MANAGED LANE CHOICES BY CARPOOLS COMPRISED OF FAMILY MEMBERS COMPARED TO NON-FAMILY MEMBERS

A Thesis

by

MANDEEP SINGH PANNU

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 2009
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Major Subject: Civil Engineering

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Approved by:

Chair of Committee,	Mark Burris
Committee Members,	Dominique Lord
	Katherine Turnbull
Head of Department,	Mark Burris

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ABSTRACT

Managed Lane Choices by Carpools Comprised of Family Members Compared to Non-Family Members. (December 2009)

Mandeep Singh Pannu, B. Tech., Indian Institute of Technology Delhi, India

Chair of Advisory Committee: Dr. Mark Burris

Carpools can be comprised of family members (fampools), non-family members (non-fampools) or a combination of both. Overall, carpool mode share has decreased during the 1980's and 1990's, even as the policies were in place to encourage carpooling, but at the same time the share of fampools increased quite significantly. By analyzing the characteristics of fampools and non-fampools, we can better understand how policies may impact each group. One area of particular interest is the impact of managed lanes on the mode choice of fampools and non-fampools.

For this research, survey data collected from both Houston and Dallas, Texas was used to investigate the mode choice of fampools and non-fampools on managed lanes. The survey data was weighted to better represent the traveler population. The weighted survey data was analyzed to better understand the characteristics of fampools and non-fampools. Non-fampools were formed more frequently in a week than fampools. The average carpool formation time was similar for both fampools and non-fampools at 6.4 minutes and 6.2 minutes, respectively. Fampools rated "drop off kids at school or day care" higher than non-fampools and non-fampools rated "sharing vehicle expenses" higher than fampools as the most important reason for the formation of their current carpool. A majority of travelers from both groups showed an interest in using managed lanes and "travel time reliability" was rated most important factor for this interest. Fampools and non-fampools were split into subgroups based on their current number of passengers. Among these four sub-groups, the majority of respondents were interested in using managed lanes.

Random parameter logit models were developed for both fampools and non-fampools. For the fampools, the value of travel time savings was estimated to be $ 22.80 per hour. Non-fampools were not sensitive to the travel time. Different travel scenarios were simulated for both fampools and non-fampools. The results showed that with increased tolls on the managed lanes the decrease in carpool mode share on managed lanes was compensated by an increase in carpool mode share on the GPLs for both fampools and non-fampools. With an increased toll, both fampools and non-fampools showed less sensitivity to the toll cost. The estimated demand elasticity was fairly inelastic for both fampools and non-fampools.

DEDICATION

I dedicate this thesis to my parents who always encouraged me to pursue my interests. I am thankful to my elder sister for helping me to stay focused on my goals through her experience. I would also like to thank my school teachers for their guidance and contribution in making me capable of achieving my dreams.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Mark Burris, for the guidance and support throughout the course of this research. I would also like to thank my committee members, Dr. Dominique Lord and Dr. Katherine Turnbull for their valuable suggestions.

Thanks also go to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience. This research work uses the data collected for Texas Transportation Institute (TTI) Project entitled "The Role of Preferential Treatment for Carpools in Managed Lane Facilities." I would like to thank the TTI research team led by Ginger Goodin as research supervisor and Dr. Mark Burris as co-research supervisor for conducting the survey to collect data and helping with the data analysis. Special thanks go to the TxDOT project director, Matt MacGregor, P.E., for his leadership and guidance. I would especially like to mention Dr. David Ungemah for programming the online survey and Maneesh Mahlwat for the initial data cleaning.

TABLE OF CONTENTS

Page

Page

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

Page

NOMENCLATURE

Term	Definition
HOV lanes	High Occupancy Vehicle lanes. HOV lanes are expressway lanes restricted to vehicles with set minimum number of occupants.
HOV2	Vehicle in which there are two occupants.
HOV3+	Vehicle in which there are at least three occupants.
SOV	Single Occupant Vehicle. A vehicle in which there are no passengers.
ML	Managed Lanes. A set of lanes within a freeway that are actively managed by pricing and vehicle occupancy.
GPL	General Purpose Lanes. Freeway lanes meant for all vehicles without vehicle occupancy, price or other such constraint.
SRS	Simple Random Sampling is the sampling technique where a sample for study is selected from a larger group (a population). Each individual is chosen entirely by chance and each member of the population has an equal chance of being included in the sample. Every possible sample of a given size has the same chance of selection.
VOT	Value of Travel-time. It is the amount an individual is willing to pay to save a particular amount of travel time.
VTTS	Value of Travel Time Savings. The VTTS is the value the traveler places on time saved using a faster (but more expensive) mode. The VTTS includes both monetary and non-monetary costs incurred in the journey.

1. INTRODUCTION

1.1 Background

Carpooling declined during the 1980's and 1990's, even as the policies were in place to encourage carpooling (Ferguson, 1997; Pisarski, 1996, 2006; Poole and Balaker, 2005). A decline in carpooling during the 1990s, coupled with the increased number of HOV lane miles, led to a broad perception of underutilization of HOV lanes (Dahlgren, 2002; Jaskevich, 2001; Poole, 2005). At the same time, budget constraints had impeded the improvements needed for the transportation system. These combined factors encouraged transportation agencies to consider applying road pricing principles. With advances in the electronic tolling technology, managed lanes became a reality in the last decade (Li et al., 2007).

Managed lanes are facilities in which usage eligibility is controlled by pricing policies and other considerations. Most managed-lane facilities in the United States are high occupancy/toll (HOT) lanes, in which single-occupancy vehicles (SOVs) are charged a toll for using the facility, but HOVs travel on the facility for free or at a reduced price (Li et al., 2007). HOT lanes are increasing in number and at the same time the carpool mode share is decreasing. Overall, carpool mode share has decreased from 20 percent of all commuters in 1980 to 12 percent in 2000 (Pisarski, 2006). The recent census data shows that the overall carpooling mode share decreased to 11 percent in 2006 (Liberles, 2009). Additionally, the majority of carpools are formed within a household with other family members (Burris et al., 2009; Li et al., 2007; Pisarski, 1996). Alan Pisarski (1996), in his study of "Commuting in America – II" found:

This thesis follows the style of Transportation Research Part A.

Most carpooling today is not carpooling in the sense we knew it just a few years ago: a voluntary arrangement among co-workers or neighbors. That is dying; most of the surviving carpool activity consists of family members with parallel destinations and timing. This study defines a term "Fampool" to describe the carpoolers who travel with other household travelers. In major metropolitan areas fampoolers are one third to two third of total carpoolers.

Most research has focused on how carpooling mode share changes with time, fuel costs, socio-economic characteristics like income, economic growth, availability of jobs, etc. (Bard, 1997; Doherty et al., 2002; Ferguson, 1997). A great deal of the research done on carpool mode share has used the National Household Travel Survey (NHTS) dataset which is limited to socio-economic and demographic variables. Another study based on the NHTS dataset looked into the important factors influencing carpool mode choice, and it found that demographic characteristics had weak correlation to carpooling. On the other hand, carpooling increased with increased trip distance, and decreased as economic conditions improved (Teal, 1987). But none of these studies examined the behavior of fampools and non-fampools in the vicinity of managed lane options which allow them to travel as a SOV after paying a toll. In such scenarios, it becomes very important to examine the characteristics and mode choice of travelers from these two groups. Managed lanes may greatly impact different carpool groups and the impacts may be considerably different by groups. This research investigates into the mode choice of fampools and non-fampools and tries to find important factors influencing their mode choice.

1.2 Research Problem

With the increased popularity of HOT lane options and decreased carpool mode share, it became crucial to examine the role of HOT lanes to encourage carpools (Parkany, 1998). In these circumstances, it has become important to understand the behavior of carpoolers. Examining the factors influencing the mode choice of different carpoolers under different managed lane scenarios can help better understand their mode choice behavior. It is important to understand the impact of toll and travel time savings on mode choice of carpoolers as HOT lanes may negatively impact carpooling. Carpoolers are comprised of two very different groups of travelers: fampools and non-fampools. It is important to understand the behavior of these two types of carpoolers and if they react differently to managed lane options. This research will examine the differences and similarities in the characteristics and mode choice of these two types of carpoolers, including how fampools and non-fampools react to different travel options. The impact of different travel time savings and tolls will be analyzed for the two types of carpoolers. Finally, how carpoolers from these two categories may switch their mode if given an option to travel alone on a managed lane for a particular price will be investigated.

1.3 Research Objectives

The objective of this research is to analyze differences between fampools and non-fampools, particularly with respect to mode choice on managed lanes. Specifically, this research will:

- Examine the similarities and differences between the groups in their interest in managed lanes, travel, and socio-economic characteristics.
- Analyze reasons for mode switching by these two groups of carpoolers.
- Develop a mode choice model to better understand the important factors/characteristics that influence the mode choice of these groups.
- Analyze the impact of different managed lane scenarios on the mode choice of these two groups.

As part of this research, and during the investigation of the above research objectives, several hypotheses were developed. These include:

1. Fampools and non-fampools will react differently to different travel options since they are fundamentally different groups.

2. Most fampools will remain intact irrespective of the available alternatives. For managed lane scenarios, given an option to travel alone for a toll, non-fampooolers are expected to split more frequently than fampoolers.

3. Fampools with children are different than fampools of adults-only and fampools of adults-only react more like carpools.

1.4 Thesis Organization

Section 2 includes a review of the available literature on carpooling characteristics. The section also includes an introduction to managed lanes facilities that are converted to a HOT lane from a HOV lane, impacts on the mode choice of different carpool groups, and characteristics of the travelers using the lanes. Section 2 continues with a discussion about the characteristics of the fampools and non-fampools. The last part of the Section discusses discrete choice modeling and the mode choice models of the fampools and non-fampools.

Section 3 focuses on data collection. The survey design, advertisement and survey administration are described. The weighting process used to adjust the survey responses to better represent the population as a whole is described in detail. It also discusses the replicate weighting process used to reduce the standard error bias due to use of non simple random sampling method.

Section 4 includes a review of the statistical data analysis conducted to analyze the characteristics of different travelers. Section 4 starts with a descriptive data analysis of the fampool and non-fampool groups based on commute, socio economic, interest in managed lanes and trip end characteristics. The fampool carpool group is further divided into fampools with children and fampools with only adult family members, to determine significant differences between these groups. The last part of Section 4 divides the fampools and non-fampools further into sub-groups based on their current mode choice of HOV2 or HOV3+ modes. Significant differences among the four sub-groups are examined in detail.

Section 5 contains the detailed results from the discrete choice modeling of the survey data. The first part of the section describes the mode choice models of fampools and non-fampools. The second part of the section describes various simulated scenarios based on the mode choice models. It discusses the impact of the different travel scenarios on the mode choice of the fampool and non-fampool carpool groups.

Section 6 contains conclusions from this thesis along with recommendations for future research.

2. LITERATURE REVIEW

This section discusses the literature reviewed on carpooling characteristics. The section also includes an introduction to managed lanes facilities that are converted to a HOT lane from a HOV lane, impacts on the mode choice of different carpool groups, and characteristics of the travelers using the lanes. The last part of the section discusses discrete choice modeling and the mode choice models of the fampools and non-fampools.

2.1 Managed Lanes

Increasing population and decreasing vehicle occupancy has placed enormous demand on transportation infrastructure. To meet the growing demand there is pressure on the system to increase capacity to provide free-flow conditions during the peak periods. The construction of more freeway lane miles is often difficult because of cost, environmental concerns and other factors. In such scenarios, transportation agencies are searching for methods to better manage traffic flow and thus improve the efficiency of the existing network. Over the time, "managed lanes" have emerged as a viable option to meet mobility needs. Managed lanes maintain free-flow conditions for particular eligible groups of travelers allowed to access the facility. Managed lanes can be defined as:

"*Managed lanes regulate access to the lanes, often by price and vehicle occupancy, to ensure free flow conditions*" (Burris, Personal communication, 2009)

There are many types of operational strategies used on managed lanes, including high occupancy vehicle (HOV) lanes, value priced lanes or high occupancy/toll (HOT) lanes, exclusive-use lanes such as bus or truck lanes, separation and bypass lanes, dual-use lanes, and lane restrictions. HOV and HOT lanes are more frequently used. The main goals of the managed lanes are:

- to improve operating level of service for high-occupancy vehicles, both public and private, thereby maximizing person-moving capacity of roadway facilities,

- to reduce fuel use,
- to improve air quality by reducing pollution caused by delay and congestion, and
- to increase overall accessibility while reducing vehicular congestion (AASHTO, 1991).

Some of the frequently used operating strategies on managed lanes are discussed in the next section.

2.2 History of HOV Lanes

HOV lanes are the oldest type of the managed lanes. Most of the HOV lanes were developed in response to congested freeway corridors. By allowing exclusive use by multi-occupant vehicles, HOV lanes were aimed at improving the people-moving capacity of these corridors (Stockton et al., 1999a; Stockton et al., 1999b) Most of the HOV lanes allow two or more occupants to access the lanes but some facilities require three or more occupants during peak travel time (HOV Systems Manual, 1998). HOV lanes were first implemented in the Washington, D.C., and northern Virginia area in 1969 (HOV Guidelines, 1991). There are four common types of HOV lanes: reversible-flow, two-way, concurrent, and contraflow.

2.2.1 Reversible HOV Lanes

The reversible lane is the most common type of separated lane HOV facility. It carries traffic one directing in the morning peak period and the opposite direction in the evening peak period. This allows maximum use of the lane during peak hours. Examples of barrier-separated reversible HOV lanes are found in Denver, Northern Virginia, Dallas, Houston, San Diego, Minneapolis, Pittsburgh, Norfolk, and Seattle (HOV Systems Manual, 1998; Stockton et al., 1997).

2.2.2 Two-way HOV Lanes

Two-way HOV lanes have separate lanes for the traffic in each direction during the peak periods or full time use. These types of lanes are implemented in the areas where traffic is closer to equal in both directions. It usually has a limited number of ingress and egress points. Examples of separate two-way HOV facilities are found in Los Angeles; Orange County, California; Seattle; and a small section in Houston (HOV Systems Manual, 1998; Stockton et al., 1997).

2.2.3 Concurrent HOV Lanes

Concurrent HOV lanes flows in the same direction adjacent to the general purpose lanes. They are not physically separated using any barriers but using pavement markings. Ingress and egress points along the facility are more frequent. Examples of concurrent-flow HOV lanes can be found in Phoenix, Vancouver, British Columbia; Sacramento; Denver; Hartford; Fort Lauderdale; Miami; Orlando; Atlanta; Honolulu; Montgomery County, Maryland; Boston; Minneapolis; New Jersey Turnpike; New York City; Portland; Ottawa, Ontario; Memphis; Nashville; Dallas; Northern Virginia; Norfolk/Virginia Beach; Seattle; Houston; and numerous California counties (HOV Systems Manual, 1998; Stockton et al., 1999b).

2.2.4 Contraflow HOV Lanes

A contraflow HOV lane is a freeway lane in the off-peak direction of travel that is used for travel by vehicles in the peak direction. Movable traffic barriers separate these facilities from oncoming traffic. Although this type of HOV lane is used primarily by buses, some contraflow lanes allow multiple occupant vehicles. Examples of contraflow HOV lanes can be found in Honolulu, New Jersey, New York City, Dallas, Boston, and Montreal (HOV Systems Manual, 1998; Stockton et al., 1999b).

2.2.5 Current Operating HOV Lanes

The development of HOV lanes in North America progressed slowly during the 1970s and early 1980s but major growth occurred from the mid 1980s to the late 1990s. At present there are 96 HOV facilities on freeways and in separate rights-of-ways in 30 metropolitan areas in North America. These facilities account for approximately 2,000 centerline miles of HOV lanes. Major HOV lanes operate in Houston and Dallas, Texas; Seattle, Washington; Los Angeles, Orange County and the San Francisco Bay region in California; Newark, New Jersey, and New York City area; and the Northern Virginia, Washington, D.C., and Maryland region. Other facilities are in various stages of planning, design, and construction (HOV Facilities Primer, 2009). In comparison, there are only 9 HOT lanes totaling approximately 106 miles (Burris and Goel, 2009).

2.3 HOV Lane to HOT Lane

Many HOV lanes have performed well and are meeting their objectives. For example, HOV lanes on I 10 and US 290 in Houston, and on I 10 in Los Angeles were so congested that HOV2s restrictions had to be shifted from HOV2+ to HOV3+. Many other HOV lanes including SR 4, SR 80, SR 160, SR 680, and I 80 in California, the New Jersey Turnpike and I 95 in New Jersey; and H-1 in Hawaii started as HOV3+ lanes and have worked well (Eisele et al., 2005). But some of the facilities had to be reclassified due to not meeting the objectives and negative popularity in public. For example, I-80 and I-287 in New Jersey were reclassified as general purpose lanes, mainly due to negative public opinion as a result of the HOV lanes not achieving their desired objectives (Turnbull and DeJohn, 2000). It is very important to optimize the performance of HOV lanes to achieve the maximum benefits from the freeway.

Figure 1 shows the potential life cycle of an HOV facility. Whenever an HOV lane is established or the occupancy requirement increases, there is typically a time period when the volume to capacity ratio is low. Figure 2 represents the life cycle of an HOV facility that utilizes this extra capacity through the inclusion of lower occupancy vehicles that pay a toll (Swisher et al., 2003).

One method used to overcome the congestion or under utilization problem in the HOV lanes is through pricing. Pricing can help improve operational efficiency of the HOV lanes as well as generating revenues. Pricing can be used as a fixed toll or one relatively new form of road pricing is value pricing, which changes the amount charged for road use based on demand. Value pricing increases the toll during periods of peak demand and reduces it during off-peak times (Eisele et al., 2005). When tolls are used to manage the demand such lanes are termed as high occupancy/toll (HOT) lanes.

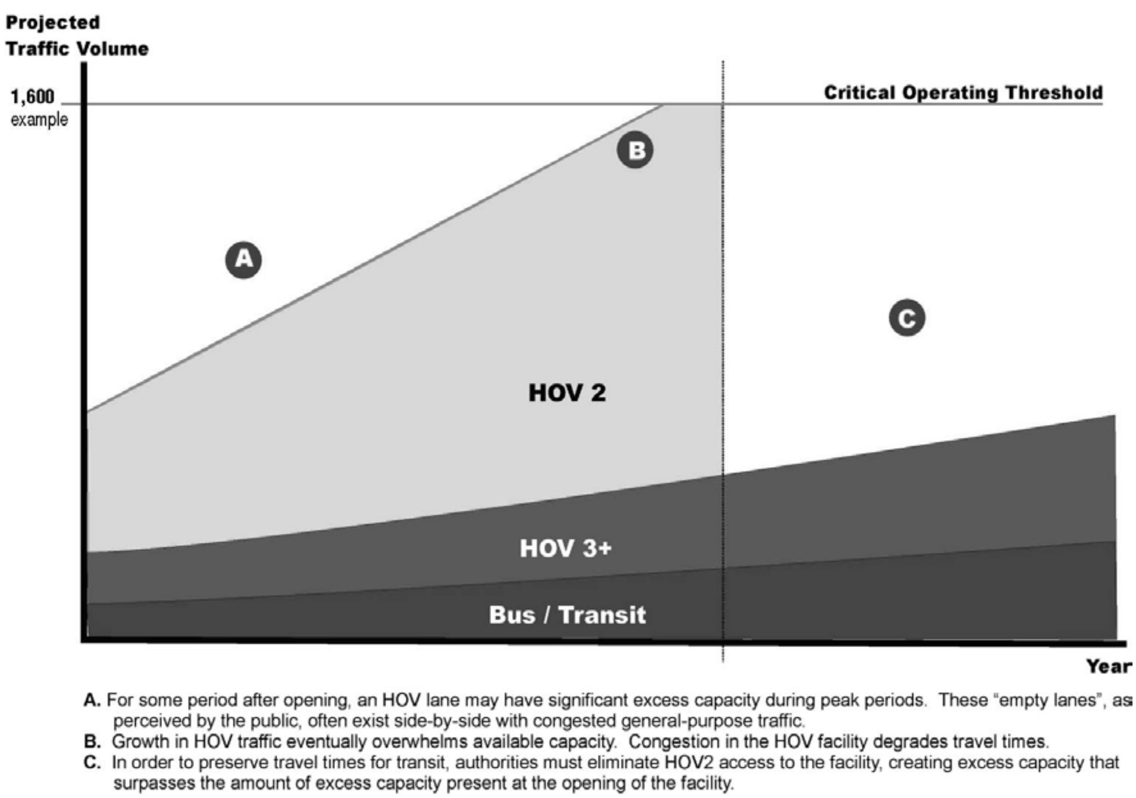

Figure 1: The Lifespan of an HOV Facility (Source: Swisher et al., 2003)

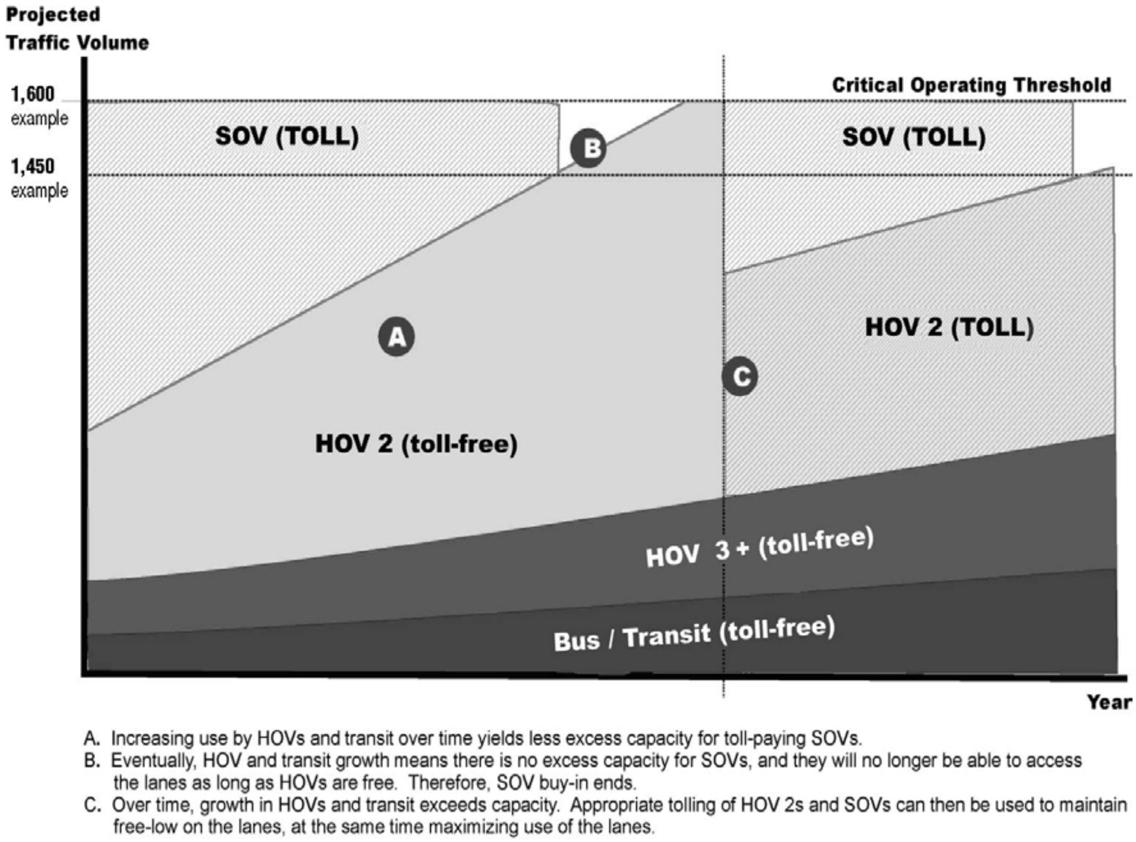

Figure 2: The Lifespan of a Managed HOV Lane (Source: Swisher et al., 2003)

2.4 High Occupancy/Toll (HOT) Lanes

HOT lanes generally allow single occupant to travel for a toll value and carpoolers are allowed to travel for free or at a reduced price. The three main benefits of the HOT lane are (Perez and Sciara, 2003):

- expanded mobility options in congested urban areas,
- new source of revenue that can be used to improve transportation system, and
- improvement of HOV lane efficiency.

