POTENTIAL SHIFT FROM TRANSIT TO SINGLE OCCUPANCY VEHICLE DUE TO ADAPTATION OF A HIGH OCCUPANCY VEHICLE LANE TO A HIGH OCCUPANCY TOLL LANE

A Thesis

by

GEOFFREY LINUS CHUM

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2007

Major Subject: Civil Engineering

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Approved by:

Chair of Committee,	Mark W. Burris
Committee Members,	Luca Quadrifoglio
	Katherine F. Turnbull
Head of Department,	David V. Rosowsky

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ABSTRACT

Potential Shift from Transit to Single Occupancy Vehicle due to Adaptation of a High Occupancy Vehicle Lane to a High Occupancy Toll Lane. (December 2007)

Geoffrey Linus Chum, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Mark W. Burris

Modifying a high occupancy vehicle (HOV) lane into a high occupancy/toll (HOT) lane generally involves allowing single occupant vehicles (SOVs) to travel on the free-flow HOV lane for a toll. This may entice some former transit riders to pay the toll to obtain the benefits of traveling in their own vehicle on the HOV lane. Thus, the introduction of a HOT lane has the potential to impact transit ridership, dramatically lowering the average vehicle occupancy of the lane.

In 2003, surveys were distributed to park-and-ride bus passengers on the Katy Freeway and Northwest Freeway corridors in Houston. Passengers' responses to questions regarding their trip characteristics, their socioeconomic characteristics, and stated preference scenarios were used to develop a mode choice model. To determine how transit passengers might react to a proposed HOT lane, HOT lane scenarios with varying tolls and travel time savings were simulated using this model.

For all scenarios, only a small percentage of transit passengers were estimated to switch to driving alone on the HOV lane. Fewer people would switch during the peak period than during the off-peak period. Transit passengers shifting to SOV on the HOV

lane would reduce the average vehicle occupancy (AVO) only about 1 percent to 2 percent. SOV drivers shifting from the general purpose lanes to the HOV lanes are likely to affect AVO much more. However, as long as free-flow conditions are maintained, this analysis shows that the HOV lane can be successfully adapted to a HOT lane and move more people, even if a few transit passengers choose to drive alone.

DEDICATION

To my parents

ACKNOWLEDGMENTS

First of all, I would like to thank God for the opportunities I have had during my time at Texas A&M University. He has blessed me and given me the ability to complete two degrees. I would also like to thank my mom and dad for their love, support, and prayers. Without their help, I could not have accomplished all that I have.

Thank you to my advisor, Dr. Burris, for his assistance and patience throughout the course of this research. Thanks also to the members of my committee, Dr. Turnbull and Dr. Quadrifoglio for their participation. I also would like to acknowledge Sunil Patil for his assistance with my mode choice model.

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TABLE OF CONTENTS

CHAPTER Page

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

CHAPTER I

INTRODUCTION

1.1 Overview

High occupancy vehicle (HOV) lanes have existed in the United States since 1969, when the bus-only lane on the Shirley Highway (I-395) opened in Northern Virginia approaching Washington, D.C. (Turnbull 2003). HOV facilities typically have three objectives: increase the average number of persons per vehicle, preserve the person movement capacity of the roadway, and enhance bus transit operations (Turnbull 2003).

In most cases, a vehicle with two or more people may use an HOV lane. However, in some locations the number of vehicles with two occupants (HOV2) has increased to a point that demand for the HOV lane has exceeded the critical operating threshold for the lane (point B in Figure 1.1). The critical operating threshold is "the traffic volume beyond which free-flow conditions begin to degrade" (Swisher et al. 2003). In order to maintain free flow conditions, some HOV lanes are restricted to vehicles with three or more occupants (HOV3+). This "hierarchy of users" gives priority to vehicles with higher number of occupants; usually buses have highest priority, then HOV3+ (including vanpools), then HOV2 (Swisher et al. 2003). If there are too many HOV lane users of a lower priority, like HOV2, that group may be completely disallowed so that higher priority users may continue to receive the travel time benefits of the HOV lane. This hierarchy is shown graphically in Figure 1.1.

This thesis follows the style of *Journal of Transportation Engineering*.

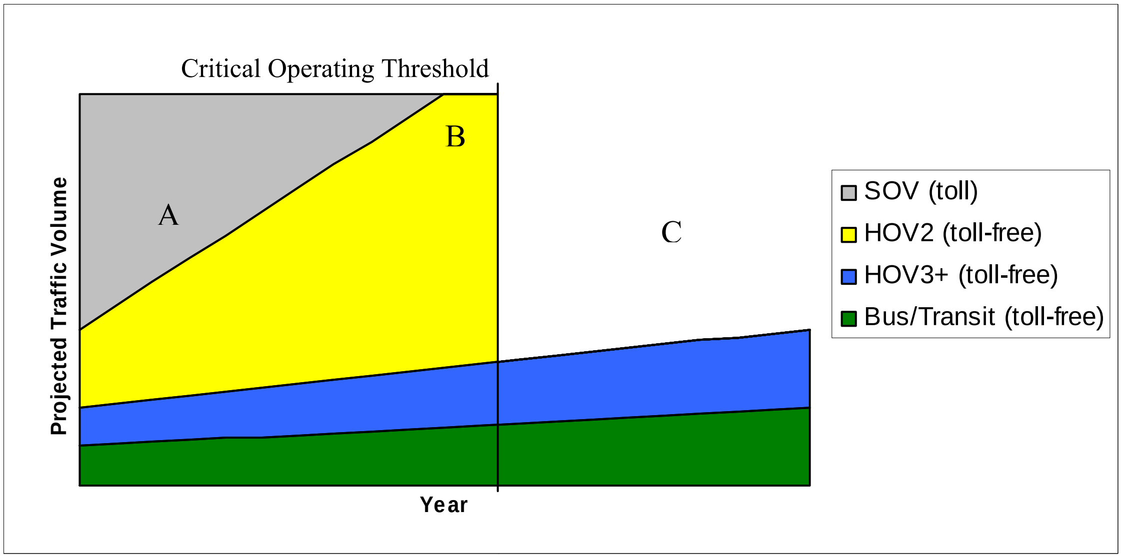

Figure 1.1. Hierarchy of HOV lane users (Swisher et al. 2003)

However, once all HOV2 users are prohibited from using the HOV lane, the lane will likely have a significant amount of available capacity (point C in Figure 1.1). This creates a situation where single occupant vehicle (SOV) and HOV2 users drive in the congested general purpose lanes, while the HOV lane has excess capacity which could carry some, but not all, HOV2 and SOV users.

At this point, adaptation of the HOV lane into a high occupancy/toll (HOT) lane may be considered. Drivers of lower occupancy vehicles, which would normally be restricted from the lane (such as SOV and HOV2), can pay a toll, using an electronic tag or transponder, to use the HOT lane. This toll price can be adjusted as needed to manage the number of vehicles using the HOT lane (leading to the term "managed lane") so that that free flow conditions are always maintained (Perez et al. 2003). Alternatively, some HOT lanes' operating agencies charge a monthly fee for unlimited use and manage volume by limiting the number of active accounts. The hierarchy and hypothetical volumes of the different types of vehicles are shown in Figure 1.2.

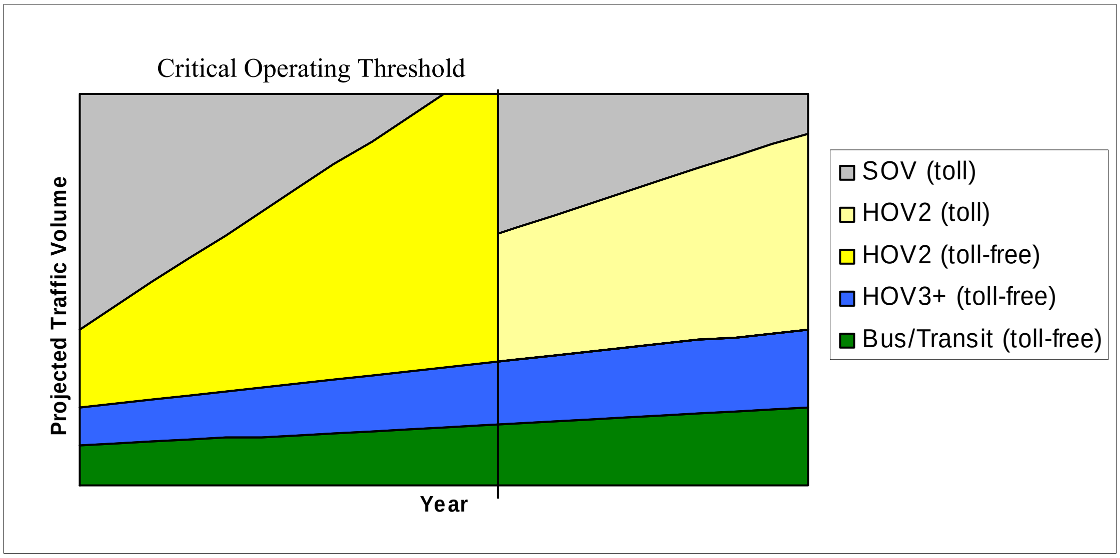

Figure 1.2. Hierarchy of HOT lane users (Swisher et al. 2003)

SOV travelers can now obtain the same travel time benefits offered by the HOT lane as transit users, so some bus riders may switch to driving themselves; this is called a modal shift. Driving alone has some benefits that riding transit does not, such as having personal space and the flexibility to travel anywhere at anytime. On the other hand, transit passengers can sleep, read the newspaper, or do other productive tasks without the stress and/or safety issues associated with multitasking while driving. In addition, the transit fare may be less expensive than the cost of operating a personal vehicle and parking fees. Choosing whether or not to shift modes is a complex decision for the traveler. It is important to study the people making this decision and the factors they take into consideration because transit riders switching to SOVs adds vehicles to already congested freeways.

While there are many different mode shifts possible due to the introduction of a HOT lane, only the shift from transit to SOV on the HOT lane will be investigated in this research. This is an important shift to study because there is the potential for a significant increase in the number of vehicles, vehicle miles traveled, and emissions, coupled with a decrease in transit ridership.

1.2 Problem Statement

One of the benefits of converting HOV lanes to HOT lanes is to allow vehicles who would otherwise be ineligible (such as SOV users) to utilize the excess capacity of HOV lanes (Perez et al. 2003). However, current carpoolers and transit riders may also become SOV users because of the additional flexibility and personal space benefits of driving alone while obtaining the travel time benefits on the HOT lane. A reduction in transit ridership and carpools reduces the person-carrying capacity of the HOT lanes and counters one of the original objectives of an HOV lane, to encourage a higher person per vehicle ratio (Turnbull 2003).

There have been a number of research papers and theses regarding SOV and HOV (non-transit) users on HOV and HOT lanes (Sullivan 2000; Supernak et al. 2002; Xu 2005; and others), but there have been few specifically regarding transit users. It is important to fill this gap in knowledge because transit riders account for a significant portion of the people who use HOV lanes.

Currently in Houston, the alternatives during peak hours to taking the bus on the HOV lane are as follows:

- driving with two passengers (HOV3) on the HOV lane, which requires coordination among the three people,
- driving with one passenger (HOV2) and pay a $2 toll, which requires coordination between two people and a fee,
- driving in a casual carpool (also known as slugging) on the HOV lane, which requires little coordination but has some risks due to traveling with strangers in a private vehicle,
- driving a motorcycle on the HOV lane, which requires a special vehicle and license, or
- driving on the main lanes, which results in longer, more unreliable travel times.

As the HOV lanes in Houston are adapted to HOT lanes over the next few years, transit passengers will now also have a choice of driving alone on the HOT lane for a fee. Most of the bus passengers examined in this research are choice riders—people who have a car but choose to take transit to work. Therefore, the option to switch to SOV on the HOT lane, which has the same travel time benefits as the riding the bus on the HOT lane, is available to many of them. However, a HOT lane is intended to maximize the use of the entire freeway facility. The best way to do this is to move existing SOV users from congested conditions on the main lanes to excess capacity on the HOT lanes, not create new SOV users from former transit riders already using the HOV lane.

Therefore, adaptation to a HOT lane has the potential to negatively impact the person-carrying capacity of the existing HOV lane, plus lower the average vehicle occupancy (AVO). Thus, it is important to investigate this potential problem as a number of HOV lanes around the country are in the process of adapting to HOT lanes that allow SOVs.

1.3 Research Objectives

The objectives of this research were as follows: determine the demographics/characteristics of people who were likely to switch from transit to SOV, estimate the percentage of transit riders that would switch to SOV on the HOT lane for given toll levels, and calculate the impacts on the HOT lane in terms of average vehicle occupancy, or AVO. A data set comprised of 584 surveys completed by transit passengers in Houston was analyzed to accomplish these objectives.

1.4 Outline of Thesis

In Chapter I, a brief background about HOV and HOT lanes and the importance of understanding the transit passengers who use them is discussed. Chapter II provides a review of the literature relating to HOV and HOT facilities, including their role in transportation demand management and an overview of existing HOT facilities in various parts of the United States. The past, present, and future of HOV/HOT lanes in

Houston and mode choice are also covered. Chapter III describes the survey design and data collection efforts. In Chapter IV, the mode choice model is developed, and scenarios with varying tolls and travel times are simulated. The demographic characteristics of people who might shift from bus to driving alone on the HOV lane and the impact of mode shift from bus to tolled SOVs are also discussed. Chapter V summarizes the findings and discusses potential areas of future research.

CHAPTER II

LITERATURE REVIEW

This chapter includes a review of HOV/HOT lanes and their role in transportation. The problem of increasing traffic congestion, and ways to manage transportation demand are discussed first. HOT lanes around the United States and their associated transit systems are reviewed next. The history of Houston's HOV lanes is covered in the following section, along with the plans for the adaptation of the HOV lanes to HOT lanes. Finally, previous research in mode choice is discussed.

2.1 The Problem of Increasing Traffic Congestion

According to the 2005 Urban Mobility Report, "congestion caused 3.7 billion hours of travel delay and 2.3 billion gallons of wasted fuel" and "urban areas are not adding enough capacity, improving operations or managing demand well enough to keep congestion from growing larger" (Schrank and Lomax 2005). The report discusses public transportation and HOV lanes as potential solutions to improve mobility. There are also ways to make better use of existing transportation facilities, like managing transportation demand. (Schrank and Lomax 2005)

2.2 Transportation Demand Management Solutions

Transportation demand management, also known as travel demand management or TDM, is "a general term for strategies that result in more efficient use of transportation resources" (VTPI 2007). TDM focuses more on the movement of people and goods rather than the movement of vehicles, especially during congested conditions (VTPI 2007).

There are four ways to manage travel demand: improved alternatives, incentives and disincentives, impediment removal, and travel time management (Pratt 1991). Some examples of TDM strategies include flextime, bike/transit integration, parking pricing, and road pricing (VTPI 2007). Flextime "allows employees to arrive and leave work outside the peak travel times" (City of Houston 2007). Bike/transit integration includes a number of strategies, including bikes on transit, either inside the vehicle or on an exterior rack, and bike lockers/racks at transit stations. A bicyclist can travel three to four times farther than a pedestrian in the same time, so integrating bicycles and transit increases "the transit catchment area about ten-fold" (VTPI 2007). Parking pricing and road pricing are ways to discourage people from using SOVs during peak times in locations of peak demand; both will be discussed in later sections.

Houston has recently implemented a number of TDM strategies. In September 2006, 140 employers in Houston participated in "Flex in the City," an initiative spearheaded by Mayor Bill White to "eliminate at least one additional peak-time commute" (City of Houston 2006). Almost 2,900 people who registered online eliminated a total of 16,687 trips during the two-week period. Based on data from two freeways, it was estimated that each person saved 1.7 minutes during each commute as compared to the period immediately before the two-week experiment (City of Houston 2006). Houston's transit agency, the Metropolitan Transit Authority of Harris County, Texas (METRO), began installing bike racks on all their buses in April 2007 and planned to have racks installed on all of its local buses by the end of 2007 (METRO 2007).

TDM involves many different modes and strategies. As previously mentioned, person movement is paramount, not vehicle movement. High occupancy vehicle (HOV) facilities, which encourage carpooling and transit usage, help to increase the average vehicle occupancy and reduce the number of vehicles, especially during peak commuting periods. HOV facilities are a commonly used TDM strategy and will be discussed in the next section.

2.3 HOV and HOT Lanes in the United States

High occupancy vehicle (HOV) facilities are also an important part of TDM because they help facilitate various TDM strategies, including carpooling and transit use (Pratt 1991). HOV lanes have existed in the United States since the first implementation on the Shirley Highway in Virginia in 1969 (Turnbull 2003). As of 2002, there were over 130 HOV facilities on freeways in 23 metropolitan areas, and the number of route and lane miles have grown steadily since 1969. Route miles are split approximately half and half between radial and non-radial corridors; busways account for a small portion of route miles. (Fuhs and Obenberger 2002)

There are a number of different types of freeway HOV lanes: concurrent flow lanes, lanes with barriers, contraflow lanes, queue bypasses, and busways. As of 2001, almost half of HOV route mileage is buffered concurrent flow HOV lanes. The majority of HOV lanes have a 2+ person occupancy requirement, and there are slightly more HOV route miles that are operated 24 hours a day rather than part time. (Fuhs and Obenberger 2002).

However, an HOV lane may not always be used to its full capacity, especially during off-peak times. On the other hand, the adjacent main lanes may be congested. In this case, an adaptation to a high occupancy toll (HOT) lane may be considered in order to allow SOV users who want to pay a toll to utilize the excess capacity of the HOV lane instead of contributing to the congestion in the main lanes. There are a number of steps which must be taken before an HOV lane is adapted to a HOT lane, including (but not limited to) determining organizational frameworks, selecting toll-collection and enforcement technologies, and educating and gaining the support of the public (Perez et al. 2003). The introduction of a new mode choice, tolled SOV on the HOT lane, may also bring shifts from existing modes to the new mode. This includes the potential shift of existing transit riders to SOV on the HOT lane, which is the focus of this research.

HOT lanes currently exist in California, Minnesota, Colorado, Utah, and Texas. The background, operation, and impacts of each are examined in the following sections.

2.3.1 Orange County, California

The State Route 91 Express Lanes (or 91X lanes) opened in December 1995 as a privately-owned facility. The facility consists of two lanes in each direction and is separated from the SR 91 main lanes by a painted buffer with pylons. The facility is 10 miles long and runs from SR 55 in Anaheim east to the Orange County/Riverside County line (Sullivan 2002), as shown in Figure 2.1.

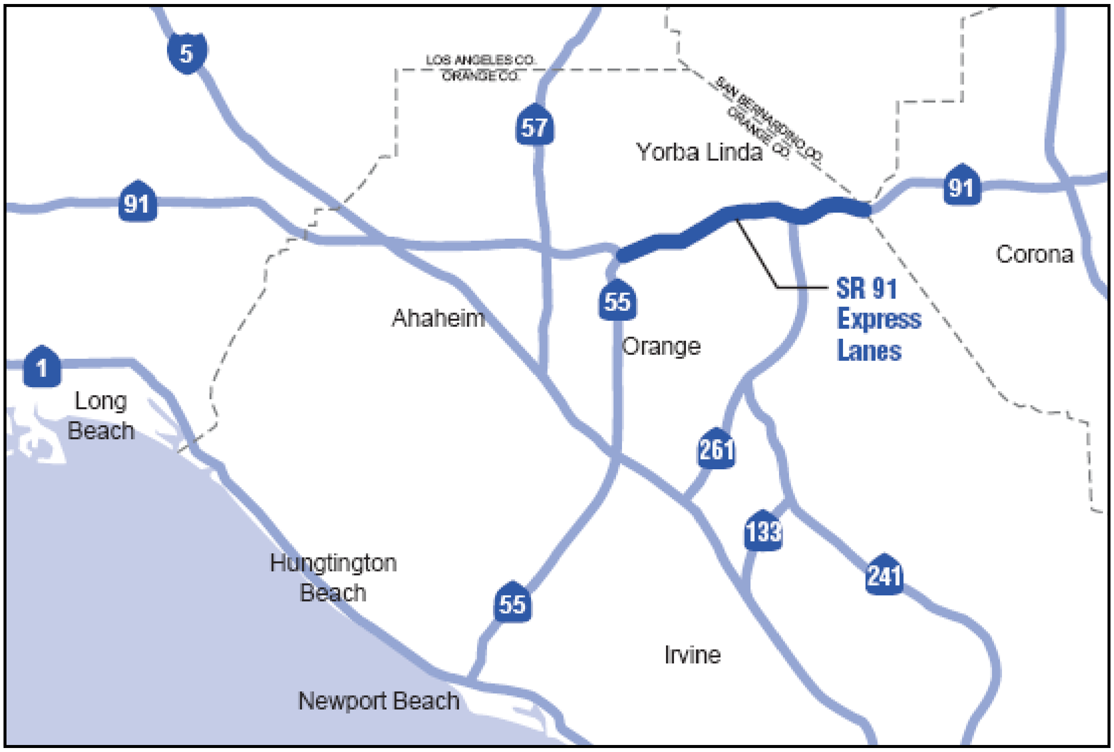

Figure 2.1. Orange County SR 91 Express Lanes (Perez et al. 2003)

The 91X lanes were not adapted HOV lanes like most other HOT facilities; rather, the Express Lanes were built as a toll facility. Vehicles with three or more occupants were allowed to use the 91X lanes for free until January 1998, when they were required to pay 50 percent of the regular toll (Sullivan 2002). Since May 19, 2003, 3+ carpools have been allowed to use the Express Lanes for free again, except on Monday through Friday, 4:00-6:00 PM, in the eastbound direction. During that time of extremely high demand, 3+ carpools pay 50 percent of the posted rate. All users of the

91X lanes must have a transponder, even carpoolers; qualified carpool vehicles use a different lane to receive the discount (OCTA *91 Express Lanes* 2007)

Toll rates may change on an hourly basis; as of April 1, 2007, tolls ranged from $1.15 to $4.05 westbound (AM peak) and $1.15 to $9.50 eastbound (PM peak). Frequent users of the 91X lanes can also receive discounts, depending on their account type. (OCTA *91 Express Lanes* 2007)

On January 3, 2003, the Orange County Transportation Authority (OCTA) purchased the SR 91 Express Lanes from the private owner. Working together with the adjacent Riverside County and other local representatives, OCTA formed an advisory committee to make decisions regarding the 91X lanes (OCTA *Welcome* 2007). A toll policy was adopted in July 2003 which specifically defines under what circumstances the tolls will be adjusted. Tolls during hours which qualify as "super peak" times may be adjusted every six months, and tolls at other times may be adjusted annually for inflation (OCTA *91 Express Lanes* 2007).

