(1+e^{-Z})}\right) \quad (3)$$

$$\text{Ln}\left(\frac{P}{(1-P)}\right) = B_0 + B_1X_1 + B_2X_2 + \ldots + B_nX_n \quad (4)$$

where:

Z = *utility of event P,*

$\text{Ln}\left(\frac{P}{(1-P)}\right)$ = the logit or log odds,

P = probability of selecting the managed lane,

B = model coefficients,

X = independent variables, and

n = number of independent variables.

Rho Square Statistic (ρ^2)

Acceptable models should have acceptable values for ρ^2. The likelihood ratio index ρ^2 suggested by McFadden is utilized to measure the goodness of fit of the logit model as in Equation 5 *(97)*. According to Hensher and Johnson (1981), a ρ^2 for the logit model between 0.2 and 0.4 is considered a good fit *(98)*. Lower ρ^2 values indicate that the predictive ability of the models are probably inadequate.

$$\rho^2 = 1 - \frac{L(\beta)}{L(0)} \quad (5)$$

The model estimation is performed using the Statisical Package for the Social Sciences (SPSS) software version 13.0 for Windows.

MODEL ESTIMATION OF MODE CHOICE

The five potential independent variables (travel distance, toll, travel time saving over GP lane, travel time saving per mile, and trip purpose) were entered into the model using a stepwise forward selection process to find the covariates and their interaction in the model. The SOV models were estimated with significant variables and statistical test values. However, the models did not predict any managed lane users. As a result, the SOV models were not acceptable. The inability to estimate an appropriate model might be due to inconsistencies in stated preference responses for the SOV users. Therefore, they were not included in this report.

Table 40 displays the results of the HOV-2 GPL versus ML binary logit models. The initial model was estimated using the primary factors such as travel distance, toll, and travel time savings. Other variables were added during subsequent model estimations. In general, the significant variables included in the HOV-2 and HOV-3+ models are similar, such as travel time saving and toll:

- A higher travel time savings will increase the probability of traveling on MLs. MLs are created to be an alternative route when traffic is congested. Therefore, the higher travel time savings by using MLs will attract travelers to them.
- Toll value has the largest impact on a traveler's decision of whether or not to travel on MLs. As the toll increases, the probability of traveling on MLs will decrease. At the same travel time savings, travelers will prefer to pay a lower toll to get the same level of service.

Table 40. HOV-2 Binary Logit Model Estimate Results.

Value Description		Model 1	Model 2	Model 3	Model 4
Constant		–0.553	–0.625	–0.594	–0.587
Travel distance (miles)		0.011		0.012	
Travel time saving over GPL			3.120		3.393
Travel time saving per mile		1.042		1.098	
Toll per mile		–7.132	–6.087	–6.593	–5.932
Trip Purpose	*Commute*			-	-
	Recreation			-	–0.339
	Work			–0.582	–0.651
	School			-	-
	Others			-	-
Number of Observations		860	884	968	968
–2LL only constant		1182.35	1213.69	1328.9	1329.0
–2LL with variable		1075.99	1115.28	1207.0	1207.0
ρ^2		0.091	0.081	0.092	0.092
Percent correct		66.2%	64.6%	67.3%	64.9%

From Table 40, a longer travel distance will also increase the probability of traveling on MLs. Travelers prefer to use managed lanes because the travel time may be greatly reduced, which will give them extra time. Recreation and work trips seem to have a negative impact on choosing to travel on MLs for HOV-2. Recreation trips usually occur during the off-peak, so there is no need to travel on MLs for these trips; furthermore, the arrival time of the traveler may not be that important. Work trips also decrease the probability of using managed lanes. This may happen because these trips are usually planned prior to their occurrence, so travelers may not need to use MLs and they may be traveling during the off-peak as well.

The values for the variables "family pool" and "income" were dropped from the HOV-2 models due to insignificance. Since these are binary choice models for the decision to use GPLs or MLs, this is a reasonable result because these factors probably have no influence on this choice given a particular mode (SOV, HOV-2, or HOV-3+). However, "income" was a significant factor in the HOV-3+ models (see Table 41). High household income users should have the ability to pay a higher toll than lower household income residents; however, they may not choose to pay higher tolls.

Table 41. HOV-3+ Binary Logit Model Estimate Results.

Value Description	Model 1	Model 2	Model 3	Model 4
Constant	0.950	0.057	0.142	–0.057
Travel time on ML (minutes)	–0.139	–0.073		
Travel time on GPL (minutes)	0.114	0.065		
Travel time saving over GPL				2.792
Travel time saving per mile	–1.248		0.868	
Toll per mile		–9.683	–8.803	–7.756
Income *< 25K*	2.387			
25K-50K	37.037			
50K-100K	–1.033			
>100K	0			
Number of observations	192	212	212	212
–2LL only constant	226.24	264.51	264.51	264.51
–2LL with variable	172.23	229.83	247.70	245.21
ρ^2	0.239	0.131	0.064	0.073
Percent correct	80.2%	75.0%	70.8%	71.2%

From Table 41, travel time on MLs and GPLs will affect the travel decision. As the travel time on the GPLs increases, the probability of using MLs will also increase. Travelers prefer to use MLs to maintain their regular travel time on trips. In contrast, as the travel time on MLs increases, the probability of using them decreases. The MLs become less attractive if travel time does not differ from that on GPLs.

From Table 40, the ρ^2 ranges of 0.081 to 0.092 indicate that the models are rather weak. The percent correct estimations for the models range from 64.9 percent to 67.3 percent. As seen in Table 41, the HOV-3+ models' ρ^2 ranges of 0.064 to 0.239 indicate that the best HOV-3+ model is significantly better than the HOV-2 models. The percent correct estimations for the models range from 70.8 percent to 80.2 percent.

IMPACT ANALYSIS RESULTS

This section includes a description of the model inputs for the impact analysis, the policy scenarios being investigated, and a report on the impact estimates.

Model Inputs

Figures 38 and 39 display the configuration of the managed lane facility being investigated and the user composition of the facility, respectively.

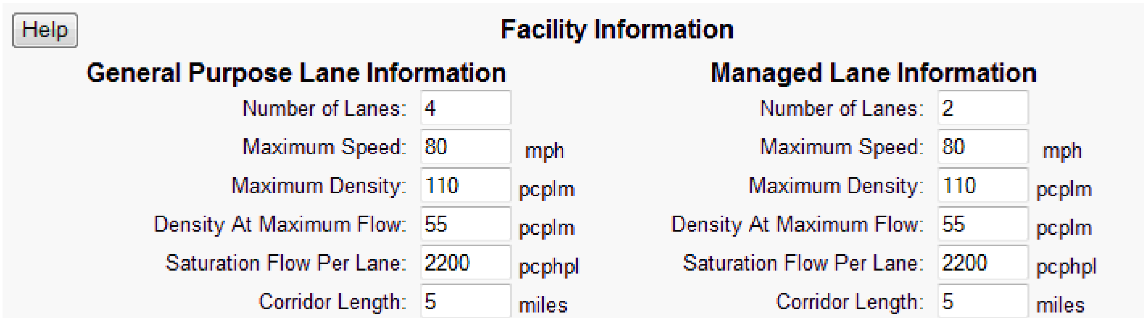

Figure 38. Facility Configuration.

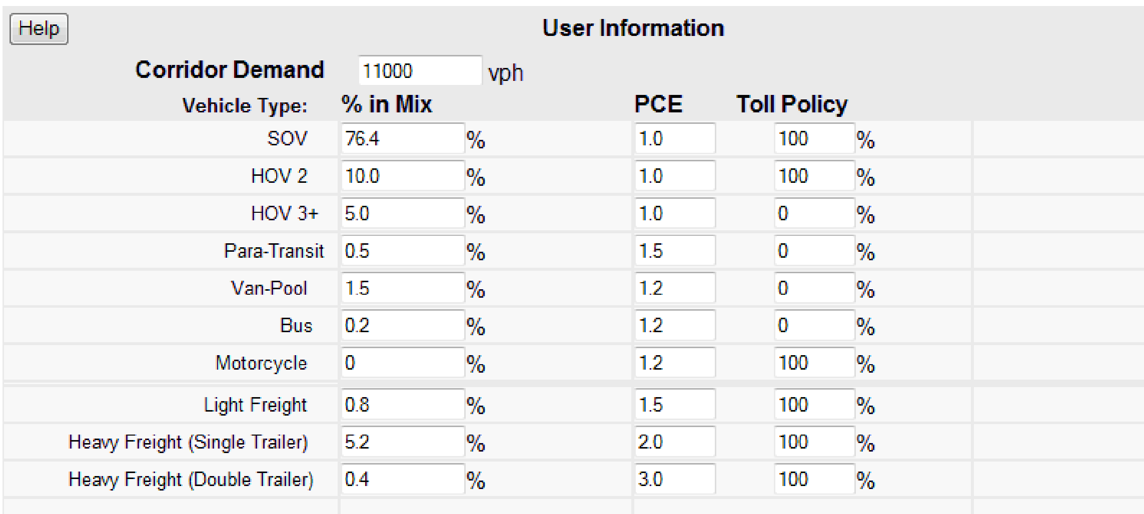

Figure 39. User Composition.