The addition of value pricing to an HOV lane allows for better utilization of the facility in addition to increased revenues. The pricing scheme can be used to adjust the proper level of service on a HOT lane. There are two main types of pricing schemes used, variable tolls and dynamic tolls. Variable tolls vary based on the time of a day but dynamic tolls vary in response to the demand, hence the later can better manage the level of service on a HOT lane. I-25, Denver, SR 91X, I-10, Houston, I-15 Utah and US 290 are using variable pricing and dynamic pricing is used on I-95, Miami, I-394, Minnesota, SR 167, Seattle and I-15, San Diego (Burris and Goel, 2009) HOT lanes are gaining popularity as a strategy for meeting multiple performance objectives in congested urban freeway corridors throughout the country. HOT lanes can provide benefits in reducing travel time, offering viable options to congestion, improving freeway efficiency, increasing the attractiveness of alternative modes, and raising revenue to offset implementation and operating costs. The next section discusses HOT lanes operating in the United States and the factors influencing the use of them.

2.5 Current Operating HOT Lanes

The information available from the HOT lanes currently in operation can better help understand the behavior of the travelers using them. Travelers on these HOT lanes had the option to choose modes from (Burris and Goel, 2009):

- Free HOV access to the HOT lane,
- Tolled SOV access to the HOT lane,
- Free HOV or SOV access to the general purpose lanes (GPLs), and often
- Transit ridership on the HOT lane (costing the transit fare)

In cases where HOV lanes were converted to HOT lanes, it would be interesting to know where the SOVs on HOT lanes came from and how did it impact the carpooling on the highway. The key findings from the seven HOT lanes are discussed in detail below.

2.5.1 I-15 HOT Lane in San Diego

The I-15 HOT lanes is a 8 mile long, two lane reversible facility which allows SOV travelers to pay a fee to use while HOV2+ carpools, motorcycles and designated hybrid vehicles are allowed to travel for free (Figure 3). The phase I, ExpressPass program ran from December 1996 through March 1998, which allowed a limited number of SOVs to use the facility for a flat monthly fee ($50 till February 1997 and $70 thereafter) for unlimited use of the I-15 Express Lanes. The second phase started in March 1998, the new FasTrak program allowed the SOVs to travel for a fee that was charged on per trip basis. Dynamic tolling was used to set the tolls. On August 31, 1998, this dynamic tolling was modified to reduce maximum tolls during the off-peak periods to maximize the usage of I-15 Express Lanes (TransNet, 2009).

Figure 3: I-15 Corridor Map Showing Original 8 Mile Section (Source: TransNet, 2009)

A survey that was conducted during the ExpressPass phase I of the I-15 Express Lanes examined the mode choice of the current ExpressPass users and the previous ExpressPass users (Golob et al., 1998). When current ExpressPass users were asked about their previous mode choice, 95 percent of the users of the I-15 corridor previously drove alone, while four percent reported that they had previously carpooled. This result indicates that very few carpools shifted to other modes as a result of the ExpressPass program, since 95 percent of current ExpressPass users previously drove alone (Table 1).

Table 1: ExpressPass Users' Previous Mode of Travel (Source: Golob et al., 1998)

Traveled corridor before ExpressPass	Current ExpressPass Users		Mode used before ExpressPass	
	Frequency	Percent	Drove Alone	Carpooled
Yes	308	94%	95%	4%
No	20	6%		

This research also examined the characteristics of the current and former ExpressPass users, and found that current ExpressPass users had distinct personal and household characteristics as compared to the former ExpressPass users. Cost was the main reason mentioned by almost 83 percent of the respondents for leaving the ExpressPass program. Another survey conducted in spring 1999 looked at the mode shifts in comparison to the previous survey of spring 1998 (Golob et al., 2000). There was not any significant decrease in the carpooling by FasTrak customers was found. It was concluded that increase in FasTrak use by established FasTrak customers was at the expense of SOVs driving without FasTrak.

2.5.2 I-394 HOT Lane in Minneapolis

I-394 HOT lanes were created under the MnPASS Express Lane project. The facility was opened to toll paying SOVs in May 2005. While SOVs pay to use the MnPASS lanes, carpoolers, bus riders, and motorcyclists may use the lanes free of charge. Tolls are adjusted using dynamic tolling so as to maintain the minimum speed between 50 and 55 miles per hour. The toll is charged on a per trip basis and depends on the entry and exit location of the SOV. The tolls range from 25 cents to $8 and average $1 to $4 during rush hour (MnDOT, 2009).

An analysis of a wave 3 attitudinal panel survey found that I-394 panelists were approximately equally as likely to have shifted from Carpool to SOV (8%) as from SOV to Carpool (7%) between Wave 1 and Wave 3 (Zmud, 2006). The implementation of MnPASS Express lanes did not negatively impact the carpooling but a large shit of HOVs to SOVs was observed in the control Corridor that was around 20 percent (Table 2). Respondents who used the MnPASS lanes were asked if they were a single driver, carpooler, or bus rider when they used the lanes, significant differences were found between the group's incomes. The majority of the lower income responses (around 75 percent) were carpooling while 40 percent of the higher income groups were paying as a SOV on the MnPASS lanes (Table3). This research analyzed the carpoolers as a whole and did not analyze them by separating into fampools and non-fampools.

Table 2: Mode Switching Behavior by Corridor (Wave 1 to Wave 3) (Among Non-Transit Panel Members) (Source: Zmud, 2006)

	Wave1 Mode-Wave3 mode			
Road	**W1SOV-W3SOV**	**W1SOV-W3Carpool**	**W1Carpool-W3SOV**	**W1Carpool-W3Carpool**
I-394	73%	7%	8%	12%
Control I-35W	64%	10%	20%	6%

Table 3: Mode of MnPASS Use by Income (among I-394 Respondents Reporting MnPASS use) (Source: Zmud, 2006)

When you have used the MnPASS lanes in the past, were you…	Lower-Income (N=75)	Mid-Income (N=306)	Higher-Income (N=282)	Total (N=648)
Paying Single Driver	7%	18%	40%	22%
Carpooler	75%	66%	52%	64%
Bus Rider	12%	13%	6%	12%
Don't Know	6%	3%	2%	3%

2.5.3 I-25 HOT Lane in Denver

A 7 mile HOT lane facility was opened on June 2, 2006 in Denver. It is a two lane, barrier separated and reversible facility that operates between downtown Denver, Colorado, north to US 36 (Figure 4). Variable pricing is used; higher tolls are charged during the peak periods so as to maintain congestion free traffic flow (**Source:** U.S. Department of Transportation, 2009).

Figure 4: Location of I-25 HOT Lanes

A study found that both carpoolers and toll paying users were evenly split on the HOT lanes. The majority of travelers who were traveling as a SOV had an annual household income more than $100,000 as compared to the household income of $50,000 to $99,999 per year for most of the carpoolers. More than half of the Express Lanes users were between 35 to 54 years of age. The majority of carpoolers who used the Express Lanes did so simply because they carpool (77 percent); they were not carpooling in order to use the Express Lanes (only 17 percent carpool in order to use the Express Lanes). This suggests that the Express Lanes were not the primary motivation for most people to carpool and that there were other factors impacting their decision to carpool. This would imply that changing the rules of the Express Lanes (by allowing SOVs) would have little impact on their mode choice as well **(**Corona Research Inc., 2008).

2.5.4 SR-167 HOT Lane in Seattle

A HOT lane opened in May 2008 on SR 167 with a single lane operating in the each direction. The nine mile long facility operates between Renton and Auburn (Figure 5). Tolls are adjusted to ensure free flow traffic conditions (Washington State DOT, 2008).

Figure 5: Location of SR 167 HOT Lanes (Source: Washington State DOT, 2008)

A survey was conducted of the respondents who had used the HOT lane at least once. Respondents were classified according to the mode including Drive Alone; Drive Alone Only, Carpool, Carpool Only, and Drive alone/Carpool. “Carpool Only” respondents had the highest proportion with annual household income of $100,000 or more and they had the lowest proportion in the household income levels of less than $99,999. “Carpool Only” respondents had the highest proportion of females. “Carpool Only” respondents had the highest proportion in age group older than 55 years **(**Washington State DOT, 2008).

2.5.5 SR-91X in Los Angeles

The SR-91 express lanes are10 miles long and have two lanes in each direction. This facility does not have any midpoint entrances or exits. In the first 2 years of operation (1996 and 1997), HOV3+ were allowed to travel for free. A half price toll was imposed on them for all times of day in January 1998. This changed again in 2003, when HOV3+ are allowed to travel for free except for 4pm to 6pm eastbound when they pay 50% of the full toll (91 Express Lanes, 2009).

A study analyzed the potential effects of the elimination of half toll price charged to HOV3+ vehicles in 2003. It was found that with toll reduction the overall HOV3+ hourly volume increased. A decline in the HOV3+ usage was found for the eastbound traffic between 4 pm and 6 pm, during which toll is still charged. It showed that toll pushed a few HOV3+ travelers in to the shoulder PM period (Li, unpublished manuscript, 2007). Another study (Sullivan, 2000) evaluated the impact of the SR 91 Value-Priced Express Lanes and found that following the opening of the express lanes, relatively more women switched to lower occupancy modes as compared to males. When examined the ridesharing behavior between 1995 and 1996, of the 20 percent who had reported a change in ridesharing behavior and with annual household income of less than $40,000, almost 90 percent of them switched to higher occupancy vehicles. A 7 percent net decrease was observed in the proportion of HOV users among all surveyed commuters as 11 percent reported switching from either HOV2 or HOV3+ to SOV, while 4 percent reported switching from SOV to either HOV2 or HOV3+. Although this research analyzed carpool mode choice in detail but did not examine for any differences between fampools and non-fampools (Sullivan, 2000).

2.5.6 I-10 and US-290 in Houston

There are two HOT lanes operating in Houston, Texas one under a program called QuickRide and other called the Katy Managed Lanes. The new Katy Freeway managed lanes have only recently opened and not much information was available on their usage.

However, several years of data on QuickRide HOT lane operations on Katy Freeway were available and are discussed below.

Katy (I-10) Freeway HOT Lane is a 13.3 miles long facility and has one reversible lane that is barrier separated from the GPLs, but it has a short 2-lane segment near the eastern end (Figure 6).

Northwest (US 290) Freeway HOT lane is a one reversible lane except near the Southeastern end where there is one lane in each direction. HOT lane is 13.5 miles long and barrier separated from the GPLs (Figure 6).

Figure 6: Location of US 290 and I-10 (Source: METRO, 2009)

A survey of the QuickRide enrollees was taken shortly after the inception of the program. The total of 185 survey responses was collected. It was found that of the total morning trips, about 10 percent of QuickRide trips were two-person carpools shifting from the shoulders into the peak hour. This time shift was relatively smaller in the evening, which indicated higher time-sensitivity for carpools in the morning than in the evening. More than half of the HOV trips were from the SOVs moving from GPLs. Almost 25 percent of the trips were from the HOV2s moving from GPLs to the HOV lane. Also, among QuickRide participants, the number of HOV3+ carpool trips in the evening had gone up by 6.1 percent. Overall this appears to have encouraged carpooling for SOVs more often than any other mode (Hickman et al., 2000). The next section discusses characteristics of fampool and non-fampools travelers.

2.6 Characteristics of Fampools and Non-fampools

Burris and Figueroa (2006) also analyzed traveler characteristics by mode choice in HOT corridors. In this study, particular effort was spent examining the characteristics of QuickRide travelers. In the QuickRide program, HOV3+ are allowed to travel for free and HOV2 carpools are allowed to travel during peak periods for a toll of $2 while SOV’s are never allowed to travel on two HOT lanes in Houston. This research found in almost 60 percent of carpools, the passengers were family members. QuickRide trips were more likely to be school trips (11%), and in 76% of these trips, travelers were traveling with a child.

Li et al. (2007) explored the issues related to carpooling directly by examining reasons behind people’s travel mode choice decision through a survey of travelers in Dallas-Fort Worth and Houston, the two largest metropolitan areas in Texas. Respondents who identified themselves as carpoolers were given a list of literature-based reasons that might affect their decision to form a carpool. Access to an HOV lane and relaxation while travelling were found to be the most important factors for carpool formation. To further investigate the variation in rating of factors that influence mode choice decisions, carpoolers were divided into fampools and non-fampools. Fampools rated “dropping off kids at school or day care” and “enjoying travel with others” higher. Non-fampools rated other factors higher on average, especially travel time and cost related factors. The factors which were rated significantly higher by non-fampools were access to HOV lanes, travel time savings, sharing vehicle expenses, reliability of arrival time, splitting tolls on toll roads, encouraged by program at work and preferred parking at work. This research also examined the potential reasons offered for not carpooling by the respondents who indicated SOV as their primary mode choice. Difficulty of finding someone with the same location and schedule, flexibility of driving alone and needing a vehicle during a day were the main factors mentioned by SOV travelers.

Li et al. (2007) also found that 75 percent of carpools were fampools. This paper also summarized different carpool formation characteristics from different studies. The commute surveys from 1998 and 2003 in the San Francisco Bay Area estimated that fampools make up one third of carpools (Poole and Balaker, 2005). Similarly:

- In California, fampooling increased from 49 percent in 1996 to 55 percent in 1999 (Southern California Association of Governments, 2000).
- In Minneapolis-St. Paul, study found 67 percent of carpoolers were fampools (Poole and Balaker, 2005).
- In Houston, previous studies found that between 70 percent and 75 percent of carpools were fampools (Burris and Figueroa, 2006).
- In a nationwide estimate of all work commute carpools from 1990 to 2001, an increase of fampools from 75.5 percent to 83 percent was found (McGuckin and Srinivasan, 2005).

Another study analyzed two data sets from an April 2003 survey sent to both current and former users of Houston QuickRide. Analysis of the data found that current users had shorter carpool formation times and higher level of fampooling was one reason for this decrease in the carpool formation time. This study focused on significant differences between the two populations' survey responses. The results supported the idea that current users took advantage of carpooling with family members more frequently than former users did. Two other travel characteristics were found to be different among the groups. Former users indicated having more difficulty carpooling, with 31.4% of them indicated that difficulty with carpooling was their main reason for quitting QuickRide while 25.1% of current users indicated that difficulty carpooling was a main reason for not using QuickRide more often. The average time spent picking up a carpool passenger was also significantly higher among the former user group. Users spent on an average only 4.3 minutes picking up their carpool partner while former users spent 12.2 minutes on average. 40.3% of current users indicated that their main QuickRide carpool partner was an adult family member, while only 31.4% of former users did. Similarly, 21.5% of current users indicated that their main QuickRide carpool partner was a son/daughter while only 12.7% of former users indicated this. These findings lead to the conclusion that current users were carpooling with family members more frequently than former users were. This conclusion was reinforced by the fact that when using QuickRide, 47.2% of former users' carpool partners helped pay the toll while only 28.2% of current users' carpool partners did. This is a logical occurrence since most people using QuickRide with a family member would consider the $2 toll as a charge to the entire household (Chen, 2003).

Based on the National Household Travel Survey (NHTS), the majority of carpool peak period trips were likely to be fampools. The majority of highest occupancy trips during peak time were not work trips. The highest occupancy trips were for social and family purposes, which also suggested the likelihood of fampooling (Poole and Balaker, 2005). It was also found that fampooling frequently did not take cars off the street as the passenger was not going to drive anyways. This research concluded that the majority of high occupancy trips were for social or family purposes.

2.7 Summary

A review of the literature reveals that a majority of the carpoolers are fampools. The percentage of fampools varied from 33 percent in San Fransisco to 75 percent in Houston. Also, in a nationwide estimate of all work or commute carpools from 1990 to 2001, an increase of fampools from 75.5 percent to 83 percent was found. Also, the majority of the highest occupancy trips during the peak time were not work trips. The highest occupancy trips were for social and family purposes, which also suggested the likelihood of fampooling.

With the increase in fampooling a study analyzed the differences and similarities between the characteristics of fampools and non-fampools. It found that access to a HOV lane and need to drop off kids at school were the most important reasons reported for carpool formation by fampools. On the other hand, non-fampools reported travel time and cost related factors as most important reasons for the carpool formation.

The review of the literature on the seven HOV to HOT lane conversions around the country found that HOT lanes did not discourage carpooling. However, its impact on the fampool and non-fampool travelers was not analyzed separately. It was also observed that the vast majority of SOV paying customers of HOT lanes were formerly SOVs on the GPLs.

2.8 Discrete Choice Modeling

The factors influencing the mode choice of fampools and non-fampools and discrete choice models are discussed in the following sections.

2.8.1 Mode Choice

Travelers choose their mode and travel time that maximizes their utility (Ben-Akiva and Lerman, 1985). Different factors influence this choice. Some of these important factors include:

- Trip Characteristics: trip purpose, number of trips, trip length, trip time, toll, number of and relationship to passengers, pay for parking, employer incentives and what you do after dropping off passengers.

- Traveler Characteristics: Age, income, ethnicity, number of people in household, auto availability, occupation and education.

- Alternative Routes: express toll road, high occupancy/toll road, high occupancy vehicle road, non-roll road.

- Alternative Modes: SOV on ML, HOV2 on ML, HOV3+ on ML, SOV on GPL, HOV2 on GPL, HOV3+ on GPL, Transit on ML, Transit on GPL.

There are other factors including behavioral, attitudinal, and value characteristics of the traveler that might affect the mode choice. Researchers have identified the following as the most important characteristics influencing the mode choice (Small et al., 1999):

- Direct monetary cost of the trip (includes tolls, fares, parking etc.).
- Travel time.
- Travel time reliability.

Ferguson (1997) examined the characteristics of fampools and non-fampools through mode choice model to differentiate between carpool and SOV modes. Researcher found that both types of carpools were difficult to distinguish from driving alone but fampools and non-fampools were easier to distinguish from one another than from driving alone. Researchers found that the high educated travelers were significantly less likely to carpool with non-household members. The least educated persons were significantly more likely to carpool with household members. As the trip distance increased, the probability of choosing a fampool declined while probability of choosing a non-fampool increased. Afro-American commuters were more likely to form a non-fampool. Vehicle availability did provide incentives for driving alone but parking and/or road pricing could have a positive effect on carpooling. Observing why and when vehicle occupancy rates rise and fall further suggested that carpools were likely to be fampools.

Other studies also analyzed the factors encouraging carpooling in general. However, the effects of these factors on fampools and non-fampools were not examined. Based on the literature, there are three main reasons for commuters to switch from driving alone to ridesharing, either as carpools or vanpools. The first reason is travel time; research indicates that commuters are likely to alter their commute choice if it reduces their commute time. As driving alone is typically the quickest means from home to work (or the reverse), total travel time is one factor that makes driving alone more attractive to drivers. Convenience is the second factor in determining mode choice. Cost is the third major influential factor, although many commuters do not use the most cost-effective commute choice, it is an influential factor (Ungemah et al., 2007). This paper concluded travel time savings, convenience and cost effective commuting are three main encouraging factors for carpooling.

Whether HOT lanes encourage or discourage carpooling was analyzed using the data from the SR 91 travelers. Researcher built different mode choice models to see the short term and long term effects on carpooling (Parkany, 1998). The first models were built to analyze the short and long-term choices between the SOV, HOV2 and HOV3+ modes. SOVs were the travelers who always drove alone during the peak periods, and HOV2 and HOV3+ were the travelers who carpooled at least once during the peak period in the last week. With increased number of vehicles per adult in the household, travelers were less likely to travel asHOV3+ carpoolers. Respondents were more likely to travel as HOV2 carpools with increased trip length. Parkany (1998) found that in the absence of Express lanes, women were more likely to carpool. Carpoolers were likely to stick with their current carpools with the opening of the Express Lanes.

The three choices were expanded to analyze how often carpoolers carpool in the corridor. The five new choices were HOV3+ always, HOV3+ sometimes, HOV2 always, HOV2 sometimes and SOV always. SOV always was taken as the base case. It found that language and gender were significant for the sometimes and HOV2 always choices. The long-term gender coefficients imply that women are more likely to form daily carpools in the long term. It also found that carpoolers showed a propensity to stay with the same size carpool, but people who carpooled in an HOV -2, before the Express Lanes opened, sometimes traveled in an HOV3+ now and a fewer number of HOV3+s now traveled in HOV2 always carpools. These coefficients implied that Express Lanes encouraged carpooling.

To further analyze whether people who drove alone before the Express Lanes opened were encouraged to form carpools by the Express lanes, a mode choice model with the five choice of HOV3+ (expected to use the Express Lanes because they can travel for free), HOV2 Express, HOV2 regular, SOV Express and SOV regular was developed. It found that SOVs on the Express Lanes were likely to be younger. Women were more likely to use Express Lanes as a carpool. The coefficients of the dummy variable HOV3+ (before the Express Lanes opened) was small and insignificant. This indicated that people are not dropping out of their carpools to use the Express Lanes. Hence, it was concluded that HOT lanes did not discourage carpooling. However, this research did not examine the mode choice of fampools and non-fampools. The next section provides information on the available and frequently used mode choice models in the transportation engineering research studies.

2.8.2 Discrete Choice Models

Discrete choice models can be used to analyze and predict a decision maker's choice of one alternative from a finite set of mutually exclusive and collectively exhaustive alternatives (Koppelman and Bhat, 2006). It is done by defining a utility function for all the available modes. The utility maximization rule states that an individual will select the alternative from his/her set of available alternatives that maximizes his or her utility. Utility is an indicator of value to an individual. Random utility theory assumes that decision maker has perfect discrimination capability. However the analyst is assumed to have incomplete information and therefore uncertainty must be taken into account. A random portion is added to the utility to take the uncertainty into consideration. The utility equations such that an individual *t* chooses an alternative *i* from choice set C_t is given as following:

$$U_{it} = V_{it} + \varepsilon_{it} \; ; \quad i \in C_t \tag{1}$$

where:

V_{it} is systematic portion of utility (which is known to analyst),

ε_{it} is random portion of utility.

According to the utility maximization theory, the alternative with highest utility is chosen. The probability that an alternative *i* is chosen by decision maker *n* from choice set C_t is given as

$$P(i\,|C_t) = P[U_{it} \geq U_{jt} \; \forall \; j \in C_t] \tag{2}$$

where:

i, j are alternatives,

P(A) is probability of occurrence of event A

Different assumptions about the distribution of the random variables associated with the utility of each alternative result in different representations of the model used to describe and predict choice probabilities (Koppelman and Bhat, 2006). The assumptions used in the development of logit type models are discussed in the next section.

2.8.3 Random Parameter Logit Model

To overcome the IIA limitation of the multinomial logit (MNL) model, the random parameter logit (RPL) model is another available option. The RPL model is similar to the MNL, except that in the RPL models, some individual parameters are randomized. For the RPL model, the utility of alternative i for individual t is:

$$U_{it} = \beta_t' x_{it} + \varepsilon_{it} \; ;$$

where:

x_{it} are observed variables of the alternative and the decision maker

$\beta_t^{'}$ is a vector of coefficients of these variables for person t

ε_{it} is a random term that is iid extreme value distributed

The choice probably for the RPL model can be given as:

$$P_{ti} = \frac{e^{\beta_t^{'} x_{it}}}{\sum_j e^{\beta_t^{'} x_{jt}}} f(\beta) d\beta \qquad (3)$$

where:

$f(\beta)$ is population density over which decision maker’s coefficient vary.

For estimating the parameters, different statistical distributions for the coefficients can be used that makes this model very flexible and can approximate any random utility model (McFadden and Train, 2000).