An extensive study completed in 1998 and a follow-up study completed in 2000 included an examination on trends in transit ridership in the corridor. Riverside Transit Agency's Route 149 runs between downtown Riverside and The Village at Orange (formerly the Mall of Orange). Although a significant portion of the route is on SR 91, it does not use the Express Lanes because it "would have to enter the freeway upstream of the Mall of Orange and eliminate local service along Santa Ana Canyon Road in Anaheim Hills" (Sullivan 2000). In addition, weaving from the end of the 91 Express Lanes to the entrance and exit ramps leading to the Mall of Orange would have been difficult. From mid-1997 to mid-2000, there were seven round trips a day; the route and schedule appears to be the same as of June 2007, indicating that ridership may not have changed significantly. The Metrolink commuter rail service opened the new Inland Empire-Orange County line parallel to SR 91 in October 1995, two months before the 91X lanes opened. Because both new modes became available around the same time, it is difficult to tell what effect, if any, one had on the other. (Sullivan 2000)

Among highway users surveyed, no one indicated that they had changed modes from riding the bus to driving solo or carpooling (Sullivan 2000). Sullivan concluded, "There is no evidence that opening the 91X lanes…affected the development of public transportation patronage in the corridor" (2002). On the other hand, some evidence indicates that some former auto users shifted to using transit, as a number of bus and commuter train riders formerly commuted in the SR 91 corridor by car (Sullivan 2000).

A new express bus service, utilizing the Express Lanes and buses with upgraded amenities, was introduced on September 10, 2006. OC Express Route 794 has seven westbound buses from Riverside/Corona to South Coast Metro in the morning and seven eastbound buses in the afternoon. Every seat has "a lap tray, power connection, reading light and comfortable high-back seating" (OCTA *Welcome* 2007). Due to the recent introduction of this service, same month comparisons are not available. According to Mr. Brian Champion, Operations Analysis Manager at OCTA, monthly ridership has varied from a high of 6644 in October 2006, to a low of 4415 in March 2007; however, the number of bus runs has remained the same since the first day. He also mentioned that, in a survey, 58 percent of passengers said they had used the bus and 76 percent said they had used Metrolink before Route 794 was introduced.

Although there has been a bus route (which did not use the Express Lanes) and a parallel commuter rail line on or near SR 91, neither provided the exact same route, trip time, and reliability that a SOV user had on the Express Lanes. Additionally, any impacts on transit ridership due to the new Express Lanes were difficult to find. Although the new Route 794 does use the Express Lanes, it was introduced more than ten years after the opening of the HOT facility. Therefore, a change from tolled SOV to transit would be more likely than from transit to tolled SOV, the mode shift of interest in this thesis. In Houston, a SOV will have access to the same route, trip time, and reliability as a bus rider on the HOT lanes, increasing the likelihood of impacts on transit ridership.

2.3.2 San Diego, California

San Diego's I-15 Express Lanes opened as HOV lanes in 1988. The Express Lanes are 8 miles long and run from SR 56 in the north to SR 163 in the south, northeast of downtown San Diego, as shown in Figure 2.2. It is a two-lane, barrier-separated, reversible facility with access points only at the ends. Since November 1997, the facility operates from 5:45-9:15 AM southbound and 3:00-7:00 PM northbound on workdays only (Supernak et al. 2002).

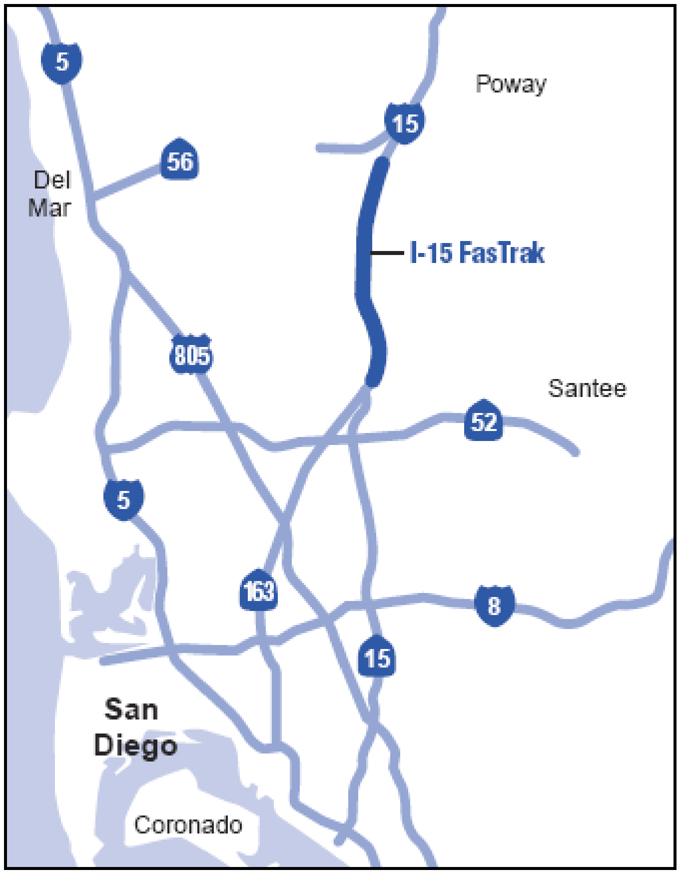

Figure 2.2. Map of San Diego I-15 Express Lanes (Perez et al. 2003)

A demonstration project was developed, partially due to underutilization of the HOV lanes, to allow SOVs to use the Express Lanes. The legislation authorizing the HOT adaptation requires that a level of service (LOS) C or better be maintained, high-occupancy vehicles be allowed free access at all times, and toll revenue be used only for transit or HOV improvements in the I-15 corridor (Supernak et al. 2002).

The HOT adaptation was done in two phases. The first phase was from December 1996 to March 1998, during which SOV travelers could pay a monthly fee for unlimited use of the Express Lanes as long as they displayed a colored permit on their windshields. In the second phase, SOV travelers were issued a transponder and paid a variable toll, usually between $0.50 and $4.00, with a maximum of $8.00 (Supernak et al. 2002)

One of the primary uses of toll revenue from the Express Lanes was to fund the new Inland Breeze service, Route 980/990, which began on November 25, 1997. During its first few years of service, buses ran every 30 minutes during the peak and every 60 minutes during the midday off-peak period. According to Kaschade et al., "The route was intended to serve work trip needs that were not adequately met by other existing services" and "to provide an alternative…for residents…who commute southbound along I-15 during the a.m. peak period" (2001). Figure 2.3 shows the most recent routing of the Inland Breeze, which had been modified from its original routing.

Several studies were led by San Diego State University researchers before and after the introduction of SOVs to the Express Lanes. Three studies focusing on transit were performed—one during the first phase, and two during the second phase. The express bus routes (routes which use the freeway for a portion of their route) were divided into routes that used the Express Lanes (5 routes) and those that did not (2 routes).

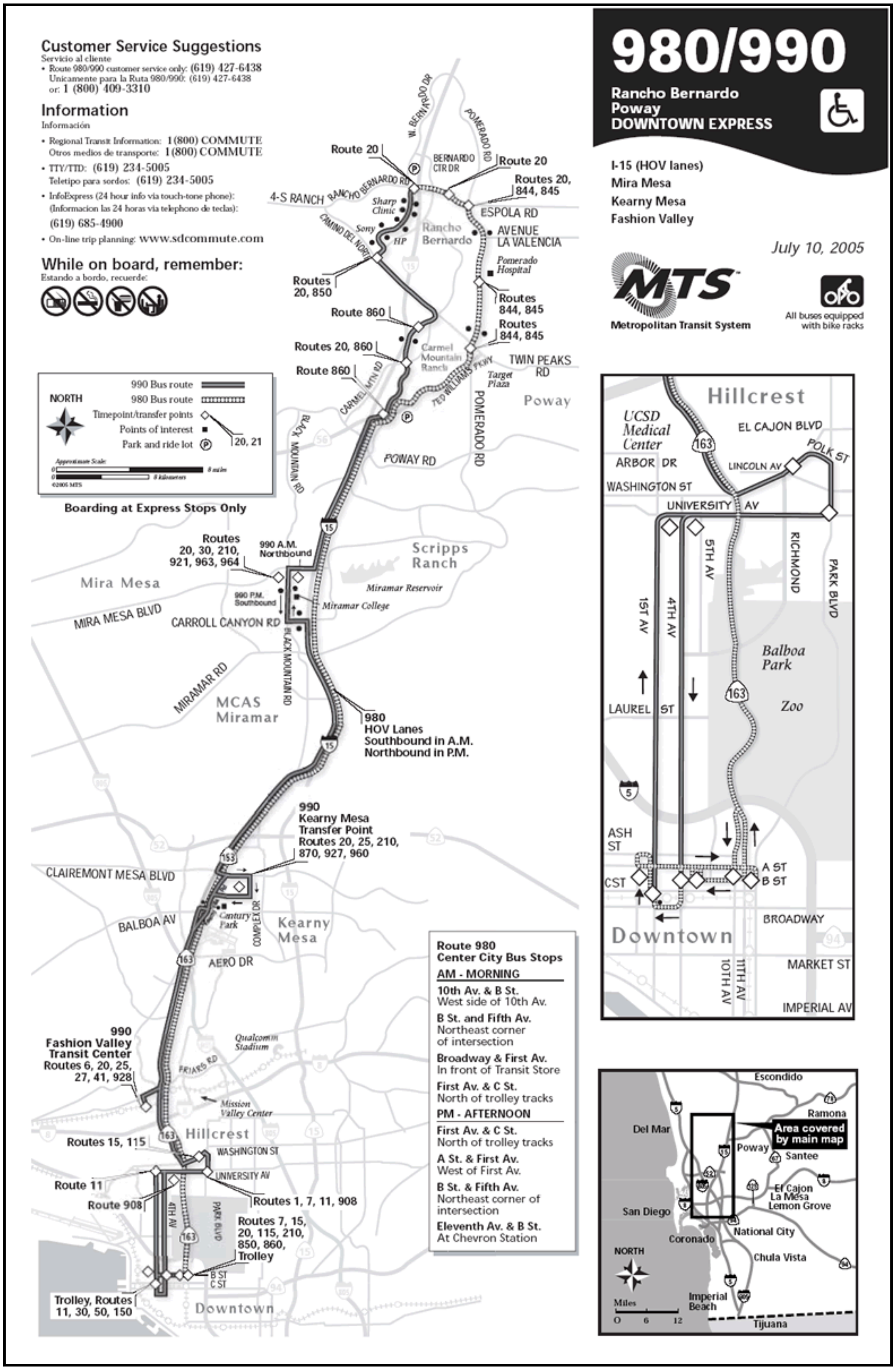

Figure 2.3. Map of Inland Breeze, Route 980/990 (MTS 2007)

During the period of the study, the ridership of the Inland Breeze grew from 188 riders on the first day to a maximum of 598 on February 21, 1999; however, the goal of 750 riders was not met in the first two years of service. After the study period ended but before the report was published, the authors noted that the Inland Breeze route carried 712 riders on the last day of April, 2000. (Kaschade et al. 2001)

Although the Inland Breeze service began after the HOV lane was already adapted to a HOT lane, there were four other bus routes which used the HOV lane before and after the adaptation. As shown in Table 2.1, the ridership for these routes decreased 3 percent between Fall (October-December) 1996 and Fall 1997, before and after the HOT adaptation. In comparison, transit ridership for the entire region increased 6 percent. However, ridership for both the corridor and the region fluctuate from season to season and year to year (Table 2.1), so no trends can be determined. Most changes from year to year were within 13 percent, plus or minus, except for Spring and Fall 1997-98; this was before and after the Inland Breeze route was introduced. The Inland Breeze had higher frequency and higher ridership than the other express routes (33 trips per day, versus 16 or 8 trips per day), so ridership increased significantly after its introduction. (Kaschade et al. 2001)

Table 2.1. Change in Transit Ridership in San Diego (Kaschade et al. 2001)

	Percent Change in Ridership				
	Fall 96-97	Spring 97-98	Fall 97-98	Spring 98-99	Fall 98-99
Express Routes Not Using Express Lanes (2 Routes)	8%	-12%	-2%	8%	-3%
Express Routes Using Express Lanes (5)	-3%	41%	58%	13%	-1%
Express Routes Using Express Lanes Except Inland Breeze (4)	-3%	-4%	4%	10%	4%
All I-15 Express Routes (7)	6%	-6%	5%	9%	-3%
Entire Region	6%	11%	10%	2%	6%

Based on passenger counts and surveys collected on the Inland Breeze route, researchers determined that most riders were commuting in the reverse direction—away from downtown in the morning, and towards downtown in the afternoon. This was consistent with ridership trends for other routes in the same corridor. In addition, most survey respondents were captive riders—they did not have a car available and rode other transit routes before the Inland Breeze service was introduced. The majority of respondents were also not familiar with FasTrak, the toll program required for SOV users to travel on the Express Lanes. (Kaschade et al. 2001)

At the conclusion of the final bus study in 2001, researchers concluded that the Inland Breeze route was "relatively successful" because overall ridership in the I-15 corridor increased. Because of the high proportion of captive riders, they suggested that future ridership growth would potentially come from attracting choice riders. (Kaschade et al. 2001)

After six years, the situation in San Diego has changed. According to Mr. Brent Boyd, Senior Transportation Planner of the Metropolitan Transit System in San Diego, the Inland Breeze route was discontinued in January, 2007, "primarily because of route duplication, but also somewhat because of low ridership." The Inland Breeze was one of many services cut due to budget reductions. Mr. Boyd said, "Ridership for the reverse commute was very low, and the main commute direction was covered by other routes." However, he also mentioned that cancellation of the Inland Breeze will not affect current plans to extend the Express Lanes further north and introduce BRT service in 2012.

Of all cities with existing HOT lanes, San Diego also has had the most extensive research on bus routes in the corridor. However, the bus routes in San Diego serve local stops in the suburbs, rather than just park-and-rides, so captive riders are more likely to be able to use these routes. Most of the riders did not have cars and were not familiar with the tolled SOV mode choice. Also, most riders in the I-15 corridor commuted in the reverse direction instead of the primary direction, towards downtown. Since the I-15 Express (HOT) Lanes only operate in the peak direction, the lanes would not be of interest to most riders.

Even though the I-15 research found that the toll-funded Inland Breeze bus route increased ridership in the corridor, passengers were mostly captive riders who were commuting in the reverse direction. The Inland Breeze service was also started after the adaptation of the HOV lane to a HOT lane. Therefore, the research was really not applicable to Houston or this thesis. This thesis focuses on choice riders, commuting in the peak direction from suburban park-and-rides to downtown and other major employment centers in the middle of the metropolitan area.

2.3.3 Minneapolis, Minnesota

The I-394 MnPASS Express Lane project adapted the existing HOV lanes on I-394 to HOT lanes. The full HOV facility was opened in 1992 and includes a four-mile, two-lane reversible section from downtown Minneapolis west to Highway 100 and a single diamond lane in each direction 7 miles further west to Highway 101 (Schier 2006; Zmud 2006) (see Figure 2.4).

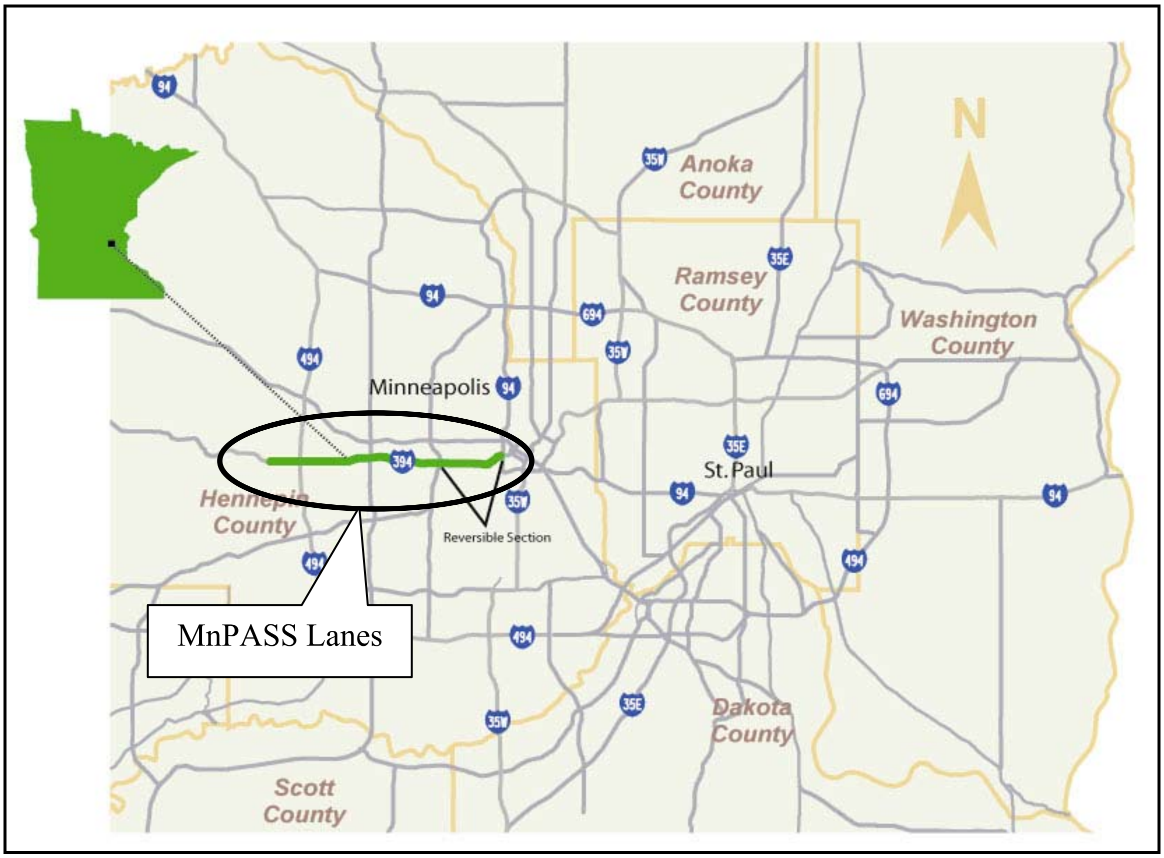

Figure 2.4. MnPASS Lanes on I-394 (Zmud 2006)

Beginning on May 16, 2005, single-occupancy vehicles were allowed to pay a toll using an electronic transponder to use the MnPASS lanes. Carpools and transit continue to use the lanes for free. The MnPASS lanes are dynamically priced based on traffic, and tolls are only charged during peak hours in the peak direction. Tolls average between $1 and $4, with a maximum of $8, and are posted on signs in advance of the multiple entrance points to the MnPASS lanes, as shown in Figure 2.5 (Mn/DOT *About MnPASS* 2005).

Figure 2.5. MnPASS toll rate sign (Courtesy of Lee Munnich)

Tolling was a new concept in Minnesota, so an attitudinal survey of travelers along the I-394 corridor was conducted, once before and twice after the opening of the MnPASS lanes, with both returning panel members and new participants. Support for the MnPASS lanes across all income groups was generally high both before and after the HOT lanes opened, and most users were satisfied with their experience using the HOT facility (Zmud 2006).