Price sensitivity parameters used for this impact analysis are shown in Table 42. HOV-2 and HOV-3+ price sensitivity parameters were derived from the price elasticity estimates based on the SP survey data collected in this project. In addition, SOV price sensitivity parameters were proportions of the SOV users' willingness to pay for the 0.5-minute, 1-minute, and 2-minute time savings observed from the TxDOT Project 0-4818 survey results.[3]

Policy Scenarios

A total of 24 policy scenarios were tested with the above price elasticity estimates. The policies include six sets of pricing scenarios, covering prices ranging from $0.10/mile to $0.50/mile with various preferential treatments for HOV-2 and HOV-3+ vehicles. The specific pricing policy scenarios studied are listed in Table 43.

[3] Information on SOV users' willingness to pay is unavailable from the stated preference survey conducted under this project for reasons stated in the section, "Model Estimation of Mode Choice."

Table 42. Price Sensitivity Parameters.

Price	0.50 (Minutes/Mile)	1.00 (Minutes/Mile)	2.00 (Minutes/Mile)
SOV			
$0.10/mile	49.9%	65.3%	87.1%
$0.20/mile	31.2%	46.2%	75.6%
$0.30/mile	17.1%	28.2%	58.5%
$0.40/mile	8.6%	15.2%	39.2%
$0.50/mile	4.1%	7.5%	22.7%
HOV-2			
$0.10/mile	34.6%	47.1%	71.7%
$0.20/mile	20.6%	30.4%	55.3%
$0.30/mile	11.3%	17.6%	37.8%
$0.40/mile	5.9%	9.5%	22.9%
$0.50/mile	3.0%	4.9%	12.7%
HOV-3+			
$0.10/mile	42.5%	53.2%	73.1%
$0.20/mile	23.4%	32.1%	52.9%
$0.30/mile	11.3%	16.4%	31.8%
$0.40/mile	5.0%	7.5%	16.2%
$0.50/mile	2.1%	3.3%	7.4%

Impact Estimates

Table 44 displays the impact estimates of various HOV preferential treatment policies based on price sensitivity parameters generated from the stated preference survey of the DFW and Houston areas. The first two of any set of policy scenarios begin with a scenario of the least preferential treatment of HOVs and the most preferential treatment, followed by four more scenario variations of preferential treatment.

Policy Scenarios 1 to 12

Scenarios 1 to 6 and 7 to 12 charge a toll of $0.10/mile and $0.25/mile, respectively. Emissions for scenarios 1 to 12 showed little to no change, regardless of the preferential treatment of HOV-2 and HOV-3+. System performance varied very little from one scenario to another. For example, the peak-hour average speed on the ML would be almost the same as that on the GPL, which are 55 mph and 51 to 52 mph, respectively, regardless of HOV preferential treatment. Similarly, peak-hour volume for these 12 scenarios is stable and consistent. For the ML, volume varies slightly from 3707 to 3745 vehicles per hour. For the GPL, volume varies slightly from 7255 to 7293 vehicles per hour.

Table 43. Policy Scenarios.

Scenario	Corridor Length (Miles)	Toll Amount ($/Mile)			
		SOV	HOV-2	HOV-3+	Trucks
1	5	$0.10	SOV	SOV	Not on ML
2	5	$0.10	Free	Free	Not on ML
3	5	$0.10	0.5 × SOV	0.5 × SOV	Not on ML
4	5	$0.10	0.5 × SOV	Free	Not on ML
5	5	$0.10	SOV	0.5 × SOV	Not on ML
6	5	$0.10	SOV	Free	Not on ML
7	5	$0.25	SOV	SOV	Not on ML
8	5	$0.25	Free	Free	Not on ML
9	5	$0.25	0.5 × SOV	0.5 × SOV	Not on ML
10	5	$0.25	0.5 × SOV	Free	Not on ML
11	5	$0.25	SOV	0.5 × SOV	Not on ML
12	5	$0.25	SOV	Free	Not on ML
13	5	$0.50	SOV	SOV	Not on ML
14	5	$0.50	Free	Free	Not on ML
15	5	$0.50	0.5 × SOV	0.5 × SOV	Not on ML
16	5	$0.50	0.5 × SOV	Free	Not on ML
17	5	$0.50	SOV	0.5 × SOV	Not on ML
18	5	$0.50	SOV	Free	Not on ML
19	5	$0.37	SOV	SOV	Not on ML
20	5	$0.45	Free	Free	Not on ML
21	5	$0.38	0.5 × SOV	0.5 × SOV	Not on ML
22	5	$0.40	0.5 × SOV	Free	Not on ML
23	5	$0.37	SOV	0.5 × SOV	Not on ML
24	5	$0.39	SOV	Free	Not on ML

However, peak-hour revenue did vary among scenarios 1 to 12. Providing MLs to HOVs for free resulted in the lowest peak revenue. Charging HOVs the same as SOVs yielded the greatest revenue. The second greatest peak-hour revenue was attained by charging the HOV-2 the same as the SOV and the HOV-3+ half as much as the SOV in both sets of $0.10/mile and $0.25/mile scenarios. As the scenarios become more preferential toward the HOV-2 and HOV-3+, toll revenues decrease from $4,594 to $1,446.

Policy Scenarios 13 to 18

Scenarios 13 to 18 with tolls of $0.50/mile begin to show significant differences in measures of effectiveness (volume, speed, emissions, and revenue) between the ML and GPL. When compared to the previous scenarios 1 to 12, these scenarios result in a steady decline in ML volume, a steady increase in ML speed, an increase in CO_2, in some scenarios increased VOC, and a decrease in CO and NOx.

Table 44. Impact Estimates by Policy Scenarios.

Scenario	Toll Amount ($/Mile)			Peak Hour Volume (vph)		Peak Hour Avg. Speed (mph)		Peak-Hour Emissions (Kilograms/Mile)					Peak-Hour Corridor Revenue ($/Peak Hour)
	SOV	HOV-2	HOV-3+	ML	GL	ML	GL	CO	VOC	NOx	CO_2	SO_2	
1	$0.10	SOV	SOV	3732	7268	55	51	50.79	0.93	5.03	2077.	0.083	$1,846
2	$0.10	Free	Free	3707	7293	55	51	50.78	0.93	5.03	2077.	0.083	$1,446
3	$0.10	0.5 × SOV	0.5 × SOV	3745	7255	55	52	50.80	0.93	5.03	2077.	0.083	$1,682
4	$0.10	0.5 × SOV	Free	3713	7287	55	51	50.79	0.93	5.03	2077.	0.083	$1,580
5	$0.10	SOV	0.5 × SOV	3719	7281	55	51	50.79	0.93	5.03	2077.	0.083	$1,770
6	$0.10	SOV	Free	3729	7271	55	51	50.79	0.93	5.03	2077.	0.083	$1,682
7	$0.25	SOV	SOV	3724	7276	55	51	50.80	0.93	5.03	2077.	0.083	$4,594
8	$0.25	Free	Free	3735	7265	55	52	50.80	0.93	5.03	2077.	0.083	$3,458
9	$0.25	0.5 × SOV	0.5 × SOV	3735	7265	55	52	50.80	0.93	5.03	2077.	0.083	$4,242
10	$0.25	0.5 × SOV	Free	3732	7268	55	52	50.80	0.93	5.03	2077.	0.083	$3,910
11	$0.25	SOV	0.5 × SOV	3737	7263	55	52	50.80	0.93	5.03	2077.	0.083	$4,458
12	$0.25	SOV	Free	3711	7289	55	51	50.80	0.93	5.03	2077.	0.083	$4,082
13	$0.50	SOV	SOV	1500	9500	72	33	44.91	1.00	4.66	2518.	0.083	$3,550
14	$0.50	Free	Free	3096	7904	61	45	49.10	0.93	4.94	2126.	0.083	$3,215
15	$0.50	0.5 × SOV	0.5 × SOV	2121	8879	68	36	45.52	0.96	4.72	2333.	0.084	$4,160
16	$0.50	0.5 × SOV	Free	2513	8487	65	38	46.38	0.97	4.75	2317	0.083	$3,791
17	$0.50	SOV	0.5 × SOV	1758	9242	70	34	45.66	1.01	4.68	2504	0.083	$3,826
18	$0.50	SOV	Free	2149	8851	68	36	45.60	0.96	4.73	2331.	0.083	$3,458
19	$0.37	SOV	SOV	3258	7742	60	47	49.24	0.94	4.94	2124.	0.083	$5,896
20	$0.45	Free	Free	3231	7769	60	47	49.23	0.94	4.94	2124.	0.083	$3,625
21	$0.38	0.5 × SOV	0.5 × SOV	3251	7749	60	47	49.23	0.94	4.94	2124.	0.083	$5,384
22	$0.40	0.5 × SOV	Free	3233	7767	60	47	49.24	0.94	4.94	2124.	0.083	$4,642
23	$0.37	SOV	0.5 × SOV	3247	7753	60	47	49.23	0.94	4.94	2124.	0.083	$5,635
24	$0.39	SOV	Free	3233	7767	60	47	49.23	0.94	4.94	2124.	0.083	$4,955

* Other simulation conditions include a 5-mile-long managed lane facility with a lane capacity of 2200 pcphpl, a free-flow speed of 80 mph, a corridor demand of 11,000 vph, and driver price sensitivities based on stated preference survey results in Houston and Dallas.

