HOT Lanes with a Refund Option and Potential Application of Connected Vehicles

by

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ABSTRACT

Priced Managed Lanes (MLs) have been increasingly advocated as one of the effective ways to mitigating congestion in recent years. This study explores a new and innovative pricing strategy for MLs called Travel Time Refund (TTR). The proposed TTR provides an additional option to paying drivers that insures their travel time by issuing a refund to the toll cost if they do not reach their destination within specified travel times due to accidents or other unforeseen circumstances. Perceived benefits of TTR include raised public acceptance towards priced MLs, utilization increase of HOV/HOT lanes, overall congestion mitigation, and additional funding for relevant transportation agencies. To gauge travelers' interests of TTR and to analyse its possible impacts, a stated preference (SP) survey was performed. An exploratory and statistical analysis of the survey responses revealed negative interest towards HOT and TTR option in accordance with common wisdom and previous studies. However, it is found that travelers are less negative about TTR than HOT alone; supporting the idea, that TTR could make HOT facilities more appealing. The impact of travel time reliability and latent variables representing psychological constructs on travelers' choices in response to this new pricing strategy was also analysed. The results indicate that along with travel time and reliability, the decision maker's attitudes and the level of comprehension of the concept of HOT and TTR play a significant role in their choice making. While the refund option may be theoretically and analytically feasible, the practical implementation issues cannot be ignored. This study also provides a discussion of the potential implementation considerations that include information provision to connected and non-connected vehicles, distinction between toll-only and refund customers, measurement of actual travel time, refund calculation and processing and safety and human factors issues. As the market availability of Connected and Automated Vehicles (CAVs) is prognosticated by 2020, the potential impact of such technologies on effective demand management, especially on MLs is worth investigating. Simulation analysis was performed to evaluate the system performance of a hypothetical road network at varying market penetration of CAVs. The results indicate that Connected Vehicles (CVs) could potentially encourage and enhance the use of MLs.

Dedicated to my parents

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CHAPTER 1

INTRODUCTION

1.1 Motivation

Traffic congestion is a global problem resulting from the imbalance between the supply and demand with significant economic, operational and public health impacts. Road network expansion was a common solution to address congestion issues in the past which turned out to be impractical due to scarcity of available land and right of way issues. Congestion pricing or tolling has been introduced as a potential solution to not only effectively manage demand but also provide a revenue source to fund future transportation projects (Vickrey, 1969). In the past decade, priced managed lanes (MLs) have been increasingly advocated as one of the effective ways to mitigating traffic congestion. There are 244 tolled facilities (both interstates and non-interstates) including priced MLs in the US, where all lanes are subject to a predetermined (fixed) price based on the time of day or a dynamic charge that varies based on real time traffic conditions (U.S. Department of Transportation, 2016). As one type of priced managed lanes, high occupancy toll (HOT) lanes are dedicated lanes on an existing freeway adjacent to the free general-purpose lanes (GPLs). High occupancy vehicles, emergency vehicles, and other exempt vehicles may use HOT lanes for free, while low-occupancy vehicles are charged a toll. The early stages of tolling relied on static pricing but owing to the advancements and innovations in technology there has been a recent shift to dynamic pricing where the toll could be varied based on demand and/or feedback mechanism (Zhang et al., 2008; Jou et al., 2012; Yang et al., 2012; Liu et al., 2017). For example, Katy Freeway in Houston, TX uses static tolls with a pricing of $4, $2 and $1 for peak, shoulder and off-peak times respectively (Patil et al., 2011). On I-15 in San Diego, CA, tolls vary between $0.50 and $8 based on traffic conditions (I-15 Express Lanes, n.d.). Similarly, on I-394 in Minnesota, tolls vary dynamically between $0.25 and $4.00 with a maximum of $8 (MnPass, n.d.). In the past five years alone, the number of operating priced ML facilities in the US has risen from 14 to 24 and an equal number of facilities are in planning (U.S. Department of Transportation, 2012, 2016).

Although priced MLs are prevalent in the US, many HOV to HOT lane conversions have been halted in metropolitan areas due to public opposition (Ungemah et al., 2005). A review by the Federal Highway Administration (FHWA) and several other focus group studies found that the public perceive tolls as double tax on top of the already-paid gas tax (Cleland & Winters, 2000; HNTB Corporation, 2010; Kockelman & Kalmanje, 2005; Perez, et al., n.d.). They are also concerned about equity, and some believe MLs benefit higher income groups more than others. Previous studies suggest that public acceptance is necessary for the implementation of toll roads (Gomez et al., 2017; Kockelman et al., 2009; Sumalee, 2001; Schade and Schlag, 2003). Some researchers suggest alternatives like transit incentives, subsidies on toll-free roads and increased awareness to overcome public opposition. (Adlerand Cetin, 2001, Odeck and Bråthen, 1997; Podgorski and Kockelman, 2006; Odeck and Kjerkreit, 2010). On the contrary, some studies reveal strong public support toward tolling. A before-after study conducted by Zmud et al. (2007) showed strong public support from all income groups both before and after the implementation of I-394 Express lanes in Minnesota. Although household income is a strong predictor of support for tolls, it also raises the red flag of equity concerns. Some studies claim HOT lanes are beneficial to those with disposable incomes and others indicate they are equitable for congestion relief (Safirova et al, 2003; Mowday, 2006).

A FHWA report states travel time savings and higher travel speeds are among the primary benefits of priced MLs and there are several supporting studies that identify travel time savings as the dominating factor to choose MLs over GPLs (Perez et al., 2012; Burris et al., 2007, Devarasetty et al., 2012, 2014). On the contrary, Sharifi and Burris (2018) found that around 11% of the trips on ML had negative travel time savings and a prior slow trip on the ML is not enough encouragement for the travellers to switch to the GPL. Many of the previous studies have researched on the willingness to pay (WTP) for MLs and the characteristics influencing the value of time (Yusuf et al., 2014; Li et al., 2010; Rose and Hensher, 2014; Burris et al., 2012). An examination of the WTP on I-394 Express lanes in Minnesota revealed that 35% of the travellers paid for a travel time saving of less than a minute (Burris et al., 2012). A study on the perceived travel time savings on SR-91 Express lanes in California revealed that nearly all the respondents overestimated their travel time savings (Sullivan, 2000). The public attitude towards MLs depends not only on the travel time savings but also on the availability of alternatives as well as how the generated revenue is utilized. The reliability of priced MLs is another important factor affecting user experience and thus travellers' attitudes towards MLs. Burris et al. (2007) analysed a stated preference (SP) survey prior to the existence of MLs on Katy Freeway and found that travel time savings and reliability are the driving forces of interest towards priced lanes. However, it is possible that sometimes travellers may not receive expected benefits from MLs due to uncertainties in traffic such as a vehicle incident that is not reflected by the time display.

1.2 Research Objective

In view of this, we argue that innovative pricing strategies could be explored to boost public acceptance of priced MLs and at the same time help achieve their design objective. On one hand, there may be less resistance from the public if they receive a tangible benefit even when they do not use MLs. In 2005, the concept of fast and intertwined regular lanes was modelled by the FHWA where the users of GPLs are provided a credit each time they use those lanes during peak hour, which in turn can be used to pay for MLs or other transportation services (Quade et al., 2005). The analysis revealed a modest improvement in travel time while concerns of equity and revenue generation remain. On the other hand, travellers may be more accepting if the perceived cost and risk of priced MLs is lower. In this study, we propose an alternative pricing strategy that provides travellers some "reassurance" via an option of travel time refund (TTR).

When choosing to pay for MLs, users are provided an opportunity to purchase an additional TTR, which ensures them a certain amount of travel time savings. The cost of TTR is a pre-determined percentage of the actual toll and always less than the actual toll. If users did not experience the "insured" travel time savings due to unforeseen circumstances, they would be refunded the toll amount but not the additional cost of TTR. Apart from providing an additional source of funding to the transportation agencies, it is anticipated that there will be a change in the negative attitudes towards priced MLs, and GPL congestion could be reduced with more users willing to use priced MLs. Ungemah and Collier (2007) showed that complicated tolling mechanisms face public opposition. To avoid any confusion, the cost of TTR (percentage of the actual toll cost) will be pre-determined and the traveler does not have to perform complex computations prior to making a decision.

This study attempts to gauge the interest towards the refund option through the following objectives:

1. Investigate traveler's attitudes and concern towards TTR of priced MLs.
2. Elicit traveler's choices of ML usage.
3. Discuss the implementation issues of TTR including the potential of using connected vehicles (CVs) to help achieve the vision.
4. Simulation analysis to determine if traffic operators can utilize CVs to encourage HOV/HOT usage.