Although extensive studies were done on travelers in the I-394 corridor, there have been no specific studies on bus riders in this corridor. Ridership data for the third quarter (July-September) of 2004, 2005, and 2006 were obtained from the Minnesota Department of Transportation for both I-394 and I-35W, a similar corridor with a regular HOV lane; the average peak period ridership (6:00-9:00 AM and 3:00-6:00 PM) for both corridors are shown in Table 2.2 (Mn/DOT *I-394 HOV Report* 2005; Mn/DOT *I-35W HOV Report* 2005; Mn/DOT *I-394 HOV Report* 2006; Mn/DOT *I-35W HOV Report* 2006; Mn/DOT, unpublished data, 2004).

Table 2.2. Average Peak Period Transit Ridership on Minneapolis HOV/HOT Lanes (Mn/DOT 2005; Mn/DOT 2006; Mn/DOT, unpublished data, 2004)

	Average Peak Period Ridership			2004-05	2005-06
	3Q 2004	**3Q 2005**	**3Q 2006**	**Change**	**Change**
I-394					
EB Reversible	3549	4014	4293	13.1%	7.0%
WB Reversible	3138	3569	3673	13.7%	2.9%
Total Reversible	**6687**	**7583**	**7966**	**13.4%**	**5.1%**
EB Diamond	2312	2635	2970	14.0%	12.7%
WB Diamond	2026	2323	2510	14.7%	8.0%
Total Diamond	**4338**	**4958**	**5480**	**14.3%**	**10.5%**
I-35W					
NB	1251	1300	1351	3.9%	3.9%
SB	1109	1092	1136	-1.5%	4.0%
Total	**2360**	**2392**	**2487**	**1.4%**	**4.0%**

During July-September, 2005, shortly after the MnPASS lanes opened, transit ridership along I-394 increased by over 13 percent (Table 2.2) over the ridership from the same period in 2004, before MnPASS was available. In comparison, transit ridership in the I-35W corridor only increased 1.4 percent. Although external events like high gasoline prices after Hurricane Katrina may have contributed to increases in transit ridership, it should have affected both corridors similarly; however, the ridership increase was significantly higher along I-394 than I-35W. Also, ridership increases between the third quarters of 2006 and 2005 were higher for I-394 than for I-35W, as shown in Table 2.2.

While these ridership statistics show that bus ridership may have been positively affected by the adaptation of HOV to HOT lanes, there has been no actual study to determine the effect that having a new SOV toll option had on existing transit users. Although the net ridership increased due to many new bus riders, it is unknown how many former transit users switched to the SOV toll mode. This thesis will attempt to estimate how many people may shift from bus to SOV in HOV-to-HOT adaptation situations like these.

2.3.4 Denver, Colorado

Denver's HOT lanes, the seven-mile, I-25 HOV/Tolled Express Lanes, opened to toll-paying SOV drivers on June 2, 2006 (CDOT 2007). The two-lane, barrier-separated, and reversible facility runs from downtown Denver north to US 36 (Figure 2.6). There are multiple access points at each end, but no intermediate entrances or exits (CDOT 2007).

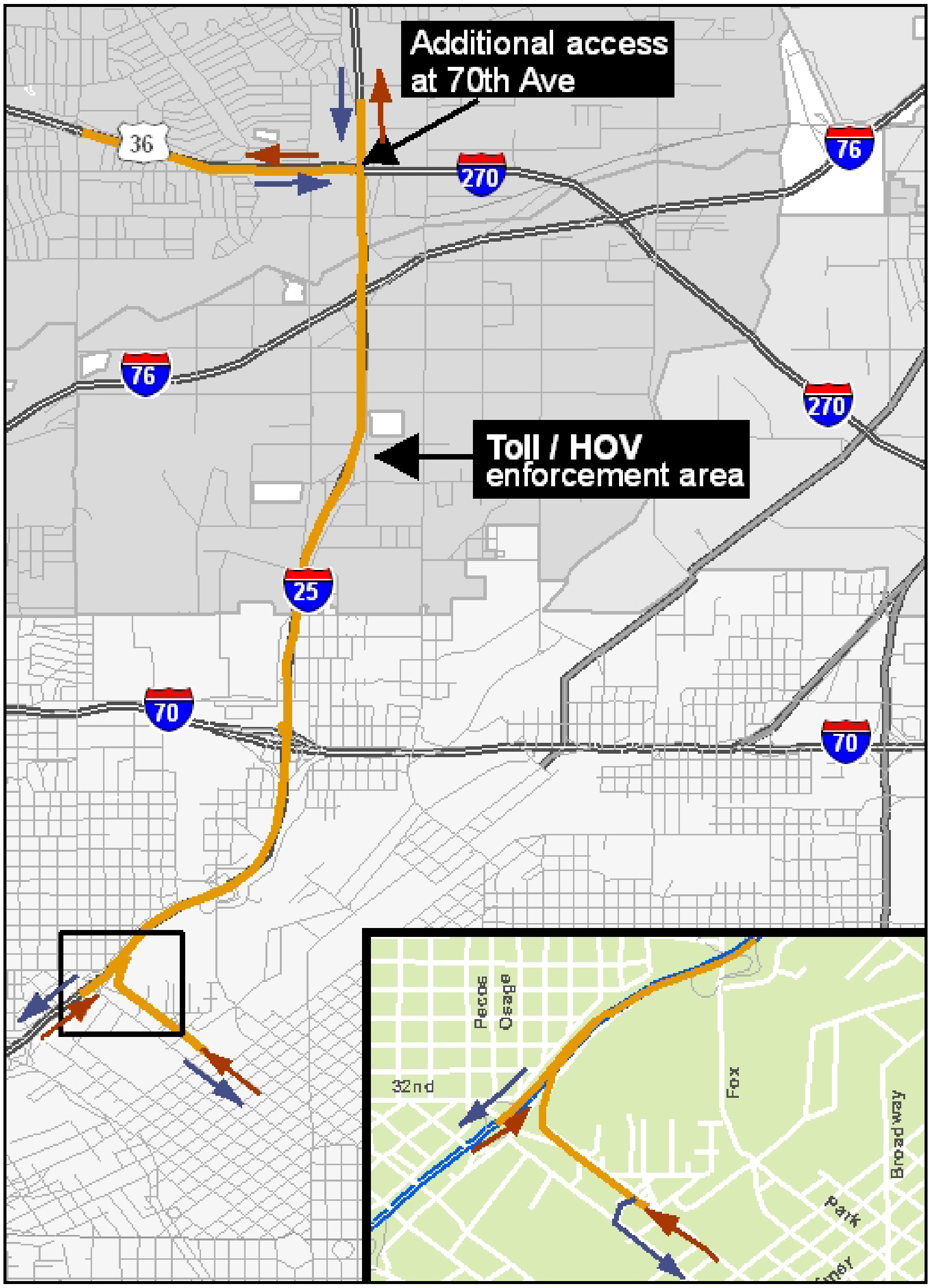

Figure 2.6. I-25 HOV/Express Lanes in Denver (CDOT 2007)

Tolls are paid using an electronic transponder, which can also be used on Denver's other toll roads. Tolls initially ranged from $0.50 to $3.25, based on the time of day; rates may change "if it is found to be insufficient at providing reliable, uncongested travel times on the facility" (CDOT 2007).

According to Mr. Jeff Dunning, a Senior Service Planner/Scheduler at the Regional Transportation District (RTD) in Denver, there are two primary routes, Route B and Route 120X, and approximately ten secondary routes which use the I-25 HOV/Tolled Express Lanes. The two primary routes account for about two-thirds of the total ridership of routes using the HOV/Express Lanes. Route B uses the HOV lane (when it is open) for less than half of its route, and Route 120X uses the HOV lane for approximately half of its route; the remainder of these routes are in mixed traffic, either on the freeway or on surface streets. In addition, there is significant ridership in the in the off-peak direction and during off-peak times, so only about half of the total passengers that ride a bus might be interested in using the HOV/Express Lanes during the peak period in the peak direction. The average weekday ridership for September-October, 2005 and 2006 is shown in Table 2.3.

Table 2.3. Average Weekday Ridership for Selected Denver Transit Routes (Courtesy of RTD)

	Daily Ridership		Change
September-October	**2005**	**2006**	**2005-06**
Route B	6,110	6,336	3.7%
Route 120X	3,126	2,901	-7.2%
Total Primary Routes	**9,236**	**9,237**	**0.0%**
Total Secondary Routes	4,746	4,797	1.1%
Total All Routes Using I-25 HOV	**13,982**	**14,034**	**0.4%**
Total Fixed Route Buses	**215,854**	**215,789**	**0.0%**
Total Light Rail	**39,216**	**39,195**	**-0.1%**
Total Bus + Light Rail	**255,070**	**254,984**	**0.0%**

Adding the two primary routes together, there was almost no change in ridership between 2005 and 2006, as shown in Table 2.3. There was a very slight increase in ridership for all routes using the I-25 HOV/Express Lanes. In comparison, there was a very small decrease in ridership for all the fixed route buses and light rail in the entire RTD system. The changes in transit ridership for all groups of routes of interest from September-October, 2005, to the same period in 2006 are all below 0.5 percent (Table 2.3), so it is difficult to make any conclusions. Mr. Dunning wrote in an e-mail, “I have noticed no change in ridership resulting from the HOV-to-HOT lane conversion.”

Just as in Minneapolis’ case, a net change of 0 percent in ridership does not mean that all the same people who rode the bus in 2005 are still riding in 2006; there may be some people who switched from transit to automobile who were replaced by an equal number who switched from auto to transit. This thesis will estimate how many people might shift from transit to SOV, and this could be used in future analysis of ridership data of transit in HOV/HOT corridors.

2.3.5 Salt Lake City, Utah

HOV lanes on I-15 from downtown Salt Lake City southward to the city of Orem opened in July 2001. They were adapted into a HOT facility, known as the Express Lanes, in September 2006 because the HOV lanes were underutilized. The 38-mile facility is the longest in the United States and has 16 access points (see Figure 2.7), each 3,000 feet long, in addition to the entrance and exit at the ends of the lane. (UDOT 2007)

Figure 2.7. Map of Salt Lake City Express Lanes (UDOT 2007)

There is one concurrent HOT lane in each direction, separated from the general purpose lanes by a two-foot buffer comprised of two solid white lines (UDOT 2007). According to Ms. Julie Kinder, Express Lanes Administrator at the Utah Department of Transportation, they are open 24 hours a day, 7 days a week.

Unlike the other existing HOT lanes, the Salt Lake City Express Lanes are not variably priced based on traffic or time of day. Rather, a user of these HOT lanes opens an account and is charged a flat fee of $50 per month for unlimited use of the lanes. To limit the number of SOVs on the Express Lanes, a maximum of 2,200 travelers are allowed in the program. (UDOT 2007)

According to Regina Radke of the Utah Transit Authority (UTA), transit buses do not use the Express Lanes because the HOT lane access points do not correspond to where buses enter and exit the freeway. In addition, she said that the buses have speed regulators limiting their speed to a rate which is below the speed of vehicles in the Express Lanes.

Because the Express Lanes are relatively new in Utah and apparently no transit buses use the facility, no conclusion can be made about mode shift from transit to tolled SOV.

2.3.6 HOT Lane Adaptation Summary

Orange County's 91X lanes have not been used by transit service until recently, and a parallel commuter rail corridor which opened around the same time made it difficult to make conclusions on mode shift. Although tolls from San Diego's HOT lanes helped fund the Inland Breeze bus service, ridership was primarily in the reverse peak direction by captive riders; also, the service was recently eliminated for multiple reasons. Bus routes on Minneapolis' I-394 HOT lanes had greater increases in ridership than bus routes on another HOV lane; however, no study was specifically done on the impacts of HOV adaptation on the bus ridership. Ridership levels on buses using Denver's HOT lanes were relatively constant before and after the adaptation from HOV lanes; again, this is based on ridership statistics only. Salt Lake City's Express Lanes are less than a year old, so no conclusion can be made on mode shift at this time.

While there have been a number of HOV-to-HOT adaptations around the country and many studies, little is known regarding how transit riders (choice riders) alter their travel when a HOV lane adapts to a HOT lane. Houston's HOV system, which will be used to gather data on this issue, is discussed in the next section.

2.4 HOV Lanes in Houston

Since the introduction of the contraflow lane in Houston in 1979, high-occupancy vehicle facilities have progressed through a number of phases, including the inclusion of vanpools and carpools, the QuickRide program, the plans for conversion of other HOV lanes to HOT lanes, and the Katy Managed Lanes.

2.4.1 Introduction of HOV Lanes to Houston

In the 1970s, the Texas Highway Department (THD, now known as the Texas Department of Transportation, or TxDOT) and the City of Houston's Office of Public

Transportation (OPT) began working together to reduce congestion on Houston's freeways (Turnbull and Kabat 1990). The city had just completed the purchase of the privately-owned Rapid Transit Lines in April 1974, after a failed referendum the previous year to create the Houston Area Rapid Transit Authority (Slotboom and Fuhs 2003).

According to Turnbull, "OPT and THD shared a common interest in addressing increasing levels of traffic congestion by encouraging greater use of buses, vanpools, and carpools" (2003). Using a federal grant, the two entities studied freeway HOV lanes and decided to proceed with a contraflow lane demonstration project (Turnbull and Kabat 1990). A contraflow lane is a lane borrowed from the off-peak direction for use by buses and other high-occupancy vehicles in the peak direction; it is marked with a temporary barrier, such as removable pylons, as shown in Figure 2.8.

Figure 2.8. I-45 contraflow lane (Courtesy of TTI)

The I-45 North Freeway was chosen for the pilot project because it had "a 65-35 percent split in the peak/off-peak directions" and "the city's highest concentration of vanpools" (Slotboom and Fuhs 2003). During the almost five years from conception to reality, the Metropolitan Transit Authority of Harris County, Texas, or METRO, was approved by voters in 1978, and took over transit operations from the city (Slotboom and Fuhs 2003).

The contraflow lane opened on August 28, 1979, and by July 1980, "total peak-period movement had grown to more than 4300 person trips, more than a threefold increase in patronage" (Taube and Fuhs 1981). Only buses and authorized vanpools, after registering and completing training from METRO, could use the contraflow lane because of its permeable nature (Turnbull and Kabat 1990). The contraflow lane, originally 9.6 miles long, was later extended as a concurrent-flow diamond lane two miles further north, and carried 15,600 passenger trips each day by the third year of operation (Slotboom and Fuhs 2003). Surveys of contraflow lane users showed that approximately 30-40 percent previously drove alone (Turnbull 2003).

2.4.2 Barrier Separated Facilities

The contraflow lane was a success, but it was always considered to be temporary. After a failed rail transit referendum, METRO decided to speed up its plans to "replace the contraflow lane with a reversible, barrier-separated transitway lane in the median of the freeway" (Slotboom and Fuhs 2003). The first section of the permanent HOV lane on the North Freeway opened in September 1984 (Turnbull 2003).

The I-10 Katy Freeway was the second corridor with an HOV lane. As part of a repaving project, the inside shoulders of the freeway would become a barrier-separated HOV lane, as shown in Figure 2.9. The project took only two-and-a-half years from the time of conception to opening on October 29, 1984 (Slotboom and Fuhs 2003). At first, only 20 buses and 66 vanpools used the Katy HOV lane, so authorized 4+ carpools were allowed to use the HOV lane beginning in April 1985. Minimum occupancy requirements were dropped to 3 person carpools in September 1985, and 2 person carpools in November 1986 (Turnbull 2003). At the end of 2002, almost 30,000 passenger trips occurred on the Katy Freeway HOV lane per day, the most of the six HOV lanes in Houston. (Slotboom and Fuhs 2003)

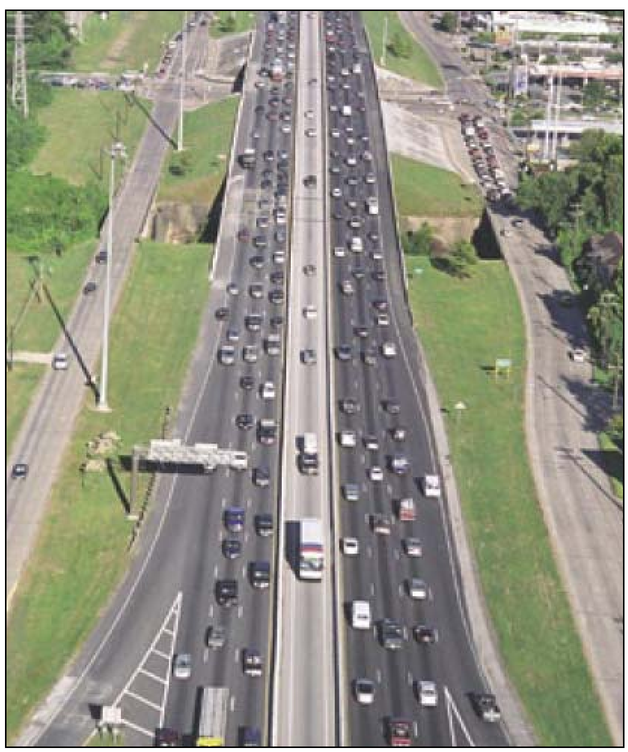

Figure 2.9. I-10 Katy Freeway HOV lane (Slotboom and Fuhs 2003)

From 1985 to 2003, Houston's HOV system expanded from two corridors to six corridors. The I-45 Gulf Freeway and US 290 Northwest Freeway HOV lanes opened in 1988, the US 59 Southwest Freeway HOV lane opened in 1993, and the US 59 Eastex Freeway opened in 1999 (Turnbull 2003); the six corridors are shown in Figure 2.10. Table 2.4 includes a brief description and some traffic volume statistics for the six corridors.

Figure 2.10. HOV lanes in Houston, highlighted in red (METRO 2007)

Table 2.4. December 2006 Houston HOV Lane Data (TTI, 2006)

	Katy I-10 W	North I-45 N	Gulf I-45 S	Northwest US 290	Southwest US 59 S	Eastex US 59 N
Length (miles)	13	19.9	15.5	13.5	14.3	20.2
Opening Date	1984	1984	1988	1988	1993	1999
Person Volume						
Total, AM Peak Hour	4,022	6,253	4,418	4,228	5,050	2,578
Buses	1,680	2,765	1,520	1,330	2,170	1,005
Carpools/Vanpools	2,322	3,462	2,884	2,877	2,869	1,557
Morotcycles	20	26	14	21	11	16
Total, Daily	27,148	31,781	21,274	22,529	25,021	11,140
Vehicle Volume						
Total, AM Peak Hour	1,168	1,688	1,447	1,379	1,421	779
Buses	44	60	34	24	42	18
Carpools/Vanpools	1,104	1,602	1,399	1,334	1,368	745
Morotcycles	20	26	14	21	11	16
Total, Daily	9,455	9,314	6,847	8,177	7,098	3,399
Average Vehicle Occupancy						
Total, AM Peak Hour	3.44	3.70	3.05	3.07	3.55	3.31
Buses	38.2	46.1	44.7	55.4	51.7	55.8
Carpools/Vanpools	2.1	2.2	2.1	2.2	2.1	2.1

2.4.3 The Components of the HOV Transit System

The HOV system in Houston includes the “HOV lanes, park-and-ride lots, transit centers, direct access ramps, and express bus service” (Turnbull 2003); all parts are necessary for the success of the commuter bus portion of METRO’s system.

The HOV lanes, approximately 110 miles total in six corridors, are mostly barrier-separated, reversible single lanes in the median of freeways. There are also some two-way portions and some non-barrier-separated diamond lanes (Turnbull 2003). The HOV lanes could be considered fixed guideways for buses because they are single-lane and barrier-separated.

Hours of operation are generally 5-11 a.m. in the inbound direction and from 2-8 p.m. in the outbound direction. There is at least a two-person requirement for vehicles in all corridors. The Katy Freeway and Northwest Freeway have a three-person requirement at certain times; this is discussed later in Section 2.4.4. (METRO 2007)

There are 28 park-and-ride lots in the six freeway corridors; each lot can hold 900 to 2,500 vehicles, and parking is free. The larger lots have large, covered waiting areas with passenger amenities and direct connectors to the HOV lane, as shown in Figure 2.11. Transit centers are similar to park-and-ride lots, except with few or no parking spaces (Turnbull 2003). They also are generally closer to the center of the city than park-and-ride lots and allow for easy transfers between local and commuter bus routes.

Figure 2.11. Kuykendahl park-and-ride lot with direct access ramp (Courtesy of TTI)

Direct access ramps provide access to the HOV lanes directly from park-and-ride lots and transit centers so that buses and carpools do not have to mix with slower-moving traffic on local streets and the freeway general purpose lanes (see Figure 2.11). In addition to direct access ramps, slip ramps provide access to and from the general purpose lanes, and wishbone ramps provide access to and from the feeder roads on either side of the freeway.

Houston primarily uses over-the-road coaches rather than traditional transit buses for its park-and-ride transit services. The majority of buses go to downtown Houston, but some serve other major employment centers, like the Texas Medical Center, Uptown, and Greenway Plaza (Turnbull 2003). Buses usually travel non-stop or one-stop to their final destination. Some routes have peak period headways as low as four minutes between buses.