Among scenarios with a full toll price of $0.50/mile, the charge-to-all scenario 13 would have the highest impact on speed with 72 mph for the ML and 33 for the GPL, the lowest CO (44.91) and NOx (4.66) emissions, and a toll revenue of $3,550. Scenarios 14 and 16 in contrast show a spike in ML volume, a dip in ML speed, and a corresponding increase in GPL speed.

Scenarios 13 and 17 (ML volumes less than 1800 vehicles per hour) result in the lowest NOx emissions and highest VOC emissions, and a decrease in CO emissions compared to other scenarios. Scenario 15 had neither the lowest nor the highest emissions. When the toll for HOV-2 and HOV-3+ was 50 percent of the rate of SOV, as in scenario 15, a peak toll revenue of $4,160 was realized.

Policy Scenarios 19 to 24

Policy scenarios 19 to 24 with tolls as low as $0.37/mile and as much as $0.45/mile are aimed at maintaining the ML speed at 60 mph. These scenarios show improved effectiveness for speed, but no significant change in effectiveness for emissions between the ML and GPL. Scenarios 20, 22, and 24 result in the lowest ML volume of 3231 and 3233 vehicles per hour, respectively.

Scenario 20 with the maximum HOV preferential treatment yielded the lowest toll revenue of $3,625 even though SOVs were charged a rate of $0.45/mile. Scenario 19, which has a toll of $0.37/mile with equal treatment for all types of users, yielded a maximum revenue of $5,896 among all 24 scenarios.

FINDINGS

A number of conclusions can be drawn from the impact analysis, keeping in mind that the simulation model represents a specific managed lanes corridor with a defined cross section and traffic characteristics. The purpose of the analysis, and the findings described below, is to highlight relative differences between HOV policy scenarios, particularly when comparing HOV preference policies with the base case of express toll lanes (all vehicles pay the same toll rate, regardless of the number of occupants).

Operational Performance Impacts

Figure 40 offers a comparison of general purpose lane operating speed under the various toll scenarios. Under all of these cases, managed lane speeds operated at 55 mph or above. Tolls below the level of $0.25/mile tend to spread out vehicles in both the general purpose and managed lanes. As a result, there is no significant difference in speeds between general purpose and managed lanes. Charging a toll of $0.40/mile or higher increases the operational performance on the managed lanes since fewer drivers choose that option.

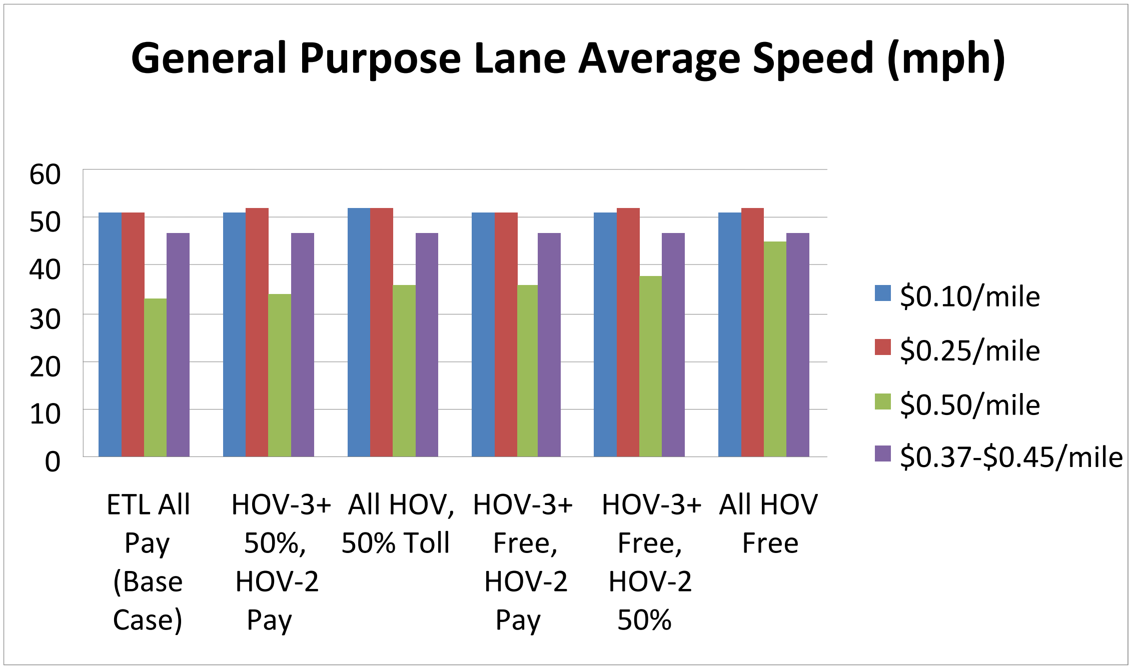

Figure 40. General Purpose Lane Operating Speeds under HOV Policy Scenarios.

At a toll rate of $0.25/mile or lower, preferential treatments of HOVs have no impact on operational performance. At the toll rate of $0.50/mile, less preferential treatment of HOVs in terms of pricing incentives increases operational performance on the managed lanes. To maintain a speed level of 60 mph on the managed lanes, it would require a tradeoff between toll rate and HOV preferential treatment, namely either a low SOV toll rate of $0.40/mile with no HOV preferential treatment, a high toll rate of $0.55/mile with free access for HOVs, or some combination of SOV and HOV pricing policies in-between.

Figure 41 shows the operating speed in the managed lanes under the various HOV policy scenarios. Under the higher toll rate, the speeds are higher in the managed lanes since fewer drivers choose to pay the toll rate, though less so where HOVs are provided toll discounts.

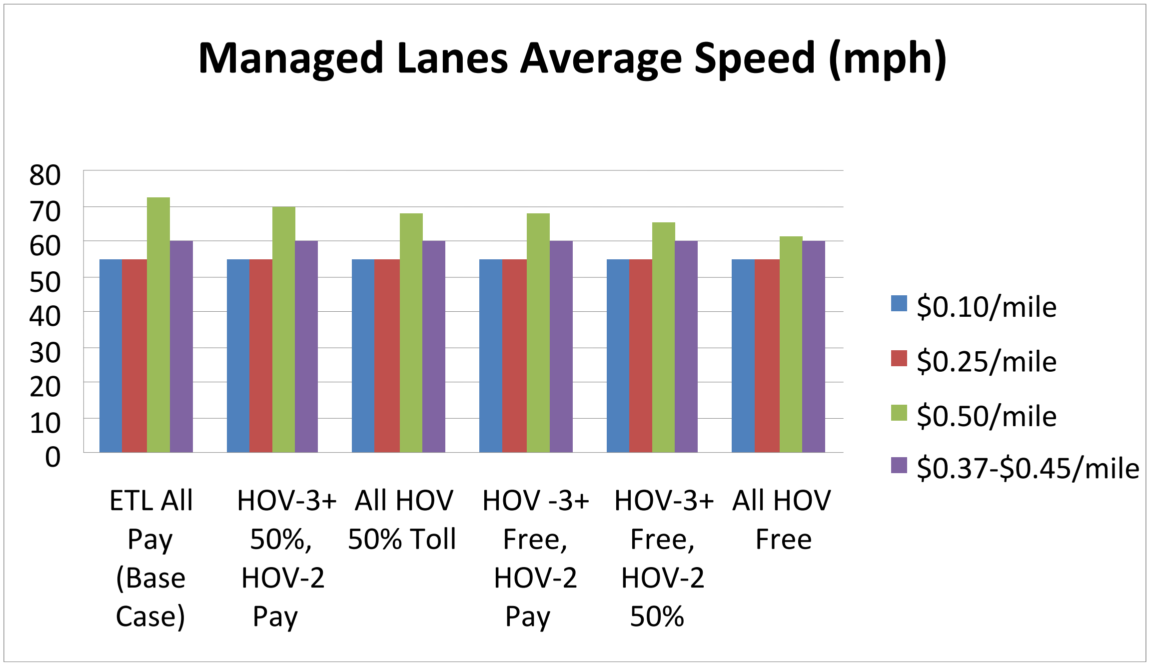

Figure 41. Managed Lanes Average Speed (mph).

Person Throughput Impacts

Figure 42 offers a picture of person throughput under the different policy scenarios. Person throughput was calculated for the peak direction for all lanes, using average vehicle occupancy rates,[4] in order to assess differences in the movement of people through the corridor as opposed to vehicles.[5] In comparison to the base case of "all HOVs pay," each HOV policy scenario provides a higher level of person movement in the corridor. However, for toll rates under $0.25/mile, the increase is less than 5 percent.