In this thesis, random parameter logit models were developed to analyze the mode switching characteristics of fampools and non-fampools. The mode choice models included socio-economic characteristics of the travelers, trip characteristics, and costs associated with the trip. Mode choice models were developed for the six modes (alternatives) available to the travelers: drive alone in a managed lane, carpool with one passenger in a managed lane, carpool with two or more passengers in a managed lane, drive alone in a general purpose lane, carpool with one passenger in a managed lane, and carpool with two or more passengers in a general purpose lane. Utility equations were developed for each mode. The reasons for choosing a random parameter logit model are discussed in the next section.

2.8.4 Reasons for Choosing Random Parameter Logit Model

As the main objective of this thesis was to analyze the impact of different toll and travel time scenario on the mode choice of different carpool groups, a random parameter logit model was selected as the final model based on the following reasons:

1. If a particular parameter is randomized using random parameter logit model, the coefficients are assumed to be distributed with some distribution, because there can be more than one person in the population with the same value for that coefficient.
2. By randomizing the toll and travel time coefficients using any specific statistical distribution in random parameter logit model give better estimation of the individual mode choice in response to the toll and travel time variations.
3. Another advantage of random parameters logit over other logit models is that random parameters logit does not suffer from the independence of irrelevant alternatives assumption. This allows the unobserved portion of utility to be correlated across choices. This correlation allows random parameters logit to avoid the IIA problem (Train, 2003).

2.9 Summary of the Literature Review

High Occupancy Vehicle (HOV) lanes were implemented across the country to manage congestion by encouraging carpooling. In cases where HOV lane was not fully utilized, the option of High Occupancy/Toll (HOT) lane was often considered. With the increased popularity of HOT lane options, it becomes very important to analyze the mode choice of different carpool groups as HOT lanes may negatively impact the carpooling. The review of literature on the seven HOV to HOT lane conversions around the country found that HOT lanes did not discourage carpooling. Based on these findings it was concluded that on most of the HOT lanes carpools remained stable. Impact of the conversion of HOV lane to HOT lane on the behavior of fampools and non-fampools in the presence of managed lanes was not analyzed in the literature. However, carpoolers have been studied in detail in general.

A review of the literature revealed that the majority of carpools are fampools. The percentage of fampools varied from 33 percent in San Fransisco to 75 percent in Houston. Also, in a nationwide estimate of all work commute carpools from 1990 to 2001, an increase of fampools from 75.5 percent to 83 percent was found. Literature also revealed that fampools had different reasons for carpool formation than the non-fampools. Non-fampools were formed due to cost and travel time related reasons. But fampools did not consider the cost and travel time as important as non-fampools did. The literature does not discuss the mode choice of fampools and non-fampools in the vicinity of managed lanes. Also, little is known about the characteristics of the travelers from these two groups.

Discrete choice models can be used to analyze and predict a decision maker's choice of one alternative from a finite set of mutually exclusive and collectively exhaustive alternatives. Different factors influence this choice including travel characteristic, socio economic characteristics, behavioral, attitudinal, and value characteristics. These variables, obtained through stated and revealed preference surveys, are used as an input to determine the mode choice of the respondents. Some of the most frequently used discrete choice models include multinomial logit model (MNL), nested logit model and random parameter logit model (RPL). Mode choice modeling can be used to estimate the number of travelers likely to use different modes under given traffic and toll conditions. Different ML scenarios were simulated using the mode choice models developed in this thesis to analyze the mode choice of different carpool groups under different travel scenarios. The results of these models are discussed in detail in Section 5.

3. DATA

3.1 Survey Design

Survey responses from both Houston and Dallas, Texas were used for this research. The survey was divided into four sections. The first section of the survey contained questions relating to trip purpose, trip time, trip origin and destination, trip length, vehicle mode and number of trips undertaken. Based on the respondent's mode choice, the remainder of the trip related questions focused on their use of that mode. The second section contained questions about the respondent's view towards managed lanes. The managed lane opinion questions asked about factors affecting likely usage and non usage of managed lanes. In the third section, respondents' were provided with stated preference questions. Four different scenarios with six alternatives each were provided. The six alternative modes provided were:

- SOV on the MLs
- HOV2 on the MLs
- HOV3+ on the MLs
- SOV on the GPLs
- HOV2 on the GPLs
- HOV3+ on the GPLs

The fourth section contained questions regarding the socio economic characteristics of the respondents.

The survey was designed such that only relevant questions were asked to each respondent based on their mode of travel. For example, the questions posed to SOV travelers were different from the carpoolers, vanpoolers and transit riders. A different set of ML opinion questions were received by those travelers who indicated an interest in using managed lanes than from the travelers who did not want to use managed lanes. This helped to keep errors to a minimum, and shorten the survey length for respondents (Mahlawat, 2008).

3.2 Survey Advertisement and Data Collection

The internet survey was advertised using newspaper articles, TV news, push cards given at tollbooths and links on different websites. Push-cards were handed out by the North Texas Tollway Authority (NTTA), the North Central Texas Council of Governments (NCTCOG), the Harris County Toll Road Authority (HCTRA), the Metropolitan Area Transit Authority (METRO), the TREK (Houston TMA), the Dallas/Houston TTI offices, and six Houston Libraries. In all, over 32,000 cards were provided for handout. An analysis of survey respondents indicated that majority of the Houston survey respondents learned of survey from a newspaper article, while in Dallas they learned of the survey from a link on a website.

It was found that over-all sample size had met the requirements of the data collection, but the sample sizes for low income Hispanics and African-Americans were too small. Paper surveys and laptop surveys were conducted in addition to the online surveys by visiting Department of Public Safety (DPS) offices in Houston and Dallas. Paper and laptop surveys were also conducted at a community center in Houston. These sites were selected based on the ethnic and economic status of the surrounding neighborhood. Table 4 shows that in both, Houston and Dallas, the majority of respondents completed the survey online (Mahlawat, 2008).

Table 4: Total Number of Survey Responses Collected

Survey Type	Dallas	Houston	Total
Web Based (Online)	1852	2405	4257
Laptop survey	49	85	134
Paper	135	85	220
Total	2036	2575	4611

After survey data has been collected, the next step was to reduce the survey data for analysis. The following section describes the process in detail.

3.3 Survey Data Reduction

The online survey was designed to reduce the potential for erroneous answers to many of the survey questions. One way to do this was to use radio buttons and checkboxes as design tools. Radio buttons allow only one alternative to be chosen. Therefore, it was very useful in questions when only one alternative should be selected. Checkboxes were useful for multiple choice answers. In the answers where text entries were made, the answers were checked for logical consistency. For example, extremely high values for typical trip length, typical toll paid per day, number of trips per week, number of vehicles in the household were carefully examined and frequently discarded.

All the respondents did not answer all the questions. Socio-economic information such as income, age, gender, ethnicity, household type, number of people in the household, number of vehicles in the household, education level, and occupation type was not answered by some of the respondents. Other critical information such as location, trip purpose and whether interested in using managed lanes was also missing. 403 respondents did not answer question regarding income, 160 respondents did not provide ethnicity information, and 310 respondents did not provide information about number of people in the household. Among socio-economic information, the least answered question was the question about household income. 325 respondents did not answer whether or not they would be interested in using managed lanes. The responses with missing values were not deleted from the survey. However, 23 responses were deleted from the original survey because they were duplicate entries of other questions. A total of 4634 responses were used for the final analysis (Mahlawat, 2008).

After cleaning and reducing the data it was found that the collected survey data were different from the actual demographics of Dallas and Houston travelers. A simple analysis of survey responses would not have been representative of Dallas and Houston travelers. The data was weighted to better represent the demographic features of the population.

3.4 General Weights

There were fewer responses from the people with low household incomes and from minority ethnic backgrounds. If the data were not weighted than it would have resulted in a non-response bias in the analysis. The data was weighted to better represent the demographic features of the population using the categories:

- four income groups
- four ethnic groups
- Toll versus non toll travelers

Another issue with weighting is that the stratification of the survey respondents has to be done such that each category contains at least the required minimum number of responses. Therefore, some ethnicity categories such as Asians, Native Americans, and others were combined into single category of ‘Others’. The weights were derived using an iterative technique that simultaneously balances the distributions of two weighting parameters – the income and ethnicity parameter and toll road usage parameter.

In the first step, population data were collected for the Houston and Dallas from the American Community Survey (2007). The population was divided into subgroups based on the four income and four ethnic groups (Table 5, Table 6). Similar tables were generated from the survey data (Table 7, Table 8).

Table 5: Dallas Population

	Caucasian	African-American	Hispanic	Others
Less than $25,000	11.27%	10.10%	2.09%	4.39%
$25,000 to $49,999	11.42%	10.85%	2.38%	5.51%
$50,000 to $99,999	14.47%	6.63%	2.40%	4.10%
$100,000 or more	9.79%	1.77%	1.21%	1.63%

Table 6: Houston Population

	Caucasian	African-American	Hispanic	Others
Less than $25,000	7.23%	7.14%	9.89%	4.32%
$25,000 to $49,999	8.75%	5.25%	9.44%	4.64%
$50,000 to $99,999	13.43%	3.88%	5.94%	3.86%
$100,000 or more	11.99%	1.06%	1.50%	1.68%

Table 7: Dallas Survey Sample

	Caucasians	Afro-American	Hispanic	Others
Less than $24,999	2.21%	2.09%	1.50%	0.84%
$25,000 to $49,999	9.75%	2.51%	2.33%	0.90%
$50,000 to $99,999	29.72%	2.63%	1.67%	2.33%
$100,000 or more	35.65%	1.32%	1.61%	2.93%

Table 8: Houston Survey Sample

	Caucasians	Afro-American	Hispanic	Others
Less than $24,999	2.39%	1.43%	2.30%	0.51%
$25,000 to $49,999	10.31%	1.93%	3.22%	0.78%
$50,000 to $99,999	29.42%	2.53%	3.27%	2.99%
$100,000 or more	32.46%	1.66%	2.21%	2.58%

In the second step initial weights were developed using the formula:

Weighting factor = *Percentage of actual population / Percentage of survey respondents*

Third step was weighting the data using the initial weighting factors shown in Table 9 and Table 10.

Table 9: Dallas Weighting Factors

	Caucasians	Afro-American	Hispanic	Others
Less than $24,999	3.89	2.61	4.34	4.03
$25,000 to $49,999	1.26	1.78	3.03	4.59
$50,000 to $99,999	0.62	1.53	2.44	1.48
$100,000 or more	0.41	0.75	0.75	0.50

Table 10: Houston Weighting Factors

	Caucasians	Afro-American	Hispanic	Others
Less than $24,999	3.02	5.00	4.30	8.54
$25,000 to $49,999	0.85	2.72	2.93	5.92
$50,000 to $99,999	0.46	1.53	1.82	1.29
$100,000 or more	0.37	0.64	0.68	0.65

In the fourth step, data was reweighted using the toll road usage weights. Annual Average Daily Traffic (AADT) data for toll and non-toll roads were obtained from Dallas and Houston AADT maps. The total AADT for toll and non-toll roads used here is listed in Table 11. Table 12 contains the number of toll road and non-toll road survey respondents. The weighting factors were obtained using equation 7 and are given in Table 13.

$$Weighting\ Factor_{Toll} = \frac{\%\ AADT_{toll\ road\ traffic\ data}}{\%\ AADT_{toll\ road\ survey}} \qquad (4)$$

where:

$\%\ AADT_{toll\ road\ traffic\ data}$ is the percentage of AADT on toll roads (the AADT on toll roads divided by the AADT on both toll and non-toll roads).

$\%\ AADT_{toll\ road\ survey}$ is the percentage of toll road travelers in the weighted survey sample.

Similarly, weighting factors for non-toll road travelers was obtained using equation (5).

$$Weighting\ Factor_{Non-Toll} = \frac{\%\ AADT_{non-toll\ road\ traffic\ data}}{\%\ AADT_{non-toll\ road\ survey}} \qquad (5)$$

where:

$\% AADT_{non-toll\ road\ traffic\ data}$ is the percentage of AADT on non-toll roads (the AADT on non-toll roads divided by AADT on both toll and non-toll roads).

$\%\ AADT_{non-toll\ road\ survey}$ is the percentage of non-toll road travelers from the survey sample.

Table 11: Combined AADT Data from Houston and Dallas (in Thousands)

	Number	Percentage
Toll road	342	8.24%
Non-toll road	3807	91.76%

Table 12: Weighted Sample Number Respondents and Percentages in Each Category

	Number	Percentage
Toll road users	946	20.67%
Non-toll road users	3633	79.33%

Table 13: Toll Road and Non-toll Road Weights

	Weight
Toll road users	0.40
Non-toll road users	1.16

In the fifth step, weights obtained in step 2 and step 4 were combined through multiplication. After weighting the data with the weighting factors obtained in the fifth step, step 1 through 5 were repeated iteratively until there was a convergence between the survey data and the actual population data and also between the survey toll and non-toll road users and the actual AADT data. The final weights obtained are provided in tables 14 through 17.

Table 14: Weighting Factors for Dallas Respondents Who Used Toll Road

	Caucasians	Afro-American	Hispanic	Others
Less than $24,999	1.39	0.81	1.36	1.18
$25,000 to $49,999	0.52	0.63	1.02	1.66
$50,000 to $99,999	0.27	0.54	0.96	0.62
$100,000 or more	0.18	0.27	0.28	0.2

Table 15: Weighting Factors for Dallas Respondents Who did not Use Toll Road

	Caucasians	Afro-American	Hispanic	Others
Less than $24,999	4.24	2.46	4.15	3.59
$25,000 to $49,999	1.57	1.92	3.12	5.07
$50,000 to $99,999	0.82	1.66	2.94	1.89
$100,000 or more	0.56	0.82	0.84	0.62

Table 16: Weighting Factors for Houston Respondents Who Used Toll Road

	Caucasians	Afro-American	Hispanic	Others
Less than $24,999	1.22	1.95	1.7	3.41
$25,000 to $49,999	0.33	1.01	1.06	2.15
$50,000 to $99,999	0.17	0.62	0.7	0.46
$100,000 or more	0.14	0.26	0.27	0.26

Table 17: Weighting Factors for Houston Respondents Who Did Not Use Toll Road

	Caucasians	Afro-American	Hispanic	Others
Less than $24,999	3.73	5.93	5.19	10.38
$25,000 to $49,999	1.01	3.07	3.23	6.54
$50,000 to $99,999	0.52	1.9	2.14	1.4
$100,000 or more	0.42	0.79	0.82	0.79

3.5 Replicate Weights

The sampling design for this survey of ML travelers was simple random sampling (SRS) followed by post-stratification. According to the SRS, for each stratum, the proportion of respondents in the sample would be the same as the proportion in the population. For example, if the surveying sampling plan was SRS and the proportion of Caucasians with annual household incomes less than twenty-five thousand dollars was ten percent in the population then it would need to be ten percent in the survey sample as well. But, the respondents were not randomly sampled from the population. The sample did have input from each segment of the population, but there were dependencies between the subjects due to the non-random sampling scheme.

A study has shown that results will be biased unless this dependency is accounted for (Brick et al., 2000). The sampling weights are random if the sampling plan is not SRS. They cannot be used like fixed weights to conduct tests of proportions or for testing other hypotheses. This is because a non-SRS methodology results in higher standard errors (SE) for the estimates. An assumption of fixed weights (with SRS) would imply lower SE. Thus, using fixed weights may lead to some results from non-SRS surveys being found statistically significant when in fact they are not. Therefore different analyses are required for survey data collected using a non-SRS method. The recommended way of handling the disproportion among groups is a method called "Replicate Weighting" (Rizzo and Judkins, 2004).

There are several methods available for the replicate weight creation, but Jackknife replication method was used for this research. The selection of methodology depends on the sample design. Since the ML survey had more than 2 Primary Sampling Units (PSU) per strata (Houston road, Dallas road, neither of given roads in Houston or Dallas, or missing location), Jackknife-n (JK-n) method was the only appropriate method. Therefore, JK-n replicate weights were created for the ML survey. The formula for the variance estimate is given in Equation (6) (Burris et al., 2009):

$$\sigma^2\left(\hat{\theta}\right)=\frac{c\sum_{g=1}^{G} f_g h_g \left(\hat{\theta}_g - \hat{\theta}\right)^2}{G-1} \tag{6}$$

where:

$\hat{\theta}_g$ is the estimate of θ based on the observations included in the g^{th} replicate,

G is the total number of replicates formed, and

c is a constant depending on the replication method. For JK-n, c = 1.

f_g is the Finite Population Correction (FPC) factor.

The formula for the FPC is:

$$FPC \quad = \quad [\ (N-n)\ /\ (N-1)\ ]^{1/2} \tag{7}$$

where N is total population and n is total sample size. For the ML survey FPC values were close to 1. The FPC is always less than or equal to 1 (equals one only if all the elements of the population are sampled).

h_g is a factor specific to JK-n methodology

The number of replicates, G, is equal to

$$G = \sum_{h=1}^{L} n_h \tag{8}$$

where L is number of strata (12 in this case) and n_h (varies from 2 to 4) is number of PSU in the stratum h. The methodology for replicate weight creation is given in detail in WesVar Manual (WesVar 4.2 Manual, 2007).

3.6 Comparison between Houston and Dallas Data

Survey data from Houston and Dallas were compared to examine if they need to be analyzed separately or can be analyzed as one group. Houston and Dallas data were analyzed based on their response to the managed lanes option in the survey to find any difference in their behavior. Many respondents selected at least one managed lane option in the stated preference questions in both Houston and Dallas. However, more Houston residents (73 percent) selected a managed lanes option than did Dallas residents (70 percent) (Table 18). Selection of MLs in each city was also examined by mode. There were no statistically significant differences in ML interest between Dallas and Houston travelers regardless of mode (Table 18). As shown in Table 18, selection of a managed lanes option was fairly consistent between the two cities in most strata. There was no significant difference in attitude towards MLs between the two cities, and therefore little need for calibration of separate behavioral models for these two cities.

Table 18: Respondents Interest in Managed Lanes

Characteristic	Percentage Choosing a Managed Lane Option				p-value
	Dallas		Houston		
	Proportion	Std. Error	Proportion	Std. Error	
Household Income					
Less than $25,000	75.3%	7.9%	73.9%	2.7%	0.39
$25,000 - $50,000	64.2%	3.8%	67.7%	2.5%	0.30
$50,000 - $100,000	66.9%	9.2%	74.9%	4.3%	0.29
Greater than $100,000	75.6%	2.5%	76.5%	1.1%	0.38
Ethnicity					
Caucasians	73.4%	3.1%	73.6%	2.7%	0.40
Afro-American	64.9%	6.9%	76.7%	2.4%	0.11
Hispanic	68.7%	7.7%	71.9%	5.6%	0.38
Others	58.2%	4.9%	68.3%	2.9%	0.08
Trip Purpose					
Commute	70.3%	3.2%	72.4%	2.8%	0.35
Recreational	71.7%	6.8%	77.8%	3.2%	0.29
Work	67.1%	6.7%	70.6%	5.1%	0.37
School	59.1%	16.3%	82.4%	6.4%	0.16
Other	46.0%	25.6%	56.0%	13.9%	0.38
Mode					
SOV	69.7%	3.6%	71.0%	2.5%	0.38
HOV-2	72.1%	5.0%	78.8%	5.4%	0.26
HOV-3+	80.6%	16.4%	75.8%	8.5%	0.39
Transit	62.2%	6.3%	72.0%	5.8%	0.21
Motorcycle	65.3%	27.3%	64.0%	16.4%	0.40
Vanpool	68.9%	31.5%	78.3%	5.9%	0.38
Total	69.5%	3.0%	72.9%	1.9%	0.25

3.7 Statistical Tests and Methods

As Stata (Stata, 2009) was used for generating descriptive statistics using replication weights, it provided the results as a summary statistics (e.g. proportions, means, standard error etc.). To test any significant differences between the groups, if there were two groups then simple "z" test was used:

$$Z = \frac{\hat{\theta}_a - \hat{\theta}_b}{\sqrt{\sigma_a^2 + \sigma_b^2}} \tag{9}$$

where,

$\hat{\theta}_k$ is the proportion for the k^{th} group

σ_k^2 is the variance for the proportion of the k^{th} group

if Z > $Z_{Critical}$, we reject the null hypothesis that two proportions are equal.

But for three or more groups, ANOVA was used for determining significant differences. Programs that calculate ANOVA such as SAS (SAS Topics, 2009) require the actual data set to calculate the results. But if we analyze the data using replicate weights in Stata, it does not allow running ANOVA along with any of the estimation commands including mean or proportion commands. Hence, it only provides summary statistics of the analysis. Larson (1992) shows that summary statistics can be used to create a surrogate dataset which satisfies the conditions necessary for ANOVA. The surrogate dataset must have the same number of data points as the original data set, and a mean and standard deviation that match the summary statistics. Let $\overline{x}$ denote the average and s denote the standard deviation of a data set of size n. Let y_i denote the surrogate data set which needs to be of size n, have mean $\overline{x}$ and sample variance s^2. The y_i's can be calculated as follows:

$$y_i = \bar{x} + \frac{s}{\sqrt{n}} \quad \text{for i} = \{1,2,\ldots,\text{n - 1}\} \tag{10}$$

$$\text{y}_\text{n} = n\bar{x} - (n-1)\left[\bar{x} + \frac{s}{\sqrt{n}}\right] \tag{11}$$

The first equation represents (n-1) data points, and the last equation is for the n^{th} data point, showing that there are n data points in the surrogate data set.

To show that the surrogate data set has the mean $\bar{x}$:

$$\bar{y} = \frac{1}{n}\sum y_i = \frac{1}{n}\left((n-1)\left[\bar{x} + \frac{s}{\sqrt{n}}\right] + n\bar{x} - (n-1)\left[\bar{x} + \frac{s}{\sqrt{n}}\right]\right) = \frac{1}{n}(n\bar{x}) = \bar{x} \tag{12}$$

To show that the surrogate data set has the variance s^2:

$$\text{var}(y) = \frac{\sum(y_i - \bar{y})}{n-1} = \frac{\sum(y_i - \bar{x})}{n-1}$$

$$= \frac{1}{n-1}\left[(n-1)\left(\bar{x} + \frac{s}{\sqrt{n}} - \bar{x}\right)^2 + \left(n\bar{x} - (n-1)\left[\bar{x} + \frac{s}{\sqrt{n}}\right] - \bar{x}\right)^2 \right]$$

$$= \frac{1}{n-1}\left[(n-1)\frac{s^2}{n} + \left((n-1)\bar{x} - (n-1)\left[\bar{x} + \frac{s}{\sqrt{n}}\right]\right)^2 \right]$$

$$= \frac{s^2}{n} + \frac{(n-1)^2}{n-1}\left(\bar{x} - \bar{x} + \frac{s}{\sqrt{n}}\right)^2 = \frac{s^2}{n} + \frac{(n-1)s^2}{n} = \frac{n}{n}s^2 = s^2$$

This surrogate data set has the structure needed for ANOVA: it is a sample of size n with mean $\bar{x}$ and sample variance s^2. Standard statistical programs can be used to analyze the data and perform tests The detailed SAS code used can be found in Larson (1992).

3.8 Summary

Section 3 summarized the survey data collection process. Survey data was collected for the travelers from both Houston and Dallas, Texas. Data regarding four major categories of traveler characteristics was collected including commute characteristics, views towards managed lanes, stated preference questions, and socio economic characteristics.

The data was weighted to better represent the demographic features of the population. The weighting was done by general weights and replicate weights. Section 3.2 has summarized general weights creation methodology. Section 3.3 has summarized procedure for creation of replicate weights.

Data from Houston and Dallas were analyzed to see if there were any differences between the carpoolers from the two cities. But it was found that carpoolers from both the cities had similar characteristics.