1.3 Overview of the Methodology

The responses from a Stated Preference (SP) survey are used in the present study to investigate the attitudes towards the proposed refund option. The survey was designed and distributed widely through various online platforms. The survey responses were analysed to gauge the general attitudes towards the refund option for priced managed lanes. Statistical techniques like ordered probit models were used to determine the factors that affect the interest of the people towards the refund option. The traveler's choices of managed lanes are elicited using multinomial logit (MNL) models and structural equation modeling framework. While the idea of the refund option may theoretically sound appealing, any practical implementation issues should not be ignored. A discussion of such issues along with the potential of using connected vehicles is also included. A simulation analysis was performed to determine if the provision of richer information using connected vehicles could encourage HOV/HOT usage.

1.4 Organization of the Document

The remaining of the document is organized as follows: Chapter 2 presents an overview of the stated preference survey design methodology along with the description of the study area, survey questionnaire and the survey scenarios.

Chapter 3 provides an exploratory analysis of the survey responses including sample weighting. Ordered choice models are used to determine the factors that influence HOT satisfaction and interest toward the refund option.

Chapter 4 investigates the impact of travel time reliability, TTR, and latent variables representing psychological constructs on travelers' choices of GPL and HOT in response to the proposed new pricing strategy. A multinomial logit (MNL) model predicting the choices of GPL and HOT with or without TTR based on socio-demographics, trip characteristics and toll and TTR rates is first estimated. Structural equation model to explore the impacts of latent variables representing psychological constructs such as attitudes and perceptions is also estimated.

Chapter 5 includes a discussion on the implementation issues of TTR and the potential of using CVs to help achieve the vision. Potential implementation issues include information provision to connected and non-connected vehicles, distinction between toll-only and refund customers, measurement of actual travel time, refund calculation and processing and safety and human factors issues.

Chapter 6 provides a better understanding of the refund option and the potential of using connected vehicles by evaluating the system performance through simulation analysis.

Chapter 7 provides the conclusions and recommendations for future work. Additional tables and figures are presented in appendices A, B and C respectively.

CHAPTER 2

SURVEY DESIGN

A stated preference (SP) survey was designed and administered to investigate the attitudes of the travelers' towards the refund option. This chapter provides an overview of the design methodology used for the SP survey. A description of the study area and the survey questionnaire including the different levels used for various factors is also included. The scenarios provided to the respondents and the demographic information are detailed in the final two sections of this chapter.

2.1 Background

The design of a survey may affect its results. Hess et al. (2014) compared orthogonal design with random block, orthogonal design with non-random blocking and D-efficient design methods and concluded a much better model fit was achieved through non-random blocking methods. Patil et al. (2011) evaluated three SP survey designs: D-efficient, random attribute level generation and adaptive random experiment, using the Katy Freeway as their backdrop. They found adaptive random experiment performed the best in negating the effects of always choosing the cheapest option. Since the focus of this study is not a comparative analysis of various design methods, a simple and effective method was preferred. Therefore, a variation of the adaptive random design approach, called branching, is adopted in the present study.

2.2 Survey Questionnaire

The survey questionnaire was designed to gauge travelers' interest and concerns towards the refund option and elicit their choices of ML (specifically HOT lane) usage under various conditions. The survey would have been ideally conducted where HOT facilities exist; however, due to the limited scope of the project, the section of I-10 in the Phoenix metropolitan area was chosen as the study area. The area extends from the Loop 101 Agua Fria freeway west of Phoenix to the Loop 202 Santan Freeway as shown in Figure 2.1.

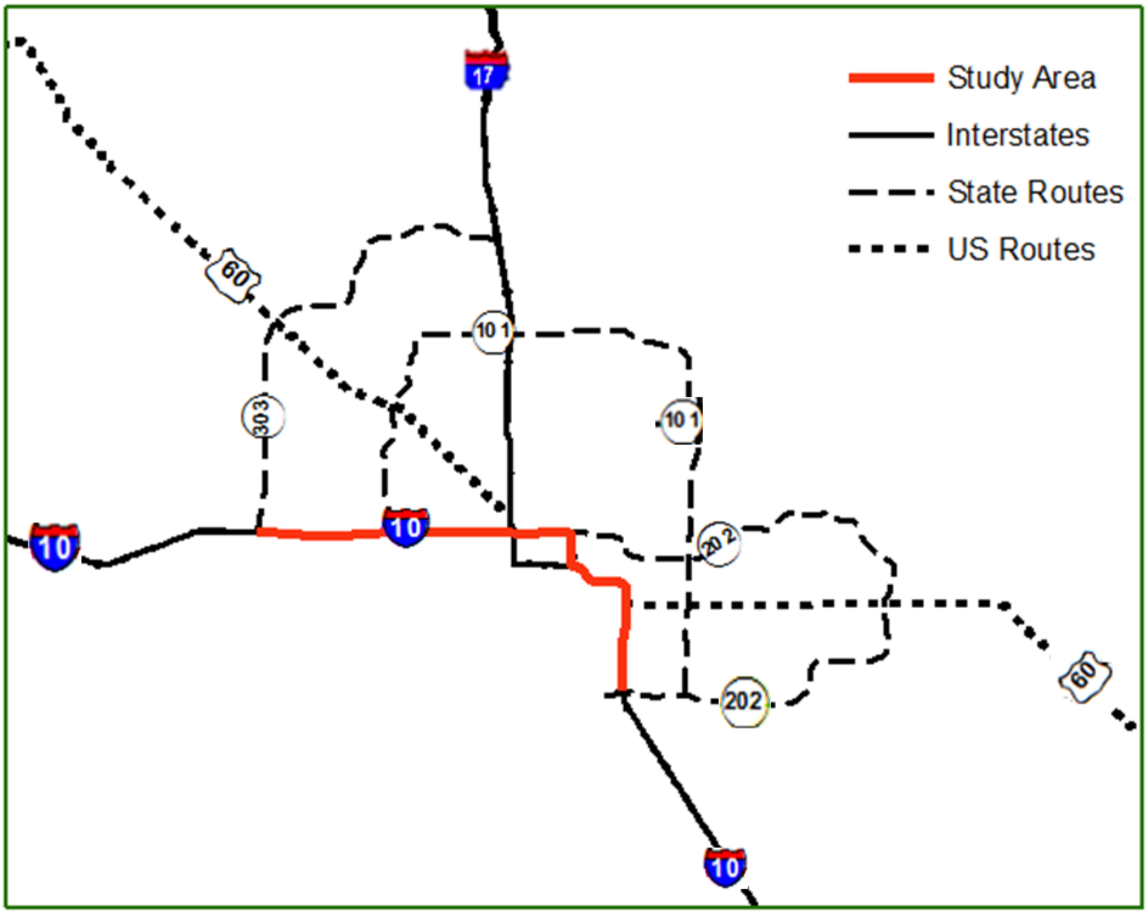


Figure 2.1 Map of Study Area

The concept of HOT lanes is not new to Arizona despite their nonexistence. The Maricopa Association of Governments (MAG) has done a feasibility study in 2012 and proposed the idea of expanding the hours of operation for the existing HOV lanes along with the introduction of pricing (Maricopa Association of Governments, 2012). The pros and cons of various pricing strategies were presented along with recommendations for making HOT lanes a reality in the valley. Although the study led to great discussions on MLs, MAG has no current plans of implementation. For the purpose of this study, a hypothetical HOT lane was presented to the survey respondents on I-10, a major east-west corridor that cuts through the heart of downtown Phoenix that houses many businesses making it a major commute route.

The survey consisted of 40 questions split into four sections that are presented in Appendix A. The first section collected information on the respondents' last trip on I-10 within the past year. The second section gathered preliminary interest on the refund option while the third section presented the stated preference scenarios where respondents had to choose between driving in the GPL, ML without refund option and ML with refund option given different factor levels. The final section collected the socio-demographic information.

2.2.1 Last I-10 Trip

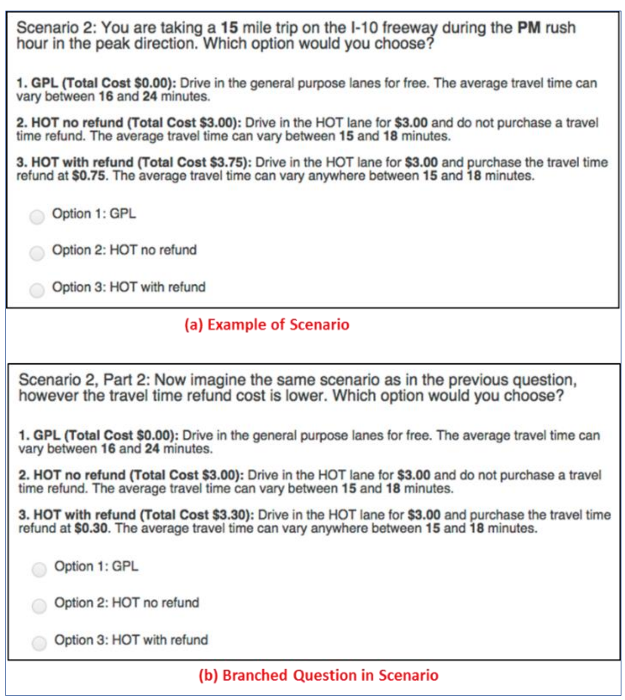
In the first portion of the survey, the respondents were asked to provide information about their last trip on I-10. This section is skipped if they have not traveled on I-10 within the past year. The users who took an I-10 trip in the past year were asked to provide information about the trip including purpose, day of the week, time of day, vehicle type, HOV lane use, number of passengers in the car, zip codes of origin and destination. They were also asked to select the entrance and exit ramps on I-10 to be used for travel time estimation.