Of note are the larger percent increases in person throughput under the higher toll rates, and the indication that HOV policies offering a minimum of HOV-3+ free can result in significant person movement increases, in some cases the equivalent of an additional lane of traffic.

Table 45 shows the change in person throughput on managed lanes using the optimized toll rate, given the assumptions embedded in the model. The degree of person throughput depends on the HOV scenario. For instance, the scenario with managed lanes with all HOVs free at the optimized toll rate results in a net increase of persons moved of 2122 over the base case. If you assume a general purpose lane moves approximately 2600 people, then the managed lanes are moving nearly an equivalent of one additional lane of traffic using that particular HOV policy.

[4] Average vehicle occupancy rates for calculating person throughput are 3.2 for HOV-3+, 6.4 for vanpools and paratransit, and 8.2 for buses.
[5] The model assumes that total demand and number of vehicles in each class are fixed.

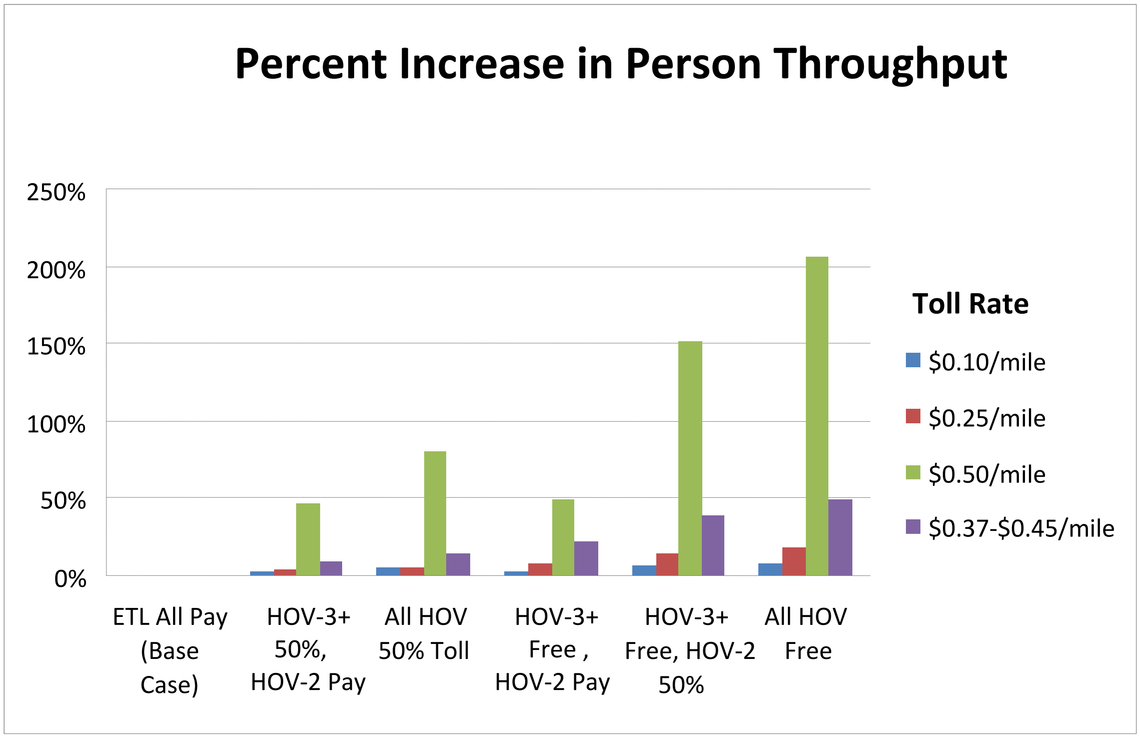

Figure 42. Person Throughput under HOV Policy Scenarios.

Table 45. Change in Person Throughput on ML for Optimized Toll Rate.

HOV Scenario	ML Vehicles	ML People	Δ People (ETL)
ETL all pay	3,258	4,281	-
HOV-3+ 50%, HOV-2 pay	3,247	4,665	384
All HOV pay 50%	3,251	4,878	597
HOV-3+ free, HOV-2 pay	3,233	5,679	1,398
HOV-3+ free, HOV-2 pay 50%	3,233	5,933	1,652
All HOVs free	3,231	6,403	2,122

Emission Impacts

From an emissions perspective, the analysis indicates that HOV preference policies result in a negligible difference in peak-hour emissions across all types, including CO, VOC, NOx, and SO_2, as illustrated in Figures 43, 44, and 45.

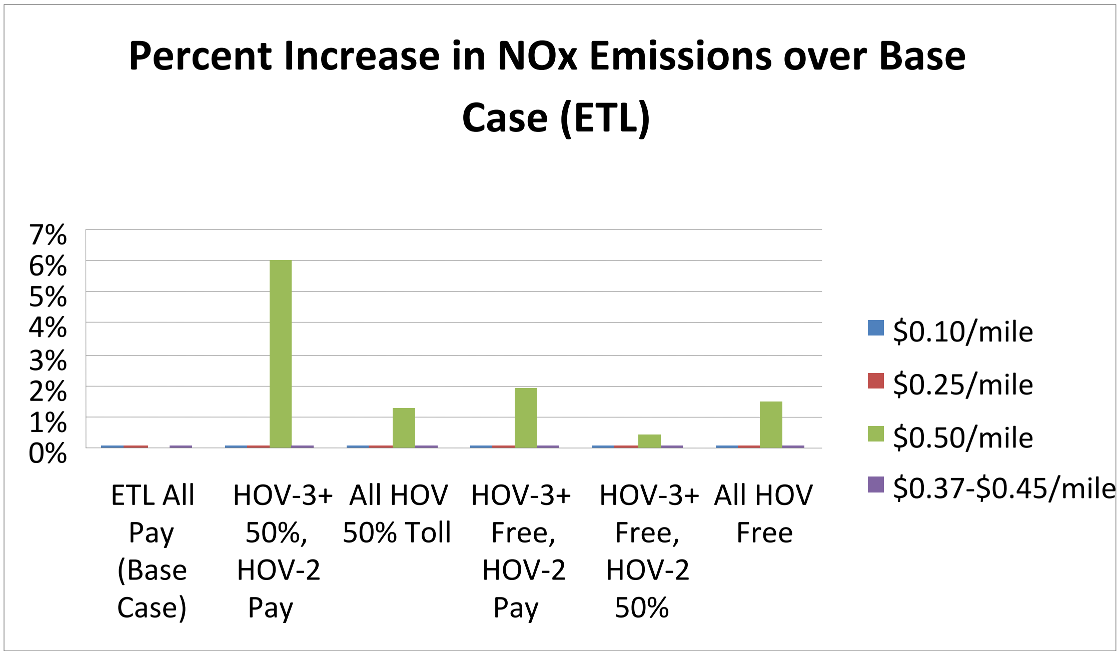

Figure 43. Percent Increase in NOx Emissions.

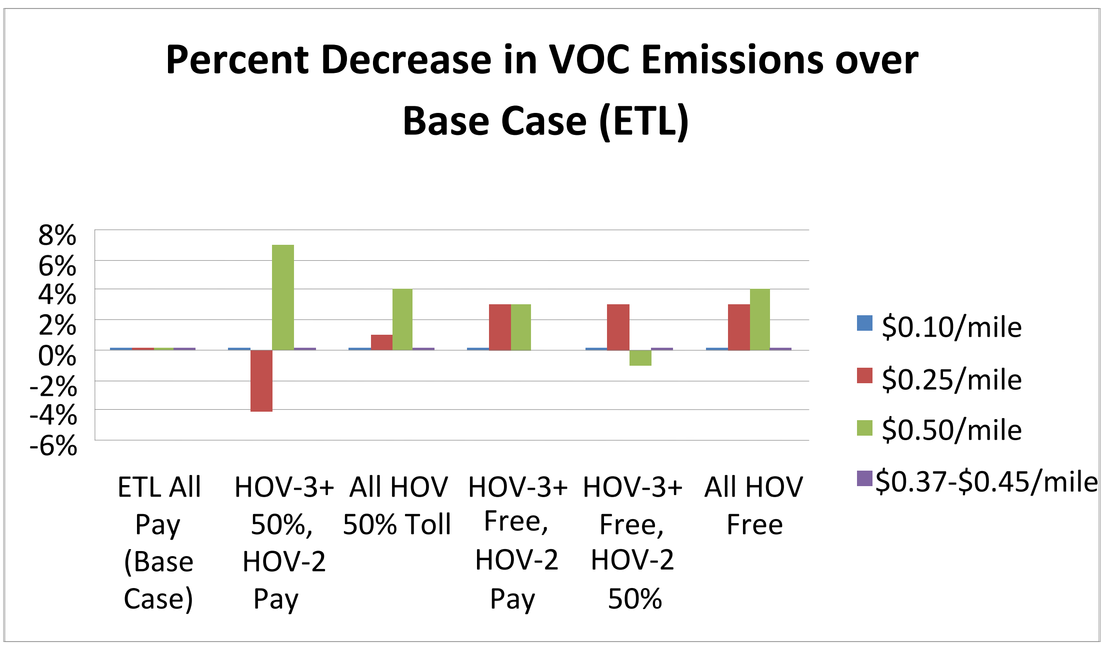

Figure 44. Percent Decrease in VOC Emissions.