According to Stockton et al., average bus speeds during the peak hour have doubled from 26 mph to 52 mph, and increased speeds led to shorter travel times, which led to higher ridership (1997). Stockton et al. also noted that, based on survey results, over 40 percent of bus riders on the Katy and Northwest Freeways previously drove alone and "fewer than 5 percent rode a bus prior to using the HOV lane" (1997). In response to another question, they determined that "35 percent to 50 percent of total bus ridership would not be riding the bus if there were no HOV facility" (Stockton et al. 1997). Thus, the existence of an HOV lane on a freeway has a significant positive influence on ridership due to its travel time savings and reliability. However, in an HOV-to-HOT lane adaptation, SOV users now also have this travel time savings and reliability, so there may be a mode shift from transit to SOV.

2.4.4 QuickRide

As commuters became more familiar with the HOV lane system and occupancy restrictions were relaxed (location 1 in Figure 2.12), peak period volumes increased to the point where travel time savings and reliability degraded, as shown at location 2 in Figure 2.12. METRO and TxDOT decided to change the occupancy requirement for the Katy Freeway to three or more persons per vehicle between 6:45 AM and 8:15 AM in October 1988 (location 2 in Figure 2.12). As a result, vehicle and person volumes decreased by 62 and 33 percent, respectively, during the AM peak hour. However, average vehicle occupancy increased from 3.1 to 4.5 and bus ridership increased 8 percent (Turnbull 2003).

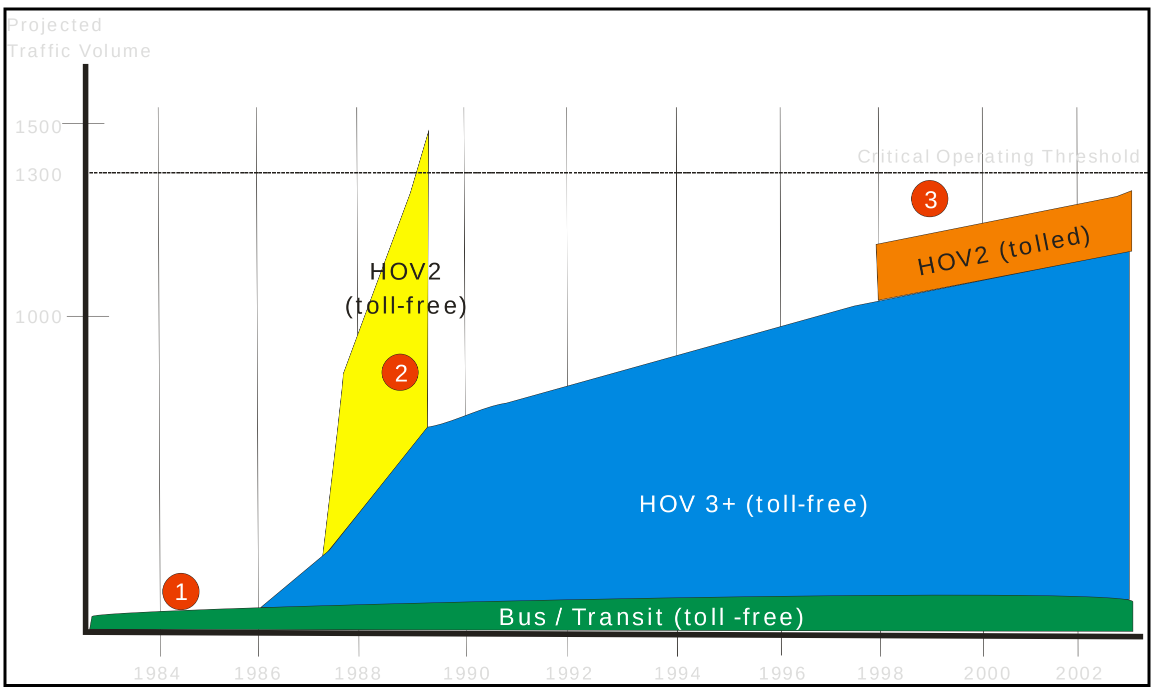

Figure 2.12. Katy Freeway volume by vehicle type (Swisher et al. 2003)

The 3+ requirement period was later adjusted to 6:45-8:00 AM in 1990, and an afternoon 3+ restriction for 5:00-6:00 PM was implemented in 1991. The Northwest Freeway HOV lane 3+ restriction for 6:45-8:00 AM went into effect in 1999 (Turnbull 2003). All other HOV facilities still have a 2+ requirement.

There was now significant excess capacity because two-person carpools were no longer allowed to use the HOV lane during peak periods (Figure 2.12). To utilize some of this excess capacity, the QuickRide program began in January 1998 on the Katy Freeway (location 3 in Figure 2.12) and November 2000 on the Northwest Freeway. A carpool with two persons could now register with the program and pay $2 (using an electronic transponder) each time they used the HOV lane during the peak periods with a 3+ restriction (Burris and Stockton 2004).

In 2003, there were about 86 QuickRide users on the Katy HOV in the morning, 55 users on the Katy HOV in the afternoon, and 67 users on the Northwest HOV in the morning. Most QuickRide participants made an average of less than 1.5 eligible trips per week in 2003 (Burris and Stockton 2004). The low rate of QuickRide usage can be attributed primarily to the two-person occupancy requirement, rather than the $2 toll (Appiah 2004). While the participation rate in QuickRide is low, future use of the HOT lane by SOV drivers will likely be much higher because there will be no occupancy requirement and there are thousands of SOVs traveling along the congested main lanes.

2.4.5 Casual Carpooling

Low participation in QuickRide may also be potentially caused by the occurrence of casual carpooling, or "slugging," in Houston. According to Winn, "Casual carpools are impromptu carpools formed among strangers in order to meet the occupancy requirements of HOV lanes" (2005). In a study done in 2003, 484 casual carpoolers were counted at three Houston-area park-and-rides during the morning peak period; this is significantly higher than the number of people using QuickRide daily, as discussed in the previous section. Many of these travelers also frequently use transit (Burris and Winn 2006), so this mode impacts both QuickRide and transit use.

2.4.6 METRO HOT Lanes

As part of METRO Solutions Phase 2, METRO will begin converting the existing reversible HOV lanes into full, two-way HOT lanes (METRO 2007). This will allow single-occupant vehicles to use any HOV lane for a fee. METRO plans to use dynamic electronic tolling to maintain an average speed of about 50 mph (METRO 2007). Unlike the other cities that currently have HOT lanes, the operator of Houston's HOT lanes (except the Katy Managed Lanes) and transit service are the same—METRO.

The guidelines METRO has established for HOV-to-HOT adaptation, in order of priority, are as follows:

1. "Move more people/vehicles in the High Occupancy Vehicle (HOV) lanes"
2. "Preserve the level of service for commuter bus routes, van pools, and carpools"
3. "Provide an additional travel alternative in the HOV lane corridors"

4. "Reduce/eliminate Metro's HOV operating costs"
5. "Offset new HOT lane operational costs" (METRO 2007)

With the adaptation of 5 HOV lanes to HOT lanes, it is critical to understand how current transit riders will react to the new opportunity to pay a toll to drive alone on the HOT lane. If the number of bus passengers who are likely to shift to tolled SOV is significant, then METRO may have to adjust its service due to reduced ridership.

2.4.7 Katy Managed Lanes

The Katy Managed Lanes will be operated by the Harris County Toll Road Authority (HCTRA), instead of METRO. The lanes will have multiple entrances and exits to the general purpose lanes along the 12-mile facility. It will have two lanes in each direction and have three electronic tolling locations. However, buses will be allowed free passage in both directions at all times, and HOV3+ users will be able to use the lanes for free during the peak hours in the peak direction, seven days a week. All other vehicles will be variably tolled to maintain LOS C or better. The opening of the Katy Managed Lanes is scheduled for Spring 2009 (TxDOT 2007).

Dynamically-priced HOT lanes without occupancy requirements will be implemented for the first time in Houston, so there is no local precedent. However, survey data are available on local transit riders on the HOV lanes and how they might react to a new tolled SOV option. This thesis uses these survey data and estimates travelers' potential reaction in terms of mode shift. This would help METRO and

TxDOT plan for any necessary or prudent adjustments before the adaptation to HOT lanes.

2.5 Estimation of Mode Choice

2.5.1 Modeling and Variables

Mode choice is modeled through discrete choice analysis. This involves the principle of utility maximization, which means "a decision maker is modeled as selecting the alternative with the highest utility among those available" (Ben-Akiva and Lerman 1985). Transportation planners and engineers estimate which mode a person would take based on characteristics of himself, his household, and his typical trip. Doing this for many people in a sample of a population on interest provides estimated volumes of travelers and the information required to appropriately plan for future transportation facilities.

Estimating a discrete choice can be accomplished using a number of different models. Mode choice is often estimated by using demographic and trip characteristic variables in a multinomial logit model. In a logit model, the probability of choosing alternative i is calculated using Equation 2.1.

$$P(i) = \exp(U_i)/\Sigma_j \exp(U_j) \tag{2.1}$$

where:

P(i) = probability of choosing alternative i

U_i = utility of alternative i

exp = exponential function

i = alternative modes

The value of U_i is calculated using equation 2.2.

$$U_i = B_{0i} + B_{1i}X_{1i} + B_{2i}X_{2i} + \ldots + B_{ni}X_{ni} \qquad (2.2)$$

where X_{1i}, X_{2i},…, X_{ni} “represent attributes of the alternative i, the decision maker, or the environment in which the choice is made and B_{ki} represents the coefficient reflecting the effect of variable X_{ki} on the utility of alternative i” (NCTCOG 2007). The coefficients, B_{ki}, can be estimated using logit model software (NCTCOG 2007).

There are some adjustments to models which can more accurately predict mode choice. For example, a sample can be divided into two groups by gender. In a study done on commuters in Montreal, males and females were modeled together and separately. It was found that “women are more likely than men to rideshare, women are less likely than men to use public transport, and women appear to be less time sensitive than men”; the lower preference of public transit by women was also noted as “striking” by the authors (Patterson et al. 2005).

2.5.2 Mode Choice Models Involving Transit

Toll and HOV facilities and their unique characteristics had rarely been modeled together with more common modes, such as drive alone and transit. Erhardt et al. developed models based on extensive data from surveys done in Houston, which included toll and HOV facilities (but not tolled HOV use) along with several other modes. These special non-general purpose freeway facilities were considered as modes rather than just routes. Variables used in the mode choice multinomial and nested logit models included total travel time, access time/auto distance, toll, time savings, distance on toll toads, distance on HOV lanes, and number of vehicles. (Erhardt et al. 2003)

The authors' model indicated that people using HOV or toll facilities have a higher value of travel time savings. For example, people with household incomes greater than $60,000 a year would pay almost $100/hour to save time by using a toll road. Also, a significant number of people used HOV or toll facilities even though these routes were not the path with the shortest travel time. Overall, the researchers found that "the additional preference for toll and HOV facilities can be explained by a perception of lower travel time, less driving stress, and higher reliability on these facilities" and that "selection of a least-cost path in trip assignment is not sufficient for modeling the use of toll and HOV facilities" (Erhardt et al. 2003).

People choose to commute by transit for a number of reasons. In Chicago, a survey was distributed to Chicago Transit Authority (CTA) park-and-ride users. Most people who parked at a park-and-ride lot and took a train did so "because it is the fastest way to make their trip, because of the high cost of parking at their destination, and because they dislike driving" (Foote 2000). Chicago park-and-ride users were mostly female (62 percent) and mostly white (70.3 percent). The average household size was 2.9, and the average household income for park-and-ride users was $51,400, which is $18,000 more than the average transit rider in Chicago. All park-and-ride users had at lease one car, and "the mean household automobile availability was 2.1 cars" (Foote 2000). Most survey respondents lived within 10 miles of their park-and-ride lot; many also were interested in amenities, such as a convenience store or bank, being provided near the park-and-ride lot. (Foote 2000)

A study in the Netherlands compared park-and-ride facility attributes and attributes of cars to determine whether changes in the characteristics of one would affect usage of the other (cross-effects). Attributes for park-and-ride facility were quality of the park-and-ride, quality of the public transportation, time lost by using the park-and-ride, and cost of using the park-and-ride. Attributes for the car were delay by using the car and cost at the destination (parking fees). Socioeconomic variables used in the model included sex, education level, age, category of car, car ownership, experience with park-and-rides, and experience with public transportation. Researchers found that higher delays when using the car and higher car costs led to a higher desirability of using the park-and-ride, even more than decreasing time and money costs of using the park-and-ride. (Bos and Molin 2006)

A study was conducted to determine how people might alter their mode of travel once new park-and-ride (P&R) facilities with transit service were constructed in Beijing. Users of existing parking lots were surveyed on both a weekday and a weekend day.

Based on the participant's responses, the sample was divided into auto captive, P&R captive, and choice user groups. In the model developed, variables included income, origin, destination, trip purpose, parking fee source, travel time, and travel cost. Lower income people had a higher preference for P&R, and higher income people had a higher preference for driving. Those going to the central city had a higher preference for P&R. Those who had to pay parking fees themselves also preferred P&R over driving. (Guan et al. 2006)

In a study of SOV, carpool, and transit travelers, researchers developed a mode choice model for the three modes and compared it with other existing models at the time. Variables which were tested included in-vehicle time, total cost, transit availability, travel distance, workplace in the CBD, and expense (perceived difference in cost between modes). A model with these variables performed better than the other models, which included variables like access, mode unreliability, cars per driver, total cost per income, and bus transfers. The author noted that variables based on perception may be more important than actual characteristics, such as the importance of perceived cost versus actual cost. Also, perceived cost and actual cost were not strongly correlated. (Lyles 1979)

A multinomial logit model developed for Portland predicted that with free parking in the central business district, 62 percent of commuters will drive alone, 16 percent will carpool, and 22 percent will take transit. In contrast, with a daily parking cost of $6, 46 percent of commuter will drive alone, 4 percent will carpool, and 50 percent will take transit (Hess 2001).

In a demonstration project on increased parking fees and free transit service at the University of Massachusetts, parking fees were increased from $5 per year to $55, $41, or $17 per year, based on the distance from the main part of campus. Multiple surveys were conducted by telephone at various times during the study. A mode choice model was developed, which included variables like walking time, parking fee, auto operating cost, status of trip maker (approximating income levels), sex, and number of autos available. Researchers determined that "availability and attractiveness of an automobile, parking fee levels at destination, and accessibility to a bus stop are the most important aspects in determining modal choice" (Kumar and Goss 1977).

In a study on urban form and automobile dependence, variables used in a logit model included trip time, trip cost divided by annual household income, sex, having children under age 5, age, vehicle ownership, distance from home to transit, trip purpose, and population density. In the cities examined—Boston, Portland, and Houston—automobile dependence, which leads to greater automobile use, was significantly influenced by vehicle ownership and home distance to transit. Boston was found to be the least auto dependent, and Houston was the most auto dependent. According to the author, "When transit access is improved, the relative attractiveness of transit increases, making transit more likely to compete successfully with driving as a travel alternative" (Zhang 2005).

An extensive study in southern Florida was conducted to develop better travel models based on current, locally-collected data. A model was developed based on data from household travel surveys and on-board travel surveys. Because many people in the

Miami area either did not have access to an auto or had only one auto in their household, there was a major focus on transit. Modes were divided by the method of access to transit (walk or auto) and type of transit (local bus, express bus, Metrorail, or Tri Rail), so there were seven transit modes (auto access to local bus was not included) plus carpooling and driving alone. Variables used for the transit models included walk time to transit, drive time to transit, in-vehicle travel time, wait time, transfer time, number of transfers, fare, and cost of driving. Mode specific constants for the transit modes included the zero, one, or two vehicles in the household. All these variables were statistically significant. All else equal, people were less likely to take transit or carpool as the number of cars in their household increased. Although a three-level nested logit model was developed, no conclusions were given regarding mode share. (Abdel-Aty and Abdelwahab 2002).

A commuter survey was done in Austin to determine the impact of stop-making and travel time reliability on mode choice and to predict potential usage of commuter rail and toll roads. Variables used in the logit model included the number of motorized vehicles per licensed adult, household income, workplace employment density, travel time and cost, commute distance, and making mid-day stops every day of the work week. Researchers determined that stop-making during the commute and in the midday has a significant effect on mode choice. People were likely to drive if they had to make stops during the day, such as dropping off/picking up a child and eating lunch at a distant restaurant when no alternatives were available near the workplace. Also, commuter rail may reduce mode share of driving alone, but a higher proportion would shift from bus and non-motorized modes than from the automobile. With a $1 or $2 toll, solo drivers would likely shift to carpooling rather than to transit or non-motorized modes. (Bhat and Sardesai 2006)

2.5.3 Mode Choice and Mode Shift

In New York City, there are many modes that can be used to get from an origin to a destination. In order to identify areas which could be improved to increase ridership, a combination of research methodologies were used. The author discusses the pros and cons of travel demand models, stated preference and discrete choice modeling, and opinion research. Participants in focus groups were asked about which modes (subway, bus, auto, taxi, and car service, which is like a taxi) they used and why they used them. New Yorkers used different modes at different times, depending on the situation. In addition, mode choices for work were different than mode choices for leisure. (Schaller 1999)

Participants in the study were also asked why they chose the subway versus other modes, or vice versa. Factors like parking, travel time, cost, and availability of mode (if the mode serves the origin and destination) influenced the choice to use the subway or other mode. Security was not a major concern when using the subway. Schaller suggests that investing in ways to reduce trip time, increase transit availability, and improve comfort would increase subway ridership. (Schaller 1999)

As in New York, travelers in Houston have many different mode options, even on just one freeway corridor. Adaptation of a HOV lane to a HOT lane adds another mode, so travelers can choose the mode that works best for them, depending on the situation. However, Houston has already made significant efforts in providing a fast, comfortable, and available commuter transit system. Therefore, this may minimize the impact on transit due to another mode being made available.

2.6 Summary

Traffic congestion is continually increasing, but there are many ways to deal with it, including transportation demand management. Using methods like variable pricing and flexible working schedules help spread out the peak demand periods. Variable pricing can be used to allow SOV users to pay a toll and utilize excess capacity on HOV lanes. Based on the experiences of HOT facilities in other cities, the introduction of the toll-paying SOV mode has not negatively affected transit ridership. However, each city has different characteristics, and what occurred in one place may not necessarily occur in another. Thus the result in Houston could be quite different and should be estimated.

Houston's HOV lane network has grown and evolved over the past 30 years. Today there are about 110 miles of barrier-separated, reversible HOV lanes on six freeway corridors. Thousands of travelers park at park-and-ride facilities around the city and ride frequently-arriving buses directly to downtown Houston and other major employment centers. As the population of greater Houston continues to grow, the HOV lanes will be adapted to HOT lanes and toll/managed lanes to utilize available capacity and provide reliable and fast travel. As this happens, transit riders will have an additional choice: SOV on the HOV lane. This could negatively impact transit ridership and should therefore be investigated. One method to estimate this modal switch is through mode choice modeling.

Discrete choice models are often developed to estimate these mode choices. Researchers often develop logit models based on responses to stated preference questions and demographic information, along with trip characteristics to estimate mode choice. Variables often include trip characteristics, like time and cost, and socioeconomic characteristics, like age, income, and number of automobiles available. In addition, a number of papers indicated that perception of values like time, cost, and reliability may be more important than the actual values themselves. Some researchers concluded that increased car-related costs, like parking fees, may discourage driving and encourage transit use. The next chapter discusses the data collected in this research to develop such a mode choice equation to estimate transit to SOV on the HOV lane mode shift.

CHAPTER III

STUDY BACKGROUND AND DATA COLLECTION

This chapter reviews the area of study and the how the survey instrument was designed and administered. The process of data reduction in preparation for analysis is also covered.

3.1 Study Area

In 2003 the Texas Transportation Institute (TTI) conducted an extensive survey of travelers on the Katy (I-10 West) and Northwest (US 290) Freeways in Houston; the two corridors are shown in Figure 3.1.

Figure 3.1. Study corridors (Houston Value Pricing 2007)

Within these two freeway corridors there are many different mode options for commuting in the peak direction; some options are only available at certain times of the day. In the morning, people on the Katy and Northwest Freeways may commute inbound by using the following modes:

- SOV or HOV2+ on the general purpose lanes (free),
- HOV2 on the HOV lane ($2 with QuickRide account 6:45-8:00 a.m., free all other times),
- HOV3+ on the HOV lane (free)
- METRO bus on the HOV lane (fare varies from $2.50 to $3.50)
- Casual carpool on the HOV lane (free), or
- Motorcycle on the HOV lane (free).

In the afternoon, the mode choices are generally the same, except that QuickRide HOV2 users must pay $2 between 5:00-6:00 p.m. to use the HOV lane on the Katy Freeway only.

All types of users participated in the survey, including users of the general purpose lanes (GPLs), HOV lane, transit, QuickRide, and casual carpooling. Surveys were customized for each mode and time of day (peak or off-peak).