2.2.2 General Attitude

This section gathered information on travelers' familiarity and general interests and attitudes towards MLs and introduced the concept of TTR. The respondents were asked about familiarity, frequency of use and satisfaction of HOV and HOT lanes. A brief explanation of the concept of TTR was provided and the respondents' interest in purchasing the TTR was questioned.

2.2.3 Stated Preference Scenarios

In this section, each survey respondent was presented with 4 different scenarios randomly generated from a pool of 288 possible scenarios. They were asked to choose between the GPL, a hypothetical HOT lane without TTR, or a HOT lane with TTR on the I-10. An example of the stated preference question is shown in Figure 2.2 where the text in bold denotes the choice descriptions and the variables related to the trip.


Scenario 2: You are taking a **15** mile trip on the I-10 freeway during the **PM** rush hour in the peak direction. Which option would you choose?

1. GPL (Total Cost $0.00): Drive in the general purpose lanes for free. The average travel time can vary between **16** and **24** minutes.

2. HOT no refund (Total Cost $3.00): Drive in the HOT lane for **$3.00** and do not purchase a travel time refund. The average travel time can vary between **15** and **18** minutes.

3. HOT with refund (Total Cost $3.75): Drive in the HOT lane for **$3.00** and purchase the travel time refund at **$0.75**. The average travel time can vary anywhere between **15** and **18** minutes.

Option 1: GPL
Option 2: HOT no refund
Option 3: HOT with refund

(a) Example of Scenario

Scenario 2, Part 2: Now imagine the same scenario as in the previous question, however the travel time refund cost is lower. Which option would you choose?

1. GPL (Total Cost $0.00): Drive in the general purpose lanes for free. The average travel time can vary between **16** and **24** minutes.

2. HOT no refund (Total Cost $3.00): Drive in the HOT lane for **$3.00** and do not purchase a travel time refund. The average travel time can vary between **15** and **18** minutes.

3. HOT with refund (Total Cost $3.30): Drive in the HOT lane for **$3.00** and purchase the travel time refund at **$0.30**. The average travel time can vary anywhere between **15** and **18** minutes.

Option 1: GPL
Option 2: HOT no refund
Option 3: HOT with refund

(b) Branched Question in Scenario

Figure 2.2 Example of Survey Questionnaire

The focus of this study is the travelers' willingness to pay (WTP) rather than their carpool choices and hence carpooling was not provided as an option. Each scenario consisted of six random variables: trip distance, time of day, GPL time range or congestion level, HOT cost, HOT lane travel time range, and TTR cost. Two of the four scenarios displayed the GPLs were 'heavily congested' in consistence with the practice that most HOT facilities only display travel time for HOT lane. The other two scenarios also displayed the GPL travel time along with that of ML to determine if there is any impact on users' choices. The factors and levels used for the random generation of scenarios are presented in Table 2.1.

Table 2.1 Alternative Specific Factors for Stated Preference Scenarios

Alternative	Attribute	Levels
All	Trip Distance (miles)	Reported, 10, 15, 25
	Peak Hour	AM, PM
	Travel Speed (mph)	55 (base)
GPLs	Travel Time Index Factor	1.2, 1.3, 1.4
	Travel Time Variability	Heavily Congested, ±20%
HOT Only and HOT with TTR	Toll Rate (cents/mile)	5, 20, 35
	Travel Time Index Factor	1, 1.1
	Travel Time Variability	±10%
HOT with TTR	TTR Cost (% of Total Toll)	25%, then 10% or 50%

The first scenario (Scenario 0) was based off the respondent's last trip, where the distance was calculated from the reported entrance and exit ramps. The remaining three scenarios (scenarios 1, 2, and 3) produced hypothetical trips of 10, 15, and 25 miles on the I-10, respectively which are considered reasonable distances currently traversed on the section of the I-10 in question. No scenario was given a distance under 10 miles, as it was assumed that most respondents would not be willing to pay for a trip that short. The distances were fixed with scenarios 1, 2, and 3 to prevent a random generation of the same scenario to the same respondent.

The displayed travel time range is calculated using travel speed, travel time index factor and travel time variability. The speed limit on I-10 is 65 mph but a base speed of 55 mph was used in all scenarios to provide more realistic peak hour travel times. The mean travel time is calculated by multiplying the travel time index factor with the base travel time. The index factor or the congestion factor for the I-10 freeway is obtained from FHWA's urban congestion report (U.S. Department of Transportation, 2010). The travel time variability, which is a percentage of the mean travel time, is used to calculate the displayed travel time interval. GPLs have a higher variability of 20% in comparison to the 10% variability for HOT lanes consistent with those used by Devarasetty et al. (2012). It is worth noting that the GPL variability of 20% in this survey actually prevents the lower bound of the travel time interval displayed for GPLs to become significantly lower than that of the MLs. The toll rates of $0.05/mile, $0.20/mile, and $0.35/mile are randomly generated for various scenarios and are consistent with those used in previous studies (Kockelman & Kalmanje, 2005). Also, when considering the possible mean travel time presented in the scenarios, $0.05/mile is equivalent to a value of time ranging from $2.50/hour to $2.73/hour; $0.20/mile a value of travel time between $10.00/hour and $10.91/hour; and $0.35/mile a value of travel time between $17.50/hour and $19.09/hour. These values of time vary around the conclusions in Kockelman and Kalmanje (2005), where a respondent's WTP was found to be $7.95 per hour. Additional literature supports these toll rates by suggesting WTP that lies between $13 and $16 per hour (Yan et al. 2002). Although some studies found WTP to be much higher at $30/hour, they suggest that the results may be biased due to a perceived higher level of safety on the HOT lane (Brownstone et al., 2003).

Branching allows the scenarios to adapt to user preferences and present factors and levels that help in determining the user's thresholds in WTP or value of time. The initial TTR which is always 25% of the HOT lane toll rate in each scenario is either increased or decreased depending on the first choice. If the respondent chooses either the GPL lane or the HOT lane without TTR in the first question, the TTR cost is lowered to 10% and if the HOT with TTR is chosen, the TTR cost is raised to 50% in the following question. This is illustrated in Figure 2.2 where the cost of HOT with refund decreased from $3.75 to $3.30 when the user has opted for GPL or HOT with no refund.

2.2.4 Demographics

The final section consisted of general demographic information like age, gender, household income, ethnicity, education, number of people and vehicles in the household. Additionally, it captured the interest in TTR after all the scenarios were completed.

2.3 Survey Distribution

The survey was distributed primarily through distribution lists in the Phoenix metropolitan area. It was also shared through social media websites so that people outside the Phoenix area could also participate for whom the region specific travel questions were hidden and a description of freeways in the Phoenix region was included. The survey has been extensively distributed through the various channels at Arizona State University (ASU) apart from sharing via the social media outlets and the Institute of

Transportation Engineers (ITE) and Intelligent Transportation Society (ITS) chapters of Arizona. 2274 responses were received out of which 80% were complete.

CHAPTER 3

EXPLORATORY ANALYSIS OF THE REFUND OPTION

This chapter provides an overview of the analysis of the survey responses. The distribution of the data indicated sample bias, which is addressed by sample weighting. The factors that influence the HOT satisfaction and interest toward the refund option are determined using ordered choice models.

3.1 Sampled Data Analysis

The descriptive statistics of the sampled data are presented in this section. Only the most relevant tables are presented in the main text while all other tables can be accessed from Appendix B.

3.1.1 Person Characteristics

The gender distribution of the responses is not ideally balanced with the apportionment between males and females being 34% and 64% respectively. The highest and lowest response rates are from users aged between 18-24 (25%) years and those older than 55 (14%). This is expected as the majority of the responses are from a university and the older demographic may not be as comfortable or familiar with responding to an online survey. The majority of the respondents identified themselves as White/Caucasian (72%) followed by Hispanic (10%), Asian (7%), African American (2%), Native American (1%) and 5% preferred not to answer. The ethnicity of the Phoenix metropolitan area appears to be more diverse with higher number of Hispanics and African Americans than that suggested by the survey responses. This discrepancy could be attributed to the major portion of the respondents being affiliated to ASU through either education or part/full time employment. The majority of the respondents (86%)

have at least a college degree including some college (27%), 4-year degree (31%), Master's (28%), Doctorate (9%) and 2% with other professional degrees like MD or JD. This skewed education data is attributable to the survey administration, which is distributed mainly to university students, employees, and staff who are expected to have pursued higher education. The majority of the respondents are from two member households (33%) followed by four (19%), three (18%), one (18%), and five (11%) members. These numbers are not an indication of any general trend in the number of people in the household for the given sample size. Most households own two vehicles (43%) followed by one (24%), three (21%), four (8%), and five (3%) vehicles. Only 1% of the respondents fall in the zero-vehicle household category. A considerable percentage of respondents favour the higher income categories with 18% reporting their income in each of the $75-$100k and $100-$150k categories. 12% reported incomes less than $30k, 17% are in $30-$50k, 15% are in $50-$75k ranges, and 10% had incomes greater than $150k.