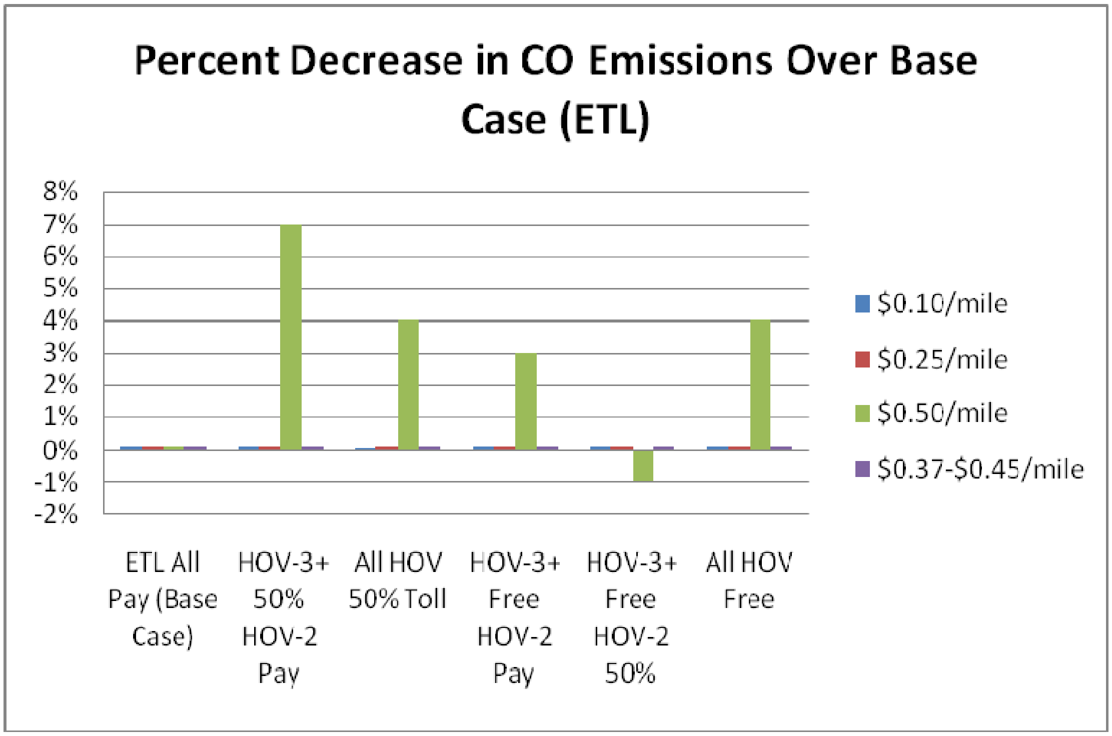

Figure 45. Percent Decrease in CO Emissions.

The one exception is CO_2 emissions. Figure 46 illustrates CO_2 emissions across all scenarios and toll rates, also indicating no significant difference between the base case and the HOV preference cases, with slight change under higher toll rates. Figure 47 provides additional illustration of peak-hour CO_2 emissions under the $0.50/mile scenario. This graphic shows a variation in emissions across the different policy scenarios, with the "all HOV free" policy resulting in the largest reduction in CO_2 emissions.

Revenue Impacts

In general, less preferential treatment of HOVs would result in an increase in toll revenue. The preferential treatments of HOVs at the toll levels of $0.10/mile and $0.25/mile do not affect peak-hour volume and speed performance or peak-hour emissions. However, Figure 48 shows they do negatively impact peak-hour revenue based on the model. In every scenario where HOVs traveled free, revenue was at the minimum for that set of scenarios. Maximum revenue was gained in scenario 19 at a toll of $0.37/mile.

Overall, among the scenarios examined, higher toll rates tend to generate higher toll revenues, reduce overall CO and NOx emissions more than lower toll rates, and shift travel demand to GPLs. HOV preferential treatments at any given toll level tend to reduce toll revenue, have no impact on or reduce system performance on managed lanes, and increase CO and NOx emissions.

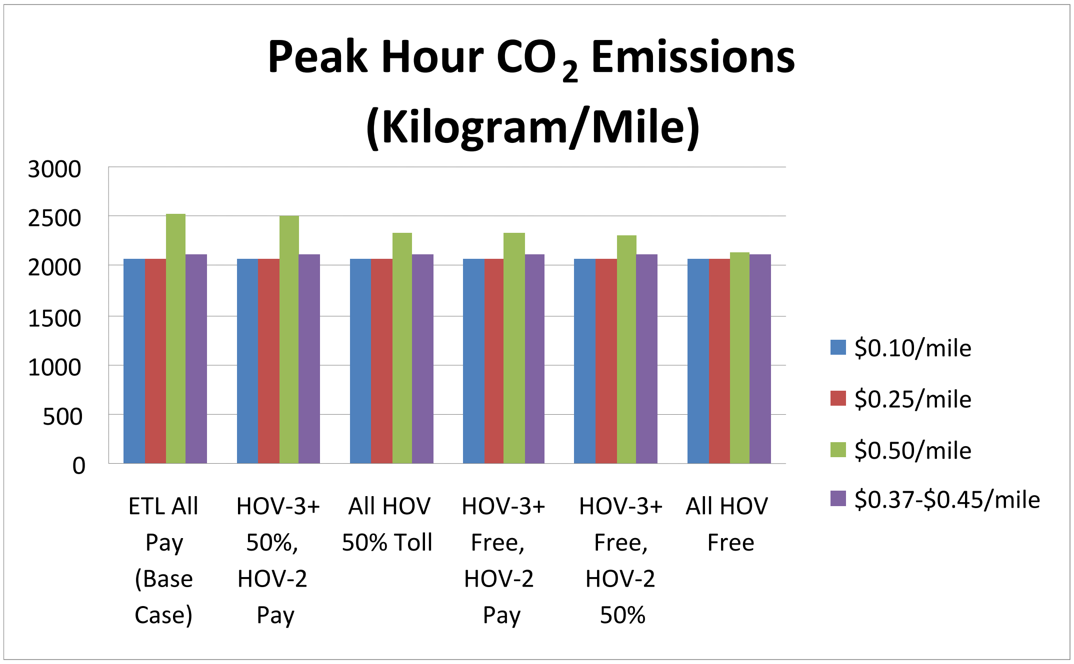

Figure 46. CO_2 Emissions under HOV Policy Scenarios.

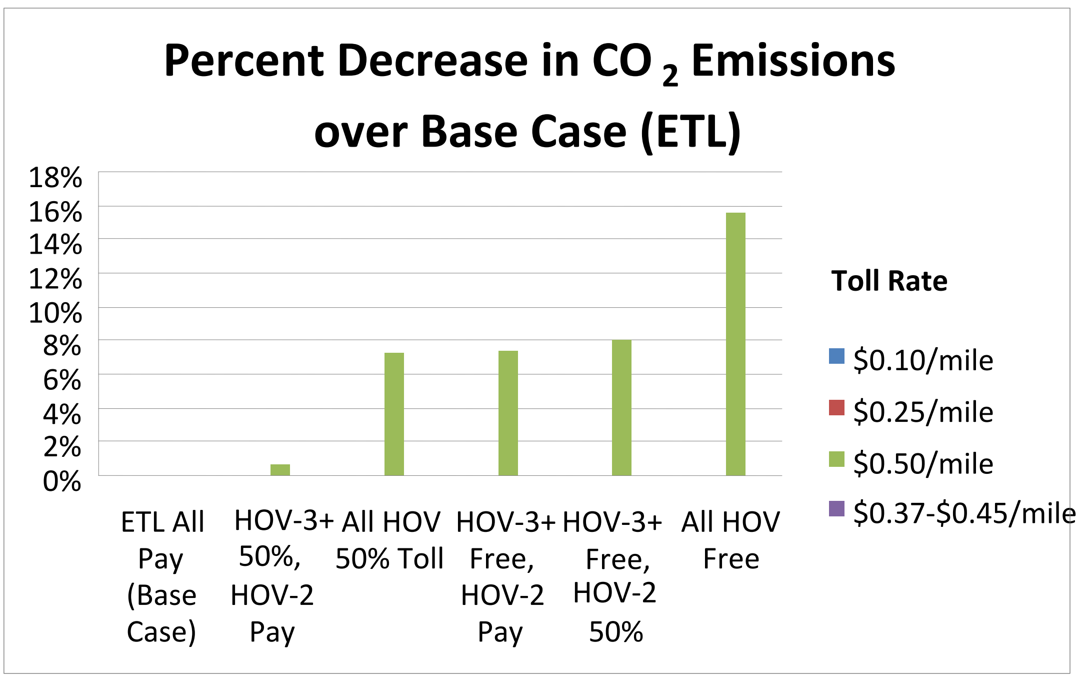

Figure 47. Decrease in CO_2 Emissions under High Toll Rate.