3.2 Survey Design and Administration

The transit rider focused version of the survey was distributed to transit riders departing from or returning to park-and-ride lots in the Katy and Northwest Freeway corridors (a sample survey instrument may be found in Appendix A). Respondents were asked about their most recent workday trip on that freeway, their knowledge and opinions on the QuickRide program, their demographic information, and their choice of mode in four different travel scenarios. These travel scenarios were presented as stated preference questions. Transit users had the choice of the following seven modes:

- SOV on the general purpose lanes, peak period (SOV-GPL-P),
- HOV2 on the HOV lane, peak period (HOV2-HOV-P),
- SOV on the HOV lane, off-peak period (SOV-HOV-OP),
- SOV on the HOV lane, peak period (SOV-HOV-P),
- Bus on the HOV lane, peak period (BUS-HOV-P),
- Bus on the HOV lane, off-peak period (BUS-HOV-OP), and
- Casual carpool on the HOV lane, peak period (CCP-HOV-P).

In order to simplify the questions for the participants, nine blocks of surveys were created, each with four different modes. The four modes were the same for all four questions on a survey, but the travel time and cost varied for each question. The mode choice of bus on the HOV lane during the peak period, the base mode, was always one of the four modes given. In addition, the choice of casual carpooling was also one of the modes given, so two of the five remaining modes comprised the last two choices.

Surveys were handed to transit riders as they boarded METRO buses on selected days in November, 2003 (Figure 3.2). Most riders were able to fill out the survey on board (Figure 3.3) and return the survey as they alighted or by postage-paid envelopes.

Figure 3.2. Surveys handed out to bus riders (Courtesy of TTI)

Figure 3.3. Bus riders completing surveys (Courtesy of TTI)

Table 3.1 shows the number of surveys handed out and returned for each park-and-ride facility. Surveys were handed out on selected inbound buses departing from 5:55 to 7:29 AM and on selected outbound buses departing from 4:15 PM to 5:21 PM in order to focus on people traveling during the peak period in the peak direction. There was a very high response rate; 536 out of 687 surveys (78 percent) distributed were returned to the surveyor as passengers alighted their bus. An additional 48 surveys were returned later by mail, for a total of 584 surveys.

Table 3.1. Response Rates by Park-and-Ride Lot

Park-and-Ride Lot	Corridor	Surveys Distributed	Surveys Collected (Same Day)	Response Rate
Addicks	Katy	263	209	79%
Kingsland	Katy	166	132	80%
Northwest Station	Northwest	154	126	82%
West Little York and Pinemont	Northwest	104	69	66%
Total		**687**	**536**	**78%**

It is important to note that there were about 13,500 person-trips per day made by bus in these two corridors in December 2006 (TTI 2006), so 584 surveys is a relatively small sample. Also, the survey was not specifically developed for transit riders only; carpoolers and SOV users also completed a similar survey. Therefore, other questions which might have contributed to the mode choice model, such as attitudinal questions about comfort of the bus, safety, etc., were not included to keep the survey to a reasonable length.

3.3 Data Reduction

After the paper surveys were collected, the responses were entered into a database. All 584 surveys returned were included in the demographic analysis, but only

446 surveys were included in the logit model because some surveys were incomplete or had unreasonable responses. In order for a survey response to be included in the model, all the demographic questions had to be answered. On the other hand, analysis of each demographic question was done separately, so even if a respondent skipped a question, his or her other questions could still be counted as part of the sample.

In order to prepare the data for analysis using the program LIMDEP, each mode option for each question required one row in the data table. Since there were four questions on each survey and each question had four modes, each participant's responses was coded into sixteen rows, and the participant's socioeconomic and travel information was copied into all sixteen rows.

CHAPTER IV

DATA ANALYSIS AND RESULTS

In order to calculate each participant's utility for each mode and determine the mode he or she would take under various scenarios, the computer program LIMDEP 7.0 was used. As mentioned in Chapter III, information regarding the mode alternatives, travel times, tolls, mode chosen, and demographic and trip characteristics for each person was entered into a data file.

Originally, since data was collected on the Katy and Northwest Freeways, it was planned that the responses from the two corridors would be compared. However, based on the raw data from the responses given, the number of people surveyed who would switch from bus to SOV on the HOV lane on each corridor was too small to develop separate mode choice models. Therefore, all responses from respondents using the two freeways were analyzed and modeled together.

4.1 Demographic Characteristics of Passengers Likely to Use SOV-HOV

The raw data from the survey responses were examined to determine if there were any demographic characteristics that were significantly different for transit passengers who were more likely to drive alone on the HOV lane if that option were available. To gather this information the stated preference (SP) questions from the survey were examined. Each respondent answered four SP questions, but a respondent may not have chosen the same mode each time. For example, in two questions, a respondent may have chosen BUS-HOV-P, and in the other two, the respondent may have chosen SOV-HOV-P. As a result, the total number of responses in a category was divided by four in order to have a total of 584, the number of transit passengers who completed surveys. For example, SOV-HOV-OP was chosen in 77 questions, so 19.25 "respondents" chose this mode. Likewise, SOV-HOV-P was chosen in 23 questions, so 5.75 "respondents" chose this mode. The socioeconomic characteristics of the respondents are shown in Table 4.1.

Table 4.1. Socioeconomic Characteristics of All Transit Riders and Those Choosing SOV-HOV

	All Transit Riders	Transit Riders Choosing SOV-HOV-OP	Transit Riders Choosing SOV-HOV-P	All Transit Riders Choosing SOV-HOV
	n = 584	n = 19.25	n = 5.75	n = 25
Trip Purpose				
Commuting	93.2%	72.7%	**100.0%**	79.0%
Recreational	0.2%	0.0%	0.0%	0.0%
Work related	4.7%	**14.3%**	0.0%	11.0%
School	1.4%	**13.0%**	0.0%	10.0%
Other	0.5%	0.0%	0.0%	0.0%
Age				
16 to 24	3.5%	**15.6%**	0.0%	12.6%
25 to 34	19.4%	13.0%	5.6%	11.6%
35 to 44	27.0%	28.6%	**50.0%**	32.6%
45 to 54	38.0%	29.9%	38.9%	31.6%
55 to 64	11.7%	13.0%	5.6%	11.6%
65 and over	0.4%	0.0%	0.0%	0.0%
Gender				
Male	48.1%	**64.4%**	**68.2%**	65.3%
Female	51.9%	35.6%	31.8%	34.7%
Household Type				
Single adult	13.5%	**23.3%**	9.5%	20.2%
Unrelated adults (e.g. room-mates)	2.8%	5.5%	4.8%	5.3%
Married without child	17.6%	12.3%	9.5%	11.7%
Married with child(ren)	56.0%	52.1%	**76.2%**	57.4%
Single parent family	7.4%	4.1%	0.0%	3.2%
Other	2.7%	2.7%	0.0%	2.1%

Note: Bold items indicate variables that are considerably higher for a group than for the whole sample; underlined items indicate those that are considerably lower.

Table 4.1. Continued

	All Transit Riders	Transit Riders Choosing SOV-HOV-OP	Transit Riders Choosing SOV-HOV-P	All Transit Riders Choosing SOV-HOV
	n = 584	**n = 19.25**	**n = 5.75**	**n = 25**
Household Size				
1	11.7%	17.4%	9.1%	15.4%
2	27.0%	17.4%	18.2%	17.6%
3	22.1%	33.3%	<u>4.5%</u>	26.4%
4	24.6%	26.1%	22.7%	25.3%
5	9.5%	5.8%	**18.2%**	8.8%
6	3.8%	0.0%	**27.3%**	6.6%
7	0.7%	0.0%	0.0%	0.0%
8	0.4%	0.0%	0.0%	0.0%
9	0.2%	0.0%	0.0%	0.0%
Vehicles in Household				
0	0.0%	0.0%	0.0%	0.0%
1	15.2%	19.5%	27.3%	21.2%
2	55.5%	64.9%	59.1%	63.6%
3	22.3%	14.3%	13.6%	14.1%
4	4.6%	0.0%	0.0%	0.0%
5	1.8%	0.0%	0.0%	0.0%
6	0.2%	0.0%	0.0%	0.0%
7	0.4%	1.3%	0.0%	1.0%
Occupation				
Professional / Managerial	57.7%	64.9%	63.6%	64.6%
Technical	14.4%	16.9%	**27.3%**	19.2%
Sales	1.1%	0.0%	0.0%	0.0%
Administrative / Clerical	21.8%	<u>5.2%</u>	<u>9.1%</u>	6.1%
Manufacturing	0.7%	0.0%	0.0%	0.0%
Student	1.2%	**13.0%**	0.0%	10.1%
Self employed	0.7%	0.0%	0.0%	0.0%
Other	2.3%	0.0%	0.0%	0.0%
Level of School Completed				
Less than high school	0.5%	2.6%	**18.2%**	6.1%
High school graduate	7.1%	7.8%	4.5%	7.1%
Some college / Vocational	24.6%	<u>9.1%</u>	13.6%	10.1%
College graduate	45.4%	42.9%	36.4%	41.4%
Postgraduate degree	22.3%	37.7%	27.3%	35.4%
Annual Household Income				
Less than $10,000	0.8%	0.0%	0.0%	0.0%
$10,000 to $14,999	0.8%	0.0%	0.0%	0.0%
$15,000 to $24,999	1.0%	0.0%	**23.8%**	5.8%
$25,000 to $34,999	5.8%	6.2%	<u>0.0%</u>	4.7%
$35,000 to $49,999	12.0%	20.0%	<u>0.0%</u>	15.1%
$50,000 to $74,999	21.4%	6.2%	19.0%	9.3%
$75,000 to $99,999	22.6%	24.6%	9.5%	20.9%
$100,000 to $199,999	32.1%	36.9%	23.8%	33.7%
$200,000 or more	3.6%	6.2%	**23.8%**	10.5%

Note: Bold items indicate variables that are considerably higher for a group than for the whole sample; underlined items indicate those that are considerably lower.

Due to the small sample size of "respondents" who chose SOV-HOV-OP and SOV-HOV-P statistical comparisons to the large population of all transit survey respondents were not meaningful. However, there were several demographic characteristics that seemed to be very different between all transit riders and the riders who chose an SOV on HOV toll option. People who were likely to switch to SOV-HOV-OP appeared to be more likely to be students, age 16-24, single adults, and/or have school or work-related travel as their trip purpose; they also seemed to be less likely to have only some college/vocational school as their highest level of education.

People who were likely to switch to SOV-HOV-P appeared to be more likely to be commuting, age 35-44, married with children, have a household size of 5 or 6, and/or have a household income of between $15,000-24,999 or $200,000 or more. These people also seemed to be less likely, than transit riders in general, to be age 55-64, a single parent, have a household size of 3, and/or have a household income between $25,000 and $49,000. Males appeared to be more likely to shift to SOV-HOV in both the peak and off-peak periods, and those with administrative/clerical occupations seemed to be less likely to shift to SOV-HOV. These variables, in particular, will be examined for their inclusion in the mode choice model.

Finally, it is important to note that no transit survey respondent had zero vehicles in his or her household. Thus, the bus rider either had to drive him/herself to the park-and-ride lot or had to be dropped off by a family member ("kiss-and-ride"). That means the transit rider chooses not to use his or her car the full distance of the trip, or does not have a car to use for most of the day because another family member is using it.

4.2 Development of Model

Information collected in the survey and analyzed for potential inclusion in the model included the following: trip purpose, total trips in the past full work week, age, gender, household type, household size, number of vehicles in household, occupation, education level completed, and annual household income; these are listed in Table 4.1. In addition, the length of the trip in minutes and whether or not the trip began during the peak HOV period (6:45-8:00 AM inbound, 5:00-6:00 PM outbound) were determined from the original data and examined in the models.

A crosstabs analysis was done on many of the variables using the computer program SPSS; one example is shown in Table 4.2. For each mode choice, it was calculated how many people chose commuting ("tpcomm") as their trip purpose (0 = no, 1 = yes). For example, of the people who chose SOV-GPL-P in their stated preference question, 88.2 percent were commuting on their most recent trip. If no one or everyone choosing a mode had the same trip or socioeconomic characteristic, that characteristic could not be used in the model for that mode because it would cause an error. This analysis, along with the data from Table 4.1, and the information gained from the literature review, helped to guide mode choice model development.

Table 4.2. Sample Crosstabs Analysis

			tpcomm		Total
			0	1	
choice	SOV-GPL-P	Count	24	180	204
		% within choice	11.8%	88.2%	100.0%
	HOV2-HOV-P	Count	12	224	236
		% within choice	5.1%	94.9%	100.0%
	SOV-HOV-OP	Count	84	224	308
		% within choice	27.3%	72.7%	100.0%
	SOV-HOV-P	Count	0	92	92
		% within choice	.0%	100.0%	100.0%
	BUS-HOV-P	Count	416	6296	6712
		% within choice	6.2%	93.8%	100.0%
	BUS-HOV-OP	Count	28	204	232
		% within choice	12.1%	87.9%	100.0%
	CCP-HOV-P	Count	40	1264	1304
		% within choice	3.1%	96.9%	100.0%
Total		Count	604	8484	9088
		% within choice	6.6%	93.4%	100.0%

In addition to the variables mentioned above, two additional variables were used for all modes—travel time of the mode alternative (“BTIME”), and toll per hourly wage (“BTOLLINC”). The toll per hourly wage was calculated as shown in Equation 4.1.

$$\text{BTOLLINC} = \text{toll of mode alternative}/(\text{annual household income}/2000) \quad (4.1)$$

Note that BTOLLINC is only a surrogate measure for the wage rate. BTOLLINC will be considerably higher than the person’s wage rate when there are multiple wage earners in a household.

Using LIMDEP, various combinations of variables were added in groups to the logit model to determine if they were significant or not ($\rho \leq 0.05$). If the value of ρ was considerably greater than 0.05, the variable was removed from the model, and the model was rerun. If the remaining variables stayed near or below the significance level, then additional variables were added. This process was repeated until all potentially significant variables were tested in the model, and the most significant ones were kept.

The descriptions for the final variables and their respective coefficients and p-values for the best model developed are shown in Table 4.3. Mode E, bus on the HOV lane during peak period, was the base mode and only had BTIME and BTOLLINC in its utility equation.

Table 4.3. Variables in Model

Mode	Variable Description	Code	Coeff.	ρ-value
All modes	Travel time of mode alternative in minutes	BTIME	-0.09	0.00
	Toll of mode alternative / (annual household income / 2000)	BTOLLINC	-3.45	0.00
Mode A SOV on general purpose lanes, peak (SOV-GPL-P)	Mode-specific constant	A_A	-2.53	0.00
	Household type is married with children, yes = 1, no = 0	BAHTYPMC	0.82	0.07
	Household size	BAHHSIZE	-0.28	0.10
	Age is 25 to 34, yes = 1, no = 0	BAAG2534	1.14	0.00
	Occupation is professional/managerial, yes = 1, no = 0	BAOCCPRO	1.09	0.00
Mode B HOV2 on HOV lane, peak (HOV2-HOV-P)	Mode-specific constant	A_B	-3.66	0.00
	Age is 45 to 54, yes = 1, no = 0	BBAG4554	-0.74	0.04
	Highest education is some college/vocational, yes = 1, no = 0	BBEDUSCV	1.95	0.00
	Highest education is college graduate, yes = 1, no = 0	BBEDUCG	1.56	0.00
Mode C SOV on HOV lane, off-peak (SOV-HOV-OP)	Mode-specific constant	A_C	-0.91	0.15
	Total number of trips made during the past full work week	BCTNTALL	-0.22	0.00
	Household type is single adult, yes = 1, no = 0	BCHTYPSA	1.08	0.00
	Highest education is postgraduate degree, yes = 1, no = 0	BCEDUPG	1.08	0.00
Mode D SOV on HOV lane, peak (SOV-HOV-P)	Mode-specific constant	A_D	-4.73	0.00
	Household size	BDHHSIZE	0.32	0.07

Table 4.3. Continued

Mode	Variable Description	Code	Coeff.	ρ-value
Mode F Bus on HOV lane, off-peak (BUS-HOV-OP)	Mode-specific constant	A_F	-1.58	0.01
	Total number of trips made during the past full work week	BFTNTALL	-0.12	0.08
	Gender, male = 1, female = 0	BFSEX	0.82	0.03
	Household type is single adult, yes = 1, no = 0	BFHTYPSA	1.98	0.00
	Trip started during peak period	BFPEAK	-0.78	0.04
Mode G Casual carpool on HOV lane, peak (CCP-HOV-P)	Mode-specific constant	A_G	-2.52	0.00
	Trip purpose is commuting, yes = 1, no = 0	BGTPCOM M	2.08	0.00
	Age is 45 to 54, yes = 1, no = 0	BGAG4554	-0.44	0.01
	Household size	BGHHSIZE	-0.16	0.00
	Occupation is administrative/clerical, yes = 1, no = 0	BGOCCAD M	-1.18	0.00
	Highest education is some college/vocational, yes = 1, no = 0	BGEDUSCV	-0.77	0.00
	Highest education is college graduate, yes = 1, no = 0	BGEDUCG	-1.38	0.00
	Highest education is postgraduate degree, yes = 1, no = 0	BGEDUPG	-1.15	0.00
	Trip started during peak period	BGPEAK	0.82	0.00
$\rho^2 = 0.62$				
ρ^2-adj = 0.62				
% correct = 61.2%				
n = 1784				

The utility equations derived from this model are shown in Equations 4.2 to 4.8.

$$U_{SOV\text{-}GPL\text{-}P} = -2.53366 - 0.08702*BTIME - 3.45329*BTOLLINC + 0.816034*BAHTYPMC - 0.27865*BAHHSIZE + 1.14162*BAAG2534 + 1.09449*BAOCCPRO \quad (4.2)$$

$$U_{HOV2\text{-}HOV\text{-}P} = -3.65669 - 0.08702*BTIME - 3.45329*BTOLLINC - 0.73862*BBAG4554 + 1.94733*BBEDUSCV + 1.56409*BBEDUCG \quad (4.3)$$

$$U_{SOV\text{-}HOV\text{-}OP} = -0.9087 - 0.08702*BTIME - 3.45329*BTOLLINC - 0.21617*BCTNTALL + 1.08293*BCHTYPSA + 1.07935*BCEDUPG \quad (4.4)$$

$$U_{SOV\text{-}HOV\text{-}P} = -4.73056 - 0.08702*BTIME - 3.45329*BTOLLINC + 0.318404*BDHHSIZE \quad (4.5)$$

$$U_{BUS\text{-}HOV\text{-}P} = -0.08702*BTIME - 3.45329*BTOLLINC \quad (4.6)$$

$$U_{BUS\text{-}HOV\text{-}OP} = -1.5799 - 0.08702*BTIME - 3.45329*BTOLLINC - 0.12041*BFTNTALL + 0.820624*BFSEX + 1.98489*BFHTYPSA - 0.78124*BFPEAK \quad (4.7)$$

$$U_{CCP\text{-}HOV\text{-}P} = -2.51558 - 0.08702*BTIME - 3.45329*BTOLLINC + 2.07806*BGTPCOMM - 0.44096*BGAG4554 - 0.15594*BGHHSIZE - 1.17802*BGOCCADM - 0.76954*BGEDUSCV - 1.37701*BGEDUCG - 1.14623*BGEDUPG + 0.817025*BGPEAK \quad (4.8)$$

Note: The description of these variables is shown in Table 4.2.

It is assumed that participant would choose the mode with the highest utility. Ideally, the chosen mode, as estimated by the model, is supposed to match the mode actually chosen in the given stated preference question. However, it is very difficult to have the modeled choice match the actual choice 100 percent of the time because of the variability of human nature. The model developed had a 61.2 percent match, which is reasonably accurate. The travel times and tolls as originally given in the stated preference questions are shown in Table 4.4. The percentage that each mode was actually chosen is also given.

Table 4.4 Mode Chosen in Stated Preference Questions

Mode	Possible Travel Times	Possible Tolls	Percentage Chosen
SOV-GPL-P	25, 35, 45 min	$0	2.3%
HOV2-HOV-P	18, 21 min	$1, $2, $3	3.0%
SOV-HOV-OP	13, 15 min	$1, $2, $3	3.1%
SOV-HOV-P	12, 16 min	$4, $6, $8	1.0%
BUS-HOV-P	17, 20 min	$2, $3	74.6%
BUS-HOV-OP	17, 20 min	$1, $2	2.4%
CCP-HOV-P	17, 21 min	$0	13.7%

Almost three-quarters of transit riders remained on the bus. The largest shift away from transit is to casual carpooling, at 13.7 percent (the effect of casual carpooling is discussed later in Section 4.4). The lowest percent of mode shift is 1.0 percent, from transit to SOV on the HOV lane during the peak period. Only a total 4.1 percent of those surveyed would change from bus to SOV on the HOV lane (any time of the day), the mode shift of interest.

One significant factor to consider when modeling travelers who travel by bus is who pays for the bus fare. Sometimes an employee's transit pass is paid for by his or her employer. Therefore, the majority of the traveler's trip (from the park-and-ride lot to the office) has no monetary cost.