3.1.2 Trip Characteristics

The strong majority of the people (93%) who have taken a trip on the I-10 in the past year yields a good sample for the current analysis. The majority of the respondents (53%) occasionally travel on the I-10 and the remaining are similarly split among once a week (15%), 2-4 days/week (16%) and 5-7days/week (15%). The primary trip purpose on I-10 for 38% of the respondents is recreational, social or entertainment followed by commute to and from work (19%), shopping or personal errands (17%), attend an educational institute (9%), work related (9%) and other purpose not covered above (8%). The significant percentage of commuters indicate I-10 is an ideal freeway to test the concept of TTR or HOT lanes in general. The last trip on I-10 follows a similar pattern as the primary trip purpose and majority of those trips occurred on a weekday (59%). HOV lane was used by 37% in the last trip in contrast to the 44% respondents who said they rarely use the HOV lane in general. 95% of the respondents used a car while the remaining 5% used motorcycles, buses and other modes. The last trip was mostly by solo-drivers (40%) followed by two people in vehicle (30%).

3.1.3 Interest towards Managed Lanes

There was considerable interest in HOT lanes and the TTR option as indicated in Table 3.1. It could be observed that a higher percentage of respondents prefer the HOT lane (with or without refund) for a 10 mile trip. This could be attributed to the explicit mention of heavy congestion in the GPL lane for 10-mile trip and given the short distance; travellers prefer to reach their destination faster. As the trip distance increases, a slightly higher percentage of respondents prefer the HOT with refund compared to that with no refund. The respondents who chose the HOT only option were asked their choice with a lower TTR cost (10%). Approximately, 40% of respondents shift preference to HOT with refund in each of the four distance scenarios. There is less than 4% preference shift towards GPL. The respondents who chose the HOT with refund option were asked their preference with a higher TTR cost (50%). Approximately, there is a 35% shift in choice preference to HOT with no refund for 10 mile and last trip scenarios. The preference of HOT with refund increases with trip distance with a 75% maximum for 25 miles. There is less than 5% preference shift towards GPL in the three hypothetical scenarios. The trip purpose and day of week information is only available for the last trip. It can be seen from Table 2 that higher percentage of respondents prefer the HOT with refund for commute and work/school related trip purposes compared to others like recreational and personal errands. 40% of the respondents who chose HOT with no refund for commute and work/school related trips change their preference to HOT with refund when the TTR cost is lowered. Ten percentage of the respondents change their preference to GPL for Shopping/Personal Errands trips. Approximately 7% of the respondents like to use GPL for commute and work/school related trips. The respondents who chose HOT with refund option were presented with an increased TTR cost. Given this higher cost for refund, 67% of respondents choose to retain their original choice for commute purposes and approximately 60% chose the same option for work/school related trips. There is a 10 % maximum shift to GPL in some trip purposes. A slightly higher percentage of respondent's prefer to use HOT lane (with or without TTR) during weekdays compared to the weekends when the TTR cost is 25%. 37% of the respondents who chose the HOT only option change their preference to HOT with refund during both weekends and weekdays when the TTR cost is lowered to 10%. When the cost of TTR is increased to 50%, approximately, 60% of the respondents who chose HOT with TTR retain their choice during both weekends and weekdays. This indicates that there is significant interest towards the refund option and it is plausible that the TTR could make the HOT facilities more appealing.

Table 3.1. Descriptives of General Interest towards Managed Lanes

Characteristic	Category Type	Percentage Interested								
		(TTR = 25% of toll)			(TTR = 10% of toll)			(TTR = 50% of toll)		
		GPL	HOT No TTR	HOT TTR	GPL	HOT No TTR	HOT TTR	GPL	HOT No TTR	HOT TTR
Trip Distance	Last Trip	61.5	20.3	18.2	3.8	60	36.2	7.3	33.7	59.1
	10 Miles	46.5	26.8	26.8	0.8	61.5	37.6	3.6	34.6	61.8
	15 Miles	61.9	18.3	19.8	1.5	62.2	36.3	4.3	27.2	68.5
	25 Miles	62.3	17.6	20.1	1.9	58.7	39.4	2.5	23.2	74.2
Trip Purpose for Last Trip	Commute to/from work	68.8	14.1	17.1	7.1	53.6	39.3	5.9	26.5	67.6
	Work Related	56.8	18.5	24.7	6.7	53.3	40	10	30	60
	To attend School/Class	61.3	16.1	22.6	6.7	53.3	40	4.8	38.1	57.1
	Recreational/Social/Entertainment	64.2	20.3	15.5	2.8	66.2	31	9.4	18.9	71.7
	Shopping/Personal Errands	73	13.2	13.8	10	55	35	4.8	33.3	61.9
	Other	56.6	19.7	23.7	6.7	66.7	26.7	11.1	44.4	44.4
Day of Week for Last trip	Weekday	58.9	22.1	19	4.5	59.1	36.4	7	35.8	57.2
	Weekend	64.9	17.9	17.2	2.5	60.7	36.9	7.9	30.7	61.4

3.1.4 Correlations

The analysis indicates significant weak but positive correlation between income and education (r = 0.247) and gender and ethnicity (r = 0.127). Hence, education and ethnicity were not used as explanatory variables in the models presented in the future sections of this manuscript.

The distribution of demographics indicates the survey sample, which essentially consists of ASU students, faculty, staff, and few commuters for the most part, is biased with a lack of representative diversity. The extension of data collection to include more number of participants is outside the budget limitations of this project and hence the sample bias is addressed by weighting the existing data as described in the next section.

3.2 Weighted Data

The synthetic population generator tool PopGen developed by Ye et al (2009) has been utilized to determine the weights for the sample data. This tool utilizes an algorithm that iteratively adjusts the weights for each household or person attributes until they match the provided marginal distributions. The household attributes used include household size, number of vehicles and income and the person attributes include age, gender and ethnicity. The constraints to match the household and person attributes for the Phoenix metropolitan region are obtained from the 2014 American Community Survey (ACS). The detailed information on obtaining the weights can be referred at Ye et al (2009).

For the weighted data, the gender distribution is ideally balanced with 52.2% males and 47.9% females. The weighted sample is diverse with White (78.5%), Black (4.4%), Asian (3.7%), Pacific Islander (0.2%), Native American (2.2%) and other

(11.1%). The majority of the households' favour incomes in \$50k-\$75k (16.8%) and less than \$20k (24.7%) followed by \$100k-\$150k (11.8%), \$75k-\$100k (11.1%), \$20k-\$30k (9.5%), \$30k-\$40k (9.4%), \$40k-\$50k (8.8%) and >150k (8%) in line with the ACS data. Thus, this weighted sample is representative of the Phoenix-Mesa metropolitan statistical area where the survey data is collected. The rest of the analysis in the paper is based on the weighted data.

3.3 Attitude Analysis

A few attitudinal questions were asked prior to the introduction of scenarios to gain an understanding of the previous knowledge of the respondents on common managed lanes existence. 99% of the respondents are familiar with a HOV lane in expectation with their prevalence in the Phoenix region. When asked about the frequency of HOV use, 38% answered they used 2-3 times a month followed by rarely (35%), 2-3 times a week (11.4%), daily (9%) and never (7%). The respondents who used a HOV lane before were asked about their satisfaction and 86% reported satisfaction levels of 6 or higher. Although this question is an indication of how much people like to use the HOV lane the rating is subjective as the reasons behind two persons choosing the same rating is different. 52% of the respondents reported familiarity with HOT lane but only 25% has actually used it before which is not very surprising considering the fact that there are no toll lanes in the entire state of Arizona. Prior to the scenarios, 33% responded they had no interest in using a HOT lane (category 0) and 9% showed interest (category 10) whereas 21% were somewhere in the middle under category 5 (Figure 3.1).