The weighted data was used for survey analysis. The replicate weights were used for generating descriptive statistics for the fampool and non-fampool survey respondents. The result from this analysis is in section 4. The normal weights were used for mode choice modeling, the results from which are in section 5.

4. RESULTS

To begin, respondents who were carpoolers were split into fampool and non-fampool groups. There were a few respondents who were using both fampool and non-fampool modes, termed as mixed carpools. Table 19 provides information about the sample sizes of fampool, non-fampool and mixed carpool groups (using weighted data).

Table 19: Sample Sze of Fampool, Non-fampool and Mixed Carpool Groups

Groups	Mode	Sample Size	Total
Fampool	HOV2	375	564
	HOV3+	187	
Non-fampool	HOV2	158	223
	HOV3+	63	
Mixed Carpool	HOV2	47	72
	HOV3+	25	

4.1 Mixed Carpool

Due to small number of mixed carpools, this group was further investigated to decide whether to exclude it, keep it as a separate group or merge with the group of fampools or non-fampools. Mixed carpools were compared to both fampools and non-fampools on the basis of their mode choice in the stated preference section of the survey. As the main objective of this thesis is to analyze the mode choice of different carpool groups, it is appropriate to compare different carpool groups on the basis of their mode choice in the survey. In this section, respondents had the option to choose from six alternative modes. The comparison of the mode choice of all three groups rendered that mixed carpools showed a different trend from fampool and non-fampool groups (Table 20). Mixed carpools had less interest in using GPLs as compared to the fampools and non-fampools. Fampools and non-fampools were further divided into subgroups based on their current mode choice of HOV2 or HOV3+ modes, but mixed carpools were not split into subgroups. Their mode choice in stated preference questions were compared to that of the mixed carpools. It was found that mode choice of the mixed carpools was different from both HOV2 and HOV3+ subgroups of fampools and non-fampools (Tables 21, 22). On the basis of this data analysis, it was concluded that mixed carpools selected different modes and could not be merged with any of the groups or subgroups of fampools and non-fampools. Due to the small sample size, it was not possible to keep the mixed carpools as an independent group for the descriptive statistics; hence mixed carpools were excluded from this data analysis.

Table 20: Mode Choice of Fampool, Non-fampool and Mixed Carpool Travelers

Group	ML SOV	ML HOV2	ML HOV3+	GPL SOV	GPL HOV2	GPL HOV3+
Fampool	12.8%	34.0%	9.3%	18.7%	20.6%	4.5%
Non-fampool	11.8%	30.1%	14.2%	18.5%	19.9%	5.5%
Mixed Carpool	13.1%	34.7%	19.8%	13.5%	11.3%	7.7%

Table 21: Mode Choice of Mixed Carpools, HOV3+ Fampools And HOV3+ Non-Fampools

Group	ML SOV	ML HOV2	ML HOV3+	GPL SOV	GPL HOV2	GPL HOV3+
HOV3+ Fampool	13.5%	17.0%	25.1%	25.8%	4.5%	14.2%
HOV3+ Non-fampool	6.5%	12.5%	36.1%	19.0%	9.7%	16.2%
Mixed Carpool	13.1%	34.7%	19.8%	13.5%	11.3%	7.7%

Table 22: Mode Choice of Mixed Carpools, HOV2 Fampools and HOV2 Non-fampools

Group	ML SOV	ML HOV2	ML HOV3+	GPL SOV	GPL HOV2	GPL HOV3+
HOV2 Fampool	12.4%	39.4%	4.7%	16.7%	25.4%	1.4%
HOV2 Non-fampool	13.6%	36.8%	5.9%	18.1%	23.8%	1.8%
Mixed Carpool	13.1%	34.7%	19.8%	13.5%	11.3%	7.7%

4.2 Characteristics of Fampools and Non-fampools

As described earlier, carpoolers were divided into fampool and non-fampool groups. Significant differences between groups of respondents were analyzed using the Jackknife replicate weight method described in section 3. The detailed descriptive statistics were generated for the commute characteristics, interest in managed lanes, and socio-economic characteristics for carpools: fampools and non-fampools. Results for both groups are provided in Table 23.

Table 23: Descriptive Statistics of Fampools and Non-fampools

Characteristics	Fampools		Non-fampools		P-Value
	Proportion	Std Error	Proportion	Std Error	
Trip Purpose					
Commute	42.7%	8.1%	57.4%	13.0%	0.34
Recreational	39.0%	8.9%	17.2%	11.3%	0.13
Work related	11.3%	6.0%	21.5%	10.3%	0.39
School	4.6%	4.7%	0.7%	1.0%	0.41
Other	2.5%	1.9%	3.2%	3.7%	0.87
Total (N)		561		221	
Typical Trip Length					
Short (0-3 miles)	1.5%	1.6%	1.9%	2.7%	0.90
Medium (4-9 miles)	17.8%	6.6%	10.2%	9.7%	0.52
Long (10-20 miles)	48.5%	8.3%	40.3%	10.6%	0.54
Very Long (more than 21miles)	32.2%	7.4%	47.6%	14.4%	0.34
Average trip distance (miles)	20.2	3.1	23.4	3.8	0.51
Total (N)		532		214	
Number of Trips per Week					
1 or 2	17.4%	8.7%	7.3%	5.2%	0.32
From 3 to 5	29.2%	6.3%	33.0%	11.0%	0.77
From 6 to 9	7.6%	3.1%	14.9%	7.8%	0.38
10	25.8%	5.7%	28.9%	7.9%	0.75
more than 10	20.0%	5.7%	15.8%	11.3%	0.74
Average number of trips	7.8	1.4	8.0	1.3	0.94
Total (N)		545		218	

Table 23: Continued

Characteristics	Fampools		Non-fampools		P-Value
	Proportion	Std Error	Proportion	Std Error	
Carpool Trips per Week					
Percentage of trips carpooled	57.1%	7.1%	78.0%	9.0%	0.07**
Total (N)		515		208	
Pay Toll					
Yes	15.7%	3.7%	20.2%	7.2%	0.58
Total (N)		543		205	
Carpool Formation Time					
Average Time (min)	6.4	2.7	6.2	1.2	0.95
Total (N)		414		170	
Age					
From 16 to 24 years old	17.4%	10.2%	11.9%	10.5%	0.71
From 25 to 34 years old	33.3%	8.6%	30.7%	5.1%	0.79
From 35 to 44 years old	22.3%	7.9%	25.1%	8.1%	0.80
From 45 to 54 years old	14.4%	10.2%	22.8%	5.6%	0.47
From 55 to 64 years old	7.9%	7.6%	8.8%	7.7%	0.93
More than 65 years old	4.7%	4.7%	0.7%	0.5%	0.39
Total (N)		555		218	
Gender					
Male	63.6%	10.2%	49.7%	6.3%	0.24
Female	36.4%	10.2%	50.3%	6.3%	0.24
Total (N)		559		213	

Table 23: Continued

Characteristics	Fampools		Non-fampools		P-Value
	Proportion	Std Error	Proportion	Std Error	
Number of Vehicles					
One or None	19.8%	10.4%	28.5%	17.6%	0.67
Two	48.5%	9.9%	35.7%	10.0%	0.36
Three or more	31.7%	6.1%	35.8%	11.7%	0.76
Total (N)		495		201	
Household Type					
Single adult	7.9%	5.6%	25.7%	13.5%	0.22
Unrelated adults (e.g., roommates)	6.1%	4.5%	12.2%	6.1%	0.42
Married without child	25.1%	11.2%	16.6%	9.6%	0.57
Married with child(ren)	47.6%	7.3%	29.2%	15.0%	0.27
Single parent	10.4%	6.7%	12.2%	9.5%	0.88
Other	2.9%	1.1%	4.0%	5.4%	0.85
Total (N)		544		214	
Household Size					
One	4.4%	4.8%	12.3%	5.5%	0.28
Two	30.0%	13.4%	30.1%	7.7%	1.00
Three	27.6%	6.3%	30.3%	10.3%	0.82
Four	23.3%	4.6%	15.3%	7.0%	0.34
Five or more	14.6%	5.0%	12.0%	9.7%	0.81
Total (N)		517		208	

Table 23: Continued

Characteristics	Fampools		Non-fampools		
	Proportion	Std Error	Proportion	Std Error	P-Value
Ethnicity					
Caucasian	39.8%	22.0%	48.4%	14.7%	0.74
Afro-American	15.8%	8.9%	15.6%	10.0%	0.99
Hispanic	31.3%	12.3%	18.8%	9.8%	0.43
Other	13.2%	10.0%	17.1%	5.7%	0.73
Total (N)		546		212	
Income					
Less than $34,999	30.6%	9.3%	38.4%	9.7%	0.56
From $35,000 to $49,999	30.3%	11.6%	18.1%	7.0%	0.37
From $50,000 to $74,999	10.2%	5.8%	13.9%	6.6%	0.67
From $75,000 to $99,999	14.1%	5.0%	13.0%	5.6%	0.88
More than $100,000	14.8%	8.7%	16.6%	11.0%	0.90
Total (N)		516		204	
Road					
Houston: Beltway 8 (only Houston toll road in list)	2.1%	0.9%	0.9%	0.8%	0.99
Houston: All other roads listed	61.7%	16.2%	67.3%	16.7%	0.87
Dallas: George Bush Turnpike and Dallas North Tollway (only Dallas toll roads in list)	3.9%	2.9%	2.4%	4.6%	0.96
Dallas: All other roads listed	26.9%	14.1%	24.5%	16.5%	0.87
No road selected	5.4%	5.5%	4.9%	5.8%	0.95
Total (N)		563		220	

Table 23: Continued

Characteristics	**Fampools**		**Non-fampools**		
	Proportion	**Std Error**	**Proportion**	**Std Error**	**P-Value**
Occupation					
Administrative	17.5%	8.5%	18.1%	6.8%	0.96
Sales, service, manufacturing, student, and self-employed	22.4%	6.3%	26.4%	10.7%	0.75
Stay-home, unemployed, others	19.1%	4.6%	10.4%	7.1%	0.30
Total (N)		552		215	
Education					
High school graduate or less	22.7%	7.8%	23.1%	8.6%	0.97
Some college/Vocational	31.5%	9.2%	34.4%	12.9%	0.85
College graduate	31.7%	5.9%	26.7%	8.7%	0.64
Postgraduate degree	14.1%	12.5%	15.8%	7.6%	0.91
Total (N)		552		214	
Pay to Park at Destination					
Yes	86.8%	3.2%	75.1%	8.6%	0.20
No	13.2%	3.2%	24.9%	8.6%	0.20
Total (N)		562		219	
After Passenger Drop Off					
Driver / Passenger have Same Destination	40.4%	14.4%	57.9%	6.6%	0.27
Continue to Final Destination	44.7%	10.3%	23.2%	5.9%	0.07**
Pick up Additional Passengers	2.3%	2.6%	0.3%	0.4%	0.44
Perform Errands	11.3%	6.9%	18.2%	8.5%	0.53
Other	1.3%	1.5%	0.5%	1.1%	0.66
Total (N)		434		185	

**Significantly different at 10 percent level of confidence

Both fampools and non-fampools were most likely to be on a commute trip. However, the second most popular trip purpose for fampools was recreation and for non-fampools was work. For both groups, carpooling increased with the increased distance. Almost 50 percent of fampools were traveling between 10 to 20 miles each day. On the other hand almost 50 percent of non-fampools were traveling more than 20 miles each day. The average trip distance for fampools was 20.2 miles as compared to 23.4 miles for non-fampools. Fampools were making 7.8 average number of trips per week and non-fampools were making average 8 trips per week. When asked about percentage of carpool trips per week, fampools were formed for almost 57 percent of their total weekly trips and non-fampools were formed for about 78 percent of their total weekly trips. This difference was significant at 10 percent level of confidence. Between 15 to 20 percent of respondents in both the groups were paying a toll on their current trips. The fampools had an average carpool formation time of 6.4 minutes as compared to 6.2 minutes of the non-fampools. Respondents aged between 25 to 34 years were most frequent carpoolers for both fampools and non-fampools. Males and females were equally distributed in non-fampools, but for fampools majority of respondents were males.

The trend observed for the number of vehicles per household was similar for both fampools and non-fampools; the households in both groups were more likely to have two vehicles. For both fampools and non-fampools, respondents were more likely to be married and have children followed by the married without children category. Most of the fampools and non-fampools had household size of either 2 or 3. For both the fampools and non-fampools, the highest proportion of respondents was of Caucasians. The second highest proportion was of Hispanics for both groups. The similar trends were observed for both fampools and non-fampools for the income category with the largest percentage of respondents having an income less than $34,999 per year. There were no particular trends observed for the road, occupation and education category and the responses were quite similar for both the fampools and non-fampools. When asked about paying for the parking at the destination, the majority of the carpoolers in both the groups were paying some amount. Approximately 40 percent of travelers in a fampool and 60 percent of travelers in a non-fampool had the same destinations as other travelers in the vehicle. About 45 percent of fampools and 23 percent of non-fampools continued to their final destination after dropping off the passenger and this difference was significant at a 10 percent level of confidence. Overall, very few significant differences in the two groups were found. Only the number of carpool trips per week and percent continuing on to a final destination were different at a 10 percent level of confidence.

When asked about the interest in using managed lanes, almost 68 percent of fampools and 66 percent of non-fampools showed interest in using managed lanes, this difference was not significant (Table 24).

Table 24: Interest in Using ML by Fampools and Non-fampools

	Fampool		**Non-fampool**		
Interested in using ML	**Proportion**	**Std Error**	**Proportion**	**Std Error**	**P-Value**
Yes	68.2%	4.9%	66.5%	18.9%	0.93
No	31.8%	4.9%	33.5%	18.9%	0.93
Total (N)	525		217		

Respondents were asked to rank different factors encouraging the use of managed lanes. A scale from 1 to 5 was used, with rank 1 as the least important and 5 as the most important factor. Both fampools and non-fampools said “discounted or free off-peak ML trips” was the most important encouraging factor to use managed lanes (Table 25). “Discount for carpoolers” was rated lowest among the all factors by both fampools and non-fampools. There were no significant differences between the groups regarding the factors influencing their use of MLs.

Table 25: Factors Encourage the Use of Managed Lanes for Fampools and Non-fampools

Factor	Fampool			Non-fampool			P-Value
	#Obs	Mean	Std Error	#Obs	Mean	Std Error	
Dynamic tolling	543	3.4	0.2	214	3.2	0.3	0.68
Discount for carpoolers	546	2.4	0.3	218	2.6	0.4	0.72
Discounted/free transit trips	474	3.3	0.4	186	3.4	0.5	0.90
Discounted/free off-peak ML travel	489	3.6	0.3	186	3.7	0.6	0.86

When asked about the reasons for interest in using managed lanes, fampools and non-fampools rated "travel time reliability" as the most important factor at 4.6 and 4.7 respectively (Table 26). The reasons were ranked on a scale from 1 to 5 with 1 as the least important and 5 as the most important factor. "Able to travel faster than GPL" was the second most important reason rated by travelers from both groups for interest in using managed lanes. There were no significant differences between the groups regarding their interest in using MLs.

Table 26: Reasons for Interest in Using Managed Lanes by Fampools and Non-fampools

Factor	Fampool			Non-fampool			P-Value
	#Obs	Mean	Std Error	#Obs	Mean	Std Error	
Able to travel alone and still use ML	352	3.9	0.3	139	4.2	0.2	0.44
Able to travel faster than GPL	348	4.5	0.1	140	4.6	0.1	0.64
Travel time reliability	350	4.6	0.1	135	4.7	0.2	0.56
Able to use carpool on ML	342	3.9	0.3	135	4.3	0.3	0.26
ML not have large trucks	349	4.5	0.2	140	4.3	0.3	0.53
ML less stressful	348	4.4	0.1	140	4.5	0.3	0.74
Other factor	60	4.4	0.4	18	4.7	0.5	0.60

Fampools rated “other” the highest for their disinterest in using the managed lanes, followed by not interested in paying a toll for the use of managed lanes (Table 27). Non-fampools were not interested in using managed lanes because of a toll cost and also because they were not interested in driving alone. The reasons were ranked on a scale from 1 to 5 with 1 as the least important and 5 as the most important factor. There were no significant differences between the two groups found regarding their disinterest in using MLs.

Table 27: Reasons for Disinterest in Using Managed Lanes by Fampools and Non-fampools

Factor	Fampool			Non-fampool			P-Value
	#Obs	Mean	Std Error	#Obs	Mean	Std Error	
Do not have a credit card to establish account	147	2.1	0.6	63	1.7	0.8	0.68
Do not want a toll transponder in my car	149	2.1	0.3	63	2.0	0.6	0.83
ML is complicated or confusing	148	2.4	0.5	63	2.4	0.5	0.94
Flexibility to travel at less congested times	149	2.7	0.5	63	2.9	1.1	0.86
Do not want to pay the toll cost	157	4.1	0.4	66	4.5	0.3	0.43
Carpool will not switch to drive alone	141	2.9	0.5	61	3.5	2.0	0.77
Other factor	33	4.7	0.4	29	2.8	2.3	0.42

Carpoolers were asked about the factors encouraging the formation for their current carpool. Factors were ranked on a scale from 1 to 5, with 1 as the least important and 5 as the most important factor. For fampools, relaxation while traveling was the most important reason and “preferred parking at work” and “encouraged by program at work” were the least important factors in the formation of their current carpool (Table 28). Non-fampools said “access to HOV lanes” was the most important and “drop off kids at school or day care” was the least important reason in the formation of their current carpool. Fampools rated “dropping off kids at school or day care” at 2.9 in comparison to 1.9 by the non-fampools and the difference was significant at 5 percent level of confidence. But non-fampools rated “sharing vehicle expenses” at 3.8 while fampools rated that factor at 3.0, the difference was significant at 5 percent level of confidence.

The other important factors rated by both the groups include “help environment or society”, “travel time savings”, “reliability of arrival time” and “enjoy traveling with others”, however, none of these was significantly different between groups. “Splitting toll on toll roads” was rated relatively lower by respondents from both the groups.

Table 28: Important Factors in the Formation of Current Carpool by Fampools and Non-fampools

	Fampools			Non-fampools			
Factor	**#Obs**	**Mean**	**Std Error**	**#Obs**	**Mean**	**Std Error**	**P-value**
Drop off Kids at School/Day Care	487	2.9	0.4	189	1.9	0.2	0.03*
Access to HOV Lanes	497	3.4	0.4	201	4.0	0.3	0.26
Relaxation while Traveling	80	3.7	0.5	32	3.8	0.8	0.91
Help Environment and Society	488	3.4	0.3	197	3.5	0.4	0.81
Travel Time Saving	497	3.1	0.2	201	3.5	0.3	0.26
Enjoy Travel with Others	507	3.5	0.3	193	3.5	0.3	0.98
Sharing Vehicle Expenses	503	3.0	0.2	211	3.8	0.2	0.01*
Reliability of Arrival Time	462	3.0	0.3	180	3.5	0.2	0.15
Splitting Tolls on Toll Roads	63	2.4	0.6	30	3.1	0.5	0.35
Get Work done while Traveling	84	2.7	0.7	32	2.3	1.1	0.77
Carpool Partner Matching Program	494	2.3	0.2	192	2.3	0.2	0.90
Encouraged by Program at Work	487	2.2	0.3	197	2.3	0.3	0.91
Preferred Parking at Work	492	2.2	0.1	201	2.2	0.3	0.92
Other	69	3.2	0.8	31	3.1	1.4	0.92

* Significantly different at 5 percent level of confidence

Overall, there were few significant differences between fampools and non-fampools. They were:

- Non-fampools were formed more often than fampools
- Fampools continued on to their final destination after dropping off the passenger more often than non-fampools
- Fampools rated “drop off kids at school/ day care” higher than non-fampools
- Non-fampools rated “sharing vehicle expenses” higher than fampools

4.3 Characteristics of Fampools of Adults, Fampools with Child(ren) and Non-fampools

To better understand the characteristics of carpoolers, fampools travelling with children were separated from the adults-only fampools. Detailed descriptive statistics were generated for the fampools of adults, the fampools with child(ren) and the non-fampools (carpools of non-family members), for the same variables as in the previous section. Table 29 provides the detailed results. ANOVA using the summary statistics was used to test any significant differences between the groups as explained in section 3. All the variables are discussed in detail below.

Table 29: Descriptive Statistics of Fampools of Adults, Fampools with Child(ren) and Non-fampools

Characteristics	Fampools of Adults		Fampools with Child(ren)		Non-fampools		P-Value
	Propo-rtion	Std Error	Propo-rtion	Std Error	Propo-rtion	Std Error	
Trip Purpose							
Commute	37.8%	7.8%	56.7%	12.8%	57.4%	13.0%	0.28
Recreational	42.8%	12.6%	28.0%	16.2%	17.2%	11.3%	0.38
Work related	12.4%	9.3%	8.0%	6.8%	21.5%	10.3%	0.71
School	4.2%	4.8%	5.8%	6.1%	0.7%	1.0%	0.81
Other	2.8%	2.5%	1.6%	1.3%	3.2%	3.7%	0.95
Total (N)		418		143		221	
Typical Trip Length							
Short (0-3 miles)	1.7%	2.2%	0.9%	0.7%	1.9%	2.7%	0.97
Medium (4-9 miles)	18.3%	7.5%	16.4%	12.3%	10.2%	9.7%	0.81
Long (10-20 miles)	45.2%	11.7%	57.7%	10.6%	40.3%	10.6%	0.71
Very Long (more than 21miles)	34.8%	8.6%	25.0%	11.5%	47.6%	14.4%	0.48
Total (N)		391		140		214	
Number of Trips per Week							
1 or 2	22.3%	10.6%	3.6%	2.5%	7.3%	5.2%	0.36
From 3 to 5	26.3%	9.2%	37.3%	11.5%	33.0%	11.0%	0.77
From 6 to 9	6.9%	3.0%	9.6%	6.4%	14.9%	7.8%	0.51
10	24.3%	9.3%	29.7%	10.9%	28.9%	7.9%	0.91
more than 10	20.1%	7.2%	19.7%	5.6%	15.8%	11.3%	0.93
Average number of trips	7.7	2.0	8.2	0.8	8.0	1.3	0.99
Total (N)		401		143		218	

Table 29: Continued

Characteristics	Fampools of Adults		Fampools with Child(ren)		Non-fampools		P-Value
	Propo-rtion	Std Error	Propo-rtion	Std Error	Propo-rtion	Std Error	
Carpool Trips per Week							
Percentage of trips carpooled	61.6%	4.9%	44.9%	13.2%	78.0%	9.0%	0.04*
Total (N)		374		141		208	
Pay Toll							
Yes	15.6%	7.5%	16.2%	12.0%	20.2%	7.2%	0.92
Total (N)		403		140		205	
Carpool Formation Time							
Average Time (min)	5.3	2.5	9.1	2.7	6.2	1.2	0.59
Total (N)		296		117		170	
Age							
From 16 to 24 years old	18.5%	13.2%	14.1%	13.5%	11.9%	10.5%	0.94
From 25 to 34 years old	30.1%	11.5%	42.4%	16.8%	30.7%	5.1%	0.80
From 35 to 44 years old	18.5%	7.0%	33.3%	9.6%	25.1%	8.1%	0.49
From 45 to 54 years old	16.3%	8.4%	9.0%	14.2%	22.8%	5.6%	0.69
More than 55 years old	16.6%	15.3%	1.2%	1.1%	9.5%	7.5%	0.79
Total (N)		412		143		218	
Gender							
Male	56.1%	10.8%	85.4%	4.5%	49.7%	6.3%	0.12
Female	43.9%	10.8%	14.6%	4.5%	50.3%	6.3%	0.12
Total (N)		416		143		213	