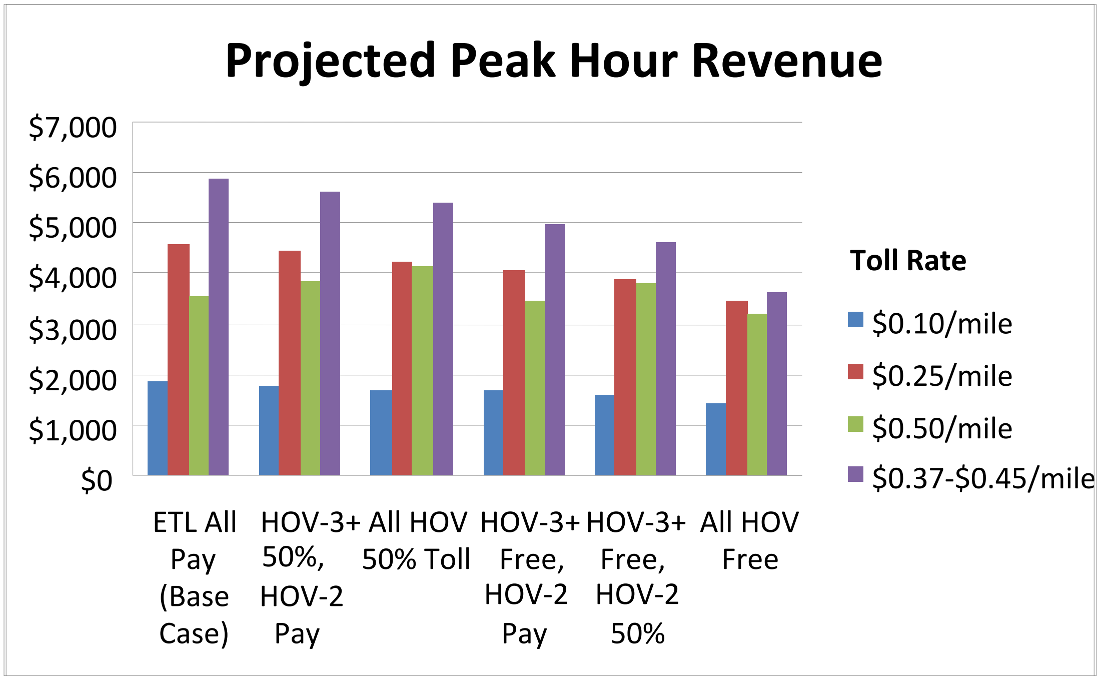

Figure 48. Revenue Estimates for HOV Policy Scenarios.

CHAPTER 6. CONCLUSIONS

Using the information collected and analyzed from the state-of-the-practice review, the user survey, and the impact analysis, the researchers developed a qualitative matrix illustrating the relative tradeoffs between alternative HOV policies for a variety of typical managed lane performance objectives. The matrix is shown in Table 46.

Table 46. Relative Comparison of HOV Policy Options for Various Managed Lane Performance Objectives.

	Carpool Policy Scenarios					
Managed Lanes Performance Objectives	**All Vehicles Pay**	**HOV3+ 50% HOV2 Pay**	**All HOV 50% Toll**	**HOV3+ Free HOV2 Pay**	**HOV3+ Free HOV2 50%**	**All Carpools Free**
Person throughput	○	◒	◒	●	●	●
Revenue generation	●	●	●	◒	◒	○
Emissions reduction	◒	◒	◒	◒	◒	◒
Operational performance	◒	◒	◒	◒	◒	◒
Enforcement and operational simplicity	●	◒	◒	◒	○	◒
Public perception and support	○	◒	◒	◒	◒	◒

Relative success in achieving performance objective: High ● Medium/Neutral ◒ Low ○

Determining the right HOV policy depends upon the project objectives and relative weights of each. The objectives are based upon the expected outcome of the project in terms of regional goals and facility objectives. There are myriad policy combinations from which to choose, but ultimately the mix and weighting objectives depend on the intended performance outcome and any financial constraints.

Table 46 highlights six different performance objectives. For each performance objective, the rating represents a policy's capacity to achieve the specific objective in comparison to the other alternative policies:

- **Person movement.** The more liberal the HOV preference policy (i.e., the level to which toll discounts and exemptions are provided), the higher the person throughput when compared to "all users pay" full toll or 50 percent toll.
- **Revenue generation.** The opposite occurs for revenue generation; the more liberal the HOV policy, the lower the revenue expectations.
- **Emissions reduction.** In general, there is little difference between alternative HOV policies in terms of reduction of emissions, with some changes possible in CO_2 reduction under more liberal HOV policies.
- **Operational performance.** In general, there is little difference between alternative HOV policies for a facility that is managed, though under high toll rates there may be reduced performance in the general use lanes.
- **Enforcement and operational complexity.** This rating is largely based on how difficult enforcement is to perform. The least complex is the express toll lane scenario, where no

differential pricing between vehicles occurs. The most complex is one in which there is differential pricing among the three different user groups.
- **Public perception and support.** This research concluded that there is high support for managed lanes, and no differentiation between types of operations was made. However, previous research suggests that managed lanes with HOV preference have a higher level of public support than those without HOV preference *(99)*.

Based upon the results of the study, the following conclusions are drawn:

- HOV preferences are common for managed lanes in operation and under development. Most provide free access to HOV-3+ as a minimum.
- There are operational, uniformity, and equity considerations on the part of agencies that influence decisions about HOV preference, including enforcement operations.
- When considering the effectiveness of carpool incentives relative to the national decline in "acquaintance" carpools (as opposed to family carpools or "fampools"), policy makers would be well advised to consider the overall contribution of incentives to the expressed objectives of the managed lanes program.
- HOV preferences in managed lanes can influence carpooling behavior. The most common reason for forming a carpool is to have access to the HOV lanes, particularly for work/commute trips. Other pressures that influence the decision to carpool—including rising gas prices and interest in sharing vehicle costs—may have become more prominent since the survey was conducted and are not addressed in this study.
- Family member carpools make up the vast majority of carpools. The degree to which these carpools would remain intact without carpool preferences was not directly measured, but survey responses on *why* people carpool suggest that HOV preferential treatment is an important factor for these carpoolers.
- There is high support for managed lanes in Texas cities that currently have toll roads and HOV lanes, and "faster travel" and "travel time reliability" were the most important reasons for support.
- There may be more to gain in person-moving capacity with policies that emphasize HOV preference.
- HOV policies in managed lanes have minimal impact on emissions, although there may be an influence associated with CO_2 emissions under higher toll rates and more favorable HOV preferences.
- The impacts of different HOV pricing policies on the overall mix of traffic on an entire freeway are small. However, the small changes to the number of HOV-3+ travelers (and even HOV-2 travelers) can represent a significant portion of travelers using these modes (10 percent or more).
- The determination of the appropriate HOV policy in managed lanes depends upon individual project objectives and what the agencies are trying to achieve in their region and with their facility. There are a myriad of HOV policy combinations that can be chosen, but ultimately the decision depends on what is to be accomplished in terms of operation and person throughput, and what the financial constraints are. The research does suggest, however, that there may be more to gain in operational efficiency (i.e., person-moving capacity) with policies that emphasize HOV-3+, and to a lesser degree HOV-2.

This research did not fully address off-peak travel behavior or emissions reduction. Further research is needed to explore these issues in more detail so that holistic managed lane policies can be formulated with the overall daily operation of the facility in mind.

In closing, there are a number of practical considerations for developing and implementing carpool preference policies in managed lanes based on experience. As illuminated in the state-of-the-practice review, pre-existing HOV lanes and associated policies play a significant role in defining managed lane carpool preferences. This is largely a result of the concern that any policy that is viewed as a "take-away" situation will meet with resistance from existing HOV lane users when expanding to HOT lanes. Among the examples of a "take-away" condition are changing existing preferences from HOV-2 to HOV-3+, changing hours of operation, changing access locations, and requiring registration of carpools or transponder use. The prospects for more flexible policies are higher in corridors or regions constructing new managed lanes without regional HOV policies. In Texas, those without legacy HOV systems, such as San Antonio, Austin, and El Paso, may have greater flexibility in defining carpool preferences that meet a variety of performance objectives. For instance, if the combined objectives are to generate revenue and target commute trip reductions (and to a lesser extent family carpools for non-commute trips), there may be greater flexibility to focus on peak-period carpool preferences. For either situation, public outreach and education will be key to changes for situations where existing HOV policies are proposed to be changed, and for brand-new HOV systems in regions where they do not currently exist.

Managed lanes experience also has demonstrated that facility performance objectives must be unambiguously defined, with clear and transparent policies for performance and predetermined thresholds for modifying operations. For example, how will price changes be determined over time? How will carpool preferences change over time? If the price reaches a certain threshold, will certain user exemptions be changed? What role does revenue play? Is there a minimum required revenue level to pay operations and maintenance? Is there a minimum required level to pay operations and maintenance some portion of capital costs? Defining all of these expectations will aid in defining carpool preference policies.