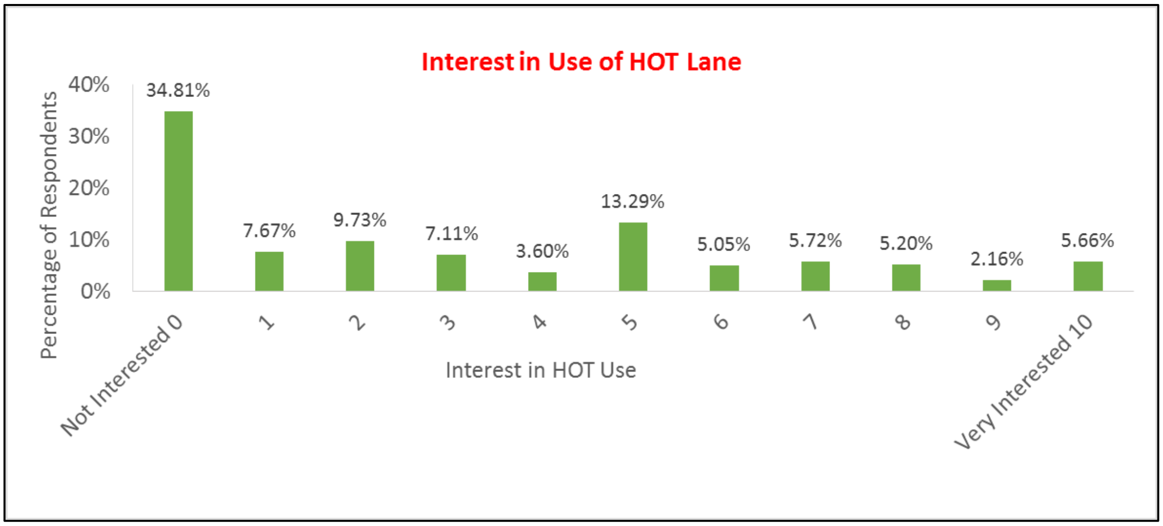


Figure 3.1 Interest in Use of HOT Lane

After the explanation of the TTR concept and the respondents answered the stated preference scenarios, they were asked to report their interest towards TTR shown in Figure 3.2. Before the scenarios, 24% of the respondents showed no interest in TTR (category 0), 27% were somewhat in the middle (category 5) and 12% were very interested (category 10). After the scenarios, 27% of the respondents showed no interest in TTR (category 0), 12% were somewhat interested (category 5) and 9% were very interested (category 10). Please note that the percentages for the most obvious categories and not all the categories are mentioned in the text above, which is why they do not add up to a 100. However, all the categories are included in the figures and their percentages add up to a 100.

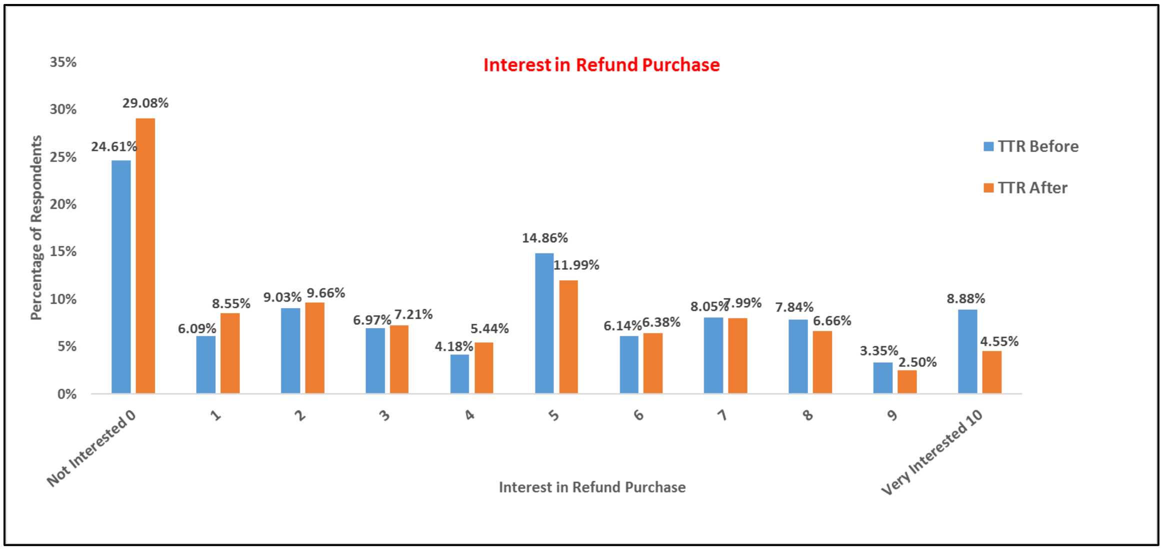


Figure 3.2 Interest in TTR Before and After the Scenarios

The mean and standard deviation of the attitudinal variables - interest towards HOT (HOT Interest), interest towards TTR before and after the scenarios (TTR Before and TTR After) for both the original ratings (0-10) and recoded ratings (0-6) are presented in Table 3.2. The original ratings were rescaled from 0-10 to 0-6 to gain a better understanding of the data. This scaling combined ratings 1 and 2, 3 and 4, 6 and 7 and finally 8 and 9 together. For the original scale, the mean (Std. deviation) of HOT Interest, TTR Before and TTR After are 3.17 (3.21), 4.11 (3.36) and 3.47 (3.16) respectively. For the recoded data, the mean (Std. deviation) of HOT Interest, TTR Before and TTR After are 3.21 (1.55), 3.49 (1.56) and 3.23 (1.49) respectively. For both the ratings, the interest towards TTR is higher than that of HOT interest. For the original ratings, statistical tests indicate that the difference between the mean values of HOT Interest & TTR Before, HOT Interest & TTR After and TTR Before & TTR After is significantly different from zero. For the recoded ratings, the mean values of HOT & TTR Before and TTR Before & TTR After are significantly different from each other whereas there is no statistical difference in the means of HOT Interest & TTR After. In summary, the observed general negative attitude towards HOT and TTR is in line with expectation and the users are less negative about TTR than HOT supporting the idea that TTR could make HOT facilities more appealing.

Table 3.2. Descriptives of HOT and TTR Interest

Data type	Characteristic	HOT Interest	TTR Before	TTR After
Original	Mean	3.17	4.11	3.47
	Std. Deviation	3.21	3.36	3.16
Recoded	Mean	3.21	3.49	3.23
	Std. Deviation	1.55	1.56	1.49

A cross tabulation analysis of attitude and demographic data is performed to further understand the general attitude towards ML use and examine the potential influence factors. The younger people in the age range 18-40 rarely use the HOV lane when compared to the other age groups. A majority of the people under the age 30 are not familiar with HOT lane compared to those who are older. Men and women are equally familiar/unfamiliar with HOT although women considerably beat men in prior HOT use (34% vs. 16%). There seem to be a correlation between income and HOT interest due to the fact that 14.3% of those with income greater than $150k responded with an 8-9 on the Likert scale for interest in using HOT compared to the 1.9% in $20-30k category. The interest in TTR after the scenarios was shown the most by those with income in the range $50-75k followed by those greater than $30-40k. Those who were interested in the HOT lane exhibited the same interest in using the TTR option. 71% of people who said they were very interested in HOT lanes said they were also as interested in the TTR option after the stated-preference scenarios were presented. Additionally, 47% of people who reported their HOT interest as a “3” or “4” also reported their TTR interest as higher at either an “8” or “9”.

A cross tabulation of the interest in TTR before and after the scenarios measured on a 0-10 Likert scale is presented in Table 3.3. The ratings of the respondents were rescaled from 0-10 to 0-6 to gain a better understanding of the data. This scaling combined ratings 1 and 2, 3 and 4, 6 and 7 and finally 8 and 9 together. .

Table 3.3 Cross tabulation of TTR interest before and after the scenarios

		Interest in TTR After Scenarios						
		0	1	2	3	4	5	6
Interest in TTR Before Scenarios	0	76.7%	6.6%	8.3%	2.6%	1.2%	.6%	4.1%
	1	25.5%	47.9%	15.2%	10.8%	.2%	.4%	0.0%
	2	23.6%	30.3%	31.4%	8.1%	5.1%	1.5%	0.0%
	3	11.7%	4.1%	45.7%	27.5%	8.1%	1.3%	1.5%
	4	2.8%	3.5%	15.3%	13.6%	19.8%	44.6%	.3%
	5	12.0%	.8%	38.6%	7.1%	16.3%	19.8%	5.4%
	6	3.4%	.6%	8.0%	4.1%	7.9%	23.4%	52.6%

Of the people who responded that they were uninterested (rated “0”) in the TTR option before the scenarios, 77% remained uninterested after the scenarios were presented to them. 7% increased their interest to that of a “1” or a “2” value. Of the people who responded that they were very interested (rated “10”) in the survey, only 53% of them remained as interested as before. 3% of those people’s interest dropped to “0” after completing the scenarios. 8% of people increased their interest from a “5” to that of a “6” or “7” after the scenarios. Similarly, 44.6% of people increased their TTR interest from a “6” or “7” to an “8” or “9”. 16% of people who responded with an interest of an “8” or “9” before the scenarios, then reported with a “6” or “7” after. Likewise, 30% of people who responded with an interest of a “3” or “4” pre-scenarios, responded with a “1” or “2” after the scenarios. It appears that slightly more people responded with a decreased interest which could be attributed to the higher costs presented in the stated preference questions than they were willing to pay