According to Julie Fernandez, Manager of Strategic Analysis at METRO, an average of 4,272 transit passes were purchased each month by companies ("RideSponsors") from March 2006 to February 2007. It was assumed that all of these passes are used by commuters who use park-and-ride bus routes. In February 2007, there were 646,891 boardings on all of METRO's park-and-ride bus routes (METRO 2007). If everyone made a round trip each day for all 20 business days in February, a total of 40 trips, there would be about 16,172 unique passengers. This would likely underestimate the number of unique passengers with employer-sponsored bus passes, but provides a reasonable estimate. Therefore, approximately 26.4 percent of park-and-ride bus passengers have no out-of-pocket commuting expenses, except to get to and from the park-and-ride lot. Note that this calculation does not include transit riders who buy their own passes and are reimbursed by their employers.

In order to determine whether having a free fare affected survey participants' responses, the logit model was run again, except with bus fares set at $0 for both peak and off-peak travel. The resulting coefficients were very similar to the original model, and the predicted mode choice totals were the same. Since the majority of park-and-ride bus passengers pay their own fare, the original model (with full bus fares) was retained.

In the next section, various tolls and travel times will be applied to different mode choices. The model will then be used to estimate how existing bus riders might react to the various toll and travel time situations.

4.3 Simulation of Potential Scenarios

In order to estimate how existing transit users might react to the new option of driving alone on the HOV lane for a fee, it was necessary to determine the travel time savings of using the HOV lane instead of the general purpose lanes (GPLs). Travel time savings in the AM peak from the 3 surveyed park & rides, as determined in a previous study, are shown in Table 4.5.

Table 4.5. HOV Lane Travel Time Savings (Winn 2005)

Park & Ride Lot	Travel Time Savings
Kingsland	3:24-22:38
Addicks	1:50-15:41
Northwest Station	2:35-19:02

For this analysis, the travel time savings levels for an SOV on the HOV lane versus an SOV on the GPLs were set at 5, 10, 15, and 20 minutes. In order to simplify multiple simulations, all six modes using the HOV lane had fixed travel times (which varied by mode), and SOV-GPL-P had travel times 5, 10, 15, and 20 minutes greater than travel times for SOV-HOV-P and SOV-HOV-OP. Based on previous research, travel times on the HOV lane averaged around 15 minutes for these two corridors (Winn 2005); this varied for different park-and-ride lots because of their distance from downtown.

Although all modes using the HOV lane have the same travel time for the portion of the trip that is actually on the HOV lane, additional time must be added at the beginning and end of the trip for carpools to pick up and/or drop off passengers or for transit riders to wait for the bus. These additional times are based on Winn's calculations (2005) and current METRO bus schedules. The mode HOV2-HOV-P required an additional 5 minutes to pick up/drop off one passenger. The modes BUS-HOV-P, BUS-HOV-OP, and CCP-HOV-P required 4 minutes and 15 seconds to walk to the bus stop/casual carpool queue and wait for the bus/casual carpool and another 4 minutes and 45 seconds to be dropped off once entering the downtown area, for a total of 9 minutes in addition to the HOV lane travel time. Table 4.6 lists the travel times used in the scenarios.

Table 4.6. Scenario Travel Times

Mode	Travel Time (min)
SOV-GPL-P	20, 25, 30, 35
HOV2-HOV-P	20
SOV-HOV-OP	15
SOV-HOV-P	15
BUS-HOV-P	24
BUS-HOV-OP	24
CCP-HOV-P	24

Toll rates for the seven modes were also developed for the scenarios. The modes SOV-GPL-P and CCP-HOV-P required no tolls, so both were set at $0. For the modes HOV2-HOV-P, BUS-HOV-P, and BUS-HOV-OP, the toll (or bus fare) was set at the average of the values originally given in the stated preference survey questions. Thus, the tolls were fixed at $2, $2.50, and $1.50 for HOV2-HOV-P, BUS-HOV-P, and BUS-HOV-OP, respectively.

In order to model shifts to peak and off-peak SOV, one toll was fixed while the other one varied. In Scenario 1, the toll for SOV-HOV-OP was fixed at $2, and the toll for SOV-HOV-P was $4, $5, $6, or $7. In Scenario 2, the toll for SOV-HOV-P was fixed at $6, and the toll for SOV-HOV-OP was $1, $2, $3, or $4. Scenarios 3 and 4 were the same as Scenarios 1 and 2, respectively, except that the bus fares for peak and off-peak were $0 instead of $2.50 and $1.50. This was to gain some insight into what effect free (employer-subsidized) fares may have on mode shift. The tolls for each scenario are shown in Table 4.7.

Table 4.7. Scenario Toll Prices

Mode	Scenario 1	Scenario 2	Scenario 3	Scenario 4
SOV-GPL-P	$0	$0	$0	$0
HOV2-HOV-P	$2	$2	$2	$2
SOV-HOV-OP	$2	$1, $2, $3, $4	$2	$1, $2, $3, $4
SOV-HOV-P	$4, $5, $6, $7	$6	$4, $5, $6, $7	$6
BUS-HOV-P	$2.50	$2.50	$0	$0
BUS-HOV-OP	$1.50	$1.50	$0	$0
CCP-HOV-P	$0	$0	$0	$0

Using the travel time savings and tolls discussed above, the model was run again with the utility equations established in Section 4.1. It was assumed that individuals would choose the mode with the highest utility. This research focused on the mode shifts from bus to SOV-HOV-OP and from bus to SOV-HOV-P. Therefore, only results for these two mode shifts are reported in detail.

4.3.1 Scenario 1: Peak Toll Varying

For the travel time savings and peak period tolls described in section 4.3, the percent of people that may shift from bus to SOV-HOV-P ranged from a high of 1.57 percent, when the toll was $4 and there were 20 minutes of travel time savings, to a low of 1.18 percent, with a $7 toll and 5 minutes saved. For a given amount of time saved, an increase in the toll rate in $1 increments significantly decreased the percentage of predicted mode shift. Also, for a given toll rate, a decrease in the time savings in 5 minute increments decreased the percentage of mode shift from bus to SOV-HOV-P, but to a lesser extent. The percentage of estimated mode shift for the various peak period tolls and time savings are shown in Figure 4.1.

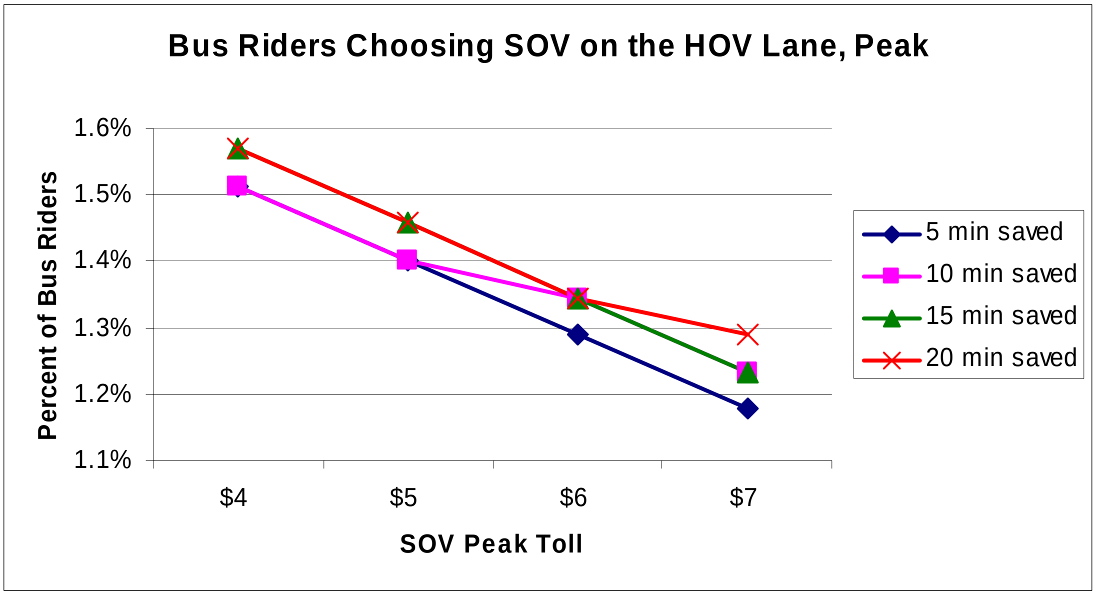

Figure 4.1. Bus riders choosing SOV-HOV-P

The SOV-HOV-OP toll was fixed at $2, and the percentage of people estimated to shift to that mode was the same for any peak toll rate for a given time savings. However, as the time savings increased, the percentage of shift to SOV-HOV-OP increased slightly, from 3.92 percent at 5 minutes saved to 4.15 percent at 20 minutes saved.

4.3.2 Scenario 2: Off-Peak Toll Varying

In the second scenario, the peak toll rate was set at $6, and the off-peak toll ranged from $1 to $4. The estimated percentage of people who would shift from bus to

SOV on the HOV, off-peak, ranged from a high of 4.48 percent, when the toll was $1 and there were 20 minutes of travel time savings, to a low of 3.36 percent, with a $4 toll and 5 minutes saved. As in Scenario 1, increased tolls caused a greater decrease in mode shift than decreased travel time savings. The percentage of estimated mode shift for the various peak period tolls and time savings are shown in Figure 4.2.

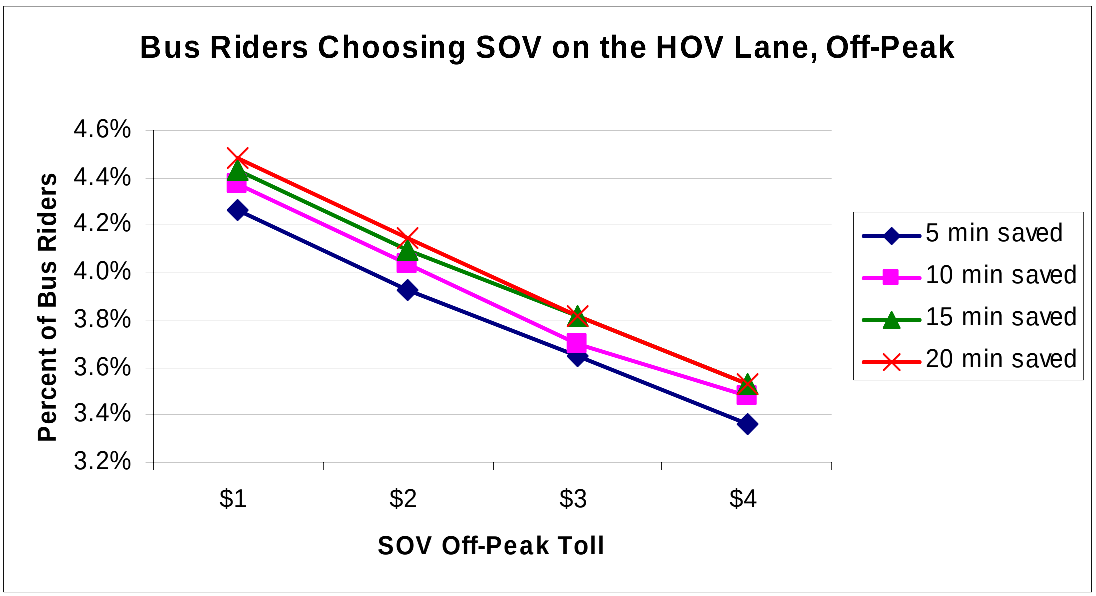

Figure 4.2. Bus riders choosing SOV-HOV-OP

For any given pair of off-peak and peak toll rates, the percentage of bus riders estimated to shift to SOV-HOV-P was relatively stable; the amount of shift ranged from 1.29 percent at 5 minutes saved to 1.35 percent at 20 minutes saved. Changing the off-peak toll rate did not affect the percentage of mode shift to SOV-HOV-P.

4.3.3 Scenarios 3 and 4: Free Bus Fare

Scenario 3 was a repeat of Scenario 1, except that bus fares were set at $0 to simulate employer-subsidized transit fares. As expected, fewer bus riders were predicted to switch to SOV-HOV-P; the percentage ranged from 1.35 percent to 1.07 percent. Similarly, Scenario 4 was the same as Scenario 2 except for free bus fares; the percentage of people switching to SOV-HOV-OP ranged from 2.91 percent to 3.81 percent. The results of these two scenarios are shown in Figures 4.3 and 4.4.

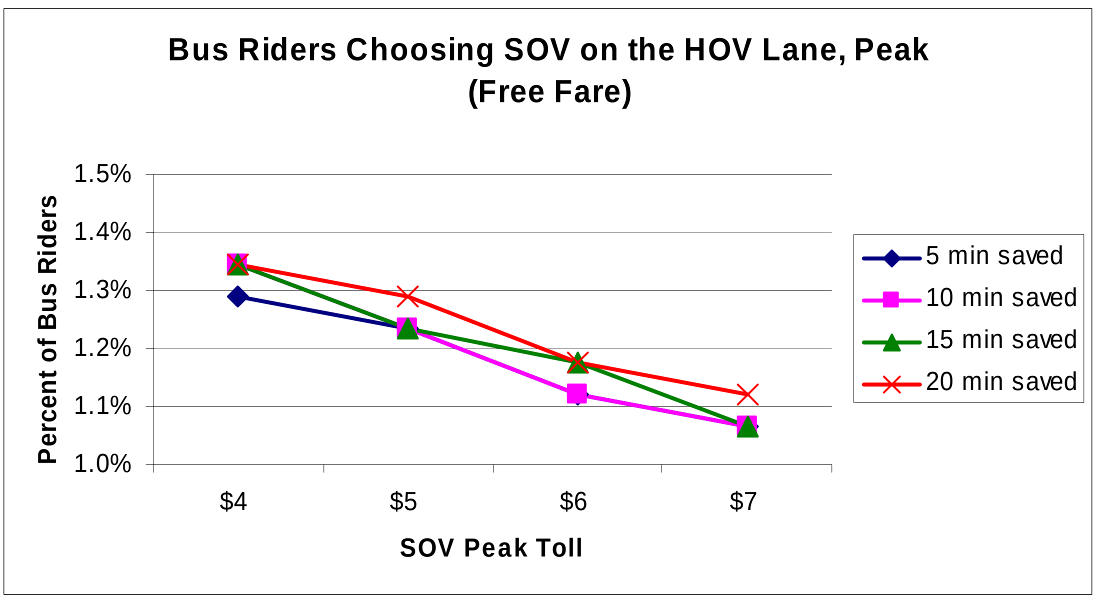

Figure 4.3. Bus riders choosing SOV-HOV-P with employer-subsidized fare

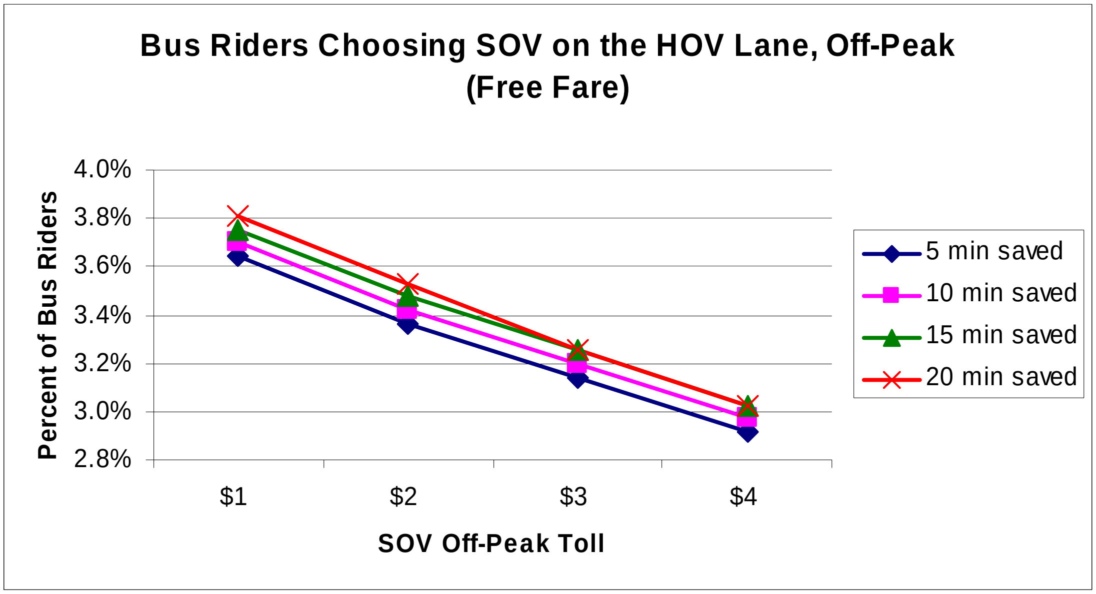

Figure 4.4. Bus riders choosing SOV-HOV-OP with employer-subsidized fare

As expected, fewer people would be likely to shift to SOV on the HOV lane if their transit fare is paid for by their company (free). However, the difference in percent shift between the free fare and regular fare models is 0.17 percent to 0.22 percent during the peak period and 0.50 percent to 0.67 percent during the off-peak period. For example, for a $5 toll and 10 minutes saved in the peak period, 1.40 percent of transit riders might switch in the regular fare scenario, but 1.23 percent would switch in the free fare scenario. The mode shift for regular fare and free fare are shown in Figure 4.5 for the peak period and Figure 4.6 for the off-peak period.

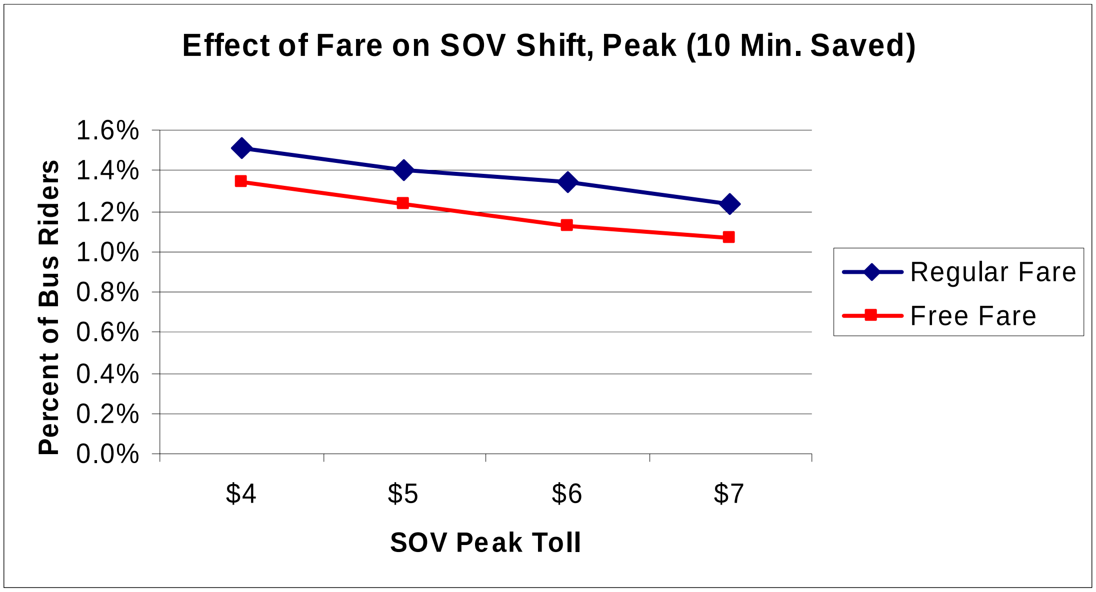

Figure 4.5. Effect of employer-subsidized fare on SOV shift, peak period

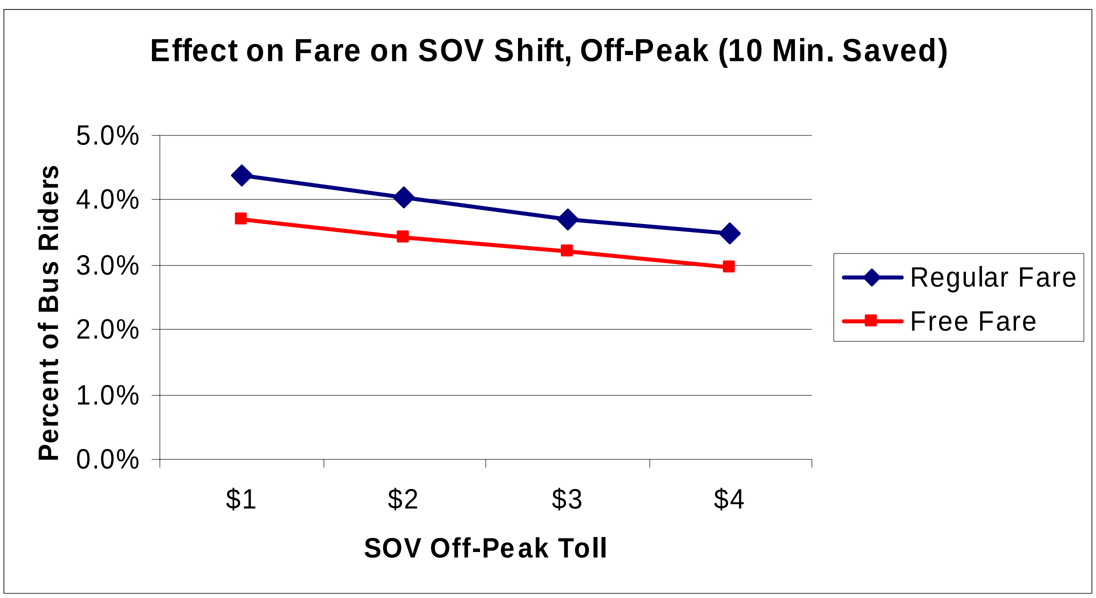

Figure 4.6. Effect of employer-subsidized fare on SOV shift, off-peak period

For bus riders who pay for their fares themselves, the difference between the toll for SOV-HOV-P and the transit fare for BUS-HOV-P would be between $1.50 and $4.50 per trip, based on the scenarios. However, for bus riders whose companies pay for their passes, switching to SOV would require them to bear the full cost of commuting, including a toll of $4-$7 per trip during the peak period, based on the scenarios.