Table 29: Continued

Characteristics	Fampools of Adults		Fampools with Child(ren)		Non-fampools		P-Value
	Propo-rtion	Std Error	Propo-rtion	Std Error	Propo-rtion	Std Error	
Number of Vehicles							
One or Less	19.9%	11.3%	16.4%	9.4%	29.7%	14.1%	0.87
Two	52.1%	10.9%	44.1%	18.1%	37.3%	14.0%	0.56
Three or more	26.1%	4.5%	39.5%	12.9%	33.0%	5.8%	0.59
Total (N)		410		134		211	
Household Type							
Single adult	9.3%	7.1%	3.5%	5.3%	25.7%	13.5%	0.32
Unrelated adults (e.g., roommates)	7.8%	6.4%	0.8%	1.0%	12.2%	6.1%	0.62
Married without child	28.5%	15.7%	14.8%	13.7%	16.6%	9.6%	0.79
Married with child(ren)	42.8%	7.8%	62.1%	13.0%	29.2%	15.0%	0.24
Single parent	8.8%	8.2%	15.3%	5.1%	12.2%	9.5%	0.89
Other	2.7%	1.2%	3.6%	3.2%	4.0%	5.4%	0.94
Total (N)		410		134		214	
Household Size							
One	5.7%	6.7%	0.5%	0.7%	12.3%	5.5%	0.59
Two	33.8%	18.9%	18.6%	14.0%	30.1%	7.7%	0.87
Three	28.1%	8.9%	26.2%	9.5%	30.3%	10.3%	0.97
Four	20.6%	4.8%	31.8%	17.0%	15.3%	7.0%	0.46
Five or more	11.9%	4.7%	22.9%	9.5%	12.0%	9.7%	0.60
Total (N)		390		127		208	

Table 29: Continued

Characteristics	**Fampools of Adults**		**Fampools with Child(ren)**		**Non-fampools**		**P-Value**
	Propo-rtion	**Std Error**	**Propo rtion**	**Std Error**	**Propo-rtion**	**Std Error**	
Ethnicity							
Caucasian	44.5%	20.3%	26.4%	24.7%	48.4%	14.7%	0.82
Afro-American	12.9%	6.5%	23.9%	16.0%	15.6%	10.0%	0.75
Hispanic	27.5%	9.5%	42.0%	20.0%	18.8%	9.8%	0.53
Other	15.1%	11.1%	7.7%	7.7%	17.1%	5.7%	0.87
Total (N)		403		143		212	
Income							
Less than $34,999	30.8%	9.8%	29.9%	13.1%	38.4%	9.7%	0.85
From $35,000 to $49,999	28.2%	10.9%	36.4%	17.9%	18.1%	7.0%	0.67
From $50,000 to $74,999	10.4%	6.5%	9.6%	7.4%	13.9%	6.6%	0.92
From $75,000 to $99,999	14.8%	5.8%	12.2%	5.1%	13.0%	5.6%	0.96
More than $100,000	15.8%	10.4%	11.9%	6.3%	16.6%	11.0%	0.97
Total (N)		381		135		204	
Occupation							
Professional	30.9%	15.5%	35.7%	8.0%	32.7%	19.9%	0.98
Technical	9.8%	3.5%	6.6%	5.7%	12.5%	5.0%	0.74
Administrative	16.2%	9.2%	21.3%	9.8%	18.1%	6.8%	0.95
Sales, service, manufacturing, student, and self-employed	25.4%	10.7%	13.5%	11.4%	26.4%	10.7%	0.78
Stay-home, unemployed, retired, and others	17.7%	4.6%	23.0%	15.6%	10.4%	7.1%	0.59
Total (N)		411		141		215	

Table 29: Continued

Characteristics	Fampools of Adults		Fampools with Child(ren)		Non-fampools		P-Value
	Propo-rtion	Std Error	Propo-rtion	Std Error	Propo-rtion	Std Error	
Road							
Houston: Beltway 8 (only Houston toll road in list)	2.6%	1.2%	0.6%	0.6%	0.9%	0.8%	0.44
Houston: All other roads listed	56.5%	16.0%	76.9%	17.4%	67.3%	16.7%	0.74
Dallas: George Bush Turnpike and Dallas North Tollway (only Dallas toll roads in list)	3.7%	3.1%	4.5%	3.4%	2.4%	4.6%	0.94
Dallas: All other roads listed	31.0%	14.2%	15.0%	13.1%	24.5%	16.5%	0.81
No road selected	6.3%	6.4%	2.9%	4.8%	4.9%	5.8%	0.95
Total (N)		419		143		220	
Education							
High school graduate or less	23.0%	9.2%	21.8%	11.7%	23.1%	8.6%	1.00
Some college/Vocational	32.3%	11.8%	29.3%	7.5%	34.4%	12.9%	0.97
College graduate	30.1%	6.7%	36.3%	9.1%	26.7%	8.7%	0.79
Postgraduate degree	14.7%	16.0%	12.6%	7.7%	15.8%	7.6%	0.99
Total (N)		411		141		214	

Table 29: Continued

Characteristics	**Fampools of Adults**		**Fampools with Child(ren)**		**Non-fampools**		**P-Value**
	Propo-rtion	**Std Error**	**Propo-rtion**	**Std Error**	**Propo-rtion**	**Std Error**	
Pay to Park at Destination							
Yes	85.0%	4.3%	91.8%	7.1%	75.1%	8.6%	0.27
No	15.0%	4.3%	8.2%	7.1%	24.9%	8.6%	0.27
Total (N)		419		143		219	
After Passenger Drop Off							
Driver / Passenger have Same Destination	48.8%	16.7%	19.2%	8.3%	57.9%	6.6%	0.30
Continue to Final Destination	38.3%	10.2%	60.9%	8.4%	23.2%	5.9%	0.07
Pick up Additional Passengers	3.2%	3.7%	-	-	0.3%	0.4%	0.55
Perform Errands	7.8%	8.4%	19.9%	8.0%	18.2%	8.5%	0.57
Other	1.8%	2.0%	-	-	0.5%	1.1%	0.62
Total (N)	311		123		185		

*difference significant at 5 percent level of confidence

There were almost no significant differences found between the groups. Fampools with adult family members were most often on recreational trips followed by commute trips. Fampools with child(ren) and non-fampools were mostly on commute trips. However, there was not any significant difference found in this category. Fampools with adults only were formed for almost 62 percent of their total weekly trips, fampools with child(ren) were formed for almost 45 percent of their weekly trips and non-fampools were formed for 78 percent of their weekly trips, and this difference was significant at a 5 percent level of confidence. When asked about carpool formation times, fampools with adults reported average carpool formation time of 5.3 minutes, non-fampools reported 6.2 minutes, but fampools with child(ren) reported 9.1 minutes. When analyzed for age, income, type of household, frequently used road type, occupation, number of trips per week and number of vehicles in a household, there were no significant differences between the fampools with adults, the fampools with child(ren) and the non-fampools. As there were almost no significant differences found, it implied that all the groups had similar characteristics.

4.4 Data Analysis of Carpoolers Based on Number of Passengers

To further analyze the characteristics of carpoolers from both the groups, respondents were divided into different subgroups based on their current number of passengers. Fampool and Non-fampool groups were divided into HOV2 and HOV3+ subgroups. Subgroups were examined for statistically significant differences based on their travel characteristics, socio-economic characteristics, and trip end characteristics. Detailed descriptive statistics are summarized in Table 30. ANOVA using the summary statistics was used to test any significant differences between the groups as explained in section 3. There were not any significant differences found but a few interesting results are discussed. Only 6 percent of HOV3+ non-fampools were on a recreational trip as compared to 34.8 percent of HOV2 fampools, 47.5 percent HOV3+ fampools and 21.7 percent of HOV2 non-fampools. Males were dominant in HOV3+ fampools. For all the sub groups travelers were more likely to be married with children, but almost 68 percent of HOV3+ fampools were married with child(ren). Most of the respondents had to pay for parking at the destination except the HOV3+ non-fampools, where respondents who were paying was almost equal to respondents who were not for parking at the destination.

Table 30: Descriptive Statistics of Fampools and Non-fampools Based on Their Number of Passengers

Characteristics	Fampool		Non-Fampool		P-Value
	HOV2	HOV3+	HOV2	HOV3+	
Trip Purpose					
Commute	50.1%	27.6%	54.9%	63.5%	0.27
Recreational	34.8%	47.5%	21.7%	6.0%	0.34
Work related	11.3%	11.2%	20.0%	25.4%	0.80
School	1.6%	10.7%	1.0%	-	0.42
Other	2.2%	3.0%	2.4%	5.1%	0.97
Total (N)	375	186	158	63	
Number of Trips per Week					
1 or 2	17.7%	16.8%	7.0%	8.1%	0.93
From 3 to 5	27.6%	32.6%	35.8%	25.8%	0.95
From 6 to 9	7.5%	7.9%	13.6%	18.3%	0.81
10	28.9%	19.3%	30.3%	25.4%	0.87
more than 10	18.3%	23.4%	13.2%	22.6%	0.90
Total (N)	367	178	157	61	
Typical Trip Length					
Short (0-3 miles)	1.8%	0.8%	2.6%	-	0.92
Medium (4-9 miles)	16.5%	20.4%	14.2%	-	0.92
Long (10-20 miles)	45.0%	56.0%	38.5%	45.0%	0.90
Very Long (more than 21miles)	36.6%	22.8%	44.7%	55.0%	0.65
Average trip distance (miles)	20.5	19.8	22.9	24.8	0.90
Average number of trips	7.6	8.4	7.6	8.9	0.96
Total (N)	362	170	154	60	

Table 30: Continued

Characteristics	Fampool HOV2	Fampool HOV3+	Non-Fampool HOV2	Non-Fampool HOV3+	P-Value
Carpool Trips per Week					
Percentage of trips in a carpool	56.8%	57.7%	75.8%	84.0%	0.39
Total (N)	347	168	152	57	
Pay Toll					
Yes	14.3%	18.7%	16.4%	29.3%	0.84
Total (N)	365	178	145	60	
Carpool Formation Time					
Average Time (min)	4.9	10.1	5.2	8.9	0.43
Total (N)	297	117	125	45	
Age					
From 16 to 24 years old	16.3%	19.4%	12.5%	10.5%	0.99
From 25 to 34 years old	32.9%	33.9%	33.7%	23.1%	0.98
From 35 to 44 years old	16.5%	34.0%	22.5%	31.7%	0.50
From 45 to 54 years old	16.9%	9.5%	22.3%	23.9%	0.92
From 55 to 64 years old	10.7%	2.3%	8.0%	10.8%	0.90
More than 65 years old*	6.6%	0.9%	0.9%	-	0.55
Total (N)	369	186	156	62	
Ethnicity					
Caucasian	50.0%	19.5%	53.6%	35.5%	0.74
Afro-American	12.0%	23.1%	5.6%	40.6%	0.33
Hispanic	22.8%	48.2%	22.3%	10.2%	0.34
Other	15.2%	9.2%	18.5%	13.7%	0.97
Total (N)	363	183	151	61	

Table 30: Continued

Characteristics	Fampool		Non-Fampool		P-Value
	HOV2	HOV3+	HOV2	HOV3+	
Gender					
Male	54.2%	82.6%	45.7%	59.4%	0.10
Female	45.8%	17.4%	54.3%	40.6%	0.10
Total (N)	373	186	151	62	
Household Size					
One	6.5%	0.1%	15.9%	3.3%	0.64
Two	39.7%	9.5%	30.0%	30.5%	0.59
Three	28.4%	25.9%	33.2%	23.0%	0.97
Four	18.6%	33.3%	8.8%	31.3%	0.41
Five or more	6.8%	31.2%	12.0%	11.9%	0.17
Total (N)	351	166	148	60	
Household Type					
Single adult	6.4%	10.9%	25.7%	25.8%	0.36
Unrelated adults (e.g., roommates)	9.1%	-	15.8%	3.1%	0.77
Married without child	33.9%	7.4%	16.4%	17.3%	0.51
Married with child(ren)	37.7%	67.7%	28.3%	31.4%	0.10
Single parent	9.3%	12.8%	9.0%	20.7%	0.89
Other	3.7%	1.2%	4.8%	1.7%	0.95
Total (N)	364	180	154	60	

Table 30: Continued

Characteristics	Fampool		Non-Fampool		P-Value
	HOV2	HOV3+	HOV2	HOV3+	
Number of Vehicles					
One or None	19.4%	20.4%	28.4%	28.7%	0.97
Two	51.1%	43.4%	36.7%	33.1%	0.79
Three or more	29.5%	36.2%	34.9%	38.2%	0.91
Total (N)	375	187	158	63	
Income					
Less than $34,999	23.5%	44.0%	40.6%	32.9%	0.44
From $35,000 to $49,999	29.3%	32.3%	18.1%	18.2%	0.87
From $50,000 to $74,999	10.3%	10.1%	12.7%	17.1%	0.96
From $75,000 to $99,999	18.6%	5.4%	12.1%	15.1%	0.49
More than $100,000*	18.2%	8.2%	16.5%	16.9%	0.93
Total (N)	338	178	147	57	
Pay to Park at Destination					
Yes	86.5%	87.4%	81.8%	57.8%	0.20
No	13.5%	12.6%	18.2%	42.2%	0.20
Total (N)	375	187	158	61	
After Passenger Drop Off					
Driver / Passenger have same destination	47.6%	24.2%	60.3%	51.1%	0.36
Continue to final destination	41.1%	52.9%	19.1%	34.7%	0.22
Pick up additional passengers	0.6%	6.2%	-	1.1%	0.58
Perform errands	8.9%	16.7%	20.3%	12.1%	0.79
Other	1.9%	-	0.3%	1.1%	0.88
Total (N)	300	134	137	48	

When asked about their interest in using managed lanes, 63 to 73 percent of the respondents expressed interest in using them (Table 31). The difference between the groups was not significant.

Table 31: Interest in Using Managed Lanes by Fampools and Non-fampools Based on Their Number of Passengers

Interested in using ML	Fampool		Non-Fampool		P-Value
	HOV2	HOV3+	HOV2	HOV3+	
Yes	70.6%	63.1%	64.0%	72.6%	0.93
No	29.4%	36.9%	36.0%	27.4%	0.93
Total (N)	356	169	153	63	

Respondents from all the sub-groups rated "discounted or free off-peak ML travel" option as the highest factor which would encouraged their use of managed lanes usually followed by discounted or free transit trips (Table 32).

Table 32: Factors That Encourage Use of Managed Lanes for Fampools and Non-fampools Based on Their Number of Passengers

	Fampools				Non-fampools				
	HOV2		HOV3+		HOV2		HOV3+		P-
Factor	#Obs	Mean	#Obs	Mean	#Obs	Mean	#Obs	Mean	Value
Dynamic tolling	369	3.3	175	3.4	152	3.1	62	3.4	0.94
Discount for carpoolers	370	2.3	176	2.6	156	2.6	62	2.5	0.96
Discounted/free transit trips	335	3.2	139	3.5	142	3.3	44	3.7	0.95
Discounted/free off-peak ML travel	344	3.5	145	3.7	142	3.7	44	3.7	0.98

When asked about the reasons for interest in using managed lanes, HOV2 fampools rated “able to travel faster than GPL” as their highest priority at 4.7 followed by travel time reliability at 4.6 (Table 33). HOV3+ fampools were interested in using managed lanes because there were “no large trucks in managed lanes” (rated 4.7). HOV2 non-fampools rated “other” as the highest factor at 4.8 followed by “travel time reliability” at 4.7. HOV3+ non-fampools said “able to travel fast” was the most important reason. HOV2 fampools rated “able to use carpool on ML” lowest among all the factors. HOV3+ fampools rated “able to travel alone and still use ML” lowest. However, no significant differences were found. ANOVA using the summary statistics was used to test any significant differences between the groups as explained in section 3. There was no significant difference found and detailed scores are provided in table 33.

Table 33: Reasons for Interest in Using Managed Lanes by Fampools and Non-fampools Based on Their Number of Passengers

Factors	Fampools				Non-fampools				P-Value
	HOV2		HOV3+		HOV2		HOV3+		
	#Obs	Mean	#Obs	Mean	#Obs	Mean	#Obs	Mean	
Able to travel alone and still use ML	245	3.9	107	3.8	98	4.2	41	4.0	0.94
Able to travel faster than GPL	241	4.7	107	4.2	98	4.5	42	4.8	0.34
Travel time reliability	250	4.6	100	4.5	93	4.7	42	4.7	0.88
Able to use carpool on ML	237	3.8	105	4.0	93	4.2	42	4.7	0.63
ML not have large trucks	244	4.4	105	4.7	98	4.1	42	4.5	0.92
ML less stressful	250	4.4	98	4.6	98	4.5	42	4.7	0.94
Other factor	38	4.3	22	4.5	16	4.8	3	4.0	0.93

Next, reasons why travelers were not interested in using MLs were examined. Both HOV2 fampools and HOV3+ fampools rated “other” highest for not being interested in using managed lanes followed by “disinterest in paying a toll”. Because “other” was so important the text that respondents entered besides “other” was examined. The vast majority of written notes were anti-toll. Both HOV2 non-fampools and HOV 3+ non-fampools were not interested in using managed lanes because of a toll cost. (Table 34).

Table 34: Reasons for Disinterest in Using Managed Lanes of Fampools and Non-fampools Based on Their Number of Passengers

Factors	Fampools				Non-fampools				P-Value
	HOV2		HOV3+		HOV2		HOV3+		
	#Obs	Mean	#Obs	Mean	#Obs	Mean	#Obs	Mean	
Do not have a credit card to establish account	98	2.3	49	1.6	50	1.7	14	1.7	0.95
Do not want a toll transponder in my car	99	2.2	50	2.0	50	1.8	14	2.6	0.93
ML is complicated or confusing	99	2.3	50	2.5	50	2.2	14	3.4	0.88
Flexibility to travel at less congested times	99	2.6	49	3.0	49	2.6	14	4.1	0.83
Do not want to pay the toll cost	103	4.2	54	4.1	51	4.5	15	4.7	0.90
Carpool will not switch to drive alone	96	3.2	45	2.4	49	3.3	12	4.4	0.83
Other factor	24	4.8	10	4.4	24	2.5	5	4.1	0.85

When asked about the important factors which effect the formation of current carpool, there was a significant difference found for “drop off kids at school or day care” at 5 percent level of confidence. Among all sub-groups, HOV3+ fampools rated it highest at 3.7 and HOV2 non-fampools the lowest at 1.9 (table 35). Respondents from all the groups rated “splitting toll on toll roads” and “get work done while traveling” relatively lower in comparison to other reasons asked. HOV 2 fampools rated “sharing vehicle expenses” at 2.7 while HOV3+ fampools rated it at 3.5.

Table 35: Important Factors for Carpool Formation for Fampools and Non-fampools Based on Their Number of Passengers

Factor	Fampools				Non-fampools				P-Value
	HOV2		HOV3+		HOV2		HOV3+		
	#Obs	Mean	#Obs	Mean	#Obs	Mean	#Obs	Mean	
Drop off Kids at School/Day Care	317	2.5	170	3.7	133	1.9	56	2.0	0.03*
Access to HOV Lanes	332	3.5	165	3.2	143	3.9	58	4.3	0.69
Relaxation while Traveling	41	3.9	39	3.6	19	3.2	13	4.7	0.87
Help Environment and Society	324	3.4	163	3.4	138	3.4	58	3.9	0.93
Travel Time Saving	328	3.1	170	3.0	143	3.3	58	4.1	0.47
Enjoy Travel with Others	334	3.4	173	3.6	137	3.4	56	3.6	0.99
Sharing Vehicle Expenses	330	2.7	173	3.5	149	3.7	62	4.1	0.27
Reliability of Arrival Time	319	2.9	143	3.1	133	3.2	48	4.1	0.49
Splitting Tolls on Toll Roads	42	2.2	21	2.7	22	3.3	7	2.6	0.75
Get Work done while Traveling	42	2.6	42	2.8	19	1.4	13	3.6	0.63
Carpool Partner Matching Program	331	2.2	162	2.5	141	2.2	51	2.7	0.79
Encouraged by Program at Work	323	2.1	164	2.5	141	2.3	56	2.3	0.85
Preferred Parking at Work	331	2.0	161	2.5	145	2.1	56	2.4	0.50
Other	37	3.2	32	3.2	27	3.1	3	2.5	1.00

* difference significant at 5 percent level of confidence

To further analyze the behavior of travelers from these four sub-groups, two-way descriptive statistics were developed (Table 36). For this separate tables were generated for a pair of variables for each sub-group and were compared for any significant differences. In almost all of the cases there were no significant differences. In almost all the cases there were no significant differences found.