3.4 Ordered Choice Modelling

An exploratory analysis of the data revealed negative interest towards HOT and TTR options in accordance with the expectations and previous studies. However, it was observed that users are less negative about TTR than HOT, supporting the idea that TTR could make HOT facilities more appealing. The satisfaction towards HOT and interest towards TTR are measured on a 0-10 Likert scale with ordinal ranking. Hence, ordered probit models are used to determine the factors that impact HOT satisfaction and TTR interest prior to the scenarios (TTR before). This interest reported by the respondents prior to actually going through the four scenarios captures their actual inclination towards the refund option without the influence of repeated measures or self-selection bias. The ratings of the respondents for HOT satisfaction and TTR interest were scaled from 0-10 to 0-6 by combining ratings 1 and 2, 3 and 4, 6 and 7 and finally 8 and 9 together. The basic idea of ordered choice modelling is that there is a latent continuous metric underlying the observed dependent variable and thresholds partition the observed data into a series of regions corresponding to the observed ordinal categories. The latent variable (y_i^*) is a linear combination of predictors (X_i's) and an error tern (ε_i) and the parameters may be assumed to be non-random (fixed effects model) or random (random effects model). A random parameter model with possible heterogeneity across individuals is estimated for HOT interest and TTR before as the dependent variables. The model is specified as

$$y_i^* = \beta X_i + \varepsilon_i + u_i$$

The latent dependent variable is censored as follows:

$$y_i = 0, \qquad if\ y_i \leq \mu_0$$

$$= 1, \qquad if\ \mu_0 \leq y_i \ \leq \mu_1$$

$$\dots ..$$

$= J, \qquad if\ \mu_0 \leq y_i \ \geq \mu_{J-1}$

Where

J is the number of ordinal response categories and μ is the threshold parameters for probabilities

X_i is the vector of explanatory variables.

β is the coefficient estimates of the explanatory variables.

ε_i is the error term that follows a standard normal distribution.

u_i is the unobserved heterogeneity that follows a normal distribution with standard deviation σ_u to be estimated.

The probability that an individual i makes choice j conditioned on the random effects is given by

$$P(y_i = j|X_i, u_i) = P(y_i^* is\ in\ the\ j^{th}\ range) = F\big(j, \mu, (\beta^T X_i + \sigma_u u_i)\big)$$

The likelihood function is given by

$$L = \prod_{i=1}^{N} F\big(j, \mu, (\beta^T X_i + \sigma_u u_i)\big)$$

No closed-form expression exists for the above over the distribution of unobserved heterogeneity and hence Halton sequence draws are used to obtain the simulated likelihood value. The random parameters model are estimated with HOT interest and

TTR before as the dependent variables using the statistical software LIMDEP (NLOGIT, 2012) are presented in the following sections.

3.4.1 Interest in HOT

The model results shown in Table 3.4 indicate men are slightly more interested towards HOT compared to women. Younger people less than 24 years old have a higher interest towards HOT compared to those greater than 40 years old, followed by those aged 31-40 and 25-30. There seems to be a negative correlation between HOT interest and income. Higher income people are less negative towards HOT compared to the lower income people. The income range $50-75k is used as the reference category. Asians showed a higher interest whereas Blacks are negatively interested towards HOT. Those who were familiar with and used the HOT before were negatively interested towards HOT.

3.4.2 Interest in TTR

The socio demographic factors, which affect the interest in TTR before, are shown in Table 3.5. Prior to the completion of the scenarios, men were positively interested in TTR in comparison to women. Younger people less than 40 years old were positively interested in TTR in comparison to those older than 40. Those in the lower income range (<$40k) were negatively interested in TTR and those with incomes ranging between $40-50k had the highest positive interest towards TTR. Those who were familiar with and used the HOT before were positively interested in TTR. The occasional users of HOV lanes (2 – 3 times a month) were positively interested in the refund option. Frequent users of HOV (daily and 2 – 3 times a week) and those who never used the

HOV before are negatively interested towards the TTR option. Asians show a significant positive interest whereas Blacks are negatively interested.

Table 3.4 Ordered Probit results for HOT Interest

Variable	Coefficient	z-statistic
Constant	0.61***	7.28
Male	0.56***	8
Age		
18-24	0.68***	5.07
25-30	0.47***	4.01
31-40	.52627***	4.48
Income		
<$30k	-0.91***	-8.87
$30-40k	-0.66***	-5.79
>$100k	-0.17*	-1.94
HOV Use		
Daily	-1.24***	-8.99
2-3 times a week	-0.36***	-3.09
2-3 times a month	.30***	3.84
Never	-0.57***	-3.55
Ethnicity		
Black	-.64***	-3.77
Asian	.38**	2.28
Familiar with HOT and Used HOT Before	-.0.15***	-1.56
Familiar but not used HOT or Vice-Versa	0.1	1.34
Threshold Parameters for probabilities		
Mu(01)	.52***	13.99
Mu(02)	0.75***	17.38
Mu(03)	1.53***	27.9
Mu(04)	1.95***	30.2
Mu(05)	2.48***	31.27
Log Likelihood	-2001.69	
Information Akaike Criterion	4045.4	

***,**,* Significance at 1%, 5%, 10% level

Table 3.5 Ordered Probit results for TTR Interest

Variable	Coefficient	z-statistic
Constant	0.82***	9
Male	0.86***	11.69
Age		
18-24	0.39***	2.94
25-30	0.64***	5.1
31-40	.63***	5.85
Income		
<$30k	-0.51***	-4.57
$30-40k	-0.30**	-2.49
$40-50k	0.30**	2.24
>$100k	-0.38***	-4.01
HOV Use		
Daily	-0.88***	-6.69
2-3 times a week	-0.48***	-4.21
2-3 times a month	.23***	2.72
Never	-0.26***	-1.76
Ethnicity		
Black	-.82***	-4.93
Asian	1.2***	6.88
Familiar with HOT and Used HOT Before	0.32***	3.72
Threshold Parameters for probabilities		
Mu(01)	.57***	12.28
Mu(02)	0.84***	15.69
Mu(03)	2.06***	27.72
Mu(04)	2.56***	31.46
Mu(05)	3.26***	34.34
Log Likelihood	-2096.09	
Information Akaike Criterion	4236.2	
***,**,* Significance at 1%, 5%, 10% level		

A comparison of the HOT interest and TTR interest reveals that men are positively interested in HOT/TTR in comparison to women. Older people (age >40) are negatively interested in HOT/TTR while the younger people are express a greater interest towards TTR. Lower income people (<$30k) are negatively interested in both HOT and TTR whereas those in income categories (>$30k) are negative towards HOT but positively interested in TTR. Those who use the HOV lane daily are more negative towards both HOT and TTR in comparison to those who use the HOV less frequently. Whites and Asians show a significant positive interest towards TTR while Blacks are negatively interested. Those who are familiar with HOT and have used them before are positively interested in both HOT and TTR indicating TTR could make HOT facilities more appealing

3.5 Conclusion

This study provided valuable insights into the attitudes of the public towards priced managed lanes by introducing the concept of travel time insurance (TTR) through a stated preference survey mainly deployed in the Phoenix metropolitan area. The TTR concept explored provides an additional incentive to the drivers to pay for MLs by insuring their travel time and refunds their toll cost if they do not arrive at their destination with the specified travel time savings. The perceived benefits of TTR include changing the negative attitudes towards priced MLs, increase in underutilized HOV/HOT lanes, overall congestion mitigation and additional funding for the transportation agencies. The survey consisted a set of questions on the last trip on I-10, opinions on priced managed lanes, demographics and hypothetical scenarios involving the TTR option. 2274 responses were obtained via newsletters of ASU, ITE and ITS chapters of

AZ and social media platforms. The data distribution indicated sample bias with lack of representative diversity which is addressed by sample weighting based on the most recent American Community Survey (ACS) information. Ordered probit models were estimated to determine the factors that impact the user interest in HOT and TTR. Both the exploratory and statistical analysis of the data revealed negative interest towards HOT and TTR options in accordance with the expectations and previous studies. However, it was observed that users are less negative about TTR than HOT, supporting the idea that TTR could make HOT facilities more appealing. The majority of the survey respondents being in Arizona and not familiar with HOT lane concepts may have affected their interest in TTR. In addition, the concept of HOT and "pay to travel in addition to the gas tax" itself may have also turned people away from the TTR option. Those with a high interest in HOT tend to be more willing to pay for TTR. This may be due to the fact that they value their time more than their money. A positive interest towards MLs could be stimulated by enhancing the awareness and knowledge of the public by communicating through social media, stakeholder interviews and focus group discussions. Moreover, TTR may receive higher support when the public becomes more familiar with the concept.