Currently, one-way cash fares on park-and-ride buses on the Katy and Northwest Freeway corridors range from $2.50 to $3.50, depending on distance. Monthly passes are also available, for $78 to $110 (also based on distance), which saves the user money after 32 one-way trips (METRO 2007). Monthly pass users who make 40 one-way trips per month save 21 to 22 percent over cash fares. Sometime in 2007, METRO will be converting to a new fare system and a smart card, known as the Q Card, and eliminating monthly passes. Instead, frequent riders will receive 5 free trips after making 50 paid trips; this would save them 9 percent averaged over 55 trips (METRO 2007). Whether or not passengers pay full cash fare or use a monthly pass, there would be a very minimal impact on the results, as even a free fare caused a very small change in the percentage of people who would shift from bus to SOV on the HOV lane.

Even if park-and-ride bus passengers do pay for their fares themselves (and approximately three-fourths of them do), it is much cheaper than the cost of tolls, parking, and gasoline associated with driving alone in their own cars on the HOV lane. For all users of all modes surveyed in the Katy and Northwest Freeways, the average cost of parking, for those people who had to pay, was $6.19. A round trip on the Katy Freeway HOV lane is about 26 miles, and a round trip on the Northwest Freeway HOV lane is about 27 miles (Table 2.4); both HOV lanes end near the I-610 loop, which is still a few miles from downtown and other major employment centers. Approximately a gallon of gas would be used for each round trip, which costs about $2.75 in June, 2007. With a toll of $4 each way, the total cost of commuting by SOV would be about $17 per day (round trip), or about $11 if parking is free. In comparison, paying for bus fare with cash only costs $5-$7 round trip, and paying with a monthly pass costs even less, explaining, in part, the estimated small shifts from transit to SOV.

4.4 Casual Carpooling

An important factor to note is the existence of casual carpooling in these two corridors surveyed. In 2003, there were an estimated 578 people participating in casual carpools. On the Katy Freeway and Northwest Freeways, casual carpoolers form at three METRO park-and-ride lots, where there is transit as a backup mode. These two freeways are the only ones in Houston where casual carpooling exists and also the only ones with HOV3+ requirements during peak hours. The HOV3+ requirement may have helped to encourage casual carpooling, as “it avoids the stigma of getting into a vehicle alone with a stranger” (Winn 2005).

Transit users chose casual carpooling 13.7 percent of the time in the stated preference questions in their surveys, the most of any mode other than bus during the peak period. In a parallel survey completed by casual carpoolers, 91.6 percent said they use the bus for similar trips. Most casual carpoolers (66.3 percent) use the bus for their evening return trip (Winn 2005). It is likely that many of the bus passengers who completed the survey also used casual carpooling occasionally, leading to a high percentage choosing casual carpooling in the stated preference questions.

Since casual carpooling only exists on two freeways in Houston which also have stricter occupancy requirements, it is not known whether the percentages of selected modes would be the same on other freeways, such as the Southwest or North Freeways. Clearly, the percentage choosing to casual carpool would be zero (because the mode does not exist on those freeways). However, casual carpool passengers help drivers who are unable to find enough passengers to meet higher occupancy requirements and bus passengers who want to save money. Without the need to meet higher occupancy requirements, there would be no drivers looking for passengers, so thrifty passengers would continue to ride the bus. Therefore, the predicted casual carpoolers from this model would likely be transit riders on corridors without casual carpooling.

4.5 Frequency of Potential SOV-HOV Usage by Transit Passengers

In the survey, transit passengers were asked, "If you could drive alone on the HOV lane for the toll listed below, how often would you drive alone on the HOV lane?" The tolls listed were \$3, \$4, \$5, and \$6. About half of respondents would be willing to drive alone on the HOV lane at least once a week for \$3, which is the average cost of a cash bus fare. However, at \$4 and above, the percentage of people who would choose this mode for at least one trip a week dropped sharply. Only 4.7 percent of transit passengers would pay \$6 to drive alone on the HOV lane one or more times per week.

The full results are shown in Figure 4.7. Note that this question did not state how much time could be saved.

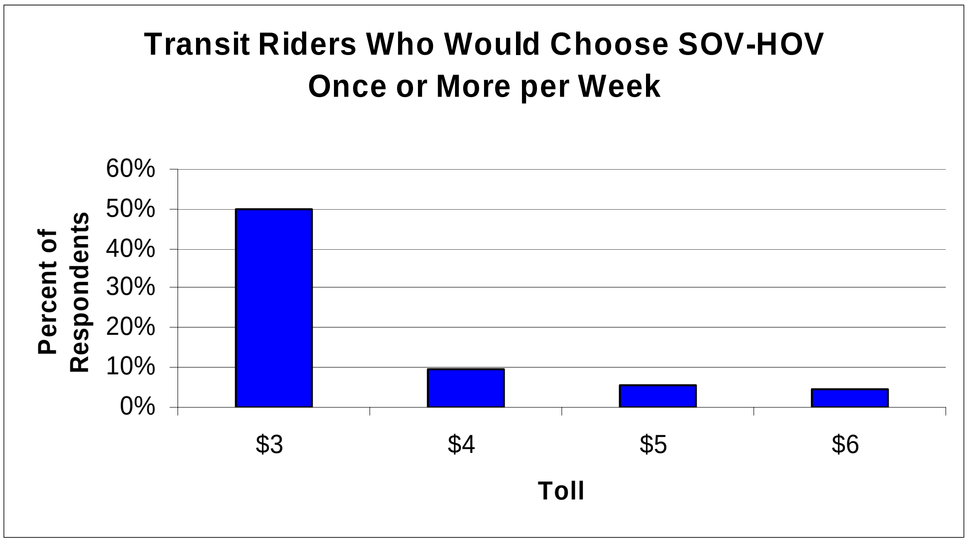

Figure 4.7. People who would choose SOV-HOV at least once a week

Of the current transit riders who would pay $3 to drive alone on the HOV lane, most would either use it for all their trips (10 trips per week) or for only one or two trips per week. The distribution of anticipated trips per week made by driving alone on the HOV lane is shown in Figure 4.8.

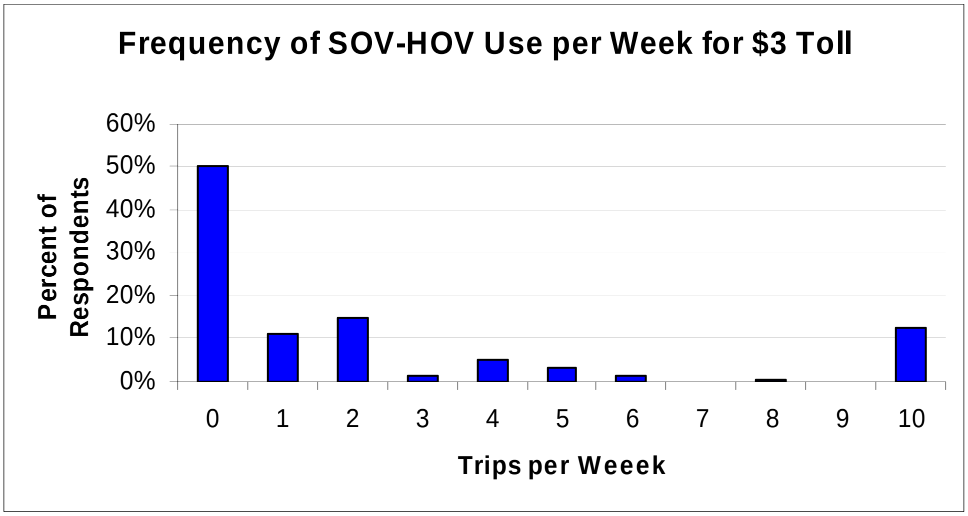

Figure 4.8. Number of times respondents would choose SOV-HOV for a $3 toll

4.6 Impact on HOV Lane Operations

Next, the impact on volume and average vehicle occupancy of people shifting from bus to SOV was estimated. The situation where SOV travelers on the HOV lane saved 10 minutes of travel time and paid $6 in the peak and $2 in the off-peak was used. Bus fare was set at $2.50, as in Scenarios 1 and 2. From these two scenarios, the percentage of shift was 1.35 percent from bus to SOV-HOV-P and 4.04 percent from bus to SOV-HOV-OP. It was assumed that bus riders who traveled during the peak hours (7-8 a.m., 5-6 p.m.) switched to SOV-HOV-P, and bus riders who traveled during the off-peak hours switched to SOV-HOV-OP. Also, it was assumed that bus schedules would remain the same. These percentages were applied to HOV lane traffic data from December 2006, as shown in Table 4.8.

Table 4.8. Impact of Bus Riders Shifting to SOV-HOV Volumes and AVO

	Katy Freeway			Northwest Freeway		
	Before	**After**	**Change**	**Before**	**After**	**Change**
Person Volume						
Total, AM Peak Hour	4,022	4,022		4228	4,228	
Buses	1,680	1657	-1.35%	1330	1312	-1.35%
Tolled SOV (Former Bus Riders)	0	23		0	18	
Total, PM Peak Hour	4,106	4,106		4162	4,162	
Buses	1,495	1475	-1.35%	1115	1100	-1.35%
Tolled SOV (Former Bus Riders)	0	20		0	15	
Total, Off-Peak Hours	19,020	19,020		14,139	14,139	
Buses	4,590	4405	-4.04%	3,435	3296	-4.04%
Tolled SOV (Former Bus Riders)	0	185		0	139	
Total, Daily	27,148	27,148		22529	22,529	
Buses	7,765	7537	-2.94%	5880	5708	-2.92%
Tolled SOV (Former Bus Riders)	0	228		0	172	
Vehicle Volume						
Total, AM Peak Hour	1,168	1,191	1.94%	1379	1,397	1.30%
Buses	44	44		24	24	
Tolled SOV (Former Bus Riders)	0	23		0	18	
Total, PM Peak Hour	1,271	1,291	1.59%	1424	1,439	1.06%
Buses	34	34		22	22	
Tolled SOV (Former Bus Riders)	0	20		0	15	
Total, Off-Peak Hours	7,016	7,201	2.64%	5,374	5,513	2.58%
Buses	114	114		76	76	
Tolled SOV (Former Bus Riders)	0	185		0	139	
Total, Daily	9,455	9,683	2.41%	8177	8,349	2.10%
Buses	192	192		122	122	
Tolled SOV (Former Bus Riders)	0	228		0	172	
Average Vehicle Occupancy						
Total, AM Peak Hour	3.44	3.38	-1.90%	3.07	3.03	-1.29%
Buses	38.18	37.67	-1.35%	55.42	54.67	-1.35%
Total, PM Peak Hour	3.23	3.18	-1.56%	2.92	2.89	-1.05%
Buses	43.97	43.38	-1.35%	50.68	50.00	-1.35%
Total, Off-Peak Hours	2.71	2.64	-2.57%	2.63	2.56	-2.52%
Buses	40.26	38.64	-4.04%	45.20	43.37	-4.04%
Total, Daily	2.87	2.80	-2.36%	2.76	2.70	-2.06%
Buses	40.44	39.25	-2.94%	48.20	46.79	-2.92%

For the peak hours, average vehicle occupancy (AVO) for all vehicles on the HOV lane dropped between 1 and 2 percent; the Katy Freeway had a greater decrease than the Northwest Freeway (for example, 1.90 percent vs. 1.29 percent in the morning). For the off-peak hours, the Katy Freeway HOV lane's AVO went down 2.57 percent (from 2.71 persons/vehicle to 2.64 persons/vehicle), and the Northwest Freeway HOV lane's AVO went down 2.52 percent (from 2.63 persons/vehicle to 2.56

persons/vehicle). Overall, each HOV lane's AVO went down a little more than 2 percent. Note that the AVO for the HOV lane would decrease further with the inclusion of SOVs that shifted from the GPLs to the HOV lane.

Bus AVO went down the same percentage as the percent of shift to SOV-HOV-OP and SOV-HOV-P. This was based on the assumption that bus service levels remained the same. It is likely that the off-peak frequency may be reduced slightly, since there was an estimated decrease of 185 and 139 riders on the Katy and Northwest Freeways, respectively, during the off-peak hours. This is a small number and percentage of transit riders who might switch, particularly if they are spread out throughout the off-peak periods.

4.7 Sensitivity Analysis

In a review of the park-and-ride lot locations in relation to the freeway, it was determined that the entrances to some facilities are a significant distance away from the nearest freeway intersection. Winn had estimated that it would take an average of an additional five minutes to access the park-and-ride facility; however, he also noted that this "was likely an overestimation of the additional time needed" (2005).

Although an additional five minutes of travel time could be added to all modes using the HOV lane (that is, all modes except SOV-GPL-P), not all modes using the HOV lane necessarily access it via a park-and-ride facility. Only travelers using BUS-HOV-P, BUS-HOV-OP, and CCP-HOV-P must enter the HOV lane from a park-and-ride lot because that is where those vehicles pick up people in the morning. Drivers choosing SOV-GPL-P must access the main lanes of the freeway via the usual entrance ramps. Depending on the drivers' origins, those using HOV2-HOV-P, SOV-HOV-OP, and SOV-HOV-P may enter the HOV lane either via a slip ramp from the main lanes (usually at the beginning of the HOV lane) or a direct access ramp from a park-and-ride lot (at selected points along the length of the HOV lane).

In addition, entering the HOV lane via a park-and-ride lot may not necessarily require more time than entering the general purpose lanes via the nearest entrance ramp. For example, if the park-and-ride lot is closer to a person's house than the freeway on-ramp, more time would be required to access the general purpose lanes than the HOV lane. Therefore, in some cases, additional travel time would have to be added to SOV-GPL-P travelers.

Because each park-and-ride lot is in a different location relative to the slip ramp at the beginning of the HOV lane, and travelers' origins are either closer to the freeway or closer to the park-and-ride, a weighted average travel time penalty was calculated. The five park-and-ride lots where surveys were distributed were grouped as follows:

- Beginning of the HOV lane (Group A): Addicks and Northwest Station
- Beyond the beginning of the HOV lane (Group B): Kingsland
- Middle of the HOV lane (Group C): West Little York and Pinemont

Since the park-and-ride lot can be either closer (designated "1") or further ("2") than the freeway from the traveler's origin, there were six possible situations (A1, A2, B1, B2, C1, and C2). If the HOV lane access point was further away than the GPL access point, then a travel time penalty of five minutes was assessed to those modes using the HOV lane. Likewise, if the GPL access point was further away, the mode SOV-GPL-P was given a five minute penalty. It was assumed the traveler's choosing HOV2-HOV-P, SOV-HOV-OP, and SOV-HOV-P would access the HOV from the nearest entrance (either via a direct access ramp from a park-and-ride or slip ramp from the GPL).

These additional travel time penalties were multiplied by the percentage of respondents for which these situations applied. It was assumed that half of the survey respondents from each park-and-ride facility were closer to the freeway and half were closer to the park-and-ride. The weighted average access travel time penalty is shown in Table 4.9. Those modes which were required to access the HOV lane from a park-and-ride lot had greater travel time penalty than those modes which could access the HOV lane from a park-and-ride or the main lanes.

Table 4.9 Weighted Average Access Travel Time Penalty

	Group						
Mode	**A1**	**A2**	**B1**	**B2**	**C1**	**C2**	**Weighted Avg.**
SOV-GPL-P	5	0	0	0	5	0	**1.5**
HOV2-HOV-P	0	0	0	0	0	5	**0.3**
SOV-HOV-OP	0	0	0	0	0	5	**0.3**
SOV-HOV-P	0	0	0	0	0	5	**0.3**
BUS-HOV-P	0	5	0	5	0	5	**2.5**
BUS-HOV-OP	0	5	0	5	0	5	**2.5**
CCP-HOV-P	0	5	0	5	0	5	**2.5**
Respondents	**129**	**129**	**104.5**	**104.5**	**34.5**	**34.5**	
Percent	**24.1%**	**24.1%**	**19.5%**	**19.5%**	**6.4%**	**6.4%**	
Note: Description of each group is discussed in the text.							

In addition, the amount of time needed to park one's vehicle at the destination was also not added to the total travel times for SOV-GPL-P, HOV2-HOV-P, SOV-HOV-OP, and SOV-HOV-P. This was also not considered in Winn's analysis (2005). It would be very difficult to determine the average time needed to park a vehicle at the destination, since everyone has different parking situations (surface lot, parking garage, entrance gates, etc.). An average time of 2 minutes and 12 seconds (or 2.2 minutes) was used for the purpose of this analysis so that the total travel time penalty for all the vehicles using the HOV lane would be 2.5 minutes. However, this may be conservative because regular transit riders who choose to drive themselves may not have a designated parking area, so they may need extra time to look for parking spaces. The weighted average and parking travel time penalty is shown in Table 4.10.

Table 4.10 Weighted Average Access and Parking Travel Time Penalty

	Group						
Mode	**A1**	**A2**	**B1**	**B2**	**C1**	**C2**	**Weighted Avg.**
SOV-GPL-P	5	0	0	0	5	0	**3.7**
HOV2-HOV-P	0	0	0	0	0	5	**2.5**
SOV-HOV-OP	0	0	0	0	0	5	**2.5**
SOV-HOV-P	0	0	0	0	0	5	**2.5**
BUS-HOV-P	0	5	0	5	0	5	**2.5**
BUS-HOV-OP	0	5	0	5	0	5	**2.5**
CCP-HOV-P	0	5	0	5	0	5	**2.5**
Respondents	**129**	**129**	**104.5**	**104.5**	**34.5**	**34.5**	
Percent	**24.1%**	**24.1%**	**19.5%**	**19.5%**	**6.4%**	**6.4%**	
Note: Description of each group is discussed in the text.							

In order to determine whether adding the additional travel time penalties affected the results of the original scenarios, the situation where SOV travelers on the HOV lane saved 10 minutes of travel time and paid \$6 in the peak and \$2 in the off-peak was examined. The 10 minutes of travel time saved is based on the portion of the trip where the HOV lane and GPLs are parallel, so additional time penalties before and after this part of the trip are not counted in the 10 minutes saved. The adjusted travel times and mode split percentages are shown in Table 4.11. Although the SOV-GPL-P mode had a different travel time penalty than the other six modes, there was no effect on the mode shifts of interest—bus to SOV on the HOV lane, both peak and off peak.

Table 4.11 Original Versus Adjusted Scenario Simulation Results

10 Minutes Saved		**Original**		**Adjusted**	
Mode	**Toll**	**Travel Time**	**Percentage**	**Travel Time**	**Percentage**
SOV-GPL-P	\$0.00	25 min	6.28%	28.7 min	5.72%
HOV2-HOV-P	\$2.00	20 min	4.09%	22.5 min	4.09%
SOV-HOV-OP	\$2.00	15 min	4.04%	17.5 min	4.04%
SOV-HOV-P	\$6.00	15 min	1.35%	17.5 min	1.35%
BUS-HOV-P	\$2.50	24 min	69.00%	26.5 min	69.39%
BUS-HOV-OP	\$1.50	24 min	2.24%	26.5 min	2.24%
CCP-HOV-P	\$0.00	24 min	13.06%	26.5 min	13.17%

In ten simulations with various amounts of travel time saved and peak and off-peak tolls, only three had a slight difference in either the SOV-HOV-OP or SOV-HOV-P mode shift percentage. In all three cases, the difference was 0.06%, or 1 out of 1784 SP questions answered.

This small change in modal split can be explained by the variables in the utility equations. Each mode's utility equation included the variables BTIME and BTOLLINC with the same coefficients (Equations 4.2 to 4.8). All other variables besides BTIME, the travel time of the mode, remained the same, so an equivalent change in BTIME for each mode resulted in an equivalent change in utility for each mode.

Although the scenarios originally simulated did not account for all portions of the travel time, specifically the access time to the park-and-ride or freeway, and parking at the destination, the results and conclusions formed from the initial results are valid. There was little to no change in the percentages of mode shift between bus and tolled SOV between the original scenarios and the adjusted scenarios. All other portions of this thesis discuss the original scenarios.