Table 36: Important Factors for Carpool Formation for Fampools and Non-fampools Based on Their Number of Passengers

Characteristics	Fampool		Non-Fampool		P-Value
	HOV2	HOV3+	HOV2	HOV3+	
Female					
By age					
Age less than 35 years	54.2%	56.6%	45.6%	37.2%	0.97
Age more than 35 years	45.8%	43.4%	54.4%	62.8%	0.98
By ethnicity					
Caucasians	46.5%	14.2%	43.9%	31.8%	0.56
Others	53.5%	85.8%	56.1%	68.2%	0.56
By education					
Some college, vocational degree or less	19.2%	42.6%	31.0%	35.2%	0.47
College graduate of higher degree	80.8%	57.4%	69.0%	64.8%	0.47
Male					
By age					
Age less than 35 years	43.6%	38.4%	49.1%	28.3%	0.99
Age more than 35 years	56.4%	61.6%	50.9%	71.7%	0.99

Table 36: Continued

Characteristics	Fampool HOV2	Fampool HOV3+	Non-Fampool HOV2	Non-Fampool HOV3+	P-Value
Male					
By ethnicity					
Caucasians	50.4%	42.2%	61.4%	39.2%	0.90
Others	49.6%	57.8%	38.6%	60.8%	0.90
By education					
Some college, vocational degree or less	7.0%	35.6%	16.7%	8.6%	0.33
College graduate of higher degree	93.0%	64.4%	83.3%	91.4%	0.32
Interested in using ML					
By education					
Some college, vocational degree or less	12.0%	29.8%	22.1%	27.5%	0.48
College graduate of higher degree	88.0%	70.2%	77.9%	72.5%	0.48
By trip purpose					
Commute	50.7%	33.7%	60.0%	64.3%	0.51
Recreational	35.5%	38.1%	15.6%	5.4%	0.30
Work, school or other	13.7%	28.2%	24.4%	30.3%	0.76
By ethnicity					
Caucasians	52.7%	23.4%	54.1%	34.6%	0.44
Others	47.3%	76.6%	45.9%	65.4%	0.45
Not Interested in using ML					
By education					
Some college, vocational degree or less	7.7%	52.6%	17.5%	14.5%	0.11
College graduate of higher degree	92.3%	47.4%	82.5%	85.5%	0.11

Table 36: Continued

Characteristics	Fampool		Non-Fampool		P-Value
	HOV2	HOV3+	HOV2	HOV3+	
Not Interested in using ML					
By trip purpose					
Commute	53.6%	24.6%	50.0%	61.1%	0.83
Recreational	32.4%	47.3%	34.2%	7.7%	0.93
Work, school or other	14.1%	28.1%	15.8%	31.2%	0.88
Not Interested in using ML					
By ethnicity					
Caucasians	42.2%	17.4%	50.5%	33.0%	0.85
Others	57.8%	82.6%	49.5%	67.0%	0.85
Not paying any toll for current trips					
By trip purpose					
Commute	51.6%	25.0%	49.3%	69.8%	0.33
Recreational	34.7%	46.5%	27.1%	1.2%	0.64
Work, school or other	13.7%	28.5%	23.6%	29.0%	0.82
By household income					
Household income less than 35,000	33.2%	61.0%	46.2%	13.9%	0.89
Household income between 35,000 and 75,000	25.9%	21.5%	24.4%	31.0%	1.00
Household income more than 75,000	40.9%	17.5%	29.4%	55.0%	0.97
By gender					
Female	52.7%	83.4%	44.1%	55.0%	0.20
Male	47.3%	16.6%	55.9%	45.0%	0.20

Table 36: Continued

Characteristics	Fampool		Non-Fampool		P-Value
	HOV2	HOV3+	HOV2	HOV3+	
Not paying any toll for current trips					
By education					
Some college, vocational degree or less	10.5%	44.1%	25.5%	25.3%	0.08**
College graduate of higher degree	89.5%	55.9%	74.5%	74.7%	0.08**
By interest in ML					
Interested in using ML	69.9%	59.9%	63.3%	68.0%	0.95
Not Interested in using ML	30.1%	40.1%	36.7%	32.0%	0.95
Paying any toll for current trips					
By trip purpose					
Commute	41.1%	30.3%	69.6%	56.0%	0.75
Recreational	32.4%	53.8%	5.9%	4.6%	0.22
Work, school or other	26.5%	15.9%	24.5%	39.4%	0.88
By household income					
Household income less than 35,000	29.0%	58.5%	30.8%	58.6%	0.90
Household income between 35,000 and 75,000	18.5%	25.1%	19.2%	36.0%	0.98
Household income more than 75,000	52.5%	16.4%	50.0%	5.4%	0.89
By gender					
Female	64.5%	79.6%	64.8%	65.6%	0.93
Male	35.5%	20.4%	35.2%	34.4%	0.94
By education					
Some college, vocational degree or less	34.5%	40.5%	18.9%	26.1%	0.96
College graduate of higher degree	65.5%	59.5%	81.1%	73.9%	0.97

Table 36: Continued

Characteristics	Fampool		Non-Fampool		P-Value
	HOV2	HOV3+	HOV2	HOV3+	
Paying any toll for current trips					
By interest in ML					
Interested in using ML	77.7%	78.2%	87.8%	78.9%	0.98
Not Interested in using ML	22.3%	21.8%	12.2%	21.1%	0.97
Income By Age					
Household income less than 35,000					
Age less than 35 years	73.7%	52.2%	64.0%	49.1%	0.68
Age more than 35 years	26.3%	47.8%	36.0%	50.9%	0.69
Household income between 35,000 and 75,000					
Age less than 35 years	54.8%	60.7%	32.0%	26.3%	0.64
Age more than 35 years	45.2%	39.3%	68.0%	73.7%	0.64
Household income more than 75,000					
Age less than 35 years	28.2%	46.7%	31.1%	27.2%	0.98
Age more than 35 years	71.8%	53.3%	68.9%	72.8%	0.97
Education By Income					
Some college, vocational degree or less					
Household income less than 35,000	71.5%	78.0%	68.2%	64.9%	0.99
Household income between 35,000 and 75,000	7.9%	14.6%	23.6%	6.9%	0.82
Household income more than 75,000	20.5%	7.4%	8.2%	28.2%	0.99

Table 36: Continued

Characteristics	Fampools		Non-fampools		P-value
	HOV2	HOV3+	HOV2	HOV3+	
College graduate of higher degree					
Household income less than 35,000	26.4%	45.9%	39.5%	20.1%	0.94
Household income between 35,000 and 75,000	27.7%	32.2%	21.8%	41.6%	0.98
Household income more than 75,000	45.9%	21.8%	38.7%	38.3%	0.98

** different at 10 percent level of significance

4.5 Katy Freeway Survey Data Analysis

The data from another survey for the Katy Freeway travelers was analyzed to compare the results from this analysis. The details descriptive statistics were developed for the travel and socio-economic characteristics. The analysis was done using the un-weighted survey data. It was found that fampools and non-fampools were very similar among all the variables tested (Table 37). Hence, it verifies the finding of this research.

Table 37: Descriptive Statistics for the Katy Freeway Survey Data

Characteristic	Fampool	Non-fampool
Trip Purpose		
Commute	72.7%	92.4%
Recreational	6.6%	0.7%
Work related	5.9%	2.8%
School	8.0%	3.1%
Other	6.9%	1.0%
Age		
From 16 to 24 years old	3.2%	2.1%
From 25 to 34 years old	23.4%	17.5%
From 35 to 44 years old	29.9%	34.6%
From 45 to 54 years old	28.1%	30.4%
From 55 to 64 years old	10.1%	12.9%
More than 65 years old	5.4%	2.4%
Gender		
Female	54.0%	43.5%
male	46.0%	56.5%
Household Type		
Single adult	3.3%	10.2%
Unrelated adults (e.g., roommates)	1.8%	3.5%
Married without child	28.6%	21.1%
Married with child(ren)	57.2%	56.5%
Single parent	5.1%	4.2%
Other	4.0%	4.6%
Household Size		
One	2.6%	8.9%
Two	31.9%	31.9%
Three	22.3%	20.2%
Four	23.4%	25.5%
Five or more	19.8%	13.5%

Table 37: Continued

Characteristic	Fampool	Non-fampool
Number of Vehicles		
One or None	9.1%	10.5%
Two	60.1%	57.0%
Three or more	30.8%	32.5%
Education		
High school graduate or less	7.6%	7.1%
Some college/Vocational	22.7%	19.8%
College graduate	45.3%	45.2%
Postgraduate degree	24.5%	27.9%
Income		
Less than $34,999	7.8%	5.4%
From $35,000 to $49,999	9.5%	7.7%
From $50,000 to $74,999	16.9%	16.2%
From $75,000 to $99,999	18.5%	23.2%
More than $100,000*	47.3%	47.5%
Intersted in using QR		
No	69.9%	70.6%
Yes	30.1%	29.4%

4.6 Summary

Section 4 summarized the descriptive statistics developed for different carpool groups using replicate weights. Fampools and non-fampools were examined based on their travel characteristics, interest in managed lanes, and socio economic characteristics to find any differences between them. Non-fampools were formed for almost 78 percent of their weekly trips and fampools were formed for almost 57 percent of their weekly trips. This difference was significant at 10 percent level of confidence. Almost 68 percent of fampools and 66 percent of non-fampools expressed interest in using the managed lanes. Both fampools and non-fampools said "discounted or free off-peak ML trips" encouraged them most to use the managed lanes. Both fampools and non-fampools rated "travel time reliability" as most important for their interest in using the managed lanes. Fampools rated "dropping off kids at school/day care" higher than non-fampools but non-fampools rated "sharing vehicle expenses" higher than fampools as important reasons for the formation of their current carpool. These differences were significant at 5 percent level of significance. No other significant differences were found for all the variables tested.

Fampools were split into two groups to examine if fampools with child(ren) were different from the fampools comprised of adults or non-fampools. Non-fampools were formed for 78 percent of total weekly trips, fampools with adult were formed for around 62 percent of their total weekly trips, and fampools with child were formed for only 45 percent of their total weekly trips. This difference was significant at 5 percent level of confidence. Fampools of adults reported 5.3 minutes of carpool formation of time in comparison to the 6.2 minutes of non-fampools and 9.1 minutes of the fampools with child, however this difference was not significant.

Fampool and non-fampool carpoolers were split further into sub-groups based on their current number of passengers. Both HOV2 fampools and HOV3+ fampools rated "other" as highest factor for not being interested in using the managed lanes, it was mainly related to anti-toll reasons. Both HOV2 non-fampools and HOV 3+ non-fampools were not interested in using the managed lanes because of a toll cost. When asked about the important factors for the formation of their current carpool, the importance of "drop off kids at school or day care" was significantly different at 5 percent level of significance. Among all sub-groups, HOV3+ fampools rated it highest at 3.7 and HOV2 non-fampools the lowest at 1.9. No other significant differences in overall rating between the groups were found. In the final step, two-way descriptive statistics were developed for all the four sub-groups. Almost no significant difference was found for all the other variables tested.

There were almost no significant differences found in all the variables tested. Using the descriptive statistics very little can be deduced about the reasons for the mode switching by different groups of carpoolers. There were many similarities between the fampools and non-fampools but very few differences. To summarize the finding it was found that fampools were formed less often in comparison to non-fampools. To "drop off kids at school or day care" was more important reason for fampools in comparison to non-fampools for their current carpool formation. But "sharing vehicle expenses" was more important to the non-fampools for their current carpool formation. Overall, there were almost no statistical significant differences found. Also the observed differences did not provide sufficient information to conclude any specific reasons for the mode switching by different groups of carpoolers. The next section discusses the mode choice of different carpool groups under different travel scenarios on the managed lanes.

5. MODE CHOICE MODELING

The first part of this section describes the mode choice models estimated using random parameter logit modeling. The second part of this section uses these mode choice models to estimate the percentage of travelers interested in driving alone, carpooling with a passenger, or carpooling with more than one passenger on the managed lanes or the general purpose lanes.

Fampool and non-fampool carpool respondents were divided into sub-groups based on their number of passengers as noted in the revealed preference section of the survey (section 3.1). Four sub-groups were formed as HOV2 fampools, HOV3+ fampools, HOV2 non-fampools and HOV3+ non-fampools. The details of how carpool respondents indicated they would switch modes in the stated preference questions were analyzed. First, the percentage of respondents in each group who switch modes was calculated (Table 38).

Table 38: Mode Choice of Respondents in the Stated Preference Section of the Survey

Current Mode	SOV ML	HOV2 ML	HOV3+ ML	SOV GPL	HOV2 GPL	HOV3+ GPL	Total
HOV2 Fampools	11.8%	37.1%	8.7%	17.1%	23.6%	1.7%	100.0%
HOV3+ Fampools	10.8%	12.6%	30.3%	30.3%	5.5%	10.4%	100.0%
HOV2 Non-fampools	12.8%	37.1%	5.3%	19.3%	20.6%	5.0%	100.0%
HOV3+ Non-fampools	5.4%	8.4%	41.8%	19.2%	9.2%	15.9%	100.0%
Total	11.3%	29.1%	15.7%	20.7%	17.7%	5.5%	100.0%

A small percentage of respondents in all four groups were choosing SOV in ML. HOV2 fampools were most likely to choose HOV2 in ML followed by HOV2 in GPL. HOV3+

fampools were equally likely to choose among HOV3+ in ML and SOV in GPL (30.3 percent). Only 10.8 percent of HOV3+ fampools were likely to choose SOV in ML. It complements the findings from the section 4, where HOV3+ fampools rated “able to travel alone and still use ML” lowest when asked about the reason for their interest in using the managed lanes. They were not interested in using the managed lanes because of a toll cost. HOV2 non-fampools were most likely to choose HOV2 in ML followed by HOV2 in GPL. Most of the HOV3+ non-fampools preferred HOV3+ in ML (41.8 percent) followed by SOV in GPL (19.2 percent). Except HOV3+ fampools, most of the respondents stuck to their current number of passengers. About 56 percent of the total respondents chose modes in managed lanes, and almost 29 percent among them were the HOV2s, followed by the HOV3+s and lastly SOVs.

Using the survey data for the same group of respondents, logit models were developed to predict traveler responses to the GPL and ML options. In the first step, a pooled multinomial logit model was developed for both the fampool and the non-fampool respondents. Different variables were used as dummy variables in the model built to predict mode use of the six options given in the stated preference section of the survey. These options were:

1. SOV on the MLs
2. HOV2 on the MLs
3. HOV3+ on the MLs
4. SOV on the GPLs
5. HOV2 on the GPLs
6. HOV3+ on the GPLs

In the second step, two different random parameter logit model with randomization of cost and travel time variables were developed one each for the fampool and non-fampool respondents. A market segmentation approach was used to decide between the pooled model and two separate models for the fampools and non-fampools. This was tested using equation (13).

$$-2 \times \left[\ell(\beta) - \sum_{s}^{S} \ell(\beta_s) \right] \geq \chi^2_{n,(p)} \quad (13)$$

where,

$\ell(\beta)$ is the log - likelihood for the pooled model,

$\ell(\beta_s)$ is the log - likelihood of the model estimated with sth market segment,

χ^2_n is the chi - square distribution with n degrees on freedom,

n is equal to number of restrictions, $\sum_{s=1}^{S} K_s - K$

K is the number of coefficients in the pooled model, and

K_s is the number of coefficients in the sth market segment model.

According to this approach, the null hypothesis, that all segments have the same choice function, is rejected when $\chi^2_n > \chi^2_{\text{critical}}$ (Koppelman and Bhat, 2006).

Detailed Calculations are shown in Table 39. At the 5 percent level of confidence, the test statistic was greater than the critical chi-square value. Therefore, we rejected the null hypothesis that all the segments had same choice function. Hence, two separate models were better representative of the mode choice of the fampools (section 5.1) and non-fampools (section 5.2).

Table 39: Test Statistics for the Pooled, Fampool and Non-fampool Models

	Pooled Model	Fampool Model	Non-fampool Model
Log likelihood function	-4010.35	-2496.2	-1060.1
Number of parameters	16	17	21
Degree of freedom (n)	23		
Test statistics	908.2		
χ_n^2 (n=22, p=0.05)	33.9		

5.1 Mode Choice Model for the Fampools

The third objective of this research was to develop the mode choice models to better understand the factors influencing the mode choice of carpoolers. To accomplish this objective, a random parameter logit model was estimated using Nlogit (Nlogit, 2009). Various utility equations with different variables were tested. The utility functions given in Table 40 were found to have best fit and explanatory ability. Driving alone on GPL was the base mode. The mode choices included: drive alone in a managed lane, drive with one passenger in a managed lane, drive with two or more passengers in a managed lane, drive alone in a general purpose lane, drive with one passenger in a general purpose lane, and drive with two or more passengers in a general purpose lane.

Table 40: Random Parameter Logit Model for Fampools

Mode	Variable	Coefficient	P-Value
All	Travel Time (min)	-0.039	0.00
	Toll Cost ($)	-0.106	0.01
SOV on the MLs	Alternative Specific Coefficient	-0.815	0.00
	On a Commute Trip	-0.921	0.00
	Paying a Toll for Current Trips	1.087	0.00
HOV2 on the MLs	Alternative Specific Coefficient	0.365	0.00
	On a Work Trip	-0.536	0.01
	Household Income between $35,000 and $50,000	-0.507	0.00
	Education: Post Graduate Degree	-0.547	0.00
HOV3+ on the MLs	Alternative Specific Coefficient	-0.886	0.00
	Household Income between $15,000 and $25,000	2.792	0.00
	Traveling in Evening Peak	0.476	0.00
SOV on the GPLs	Base Mode		
HOV2 on the GPLs	Alternative Specific Coefficient	0.270	0.01
	Ethnicity: Hispanic	-1.742	0.00
	Married with No Child(ren)	0.727	0.00
HOV3+ on the GPLs	Alternative Specific Coefficient	-1.041	0.00
	Education: Post Graduate Degree	-1.743	0.01
Standard Deviation	Travel Time (min)	0.012	0.00
	Toll Cost ($)	0.019	0.01
Summary			
Number of Observations		1887	
Log Likelihood		-2496	
$\bar{\rho}^2$		0.17	
Percent Estimated Correctly		24.4%	

All the variables were significant at the 5 percent confidence level (Table 40). Apart from the statistical significance of each variable in the model, each coefficient was examined for its sign and magnitude. A negative coefficient for a variable for a particular mode indicates that particular coefficient's impact is to lessen the likelihood of a traveler using that mode. A positive coefficient for a variable for a particular mode will make it more likely a traveler will use the mode. Coefficients of time and cost were negative, indicating that an increase in cost and time lead to decreasing utility of using the mode. Travelers who were paying a toll for their current trips were more likely to travel as a SOV on MLs. Travelers on a commute trip were less likely to choose SOV in MLs. Travelers on a work trip were less likely to travel as a HOV2 carpool in MLs. Travelers with household income between $35,000 and $50,000 were less likely to travel as a HOV2 carpool in MLs, but travelers with household income between $15,000 and $25,000 were more likely to travel as a HOV3+ carpool in managed lanes. It was interesting to note that the travelers who were married with no children were more likely to use the HOV2 carpool option in GPLs. All the parameters used in the model were justified based on their statistical and physical significance. The overall model provided an acceptable adjusted ρ^2 value of 0.17.

5.1.1 Value of Travel Time Savings for Fampools

If in the logit model, the two parameters used in deriving measures of value of travel time savings (VTTS) are estimated using non-random parameters, then VTTS can be calculated by diving the time coefficient by the cost coefficient. If, however, one or more of the parameters used in calculating VTTS are estimated as random parameters, then VTTS calculations must take that randomness into account. For this, random draws are taken for both cost and travel time using the statistical distributions used to randomize these parameters and VTTS is calculated for each individual, and then using those individual VTTS values, a final distribution is obtained with a fixed mean and standard deviation (Hensher and Green, 2003; Hensher et al., 2005).

Another important point to note is that using this method there is a possibility of obtaining negative VTTS. This happens due to the use of an unconstrained distribution to calculate VTTS from the conditional parameter estimates. Negative VTTS implies individuals require payment to save travel time as opposed to their being willing to pay to save travel time. It is unlikely to have such situations in a real life. The negative VTTS values can be avoided by putting a constraint on the standard deviation while estimating the random parameters in the model (Hensher and Green, 2003). However, the literature does not report any good criteria or range of values to constrain the random parameters.

For the random parameter model estimated for the fampools shown in Table 40, both travel time and cost parameters were randomized using the normal distribution. Several other distributions were also tested but the normal distribution showed the best fit. To avoid any negative VTTS values, standard deviation for the travel time coefficient was constrained to the 18 percent of the mean (i.e. standard deviation = 0.18 times mean of the coefficient of the travel time) and for the cost coefficient it was constrained to the 30 percent of the mean (i.e. standard deviation = 0.3 times mean of the coefficient of the cost). These values were selected after several iterations so as to reduce number of negative VTTS values. The VTTS was calculated for all the individuals as described above and the following distribution was obtained (Figure 7).

There was one negative VTTS value out of 1887 total values, and that was removed prior to fitting any statistical distribution. Several statistical distributions including normal, lognormal and weibull were tested, Weibull distribution showed the best fit and was significant at 95 percent confidence level. Equation (14) gives the details of weibull distribution and the estimates are provided in Table 41. The estimated VTTS was $ 22.8 per hour for the fampools.

$$f(x;\lambda,k)=\begin{cases}\frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k} & x\geq 0\\ 0 & x<0\end{cases} \tag{14}$$

where, $k > 0$ is the *shape parameter* and $\lambda > 0$ is the *scale parameter* of the distribution (Menon, 1963).

Table 41: Estimates of the Weibull Distribution for the VTTS of the Fampools

Type	Parameter	Estimate
Scale	λ	25.55
Shape	*k*	2.9
Mean VTTS ($/hour)	22.8	
Std. Deviation VTTS ($/hour)	8.07	
Maximum VTTS ($/hour)	121.1	
Minimum VTTS ($/hour)	0.05	

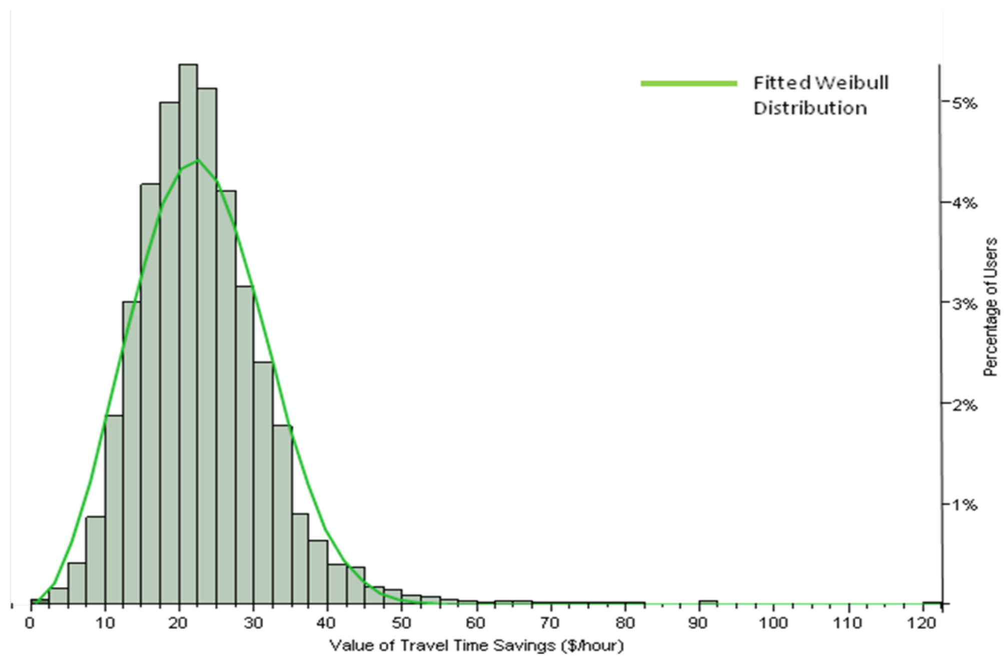

Figure 7: Distribution of VTTS with Fitted Weibull Distribution for Fampools

5.2 Mode Choice Model for the Non-fampools

Similar to the development of the fampool mode choice model, a random parameter logit model was developed for the non-fampools. Similar to the fampool mode choicemodel, the cost coefficient was constrained to the 30 percent of the mean (i.e. standard deviation = 0.3 times mean of the coefficient of the cost). All the variables used in the non-fampool model were significant at the 5 percent confidence level (Table 42). The cost coefficient was negative, indicating that an increase in cost led to decreasing utility of using the mode. Travelers that were making 1, 2 or 6 to 9 weekly trips were more likely to drive alone in the MLs. Travelers with an annual household income between $35,000 and $50,000 were less likely to travel as a HOV3+ in the MLs. Travelers that were married with no children were less likely to travel as a HOV2 carpool in MLs. All the parameters used in the model were justified based on their statistical and physical significance. The overall model provided an acceptable adjustable ρ^2 value of 0.18. Travelers on a work trip were less likely to choose HOV2 carpool in the MLs but were more likely to travel as a HOV3+ carpool in ML. Travelers on a commute trip, recreational trip or work trip were less likely to travel as a HOV3+ carpool in GPLs. It was interesting to note that time was not a significant variable in this model. It implied non-fampools were not sensitive to the time. It is discussed in more detail below.

Table 42: Random Parameter Logit Model for Non-fampools

Mode	Variable	Coefficient	P-Value
All	Toll Cost ($)	-0.104	0.01
SOV on the MLs	Alternative Specific Coefficient	-0.772	0.00
	Number of Weekly Trips between 6 to 9	1.906	0.00
	Number of Weekly Trips between 1 to 2	1.488	0.00
HOV2 on the MLs	Alternative Specific Coefficient	1.933	0.00
	On a Work Trip	-1.498	0.00
	Household Type: Married with No Children	-1.207	0.00
	Trip Distance	-0.052	0.00
HOV3+ on the MLs	Alternative Specific Coefficient	-1.241	0.00
	Household Income between $35,000 and $50,000	-2.047	0.00
	Traveling in Evening Peak	1.442	0.00
	On a Work Trip	1.387	0.00
SOV on the GPLs	Base Mode		
HOV2 on the GPLs	Alternative Specific Coefficient	-0.473	0.01
	Household Type: Married with Children	0.590	0.01
	Number of Weekly Trips between 3 to 5	0.518	0.02
HOV3+ on the GPLs	Alternative Specific Coefficient	1.863	0.00
	On a Commute Trip	-3.073	0.00
	On a Recreational Trip	-2.901	0.00
	On a Work Trip	-2.197	0.00
	Household Income between $35,000 and $50,000	-1.770	0.00
Standard Deviation	Toll Cost ($)	0.031	0.01
Summary			
Number of Observations		769	
Log Likelihood		-1060	
$\bar{\rho}^2$		0.18	
Percent Estimated Correctly		24.3%	

As time was not a significant variable, according to the mode choice model in Table 42, any changes in travel time did not impact the mode choice of fampools. To investigate this unusual result the survey data was analyzed further. Data was analyzed based on the mode choice by the non-fampools in the stated preference section of the survey and travel time savings offered by the managed lanes for a specific toll cost. It was found that even with the large travel time savings non-fampools were equally likely to choose between MLs and GPLs (Figure 8). When mode choice of non-fampool was analyzed based on the travel time savings, it was found that percentage of respondents choosing MLs and GPLs were very close for all the travel time savings (Figure 9). It confirmed that non-fampools were not sensitive to the time and were equally likely to choose between MLs and GPL. The findings from section 4 also confirm that non-fampools were more sensitive to the price in comparison to the fampools.