This study is a very first step towards exploring TTR, as a new pricing strategy for MLs. Future research must include an exploration of the stated preference scenarios to determine the factors that influence the people's choices of GPL, HOT with and without TTR. A statistical model predicting these choices based on the socio-demographic attributes, trip characteristics, toll and TTR rates will also be estimated to determine the people's WTP for MLs. The incorporation of psychological and economic theories is also an interesting aspect for future studies to possibly model HOT and TTR use. Previous research (Hogarth and Kenreuther, 1989) found that insurance purchase decisions of consumers are affected by (a) attitudes toward risk as expressed in their utility functions and (b) the means of their probability distributions over the probability of experiencing the known loss. An in-depth review of this concept will be performed and plausible models will be estimated in future studies.

CHAPTER 4

CHOICE MODELS INCORPORATING TRAVELER'S ATTITUDES

This chapter investigates the impact of travel time reliability, TTR, and latent variables representing psychological constructs on travelers' choices of GPL and HOT in response to the proposed new pricing strategy. A multinomial logit (MNL) model predicting the choices of GPL and HOT with or without TTR based on socio-demographics, trip characteristics and toll and TTR rates is first estimated. We further employed structural equation modeling to explore the impacts of latent variables representing psychological constructs such as attitudes and perceptions.

4.1 Background

Despite the increasing number of priced ML facilities, public opposition and perception of tolls as double tax on top of the already paid gas tax along with equity concerns has hindered what could have been a wider-spread conversion of HOV lanes to HOT lanes in the US (Cleland, Winters, 2000; Perez, B.G., & Sciara, G.C, n.d.; Kockelman & Kalmanje, 2005; Peachtree & Nw, 2010; Ungemah, Swisher, & Tighe, 2005). In addition, it is possible that sometimes travellers will not receive expected benefits from MLs due to uncertainties in traffic such as a vehicle incident that is not reflected by the time display. Considerable research has shown the importance of travel time reliability to travellers and has advocated its consideration and inclusion in transportation policy. Reliability focuses on improving the predictability, i.e. reducing the variability, of travel time. Early research found that risk-averse travellers would choose the mode with less travel time variability (Guttman, 1979; Menashe & Guttman, 1986). Empirical studies from the 90's and early 2000's have also revealed the willingness of travellers to pay for reduction in travel time variability along with travel time savings (Bhat & Sardesai, 2006; Small, 1999; Hensher, 2001a, 2001b; Senna, 1994). More recent research from both stated preference (SP) surveys and actual ML usage have further confirmed that the public attitude towards MLs is affected by reliability, availability of alternatives and the utilization of generated revenue (Carrion & Levinson, 2012; Devarasetty et al., 2012; Kato & Uchida, 2018). A more recent study revealed that 11% of travellers on Katy Freeway MLs were willing to pay and not switch to GPL lanes despite the negative travel time savings (Sharifi and Burris, 2018).

In this chapter, we investigate an alternative pricing strategy that provides travellers some "reassurance" via an option of travel time refund (TTR), which essentially is an insurance. When choosing to pay for MLs, users are provided an opportunity to purchase an additional TTR which ensures them a certain amount of travel time savings. We are interested in the impact of travel time reliability, TTR, and latent variables representing psychological constructs on travellers' choices of GPL and HOT in response to this new pricing strategy. It is assumed that the technologies needed for implementation and enforcement of TTR are in place. The cost of TTR is assumed to be always less than the actual toll. For any toll road, the toll operator aims to provide a certain level of service while maximizing revenue. Previous research indicates that the toll authorities can achieve this objective by employing various pricing techniques. A number of studies have examined the feasibility of multiple tolling strategies including dynamic pricing, distance based tolling, self-adaptive tolling, dynamic traffic assignment etc. using simulation and/or operation analyses techniques (Jang et al., 2010; Zhang et al., 2014; Laval et al., 2015; Chen et al.,2018; Ma et al., 2018). The determination of the tolling strategy and the actual TTR is another research topic in its entirety that is beyond the scope of the present study. A fixed toll rate from a set of predetermined rates ($0.05/mile, $0.20/mile, and $0.35/mile) consistent with the previous studies is randomly generated for various scenarios in the survey (Kockelman & Kalmanje, 2005). If the users did not experience the "insured" travel time savings due to unforeseen circumstances, they would be refunded the toll amount but not the additional cost of TTR. Our previous analysis has shown that the travellers are less negative about TTR than HOT alone (Lou et al., 2015). Therefore, apart from providing an additional source of funding to the transportation agencies, it is anticipated that there will be a change in the negative attitudes towards priced MLs, and GPL congestion could be reduced with more users willing to use priced MLs.

A multinomial logit (MNL) model predicting the choices of GPL and HOT with or without TTR based on socio-demographics, trip characteristics and toll and TTR rates is first estimated. We further employed structural equation modelling to explore the impacts of latent variables representing psychological constructs such as attitudes and perceptions. Previous research recognized that the utility of an alternative is influenced by such psychological constructs; and the extension of traditional choice models to incorporate latent variables representing attitudes, perceptions, values, life style preferences etc. improves the models' explanatory power (Ben-akiva et al., 2002; Choo & Mokhtarian, 2004; Collins & Chambers, 2005; Nordlund, Annika & Jorgen, 2003; Paulssen et al., 2014; Walker & Li, 2007). Moreover, psychological and economic factors may also impact the choice of insurance purchase. Hogarth and Kenreuther (1989) found that insurance purchase decisions of consumers are affected by (a) attitudes toward risk as expressed in their utility functions and (b) the means of their probability distributions over the probability of experiencing the known loss. The estimation of structural equation models is computationally intensive and often requires the development of customized computer programs. For this reason, most of the current applications are limited to binary choice models and only consider the direct effect of latent variables on choices without including the causal relationships among the latent variables (Ashok, Dillon, & Yuan, 2005; Ben-akiva et al., 2002; Dellaert & Stremersch, 2005). In contrast, this chapter investigates the impacts of latent variables on travellers' responses to ML options, which is a multinomial choice problem (GPL, HOT with and without TTR). The relationship between various latent variables, if any, is also examined.

4.2 Multinomial Logit Models

We first estimated MNL models using NLogit software package (NLOGIT Version 5.0, 2012). Since each survey respondent was presented with four randomly generated scenarios, it is important to account for correlation among repeated choices made by the same individuals using panel data. A separate MNL model for just the first choice scenario (based on traveller's reported last trip on I-10) is also estimated. The last-trip scenario provides additional trip-related information such as purpose, day of the week, time of day, vehicle type, HOV lane use, number of passengers in the car etc., which is unavailable in the other three hypothetical scenarios. The panel data model with all four scenarios is described in the next subsection followed by the estimation results for the last-trip scenario only.

4.2.1 Panel Data MNL

The panel data MNL model takes into account all the four scenarios, including the last trip and three hypothetical 10, 15 and 25 mile trips. The same individual or traveler makes repeated choices for varying trip distances and hence the data can be treated as observation of cross-section of individuals over time.

The utility of the MNL model is given by

$$U_{ijt} = \gamma_j + \beta_j^T x_{ijt} + v_i + \varepsilon_{ijt}$$

Where,

U_{ijt} is the utility for individual i to choose alternative j in scenario t

γ_j is the alternative-specific constant

x_{ijt} denotes the vector of explanatory variables related to both decision-maker and alternative attributes in scenario t

β_j is the vector of coefficient estimates of the explanatory variables

v_i is the unobserved heterogeneity that enters the utility function in the form of a random effect across individuals. $[v_1, v_2, \ldots, v_i, \ldots, v_N]$ follows a multivariate normal distribution with τ as the covariance matrix. Note that this heterogeneity is independent from the scenario t, and τ is to be estimated.

ε_{ijt} is the error term that follows Type 1 extreme value distribution

The probability that an individual i makes choice j in scenario t conditioned on the random effects is given by

$$P_{ijt}|v_i = \frac{\exp(\gamma_j + \beta_j^T x_{ijt} + v_i)}{\sum_k \exp(\gamma_k + \beta_k^T x_{ikt} + v_i)}$$

Let d_ijt=1 if individual i chooses alternative j in scenario t, and 0 otherwise. The likelihood function is then given by

$$L = \prod_i \int \prod_t \prod_j \left\{ \frac{\exp(\gamma_j + \beta_j^T x_{ijt} + v_i)}{\sum_k \exp(\gamma_k + \beta_k^T x_{ikt} + v_i)} \right\}^{d_{ijt}} f(v) dv$$

No closed-form expression exists for the above integration over the distribution of unobserved heterogeneity. Therefore, Halton sequence draws (Train, 1999) are used to obtain the following simulated likelihood (SL) value.

$$SL = \prod_i \frac{1}{R} \sum_{r=1}^{R} \prod_t \prod_j \left\{ \frac{\exp(\gamma_j + \beta_j^T x_{ijt} + v_i)}{\sum_k \exp(\gamma_k + \beta_k^T x_{ikt} + v_i)} \right\}^{d_{ijt}}$$

The model estimated with panel data is shown in Table 4.1. The variable “cost” is the sum of the toll rate and the cost of TTR. Various measures exist in the literature to define reliability, such as (a) travel time variation from the mean, (b) difference between the 80th (90th) percentile of travel time and the mean, (c) difference between the 80th (90th) percentile of travel time and the median (Carrion & Levinson, 2012; Devarasetty et al., 2012; Lam & Small, 2001). In this study, we used the difference between the upper and lower bounds of the provided travel time window as the measure of reliability. The interest and attitude towards the managed lanes and the refund option is reflected by variables “HOV satisfaction”, “HOT interest” and “TTR interest” measured on a 0-10 Likert scale. The coefficients of variables “cost”, “travel time” and “reliability” are specified to be random with a normal distribution, whose standard deviations are found to be significant as shown in Table 4.1.