4.8 Summary

Based on responses to the question, "If you could drive alone on the HOV lane for the toll listed below, how often would you drive alone on the HOV lane?", many people said they would drive alone on the HOV lane for $3. However, most would not do it for all their trips. People who chose SOV-HOV-OP in their SP questions appeared to be more likely to be students, age 16-24, single adults, and/or have school or work-related travel as their trip purpose; they also seemed to be less likely to have only some college/vocational school as their highest level of education.

People who chose SOV-HOV-P in their SP questions appeared to be more likely to be commuting, age 35-44, married with children, have a household size of 5 or 6, and/or have a household income of between $15,000-24,999 or $200,000 or more. These people also seemed to be less likely, than transit riders in general, to be age 55-64, a single parent, have a household size of 3, and/or have a household income between $25,000 and $49,000. Males appeared to be more likely than females to pay to drive alone on the HOV lane in both the peak and off-peak periods; existing transit riders with administrative/clerical occupations seemed to be less likely shift to SOV-HOV.

Using SP question responses and selected demographic data, a mode choice model was developed. This mode choice included modes currently available to travelers, plus traveling by SOV on the HOV lane for a toll. Various scenarios with different SOV on the HOV lane toll prices and travel time savings were simulated with the model. It was found that few transit passengers were likely to switch to SOV-HOV at reasonable toll prices and travel time savings. If bus fares were subsidized by employers, even fewer transit passengers would switch to driving alone on the HOV lane.

Since many casual carpoolers also use transit in the Katy and Northwest Freeway corridors, it is likely that many of the bus passengers who completed the survey also have used casual carpooling occasionally. As a result, there was a high percentage of respondents choosing casual carpooling in the stated preference questions. In corridors where casual carpooling is not a mode choice, those who chose casual carpooling on the survey would probably choose transit instead.

For 10 minutes of travel time saved and $6 peak/$2 off-peak tolls, 1.35 percent of bus riders were likely to switch to SOV-HOV-P and 4.04 percent were likely to switch to SOV-HOV-OP. Although this would reduce AVO slightly, there appeared to be minimal impact on HOV operations; for example, on the Katy Freeway, only about 20 transit riders would drive themselves during each peak and about 185 would drive themselves during the off-peak. It is important to note that this is only the shift from transit, not the total shift from all modes. It is likely that a larger number of SOV users would switch from the GPLs; however, that was not included in this study. It is also important to note that the shift from transit to SOV paying to use the HOV lane was uniformly low across reasonable toll levels and travel time savings. Therefore transit riders were relatively loyal to their mode.

CHAPTER V

CONCLUSION

5.1 Findings

For many years, riding the bus or driving in a carpool/vanpool have been the primary ways to gain the travel time savings of the HOV lane. With the introduction of tolled SOVs to the list of vehicles allowed on the HOV lane, some people, including transit passengers, may be willing to pay a little extra in order to have the flexibility and privacy benefits of traveling in their own vehicles while enjoying the time savings of traveling on the HOV lane. There are benefits to allowing tolled SOVs from congested GPLs to fill up the excess capacity of the HOV lane. However, if a significant number of existing transit passengers decided to drive their own cars, then it would reduce the person carrying capacity of the HOV lane, because each former transit passenger would be taking up more space on the road in his or her car than if he or she had stayed on the bus.

In November, 2003, surveys were distributed to park-and-ride bus passengers in the Katy and Northwest Freeway corridors in Houston, and a total of 584 surveys were returned. Passengers' responses to trip and socioeconomic characteristics questions and stated preference questions were entered into a database. A mode choice model and utility equations were developed, and scenarios with varying tolls and travel time savings were simulated. It is important to note that the sample of 584 transit passengers is relatively small compared to the 13,500 person-trips per day made by bus in these two corridors in December 2006. Also, the survey was not specifically developed for transit riders, so other questions which might have contributed to the mode choice model, such as attitudinal questions about comfort of the bus, safety, etc., were not asked.

Only a small percentage of existing bus riders would be likely to switch to driving alone on the HOV lane for 10 minutes of travel time saved and a toll of $6 peak/$2 off-peak. Approximately 1.35 percent of passengers would drive alone during the peak period, and 4.04 percent would drive alone during the off-peak period. Bus riders were less likely to switch to SOV on the HOV lane at higher toll rates and/or lower travel time savings. If transit fares are subsidized by employers, passengers would be slightly less likely to shift away from the bus; however, only approximately one-quarter of park-and-ride passengers have their transit pass paid for by their companies. Although casual carpooling exists in these two HOV corridors and not in the other four in Houston, it is expected that the availability of this mode would not affect the percentage of people who would switch to SOV on the HOV lane. Most casual carpool passengers are also transit passengers, and one of the primary reasons to ride in casual carpool is to save money; paying a toll to drive alone on the HOV lane would be contrary to that.

People who were likely to switch to SOV-HOV-OP appeared to be more likely to be students, age 16-24, single adults, and/or have school or work-related travel as their trip purpose; they also seemed to be less likely to have only some college/vocational school as their highest level of education.

People who were likely to switch to SOV-HOV-P appeared to be more likely to be commuting, age 35-44, married with children, have a household size of 5 or 6, and/or have a household income of between $15,000-24,999 or $200,000 or more. These people also seemed to be less likely, than transit riders in general, to be age 55-64, a single parent, have a household size of 3, and/or have a household income between $25,000 and $49,000. Males appeared to be more likely to shift to SOV-HOV in both the peak and off-peak periods, and those with administrative/clerical occupations seemed to be less likely to shift to SOV-HOV.

In general, very few bus riders will shift to driving themselves on the HOV lane. Even if some of them do switch, they will likely not drive alone for all their trips. Transit passengers shifting to SOV on the HOV lane reduces average vehicle occupancy only about 1 percent to 2 percent. SOV drivers shifting from the general purpose lanes to the HOV lanes are likely to affect AVO more. However, as long as dynamic pricing is used appropriately to maintain free-flow conditions, the HOV lane can be successfully adapted to a HOT lane and move more people, even if a few transit passengers choose to drive alone.

5.2 Recommendations

It is important to note that this thesis only examined existing bus riders' mode shift to SOV on the HOV lane. It is likely that the majority of people who will choose to pay to drive alone on the HOV lane will come from the general purpose lanes rather than from transit. As the Katy Freeway's new managed lanes will open two years from now, follow-up studies should be done to see how the new mode option actually affects transit ridership. Surveys in corridors without casual carpooling may also be considered in order to determine if predicted mode shift from transit to SOV on HOV lanes without casual carpooling is similar to that found for the Katy and Northwest Freeways.

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APPENDIX A

SAMPLE SURVEY FOR TRANSIT USERS

Part I: Please tell us about your most recent trip on the Katy Freeway (I-10) traveling towards downtown Houston during the work week (Monday through Friday).

1. What was the purpose of the trip?
   - ▢ Commuting (going to or from work)
   - ▢ Recreational / Social / Shopping / Entertainment / Personal errands
   - ▢ Work related (other than going to or from work)
   - ▢ School
   - ▢ Other (*specify*): ______________________________

2. What time of day did your trip start (for example, when did you leave your driveway)?

   [ ] ***a.m. p.m.*** *(circle one)*

3. Would it have been possible to start your trip earlier or later?
   - ▢ I could have easily made the trip [ ] minutes earlier/later.
   - ▢ I could have made the trip anytime the same day.
   - ▢ I could not take the trip at any other time.

4. Do you allow for extra travel time due to possible traffic congestion on Katy Freeway (I-10)?

   ▢Yes ▢No

   If yes, how much extra time do you try to allow?_________ minutes.

5. Near what major cross streets did your trip start? *Example: Kingsland Blvd. and Mason Creek.*

   [ ] ***and*** [ ]

6. What time of day did your trip end (for example, when did you arrive at work)?

   [ ] ***a.m. p.m.*** *(circle one)*

7. Near what major cross streets did your trip end? *Example: Main St. and Texas Ave.*

   [ ] ***and*** [ ]

8. Did you have to pay to park in Houston?

   ▢Yes ▢No

   If yes, how much does it cost per day? $_________

9. How many people, including yourself, were in the vehicle?

▫ 1	▫ Motorcycle	▫ Took a bus → *If you travel by yourself or take the bus, please skip questions10 to 12 and go to question 13.*	
▫ 2	▫ 3	▫ 4	▫ 5 or more

10. Who did you travel with? (*check all that apply*)
- ▫ Co-worker / person in the same or a nearby office building
- ▫ Neighbor
- ▫ Adult family member
- ▫ Another commuter in a casual carpool (also known as slugging)
- ▫ Child
- ▫ Other (*specify*): ______________________________

11. How much extra time did it take to pick up and drop off the passenger(s)?

[   ] minutes

12. Did you use the High Occupancy Vehicle (HOV) lane? ▫ Yes ▫ No

If yes, how much travel time do you think you **saved** compared to the main lanes?

[   ] minutes.

13. How many ***total trips*** did you make during the past full work week (Monday to Friday) on the Katy Freeway? (Count each direction of travel as one trip, include trips on the HOV or main lanes)

[   ] trips

14. Do you sometimes use a route other than the Katy Freeway to make trips with a similar purpose?
▫Yes ▫No

Part II: Questions Regarding the QuickRide Program

During most of the time the HOV lane is open, vehicles with 2 or more occupants can use the HOV lane on the Katy Freeway (I-10), free of charge. However, during peak traffic periods (from 6:45 a.m. to 8:00 a.m. and 5:00 p.m. to 6:00 p.m.) toll-free use of the HOV lane is restricted to vehicles with 3 or more occupants.

Under a program called QuickRide, vehicles with only 2 occupants are permitted to travel on the HOV lane during peak traffic periods for a $2.00 toll per trip. Participants must set up a

QuickRide account with their credit card before using the program. Enrollees are issued toll transponders that electronically charge the toll each time QuickRide is used. Additionally, a $2.50 monthly administration fee is charged to each account. For more information, please call 713-224-RIDE or 1-888-606-RIDE (toll free) or visit http://www.hou-metro.harris.tx.us/services/quickride.asp

15. Prior to this survey, had you heard of the QuickRide program?
    - ▫ Yes → Go to Question 16
    - ▫ No → Go to Question 17

16. How did you hear about QuickRide? (*Check all that apply*)
    - ▫ TV
    - ▫ Radio
    - ▫ Mail
    - ▫ Newspaper
    - ▫ METRO website
    - ▫ Family / Friend
    - ▫ On the bus
    - ▫ I don't remember
    - ▫ Other (*specify*):____________________________

    → Go to Question 18

17. Now that you know about the QuickRide program would you be interested in using it?

    ▫ Yes If Yes, what interests you **most** about QuickRide? (*check only one*)
    - ▫ Being able to carpool with just one other person and still use the HOV lane
    - ▫ Being able to use the HOV lane more often because it is much faster than the main freeway lanes
    - ▫ Being able to use the HOV lane more often because the travel times on the HOV lane are consistent
    - ▫ Being able to use the HOV lane more often because it is safer / less stressful than on driving main freeway lanes
    - ▫ Other (*specify*):____________________________________

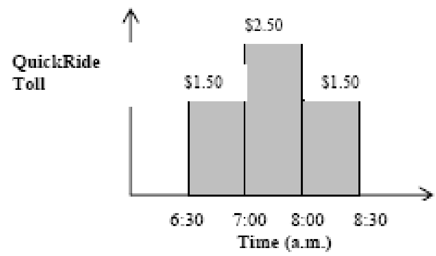
    ▫ No If No – what are the primary reasons you would not use QuickRide? (*check all that apply*)
    - ▫ Participation in a carpool is difficult / undesirable
    - ▫ I do not want to set up a QuickRide account
    - ▫ I do not have a credit card needed to set up an account
    - ▫ I do not want to pay the $2.50 monthly administration fee
    - ▫ I do not want a toll transponder in my car
    - ▫ Access to the HOV lane is not convenient for my trips
    - ▫ The HOV lane does not offer me enough time savings
    - ▫ The HOV lane is sometimes just as congested as the main freeway lanes
    - ▫ The QuickRide program is complicated or confusing
    - ▫ I have the flexibility to travel at less congested times
    - ▫ I do not want to pay the $2.00 per trip cost of QuickRide
    - ▫ Other (*specify*):____________________________________

The questions in this part of the survey are to find out your views on a number of potential options for improving QuickRide. The options raised are only examples and do not represent local, state or federal policy.

18. Which of the following would cause you to try using QuickRide? (*Check all that apply*)
- ❑ Longer QuickRide operating hours
- ❑ The ability to pay to drive alone on the HOV lane
- ❑ A message sign that told me exactly how long the trip would take on the HOV lane before I paid to enter (for example, "At 7:15 a.m. travel to downtown on the HOV lane takes 14 minutes.")
- ❑ Increased traffic on main freeway lanes
- ❑ A reduction in the $2 QuickRide toll. Please enter the toll amount you would be willing to pay to try QuickRide: $ ☐
- ❑ Other (*specify*)________________________

19. To maintain a smooth traffic flow, the QuickRide toll could change with the time of day. As shown in the graph below, lower tolls could be charged for travel at specific times (for example, 6:30 a.m. to 7:00 a.m.) and higher tolls during the most congested times (for example, 7:00 a.m. to 8:00 a.m.). What is your initial feeling regarding this option? (*Check only one*)

- ❑ Strongly favor
- ❑ Somewhat favor
- ❑ Indifferent
- ❑ Somewhat oppose
- ❑ Strongly oppose



20. The QuickRide toll could also change with the amount of traffic in the HOV lane. For example, if the HOV lane was not congested then the toll might be less than $2.00. However, if the HOV lane was very congested the toll might be higher than $2.00 to maintain the smooth flow of traffic. What is your initial feeling regarding this option? (*Check only one*)
- ❑ Strongly favor
- ❑ Somewhat favor
- ❑ Indifferent
- ❑ Somewhat oppose
- ❑ Strongly oppose

21. How do you feel about allowing people who drive alone to use the HOV lane for a higher toll than carpoolers?
- ❑ Strongly favor
- ❑ Somewhat favor
- ❑ Indifferent
- ❑ Somewhat oppose
- ❑ Strongly oppose

22. If you could drive alone on the HOV lane for the toll listed below, how often would you drive alone on the HOV lane?

Toll	*Number of trips per week (count each direction of travel as one trip)*
$3.00	________
$4.00	________
$5.00	________
$6.00	________

Part III: Travel Scenarios

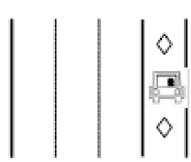
Each of the following questions asks you to choose between four potential travel choices on the Katy Freeway (I-10). For your most recent trip, please circle the one option that you would be most likely to choose if faced with these specific options. Remember that main lane traffic tends to be congested and could be slower than shown here if congestion is worse than usual. HOV lane traffic is fast moving. Peak hours are 6:45 a.m. to 8:00 a.m.

23. Circle the option you would choose:

A

Drive alone on the HOV lane during peak hours.

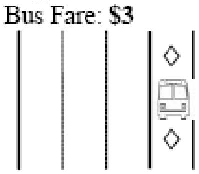
Travel time is **12** minutes
Toll for HOV lane: **$4**



B

Take a METRO Park & Ride bus during peak hours.

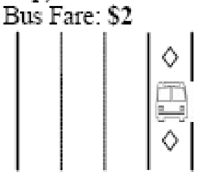
Travel time is **17** minutes (this includes 5 minutes for waiting for the bus and walking from the bus stop)
Bus Fare: **$3**



C

Take a METRO Park & Ride bus during off-peak hours.

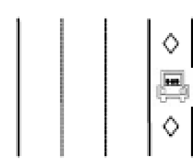
Travel time is **20** minutes (this includes 5 minutes for waiting for the bus and walking from the bus stop)
Bus Fare: **$2**



D

Casual Carpool on the HOV lane during peak hours.

Travel Time is **21** minutes (this includes 5 minutes to wait for the carpool to form)
Toll for HOV lane: **$0**

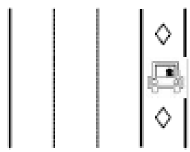


24. Circle the option you would choose:

A

Drive alone on the HOV lane during peak hours.

Travel time is **16** minutes
Toll for HOV lane: **$8**



B

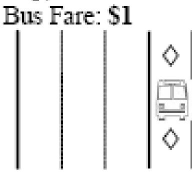
Take a METRO Park & Ride bus during peak hours.

Travel time is **17** minutes (this includes 5 minutes for waiting for the bus and walking from the bus stop)
Bus Fare: **$3**

C

Take a METRO Park & Ride bus during off-peak hours.

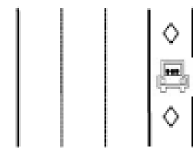
Travel time is **17** minutes (this includes 5 minutes for waiting for the bus and walking from the bus stop)
Bus Fare: **$1**



D

Casual Carpool on the HOV lane during peak hours.

Travel Time is **17** minutes (this includes 5 minutes to wait for the carpool to form)
Toll for HOV lane: **$0**

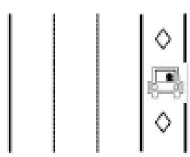


25. Circle the option you would choose:

A

Drive alone on the HOV lane during peak hours.

Travel time is **12** minutes
Toll for HOV lane: **$6**



B

Take a METRO Park & Ride bus during peak hours.

Travel time is **17** minutes (this includes 5 minutes for waiting for the bus and walking from the bus stop)
Bus Fare: **$2**

C

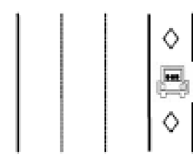
Take a METRO Park & Ride bus during off-peak hours.

Travel time is **17** minutes (this includes 5 minutes for waiting for the bus and walking from the bus stop)
Bus Fare: **$2**

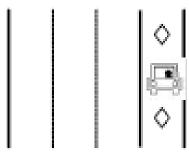
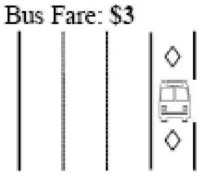
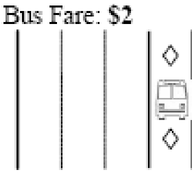
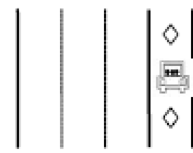
D

Casual Carpool on the HOV lane during peak hours.

Travel Time is **17** minutes (this includes 5 minutes to wait for the carpool to form)
Toll for HOV lane: **$0**



26. Circle the option you would choose:

A	B	C	D
Drive alone on the HOV lane during peak hours. Travel time is **16** minutes Toll for HOV lane: $4 	Take a METRO Park & Ride bus during peak hours. Travel time is **20** minutes (this includes 5 minutes for waiting for the bus and walking from the bus stop) Bus Fare: **$3** 	Take a METRO Park & Ride bus during off-peak hours. Travel time is **17** minutes (this includes 5 minutes for waiting for the bus and walking from the bus stop) Bus Fare: **$2** 	Casual Carpool on the HOV lane during peak hours. Travel Time is **21** minutes (this includes 5 minutes to wait for the carpool to form) Toll for HOV lane: **$0** 

Part IV: User Information

The following questions will be used for statistical purposes only and answers will remain confidential. All of your answers are very important to us and in no way will they be used to identify you.

27. What is your age?
- ❑ 16 to 24
- ❑ 25 to 34
- ❑ 35 to 44
- ❑ 45 to 54
- ❑ 55 to 64
- ❑ 65 and over

28. What is your gender?
- ❑ Male
- ❑ Female

29. Please describe your household type.
- ❑ Single adult
- ❑ Unrelated adults (e.g. room-mates)
- ❑ Married without child
- ❑ Married with child(ren)
- ❑ Single parent family
- ❑ Other (*specify*): ______________________

30. Including yourself, how many people live in your household?

[   ]

31. All together, how many motor vehicles (including cars, vans, trucks, and motorcycles) are available for use by members of your household?

32. What category best describes your occupation?
- ❑ Professional / Managerial
- ❑ Technical
- ❑ Sales
- ❑ Administrative / Clerical
- ❑ Manufacturing
- ❑ Stay-at-home homemaker / parent
- ❑ Student
- ❑ Self employed
- ❑ Unemployed / Seeking work
- ❑ Retired
- ❑ Other *(specify)*: ________________________________

33. What is the last year of school you have completed?
- ❑ Less than high school
- ❑ High school graduate
- ❑ Some college / Vocational
- ❑ College graduate
- ❑ Postgraduate degree

34. What was your annual household income before taxes in 2002?
- ❑ Less than $10,000
- ❑ $10,000 to $14,999
- ❑ $15,000 to $24,999
- ❑ $25,000 to $34,999
- ❑ $35,000 to $49,999
- ❑ $50,000 to $74,999
- ❑ $75,000 to $99,999
- ❑ $100,000 to $199,999
- ❑ $200,000 or more

35. Please list any comments or suggestions you have regarding travel in the Katy Freeway (I-10) corridor:

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Thank you for your participation.

VITA

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