Finally, the research revealed that there are opportunities to better coordinate regional ridesharing objectives and managed lane policies so the two are more closely aligned. This can be achieved not only through linking project-level operating policies and regional transportation goals, but through close coordination of ridematching programs and TDM services with managed lanes operations.

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APPENDIX A. SURVEY QUESTIONS

1. Location of survey source?
   1) Dallas
   2) Houston

2. Which road do you travel on most frequently?
   If Dallas
   - Dallas North Tollway
   - East Loop 820
   - I-20
   - I-30
   - I-35E
   - I-45
   - I-635
   - Loop 12
   - Pres. George Bush Turnpike
   - SH-114
   - SH-121
   - SH-161
   - SH-183
   - SH-360
   - Spur 408
   - US 175
   - US 67
   - US 75
   - US 80
   - None

   If Houston
   - Sam Houston
   - I-10 Katy Freeway
   - I-45 Gulf Freeway
   - I-45 North Freeway
   - I-610 Loop
   - SH-225 LaPorte
   - SH-288 South
   - US 59 Southwest
   - US 290 Northwest
   - None

3. What is the main reason you generally do not travel using any of the highways listed on the previous page?
    1) Roads convenient (other roads are more convenient)
    2) Roads congested (other roads less congested)
    3) Transit (use transit)
    4) No travel (do not travel much)
    5) Other

4. What is the main purpose of most (or all) of these trips?
    1) Commute
    2) Recreational (includes social, shopping, errands, and entertainment)
    3) Work (work related, not commuting)
    4) School
    5) Other

5. When do you generally travel on this road?
    1) Early AM (midnight - 6 a.m.)
    2) Peak AM (6 a.m. - 9 a.m.)
    3) Midday (9 a.m. - 4 p.m.)
    4) Peak PM (4 p.m. - 6:30 p.m.)
    5) Late PM (6:30 p.m. - midnight)

6. Near which major cross streets do your trips start (such as your home)?

7. Near which major cross streets do your trips end (such as your work, school, or shopping location)?

8. How many miles is your typical trip on <selected road>?

9. Do you have to pay to park at your destination?

10. If yes, how much does it cost per day?

11. How many people, including you, are there in the vehicle on your typical trip on <selected road>?
    1) 1
    2) 2
    3) 3
    4) 4
    5) 5
    6) Bus
    7) Motorcycle
    8) Train
    9) Vanpool

12. Are you a driver or a passenger on these trips?
    1) Driver
    2) Passenger
    3) Alternate between driver/passenger
    4) NA (not applicable)

13. Do you pay a toll or a bus/train fare on these trips?
    1) Yes
    2) No

14. If yes, how much is the toll or fare?

15. How many trips do you make during a full week (Monday to Sunday) on <selected road> for the same trip purpose?

16. What is your primary reason for traveling by bus or train?
    1) Cheaper than driving a car
    2) Convenient to use bus/train
    3) Bus/train runs frequently
    4) Trip takes less time than by car
    5) No car available
    6) Other

17. Whom do you generally travel with?
    1) Co-worker/person in nearby office
    2) Neighbor
    3) Adult family member
    4) Casual carpool
    5) Child
    6) Other

18. How much extra time does it take you to pick up and drop off the passenger(s)?

19. How important are the following factors in the formation of your current carpool? Rank 1 (not important) to 5 (very important).
    1) Sharing vehicle expenses
    2) Access to HOV lanes
    3) Preferred parking at work
    4) Relaxation when traveling
    5) Get work done while traveling
    6) Travel time savings due to carpooling
    7) Carpool partner matching program
    8) Encouraged by program at work
    9) Enjoy traveling with others
    10) Rely on carpool to reach destination at certain time
    11) Splitting tolls on the toll road

12) Help the environment/society
13) Drop kids off at school/daycare
14) Other

20. Of your trips per week on <selected road>, how many trips do you carpool?

21. What do you do after you drop off the passenger(s) in your carpool?
    1) Driver/passenger have same destination
    2) Continue to my final destination
    3) Pick up additional passengers
    4) Perform errands
    5) Other

22. Do you generally split the toll?
    1) Yes
    2) No

23. If no, who pays the toll?

24. How much extra time does it take you to pick up and drop off the passenger(s)?

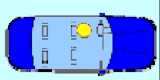
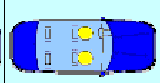
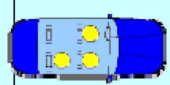
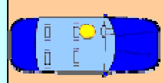
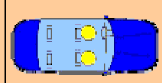
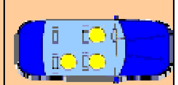
25. How important are the following factors in the formation of your current vanpool? Rank 1 (not important) to 5 (very important).
    1) Sharing vehicle expenses
    2) Access to HOV lanes
    3) Preferred parking at work
    4) Relaxation when traveling
    5) Get work done while traveling
    6) Travel time savings due to vanpooling
    7) Vanpool partner matching program
    8) Encouraged by program at work
    9) Enjoy traveling with others
    10) Rely on vanpool to reach destination at certain time
    11) Splitting tolls on the toll road
    12) Help the environment/society
    13) Other

26. Of your trips per week on <selected road>, how many trips do you vanpool?

27. What do you think are the most important reasons why you do not carpool or vanpool?
    1) No one with same location/schedule
    2) Potential partners have traits I disagree with
    3) Like flexibility by not carpooling
    4) Need a vehicle during the day
    5) Need to make other stops during trips
    6) Like to listen to radio that others don’t

7) Appreciate ‘alone time’
8) No vanpool/carpool matching
9) Other

28. The following four scenarios ask you to choose among a few potential travel choices. You are choosing between different toll prices, total passengers in your car, and travel times for each scenario. **For a typical trip, please check the one option <u>for EACH ROW</u> that you would be most likely to choose if faced with these specific options.** Remember that regular lane traffic (in orange) tends to be congested and could be slower than managed lane traffic (in light blue).

	Managed Lane Options			Non-Toll (Regular) Lane Options		
	Drive Alone	Drive with 1 passenger	Drive with 2 passengers	Drive Alone	Drive with 1 passenger	Drive with 2 passengers
						
Travel Time	**14 min**	**19 min**	**24 min**	**23 min**	**28 min**	**33 min**
Scenario 1 →	O $ 1.00	O $ 1.00	O $ 0.50	O FREE	O FREE	O FREE
Scenario 2 →	O $ 2.00	O $ 2.00	O $ 1.00	O FREE	O FREE	O FREE
Scenario 3 →	O $ 0.25	O $ 0.25	O $ 0.00	O FREE	O FREE	O FREE
Scenario 4 →	O $ 1.50	O $ 1.50	O $ 0.75	O FREE	O FREE	O FREE

29. Please select the one option that you would be most likely to choose if faced with these specific options.
1) SOVML (drive alone in ML)
2) HOV2ML (HOV-2 in ML
3) HOV3ML (HOV-3 in ML)
4) SOVGP (drive alone in GP)
5) HOV2GP (HOV-2 in GP)
6) HOV3GP (HOV-3 in GP)

30. What is your age?
1) 16 to 24
2) 25 to 34
3) 35 to 44
4) 45 to 54
5) 55 to 64
6) 65 and over

31. What is your ethnicity?
1) Caucasian
2) African American
3) Hispanic
4) Asian
5) Native American
6) Other

32. Please describe your household type.

33. How many motor vehicles are available for use by members of your household?

34. What category best describes your occupation?
   1) Professional
   2) Technical
   3) Sales
   4) Administrative
   5) Service
   6) Manufacturing
   7) Stay home
   8) Student
   9) Self-employed
   10) Unemployed
   11) Retired
   12) Other

35. What is the last year of school you have completed?
   1) Less than high school
   2) High school graduate
   3) Vocational
   4) College graduate
   5) Postgraduate

36. What was your annual household income before taxes in 2005?
   1) Less than $10,000
   2) $10,000 to $15,000
   3) $15,000 to $25,000
   4) $25,000 to $35,000
   5) $35,000 to $50, 000
   6) $50,000 to $75,000
   7) $50,000 to $75,000
   8) $75,000 to $100,000
   9) $100,000 to $150,000
   10) $150,000 to $200,000
   11) More than $200,000

37. How did you find out about this survey?
   1) News article
   2) TV
   3) Tollbooth card
   4) Bus card
   5) Road card
   6) Employer

7) Website
8) Family or friend
9) Other

38. Would you be interested in using managed lanes?
    1) Yes
    2) No

39. Please let us know what features you like most about the managed lane concept. Rate 1 (not important) to 5 (critical feature).
    1) Able to travel alone and still use ML
    2) Able to use transit on the ML
    3) Able to travel faster than GP
    4) Travel time reliability
    5) Able to use carpool/vanpool on ML
    6) ML does not have large trucks
    7) ML is less stressful
    8) Other factor