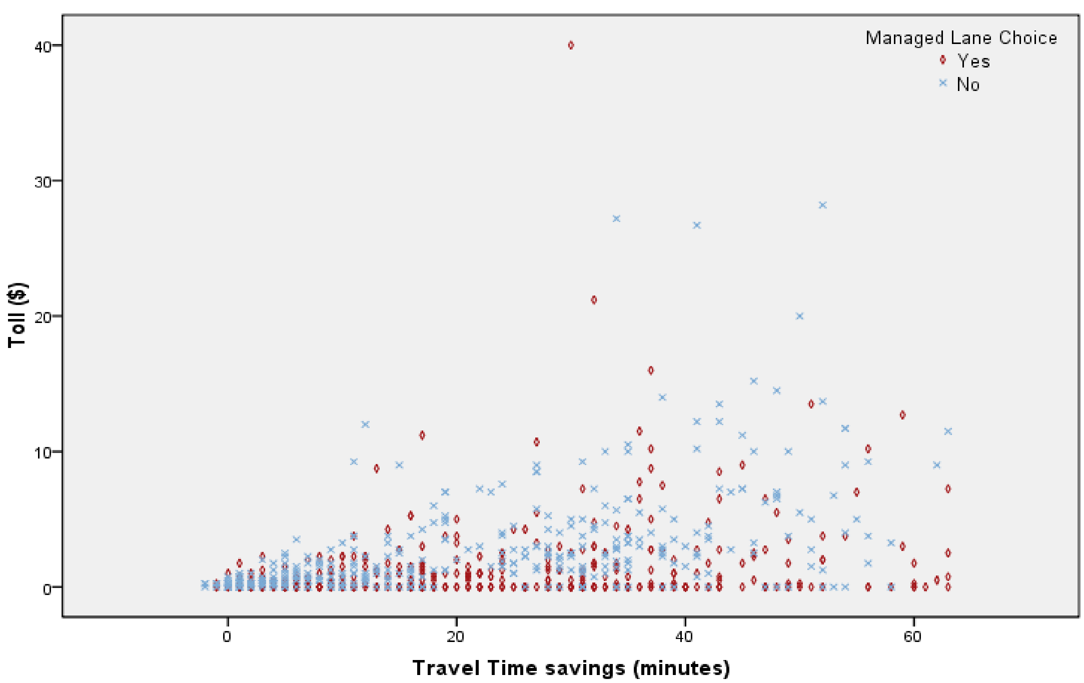

Figure 8: Mode Choice of Non-fampools

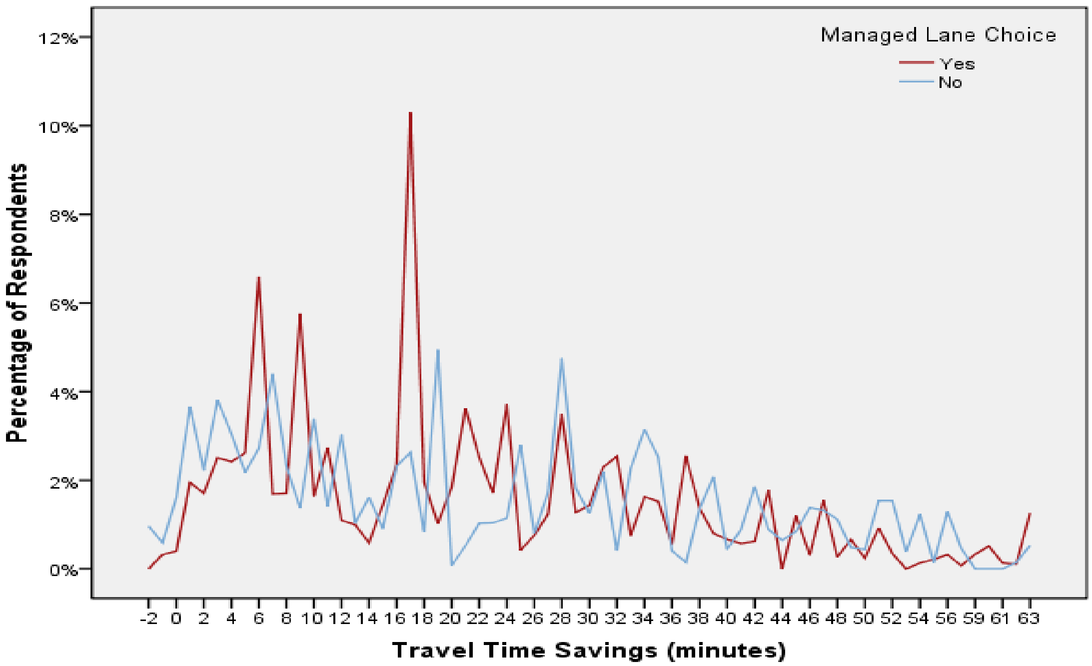

Figure 9: Mode Choice of Non-fampools Based on Travel Time Savings

5.3 Simulation Results for the Fampools and Non-fampools

The mode choice models described in the previous section were used to estimate the percentage of travelers willing to use managed lanes under realistic toll and travel time savings scenarios. The main focus was on to analyze any mode switching by different carpoolers.

The simulation had to include several assumptions:

1. The trip length was assumed to be 10 miles
2. The managed lane speed was assumed to be 65 mph
3. The speed on general purpose lanes was assumed to be 40 mph
4. Toll was varied between $0 and $5 in increments of $0.5

5. Total travel time was the combined time of the actual travel time plus carpool formation time

5.3.1 Carpool Formation Time

The time required to pick up and drop off the passenger was calculated from the reported carpool formation time by the respondents in the survey. There were some respondents who reported exceptionally high carpool formation times. After the analysis, it was concluded that the survey question wasn't properly understood by some of the respondents. The highest reported carpool formation time was 90 minutes. The responses were removed for the HOV2 carpoolers that reported carpool formation time of greater than 20 minutes and for HOV3+ carpoolers that reported carpool formation time of greater than 30 minutes. A total of 25 (weighted) cases were removed for the HOV2s out of 422 (weighted) responses. In addition 18 (weighted) responses out of 162 (weighted) responses were removed for the HOV3+s. Figures 10 and 11 provide the detailed carpool formation time reported by the respondents. HOV2s reported an average carpool formation time of 5.0 minutes and HOV3+s reported an average carpool formation time of 9.8 minutes. This time was added to the actual travel time to get the total travel time for the simulations.

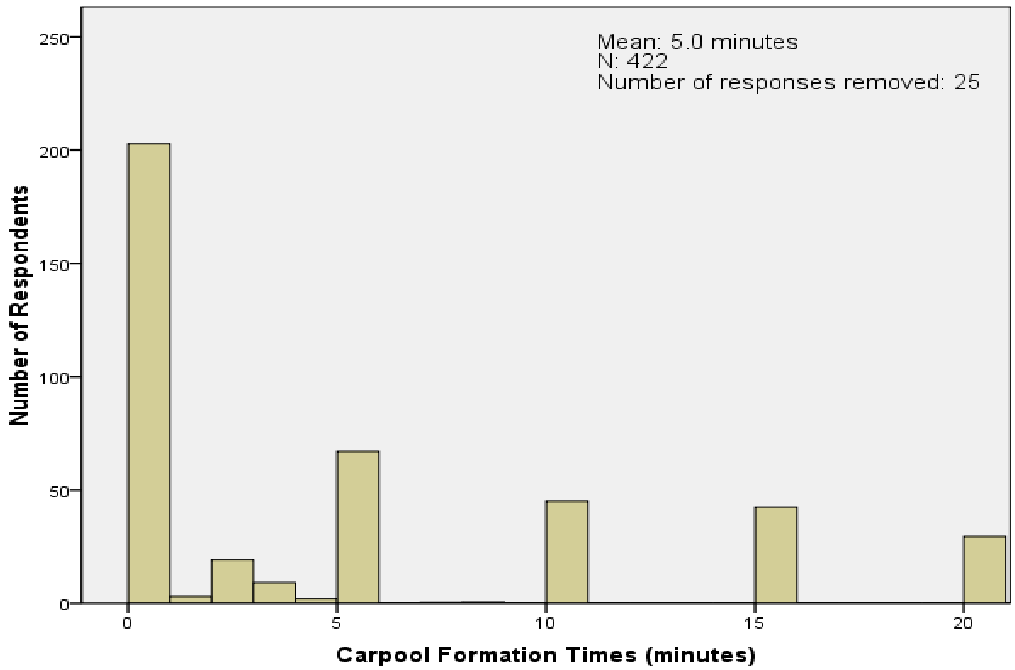

Figure 10: Carpool Formation Time Reported by the HOV2s

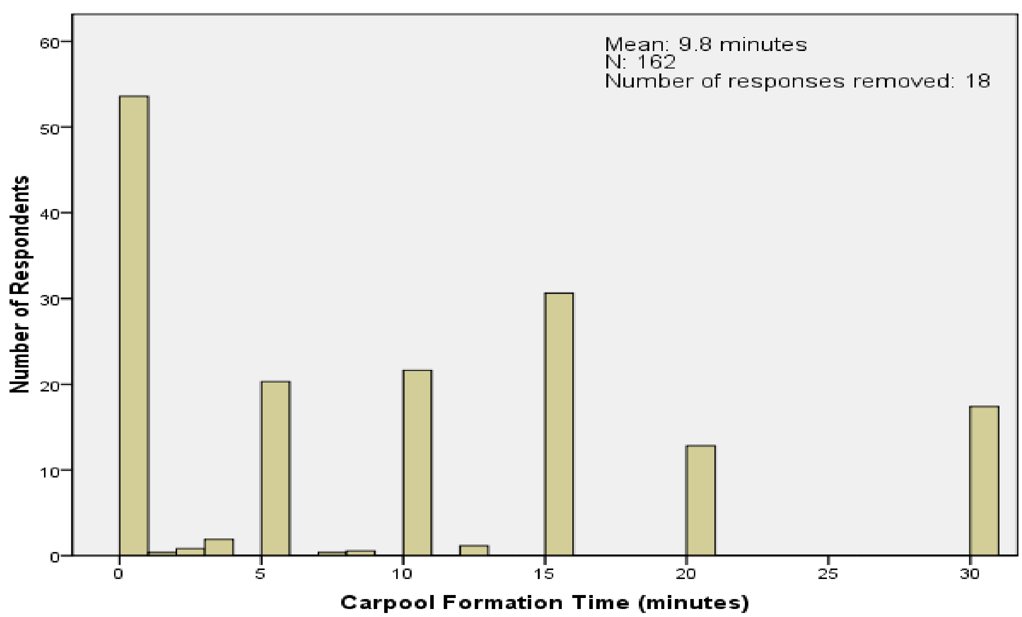

Figure 11: Carpool Formation Time Reported by the HOV3+s

5.3.2 Simulated Results for the Fampools

Three different scenarios were simulated for the fampools. In the first scenario, the SOV toll was varied from the $0.50 to $5.00, the HOV2 toll was kept at half of the SOV toll, and HOV3+ were allowed to travel for free. As the toll was increased from $0.50 to $5.00, SOV on ML mode users decreased by 3.7 percent and HOV2s on the ML decreased by 3.1 percent, but there was an increase of 1.1 percent for HOV3s on the ML (Figure 12, Table 43). The highest increase was observed for the HOV2 travelers on GPL, there was a 2.8 percent increase in this group. The overall percentage of carpoolers went up by 1.2 percent as the SOV toll increased from the $0.50 to $5.00.

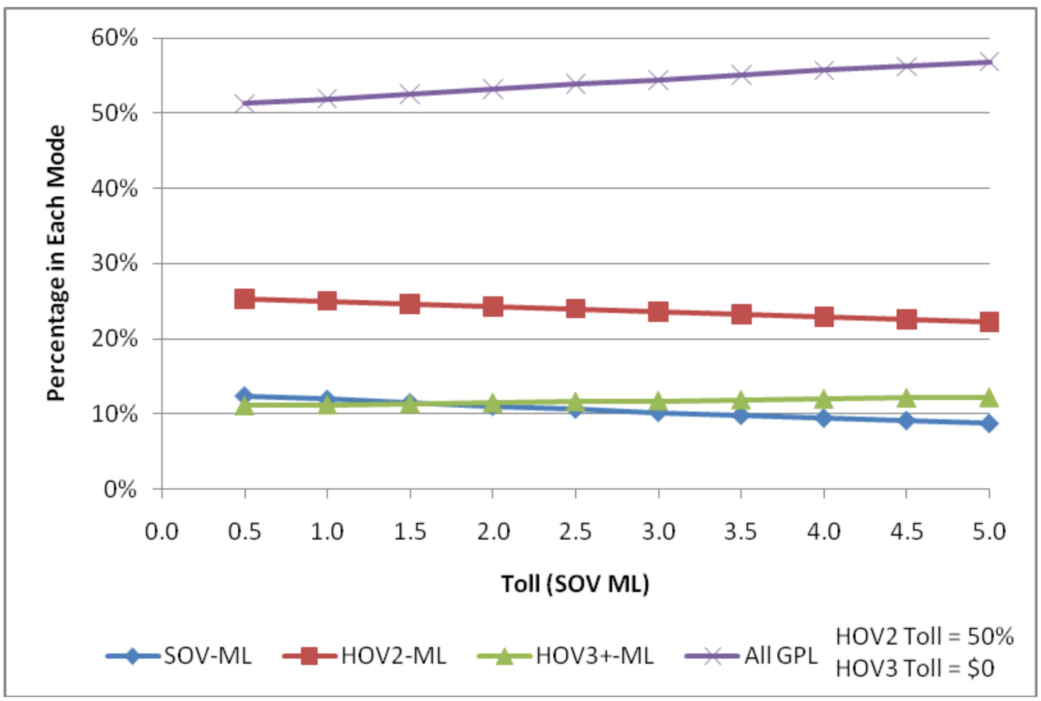

Figure 12: Mode Choice of Fampools: Scenario 1

Table 43: Mode Choice of Fampools: Scenario 1

Toll (SOV-ML)	ML			GPL			Total HOV
	SOV	HOV2	HOV3+	SOV	HOV2	HOV3+	
$0.50	12.4%	25.3%	11.1%	21.3%	25.8%	4.2%	66.4%
$1.00	11.9%	25.0%	11.2%	21.5%	26.2%	4.2%	66.6%
$1.50	11.5%	24.6%	11.3%	21.8%	26.5%	4.2%	66.7%
$2.00	11.0%	24.3%	11.5%	22.1%	26.8%	4.3%	66.9%
$2.50	10.6%	24.0%	11.6%	22.4%	27.1%	4.4%	67.1%
$3.00	10.2%	23.6%	11.7%	22.6%	27.4%	4.4%	67.1%
$3.50	9.8%	23.3%	11.9%	22.9%	27.7%	4.5%	67.3%
$4.00	9.4%	22.9%	12.0%	23.1%	28.0%	4.6%	67.5%
$4.50	9.1%	22.6%	12.1%	23.4%	28.3%	4.6%	67.5%
$5.00	8.7%	22.2%	12.2%	23.7%	28.6%	4.6%	67.6%

In the second scenario, the SOV toll on the managed lanes was kept constant at $5 but the HOV2 toll on the managed lanes varied from $0.00 to 4.50. HOV3+s were still allowed to use the managed lanes for free. With the increased toll, travelers in HOV2 mode on ML decreased (by 8.1 percent), while all other modes increased (Figure 13, Table 44). SOVs on the MLs increased by 0.9 percent. The highest increase was observed for HOV2s on GPL with 2.9 percent. The overall percentage of HOVs went down by 3.5 percent.

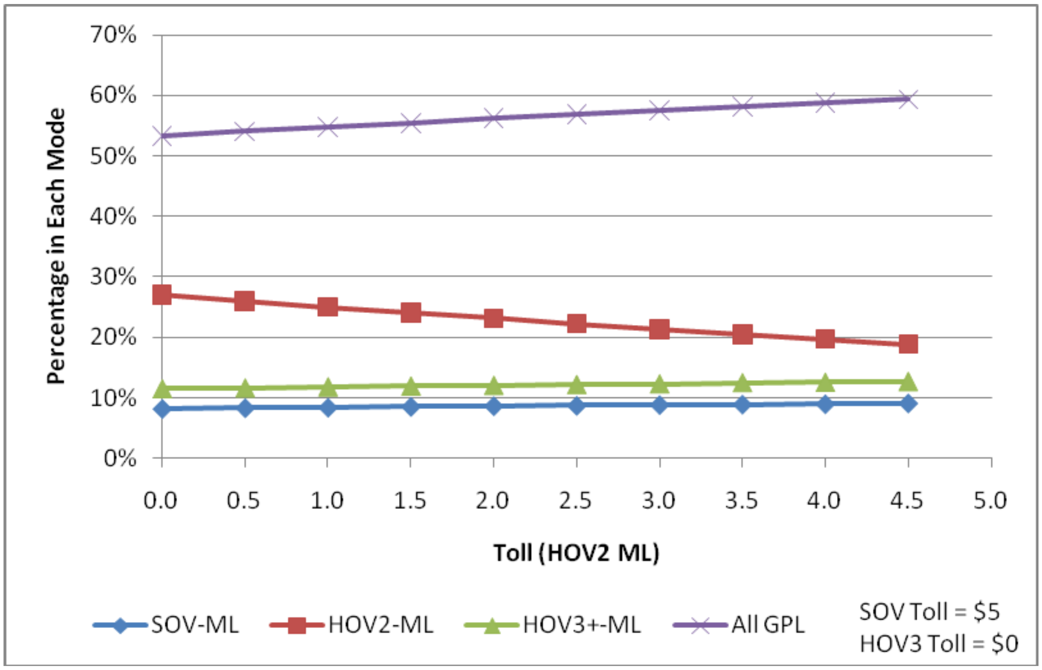

Figure 13: Mode Choice of Fampools: Scenario 2

Table 44: Mode Choice of Fampools: Scenario 2

Toll (HOV2-ML)	ML			GPL			Total HOV
	SOV	HOV2	HOV3+	SOV	HOV2	HOV3+	
$0.00	8.2%	27.0%	11.5%	22.1%	26.9%	4.3%	69.6%
$0.50	8.3%	26.0%	11.6%	22.4%	27.2%	4.4%	69.2%
$1.00	8.4%	25.0%	11.8%	22.8%	27.6%	4.4%	68.8%
$1.50	8.5%	24.0%	11.9%	23.1%	27.9%	4.5%	68.3%
$2.00	8.7%	23.1%	12.1%	23.4%	28.3%	4.6%	68.0%
$2.50	8.7%	22.2%	12.2%	23.7%	28.6%	4.6%	67.6%
$3.00	8.8%	21.3%	12.3%	23.9%	28.9%	4.7%	67.2%
$3.50	8.9%	20.5%	12.5%	24.2%	29.2%	4.7%	66.9%
$4.00	9.0%	19.7%	12.6%	24.5%	29.5%	4.8%	66.5%
$4.50	9.1%	18.8%	12.7%	24.7%	29.7%	4.9%	66.2%

In the third scenario, the HOV3 toll varied from $0.50 to $2.50 but the SOV toll was constant at $5 and the HOV2 toll was also kept constant at $2.50. With increased toll, HOV3 travelers on the MLs decreased by 2.3 percent, but travelers in all other modes increased (figure 14, table 45). Travelers in SOVs on ML and HOV2s on ML increased by 0.4 percent and 0.9 percent respectively. There was an overall decrease of 0.9 percent in total HOV travelers.

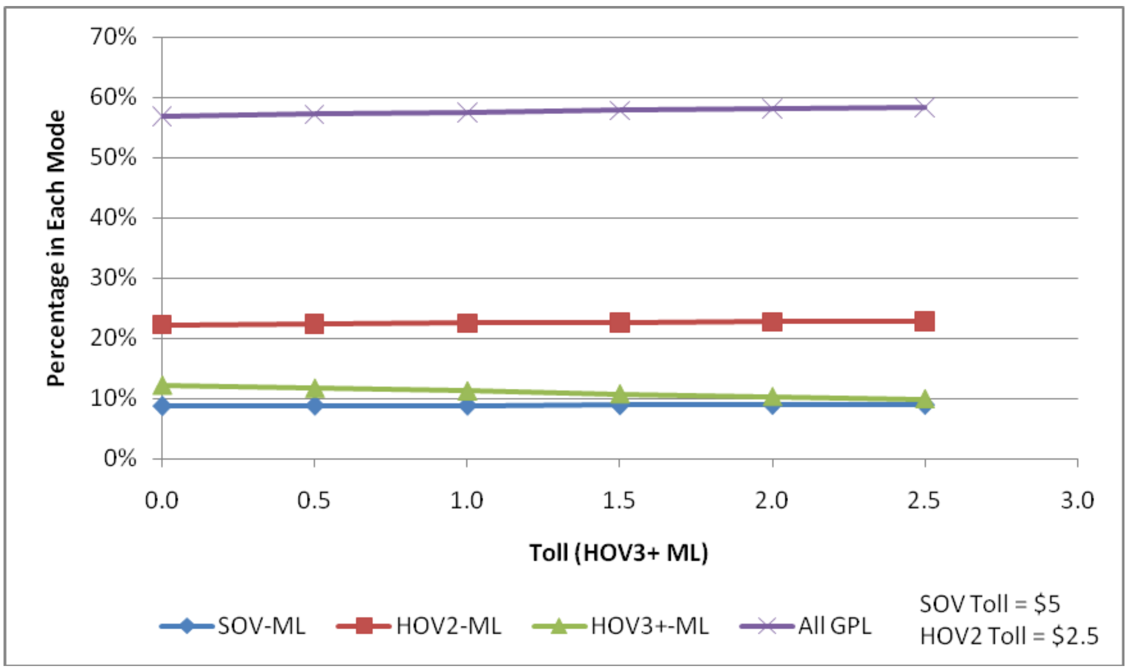

Figure 14: Mode Choice of Fampools: Scenario 3

Table 45: Mode Choice of Fampools: Scenario 3

Toll (HOV3+-ML)	ML			GPL			Total HOV
	SOV	HOV2	HOV3+	SOV	HOV2	HOV3+	
$0.00	8.7%	22.2%	12.2%	23.7%	28.6%	4.6%	67.6%
$0.50	8.8%	22.4%	11.7%	23.8%	28.7%	4.7%	67.4%
$1.00	8.8%	22.5%	11.2%	23.9%	28.9%	4.7%	67.3%
$1.50	8.8%	22.6%	10.7%	24.1%	29.0%	4.7%	67.1%
$2.00	8.9%	22.7%	10.3%	24.2%	29.2%	4.7%	66.9%
$2.50	8.9%	22.8%	9.9%	24.3%	29.3%	4.7%	66.7%

5.3.3 Elasticity of Demand for Managed Lanes by Fampools

Elasticity is another measure that can be used to quantify the extent to which the mode choices are influenced by changes in a toll value. It can be used to check the reasonableness of the percentage of travelers willing to use managed lanes at different toll levels. Equation 18 is used to calculate elasticity.

$$E_{ML\ Demand} = \frac{\%\ change\ in\ managed\ lane\ usage}{\%\ change\ in\ toll} \tag{18}$$

where:

$E_{ML\ Demand}$ is demand elasticity of travel on managed lanes

$$\%\ change\ in\ managed\ lane\ usage = \frac{(\%\ initial\ ML\ usage) - (\%\ final\ ML\ usage)}{\%\ ML\ usage\ at\ inital\ toll\ level}$$

and $\%\ change\ in\ toll = \dfrac{initial\ toll - final\ toll}{initial\ toll}$

Elasticity calculations were done for scenario 1 to test the reasonableness of the SOV and HOV2 modes on ML for every $0.5 increase in toll value. Table 46 provides the detailed calculations. For SOVs elasticity varied between -0.04 and -0.38 and for HOV2s elasticity varied between -0.01 and -0.13. According to the literature these values seemed reasonable and demand elasticity was fairly inelastic (Matas and Raymond, 2002).