40. Please let us know what features of managed lanes are the most important in your decision not to use them. Rate 1 (not important) to 5 (critical issue).
    1) Do not have a credit card to establish account
    2) Use bus or train, and will not change
    3) Do not want a toll transponder in my car
    4) ML is complicated or confusing
    5) I have flexibility to travel at less congested times
    6) Do not want to pay the toll cost
    7) Carpool, and will not switch to drive alone
    8) Travel on uncongested roads, and will not switch to ML
    9) Other factor

41. The toll on a managed lane could change with the amount of traffic. What is your initial feeling regarding this option?
    1) Strongly favor
    2) Somewhat favor
    3) Indifferent
    4) Somewhat oppose
    5) Strongly oppose

42. How do you feel about allowing carpoolers to pay a smaller toll to use the managed lane than people who drive alone?
    1) Strongly favor
    2) Somewhat favor
    3) Indifferent
    4) Somewhat oppose
    5) Strongly oppose

43. Please let us know how any of the following rewards might influence your travel on managed lanes. Rank 1 (not important) to 5 (very important).
    1) Airline frequent flyer miles
    2) Discounts from retailers
    3) Discounted/free transit trips
    4) Discounted/free off-peak ML travel
    5) Other reward

44. Wireless hotspots for passengers: willing to carpool in ML?
    1) Yes
    2) Maybe
    3) No
    4) Avoid

45. Wireless hotspots for passengers: pay to use ML as carpool?
    1) Yes
    2) Maybe
    3) No
    4) Avoid

APPENDIX B. MODEL VALIDATION

The main goal of model validation is to ensure the accuracy of TPM-3.1's prediction. To achieve its goal, the model validation entailed comparing the TPM-3.1 model outputs to two data sets, one from a Wilbur Smith Associates (WSA) study and a second from the I-394 ML corridor in Minnesota *(91, 92)*. There are two main reasons for selecting these two data sets for validation purposes:

- The WSA results were estimates based on the *same* facility conditions as this study with *different* methodologies. It is useful to crosscheck the TPM-3.1 results with the WSA's estimates to analyze variations between the two sets of estimates.
- The field data from the I-394 ML corridor in Minnesota provide an opportunity for a reality check. A comparison of TPM-3.1 outputs with the field data can help answer the question of how much the TPM-3.1 model simulation results differ from reality.

To validate the model, facility conditions obtained from both sources were input into TPM-3.1. In addition, a 5 percent HOV+ rule, which assumes that about 5 percent of the HOVs would not use managed lanes regardless of the change in pricing policies, was applied to the TPM-3.1 model estimations for the I-394 ML corridor in Minnesota. The model results were then compared to the estimated or observed volume shares for the managed and general purpose lanes.

1. ESTIMATES OF THE WILBUR SMITH ASSOCIATES STUDY AND MODEL VALIDATION INPUTS

The estimates of the WSA study are based on the travel demand model databases developed under basic assumptions provided by NCTCOG and micro-simulation using VISSIM *(91)*. SOVs are charged for full toll depending on the time of day, but HOVs are charged different rates in each tested scenario. The facility being investigated in the WSA study has four GPLs and two MLs. Specific facility information is displayed in Figure 49. User compositions and the eight toll pricing scenarios that were considered as part of this model validation effort are summarized in Table 47. The SOV toll is represented in the table as price per miles.

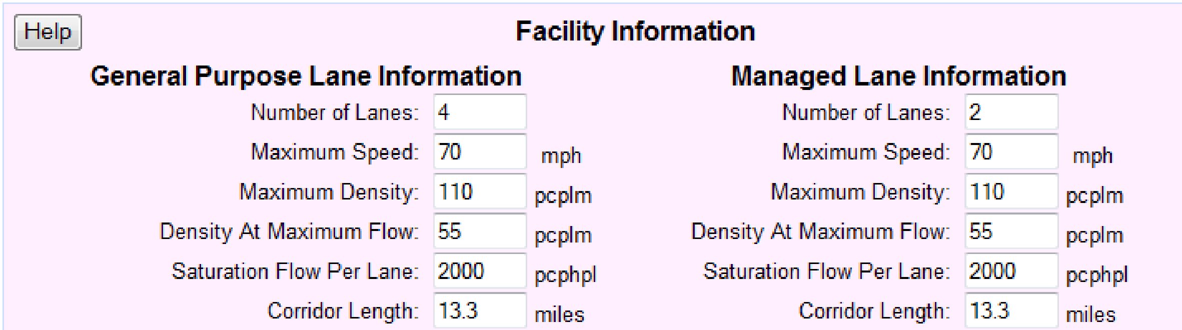


Figure 49. Facility Inputs for the WSA Model Validation.

Table 47. Scenarios and User Compositions for WSA Model Validation.

Scenario	Section	Time Period	Year	SOV Toll ($/Mile)	HOV-2+ Toll	User Composition		
						SOV	Trucks	HOV-2+
1	I-30 at Belt Line Road	AM	2015	$0.30	0.5 × SOV	70%	5%	25%
2	I-30 at Belt Line Road	PM	2015	$0.25	0.55 × SOV	65%	6%	29%
3	I-30 at Westmoreland Road	AM	2015	$0.30	0.55 × SOV	73%	5%	22%
4	I-30 at Westmoreland Road	PM	2015	$0.25	0.55 × SOV	68%	6%	26%
5	I-30 at Belt Line Road	AM	2015	$0.20	SOV	70%	5%	25%
6	I-30 at Belt Line Road	PM	2015	$0.20	SOV	67%	6%	27%
7	I-30 at Westmoreland Road	AM	2015	$0.20	SOV	73%	5%	22%
8	I-30 at Westmoreland Road	PM	2015	$0.20	SOV	69%	6%	25%

2. MINNESOTA FIELD DATA AND MODEL VALIDATION INPUTS

The Minnesota field data are obtained from the Minnesota Department of Transportation *(92)*. The data were recorded using loop detectors installed at Penn Avenue in both general purpose and managed lanes. The detectors count the number of vehicles that are passing at the location and convert it into hourly volumes. This section of the I-394 managed lane facility has two MLs and three GPLs. SOVs are charged full toll based on the demand, although the full toll varies in amount by time of day. However, HOVs are free of toll on this facility. I-394 facility information is shown in Figure 50. User compositions and the policy scenarios for model validation with the I-394 field data are exhibited in Table 48. Like the WSA model validation, the SOV toll is represented in the table as price per miles.

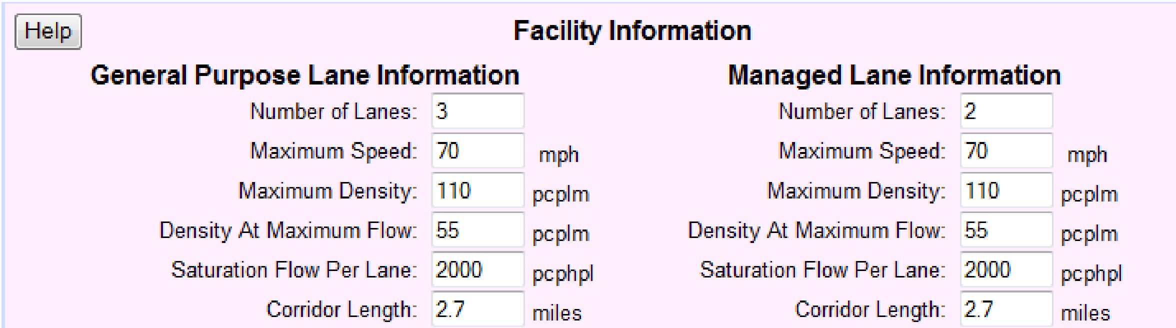


Figure 50. Facility Inputs for I-394 Model Validation.

Table 48. Scenarios and User Compositions for I-394 Model Validation.

Scenario	Section	Time Period	Year	SOV Toll ($/Mile)	HOV-2+ Toll	User Composition		
						SOV	Trucks	HOV-2+
9	I-394 at Penn Ave.	AM	2007	$0.95	Free	83%	16%	1%
10	I-394 at Penn Ave.	PM	2007	$0.76	Free	83%	16%	1%
11	I-394 at Penn Ave.	AM	2007	$0.67	Free	83%	16%	1%
12	I-394 at Penn Ave.	PM	2007	$0.52	Free	83%	16%	1%

3. VALIDATION RESULTS

Tables 49 and 50 display the ML shares of the TPM-3.1 model outputs and the received data for the 12 simulated scenarios. Comparisons are discussed by SOV, HOV-2+, and total volumes.

SOV Difference

As seen in the SOV outputs, the results from TPM-3.1 show reasonable agreement with the WSA study (see Table 49), with most values showing less than 4 percent difference in the AM and 3 percent difference in the PM. In the low-volume AM scenario, MLs become unattractive to SOV users if the ML travel times do not differ or are only slightly lower than the GPL travel times; travelers are likely to continue using the GPLs. The model is less accurate in low-volume scenarios due to application of price elasticities and user preferences under peak conditions. As the volume increases during the PM to the point where volumes can greatly increase the travel time on the GPLs, the probability of using MLs will also increase. In the WSA study, the differences range from –4 percent to 3 percent, with the greatest differences in scenarios 1 and 5 (both are 4 percent).