Table 46: Elasticity of SOV and HOV2 on ML for the Fampools

Toll (SOV ML)		**ML Elasticity**	
Initial	**Final**	**SOV**	**HOV2**
$0.50	$1.00	-0.04	-0.01
$1.00	$1.50	-0.08	-0.03
$1.50	$2.00	-0.12	-0.04
$2.00	$2.50	-0.14	-0.05
$2.50	$3.00	-0.21	-0.08
$3.00	$3.50	-0.23	-0.08
$3.50	$4.00	-0.27	-0.10
$4.00	$4.50	-0.27	-0.13
$4.50	$5.00	-0.38	-0.13

5.3.4 Simulated Results for the Non-fampools

The three scenarios simulated for fampools were now simulated for the non-fampools. In the first scenario, the SOV toll was varied from $0.50 to $5.00, the HOV2 toll was kept at 50 percent of the SOV toll and the HOV3+s were allowed to travel for free. As the toll increased, SOV travelers on ML decreased by 3.6 percent and HOV2s on managed lanes decreased by 2.7 percent. SOVs on GPL increased by 2.1 percent. Travelers increased in all other modes. With the increased toll, the total number of HOV travelers decreased by 1.5 percent (Figure 15, Table 47).

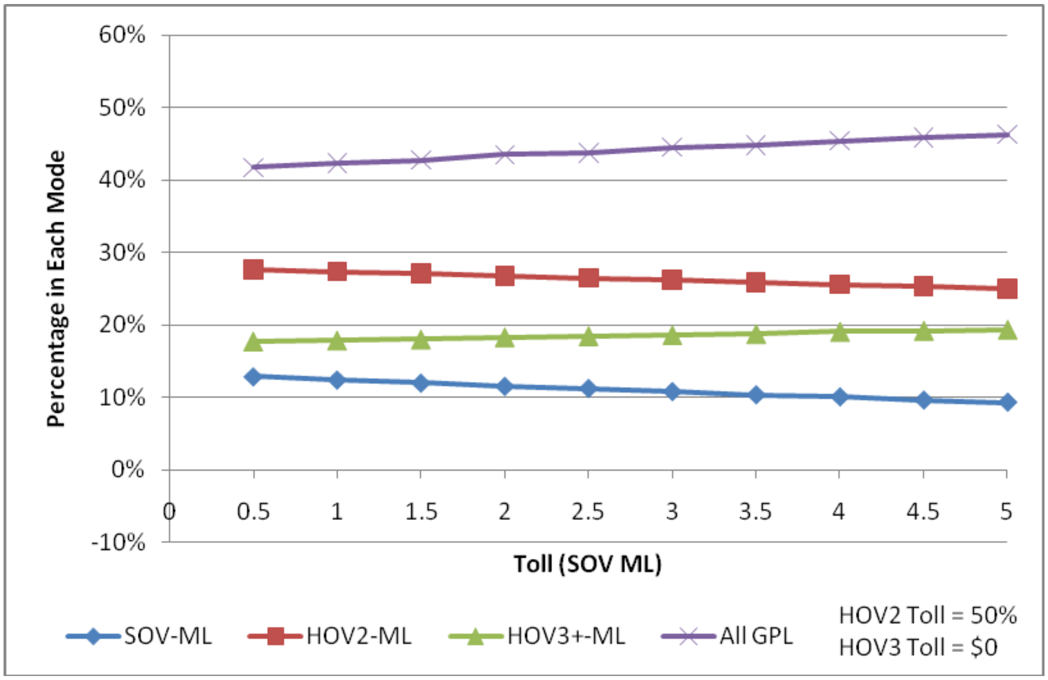

Figure 15: Mode Choice of Non-fampools: Scenario 1

Table 47: Mode Choice of Non-fampools: Scenario 1

Toll (SOV-ML)	ML			GPL			Total HOV
	SOV	HOV2	HOV3+	SOV	HOV2	HOV3+	
$0.50	12.9%	27.7%	17.8%	18.0%	17.2%	6.5%	69.1%
$1.00	12.4%	27.4%	17.9%	18.3%	17.5%	6.5%	69.2%
$1.50	12.0%	27.1%	18.0%	18.5%	17.6%	6.7%	69.4%
$2.00	11.5%	26.8%	18.3%	18.8%	17.9%	6.8%	69.8%
$2.50	11.2%	26.5%	18.5%	18.9%	18.0%	6.8%	69.8%
$3.00	10.8%	26.2%	18.6%	19.2%	18.3%	7.0%	70.1%
$3.50	10.4%	25.9%	18.8%	19.4%	18.5%	7.0%	70.1%
$4.00	10.1%	25.6%	19.1%	19.7%	18.6%	7.1%	70.4%
$4.50	9.6%	25.3%	19.2%	19.8%	18.9%	7.1%	70.6%
$5.00	9.3%	25.0%	19.4%	20.1%	19.1%	7.1%	70.6%

For the second scenario, the HOV2 toll varied from $0.00 to $4.50, the SOV toll was constant at $5 and HOV3+s were allowed to travel for free (Figure 16, Table 48). With the increased toll, there was a sharp decrease in number of HOV2 travelers on ML, it decreased by 7.5 percent. The highest increase of 2.2 percent was observed for the SOV travelers on GPL.SOV travelers on the ML increased by 1.0 percent. The total number of HOVs decreased by 3.3 percent.

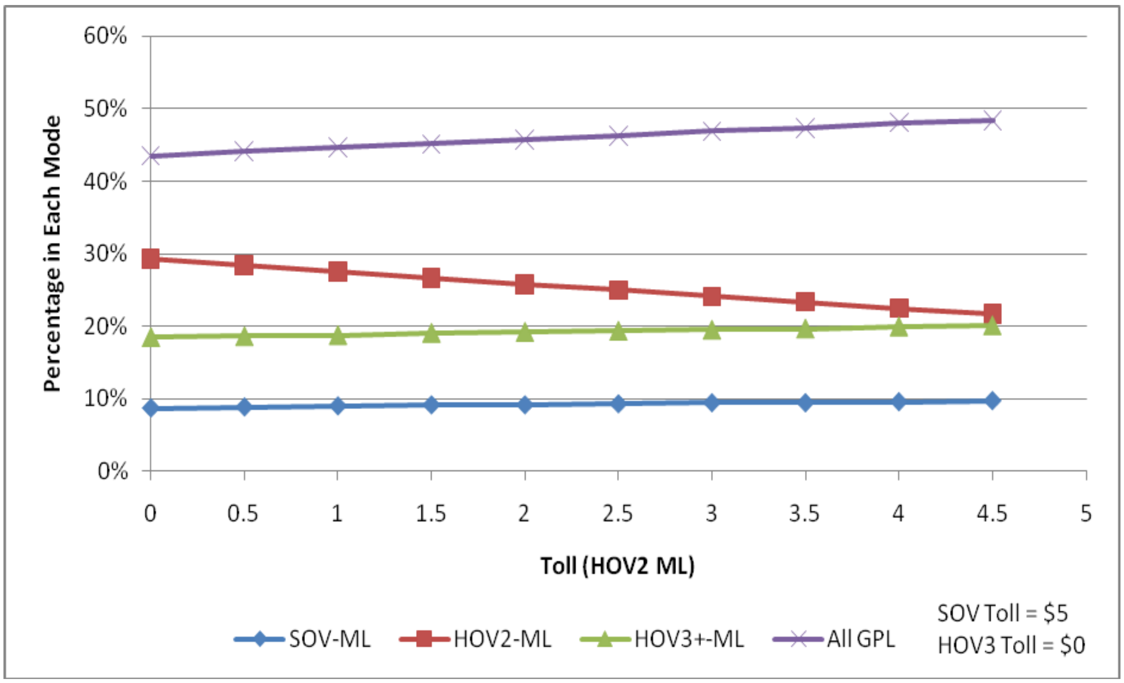

Figure 16: Mode Choice of Non-fampools: Scenario 2

Table 48: Mode Choice of Non-fampools: Scenario 2

Toll (HOV2-ML)	ML			GPL			Total HOV
	SOV	HOV2	HOV3+	SOV	HOV2	HOV3+	
$0.00	8.7%	29.3%	18.5%	18.8%	17.9%	6.8%	72.5%
$0.50	8.9%	28.4%	18.6%	19.1%	18.2%	6.8%	72.0%
$1.00	9.0%	27.5%	18.8%	19.4%	18.3%	7.0%	71.6%
$1.50	9.2%	26.6%	19.1%	19.5%	18.6%	7.0%	71.3%
$2.00	9.2%	25.7%	19.2%	19.8%	18.8%	7.1%	70.9%
$2.50	9.3%	25.0%	19.4%	20.1%	19.1%	7.1%	70.6%
$3.00	9.5%	24.1%	19.5%	20.3%	19.4%	7.2%	70.3%
$3.50	9.5%	23.4%	19.7%	20.6%	19.5%	7.2%	69.8%
$4.00	9.6%	22.5%	20.0%	20.9%	19.8%	7.4%	69.7%
$4.50	9.8%	21.7%	20.1%	21.0%	20.0%	7.4%	69.2%

In the third scenario, the HOV3+ toll was varied from $0.50 to $2.50, the toll for SOVs and HOV2s toll remained constant at $5.00 and $2.50 respectively (Figure 15, Table 49). As the toll increased, HOV3+ travelers on ML decreased by 3.4 percent, and a small increase was observed in all other modes. SOVs on GPL increased by 0.9 percent and HOV2s on GPL increased by 0.9 percent. But overall, the total number of HOVs decreased by 1.3 percent.

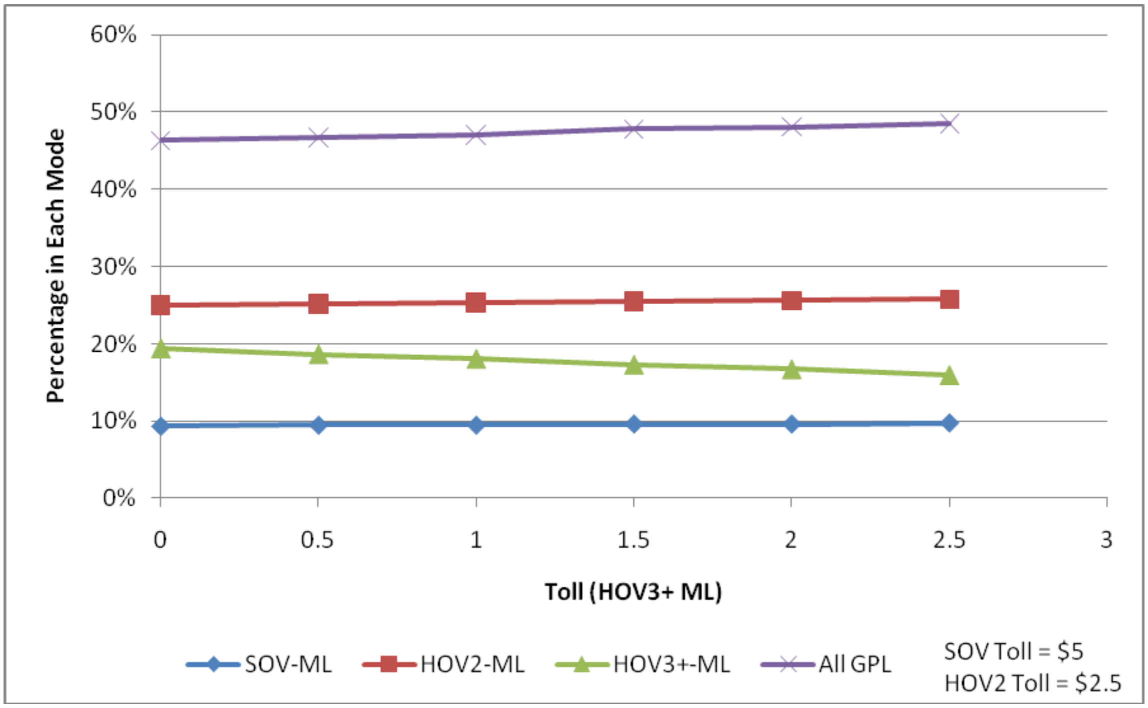

Figure 17: Mode Choice of Non-fampools: Scenario 3

Table 49: Mode Choice of Non-fampools: Scenario 3

Toll (HOV3+-ML)	ML			GPL			Total HOV
	SOV	HOV2	HOV3+	SOV	HOV2	HOV3+	
$0.00	9.3%	25.0%	19.4%	20.1%	19.1%	7.1%	70.6%
$0.50	9.5%	25.1%	18.6%	20.3%	19.2%	7.2%	70.3%
$1.00	9.5%	25.3%	18.0%	20.4%	19.4%	7.2%	70.0%
$1.50	9.6%	25.4%	17.3%	20.7%	19.7%	7.4%	69.8%
$2.00	9.6%	25.6%	16.7%	20.9%	19.8%	7.4%	69.5%
$2.50	9.8%	25.7%	16.0%	21.0%	20.0%	7.5%	69.2%

5.3.5 Elasticity of Demand for Managed Lanes by Non-fampools

Similar to fampools, ML elasticities were calculated for the non-fampool SOVs and HOV2s for the first scenario. For the SOVs, elasticity varied between -0.00 and -0.35, it was different from the fampools (Table 50). For the HOV2s elasticity varied between 0.01 and -0.11. The estimated demand elasticity was inelastic towards the toll variations.

Table 50: Elasticity of SOV and HOV2 on ML for the Non-fampools

Toll (SOV ML)		ML	
Initial	**Final**	**SOV**	**HOV2**
$0.50	$1.00	-0.03	-0.01
$1.00	$1.50	-0.07	-0.02
$1.50	$2.00	-0.11	-0.03
$2.00	$2.50	-0.10	-0.04
$2.50	$3.00	-0.20	-0.06
$3.00	$3.50	-0.25	-0.07
$3.50	$4.00	-0.20	-0.08
$4.00	$4.50	-0.35	-0.09
$4.50	$5.00	-0.28	-0.11

5.3.6 Comparison between Fampools and Non-fampools

It was observed that travelers from both groups were showing low sensitivity to the variation in toll value. For the first scenario, the SOV toll on managed lanes varied between $0.00 and $5.00 and HOV2 toll remained at half of the SOV toll and the HOV3s allowed to travel for free. For both fampools and non-fampools, the similar trends observed were observed. There was a decrease in the SOVs and HOV2s on the ML for both non-fampools and fampools. As the toll increased, most of the fampools switched to HOV2 mode n GPLs and most of the non-fampools switched to SOV mode on GPL. Overall, the carpool mode share decreased for both non-fampools and fampools.

In the second scenario, the HOV2 toll on the MLs varied between $0.00 and $4.50, and SOV toll remained at $5 while HOV3+ allowed to travel for free. There was a sharp decrease in HOV2 on the ML for both non-fampools and fampools. The highest increase observed in SOVs on GPLs for the non-fampools and HOV2s on GPLs for the fampools. There was a similar decrease observed in the overall carpool mode share for both fampools and non-fampools.

In the third scenario, the HOV3+ toll on the MLs varied between $0.00 and $2.50 and the SOV and HOV2 toll remained at $5.00 and $2.50 respectively. For the fampools, HOV3+s on the MLs decreased by a small percentage and a small percentage increase observed in all other modes. There was a small decrease observed in the overall carpool mode share. For the non-fampools, a decrease in the HOV3+s on the MLs observed. HOV2s and SOVs on the ML increased by a small percentage. The overall carpool mode share decreased which was similar to the fampools.

To summarize the findings, it was concluded that both fampools and non-fampools were very less sensitive towards the toll cost. As the toll increased non-fampools were likely to switch to SOVs on the GPLs. Fampools were more likely to switch to HOV2s on the GPLs. These results confirmed the finding from section 4 that fampools rated “drop off kids at school or day care more” higher than the non-fampools, hence were more likely to stay with their current carpool. For both fampools anf non-fampools the demand elasticity was fairly inelastic in response to the toll variations. Overall, both fampools and non-fampools were showing a similar trend and were very less sensitive towards the toll cost. It was in confirmation with the findings from the descriptive statistics developed in section 4 that both fampools and non-fampools had similar characteristics. The next section discusses the conclusions from this thesis along with recommendations for future research.

5.4 Summary

Two separate mode choice models were developed for fampool and non-fampool survey respondents. After trying various models including multinomial logit models and nested logit models, a random parameter logit model showed the best fit and explanatory ability. Fampools had VTTS of $22.8 per hour, which is higher than the national average. The mode choice models confirmed that non-fampools were not at all sensitive to the travel time. For both fampools and non-fampools, different cases were simulated to examine the impact of toll and travel time savings on mode choice. Simulation results confirmed that both fampools and non-fampools were less sensitive to the toll cost. Non-fampools were more likely to switch to SOVs on the GPLs. Fampools were more likely to switch to HOV2s on the GPLs and showed a tendency to remain as a carpool even after switching to the GPLs. However, this percentage shift was very small. The estimated demand elasticity was fairly inelastic for both fampools and non-fampools.

6. CONCLUSIONS

6.1 General Conclusions

The literature summarized in section 2 of this thesis suggested that the conversion of HOV lanes to HOT lanes did not discourage carpooling, in fact in some places carpooling increased after the implementation of HOT lanes. It was also found that the majority of SOV paying travelers on the HOT lanes came from the SOVs on the GPLs. In the last three decades, the overall carpool mode shared decreased nationwide while fampooling increased significantly during the same. The review of literature also revealed that carpool trips on the managed lanes were likely to be fampools.

This thesis has summarized the projected mode choice of fampools and non-fampools on managed lanes based on the survey data collected from the travelers in Houston and Dallas, Texas. Travel behavior, socio-economic characteristics, and stated preference data was collected through an online survey augmented by a paper and laptop survey. Both Houston and Dallas carpoolers were found to have similar characteristics. When fampools were compared with non-fampools, it was found that almost 68 percent of fampools and 66 percent of non-fampools expressed interest in using managed lanes. Non-fampools were formed more frequently in a week than the fampools. When asked about the important reasons for the formation of their current carpool, Fampools rated “dropping off kids at school/day care” higher than non-fampools but non-fampools rated “sharing vehicle expenses” higher than fampools.

When fampools were split into two groups to see if fampools with a child(ren) had different characteristics than the fampools comprised of adults only or non-fampools, it was found that non-fampools were formed more frequently (78 percent of weekly trips) in a week and fampools with child were formed the least (45 percent of weekly trips) in a week. Fampools with a child(ren) reported their highest average carpool formation time of 9.1 minutes in comparison to the 5.3 minutes for fampools with adult and 6.2 minutes for non-fampools.

Fampool and non-fampool carpoolers were also split into sub-groups based on their current number of passengers and compared for significant differences. 72.6 percent of HOV3+ non-fampools were interested in using managed lanes in comparison to the 70.6 percent of HOV2 fampools, 64 percent of HOV2 fampools and 63.1 percent of HOV3+ fampools. When asked about carpool formation time, HOV3+ fampools reported highest average of 10.1 minutes, HOV3+ non-fampools reported 8.9 minutes, HOV2 non-fampools reported 5.2 minutes, and HOV2 fampools reported 4.9 minutes. However, none of these differences were significant. When asked about the important factors for the formation of their current carpool, among all sub-groups, HOV3+ fampools rated "drop off kids at school or day care" highest and HOV2 non-fampools rated this the lowest. This difference was significant at a 95 percent level of confidence.

There were almost no significant differences found in all the variables tested. Therefore it was difficult to deduce any specific reasons for potential differences in mode switching by the fampools and non-fampools through descriptive statistics. Fampools indicated that dropping off kids at school or day care was the most important reason for their current carpool formation in comparison to the non-fampools. Sharing vehicle expenses was more important to the non-fampools than the fampools. This was one of the few clues behind any possible differences in how the two groups may change mode in the presence of MLs.

To better understand how these travelers would react to MLs, mode choice models were developed for the fampool and non-fampool carpool groups. The value of travel time for the fampools was estimated to be $ 22.8 per hour and it could not be estimated for the non-fampools as time was not significant variable in the non-fampool model. Non-fampools with an annual household income between $35,000 and $50,000 were less likely to be a HOV3+ carpool on the MLs. Non-fampools making 1, 2 and 6 to 9 trips per week were more likely to choose SOV on the MLs. Non-fampools on a work trip chose to travel as a HOV3+ carpool on MLs and were less likely to choose HOV2 mode on the MLs. Fampools who were commuting were less likely to choose SOV mode on the MLs. Fampools with an annual household income between $35,000 and $50,000 and were on a work trip were less likely to choose HOV2 mode on the MLs. Fampools with an annual household income between $15,000 and $25,000 were more likely to travel as a HOV3+ carpool on MLs.

Next a simulation study was done using these models to estimate the percentage of fampools and non-fampools that would likely use managed lanes under different travel scenarios. A very small percentage of fampools and non-fampools chose SOV on ML. Both fampools and non-fampools were less sensitive to the tolls. Fampools were more likely to stay with their current carpools but non-fampools were switching more often. As the toll increased non-fampools were likely to switch to SOVs on the GPLs and fampools were more likely to switch to HOV2s on the GPLs. The estimated demand elasticity was fairly inelastic for both fampools and non-fampools.

Although the survey sample size was large, the number of travelers in some categories, for example HOV3+ non-fampool, was small. This, combined with considerable variation in the characteristics of the travelers, often resulted in large standard deviations for the descriptive statistics of the groups. After analyzing the descriptive statistics and the results from the simulations developed using mode choice models, it was concluded that fampool and non-fampool travelers were very similar. There were very few significant differences. The differences were:

- Non-fampools were formed more often than fampools
- Fampools continued on to their final destination after dropping off the passenger mor often than non-fampools
- Fampools rated “drop off kids at school/ day care” higher than non-fampools

- Non-fampools rated “sharing vehicle expenses” higher than fampools
- HOV3+ fampools rated “drop off kids at school/ day care” highest at 3.7 and HOV2 non-fampools rated it lowest at 1.9, HOV2 fampools rated it at 2.5 and HOV3+ non-fampools rated it at 2.0
- Non-fampools were not at all sensitive to the travel time variations
- Non-fampools with annual household income between $35,000 and $50,000 were less likely to be a HOV3+ carpool on the MLs
- Non-fampools on a work trip were likely to travel as a HOV3+ carpool on MLs and were less likely to choose HOV2 mode on MLs
- Fampools who were commuting were less likely to choose SOV on MLs
- Fampools with annual household income between $35,000 and $50,000 and were on a work trip were less likely to choose HOV2 mode on the MLs
- Fampols with annual household income between $15,000 and $25,000 were more likely to travel as a HOV3+ carpool on MLs
- A very small percentage of fampools and non-fampools chose SOVs on MLs
- Both non-fampools and fampools were less sensitive to the toll cost
- As the tolls increased non-fampools were most likely to switch to SOVs on GPLs
- As the tolls increased fampools were mostlikely to switch to HOV2s on GPLs

6.2 Future Research and Recommendations

Future research can be focused on to better understanding the characteristics of the carpooling passengers. The survey data used for this research had limited information about the carpooling passengers. For example, it was not known if the passenger had the ability to drive if given an option or was carpooling because of not being able to drive. It would be interesting to know the mode choice of the carpooling passengers on the managed lanes. The willingness to pay and value the travel time savings can be estimated for them and compared to other carpool groups. Apart from this fampools with a child(ren) can also be analyzed in more depth to estimate their willingness to pay and their mode choice in the vicinity of managed lanes.

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