Table 4.1 MNL model results for panel data

Explanatory Variable	HOT	TTR	GPL
Constant	-0.85***	-3.01***	
Cost	-0.59***	-0.59***	
Travel Time	-0.21***	-0.21***	-0.21***
Income			
<30k	-1.19***	0.55***	
30-40k	-2.76***	0.54***	
40-50k	-1.48***	-0.83***	
75-100k	-0.97***	-0.29***	
>100k	-1.001***	-0.34***	
HOV Satisfaction	-0.05***	-0.063***	
HOT Interest	0.43***	0.57***	
TTR Interest	0.39***	0.73***	
Standard Deviations of random parameters			
Constant-HOT	0.89***		
Constant-TTR	1.96***		
Cost	0.23***		
Travel Time	0.16***		
R-Square	0.335		
***,**,* Significance at 1%, 5%, 10% level			

The estimated model has an R-square of 0.335 and all the estimates are significant at 1% level. The results indicate that higher toll and TTR rates and longer travel time increase the disutility of an alternative. All income groups are negative towards the HOT option in comparison to the 50-75k category. On the contrary, lower income groups (less than $40k) are positively interested towards TTR compared to the higher income groups. A possible explanation for this could be that lower income groups see value in the money-back guarantee while the higher income groups do not care and view the TTR option as redundant, unnecessary or additional stress. In addition to this, trip purpose could have a significant role in TTR choice making which is evaluated in the next subsection. Those with higher satisfaction levels towards HOV are less likely to choose the HOT or TTR options. A higher interest towards HOT and TTR is likely to increase the utility of HOT and TTR respectively.

4.2.2 Impact of Trip Purpose

The effects of trip attributes on ML usage is worth investigating although the trip purpose information is available only for the last-trip and not for the various hypothetical scenarios. An MNL model was estimated for the last-trip scenario alone. The model has an R-square of 0.47 and the estimates are shown in Table 4.2. The model results indicate negative coefficients for cost and travel time, which is intuitive. Higher costs and longer travel times for an alternative is more likely to increase its disutility. Lower income groups (<$50k) are more positively interested towards TTR options in comparison to the higher income groups. People who used the I-10 on a weekday are more willing to pay for the HOT lane in comparison to the weekend. Trip purpose seems to have a high influence on the decision of the traveller. Those who are traveling for work or work-related reasons are more likely to pay for HOT than TTR. Social and recreational users are more inclined towards HOT than TTR. Those with a higher HOT interest are more likely to choose TTR than HOT. Those with a higher TTR interest are more likely to choose TTR.

Table 4.2 MNL model results with trip purpose for last trip

Explanatory Variable	HOT	TTR	GPL
Constant	-11.98	-16.64	
Cost	-0.99	-0.99	
Travel Time	-0.50	-0.50	-0.50
Income			
<30k	-0.66	7.05	
30-40k	-11.81	2.86	
40-50k	-8.64	1.36	
75-100k	-2.27	0.06	
>100k	-2.07	0.69	
weekday	2.48	-1.723	
Trip Purpose			
Commute	4.77	-0.09	
Work Related	10.76	0.48	
Class	6.22	-1.22	
Social/Recreational	6.87	-0.71	
Shopping	-1.68	-1.36	
HOV Satisfaction	-0.011	1.30	
HOT Interest	1.09	1.12	
TTR Interest	0.80	1.69	
HOT Interest*Work	-0.44		
TTR Interest*Work		0.48	

4.3 Structural Equation Model

This section extends the traditional MNL models to incorporate latent variables as recognized in previous studies (Ben-akiva et al., 2002; Choo & Mokhtarian, 2004; Lam & Small, 2001; Paulssen et al., 2014; Walker & Li, 2007). The concept of tolls is new to the residents of Arizona and hence their attitudes towards priced MLs could play a significant role in their decision-making. A latent variable "attitudes" is introduced in the model with HOV satisfaction and HOT interest as the measurement indicators. "Attitudes" captures the overall interest and inclination towards the toll lanes. On the other hand, the concept of tolls and the refund, as well as the nature of travel time uncertainty, should be well understood and comprehended by the traveller in order to be able to make a well-informed decision between the priced and toll-free lanes. Although these fundamental concepts have been thoroughly explained along with the survey questionnaire, there is no direct way to measure respondents' comprehension except through a latent variable and indirect indicators. All measurement indicators of the latent variable are obtained from the SP survey response. Note that in the scenarios, reliability is not directly provided to the respondents; rather, a travel time window is presented for each alternative. The reliability measure as calculated from the time window is not necessarily the perceived value by the respondents. Therefore, the reliability measure is considered to affect the latent variable. The utilities in the choice part may depend on both the observed and the latent characteristics of the decision maker and the alternatives. The proposed model not only allows plausible relations among latent variables but also the influence of exogenous variables on latent variables. The integrated choice model with latent variables is estimated using a comprehensive software package called MPlus for structural equation models (Muthén & Muthén, 2007). The model framework shown in Figure 4.1 can be translated as testing the following propositions. The dotted lines in the figure denote the measurement indicators of the latent variables and the solid lines indicate the proposition being tested.

1. Attitudes affect the choice of GPL or HOT with and without TTR
2. Socio-demographics affect attitudes
3. Socio-demographics affect the choice of GPL or HOT with and without TTR
4. Alternative specific attributes – travel time and travel cost affect the choice of GPL or HOT with and without TTR

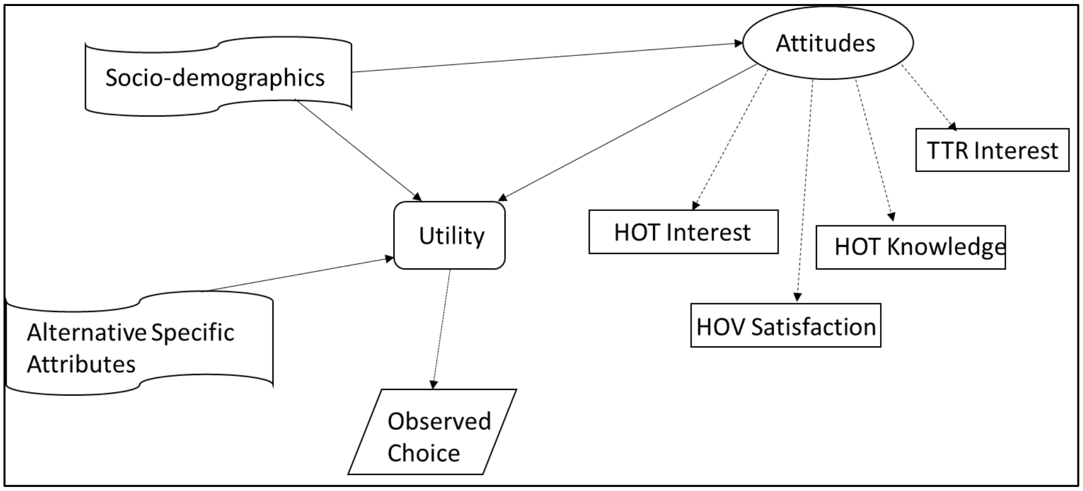


Figure 4.1. Structural equation model framework

4.3.1 Model Specification

The integrated model can be divided into two parts: (a) latent variable part with several measurement indicators, along with the relationship of the two latent variables if any, and (b) the utility of the choice model, which is accounted for both by the latent variables and the observed exogenous variables. These specifications are enumerated in the following.

<u>Latent Variable Model</u>: The unobserved latent variables (η's) are measured by several indicator or manifest variables (y's). The latent variables are reflected or manifested into the indicators with the following linear equation

$$y_{ijt} = \Lambda\eta_{ijt} + \varepsilon_{ijt}$$

y_{ijt} is a $P \times 1$ vector of indicator variables, Λ is a $P \times M$ matrix of factor loadings, η_{ijt} is a $M \times 1$ vector of latent variables, and ε_{ijt} is a $P \times 1$ vector of i.i.d multivariate normal measurement errors.

The relationship between the latent variables is given by the linear equation

$$\eta_{ijt} = B\eta_{ijt} + \Gamma x_{ijt} + \zeta_{ijt}$$

where B $(M \times M)$ and Γ $(M \times L$, where L is the number of explanatory variables) are unknown regression coefficient matrices and ζ (M×1) represents a vector of i.i.d multivariate normal error term.

Discrete Choice Model: A decision maker ($i = 1, \ldots, I$) provided with a finite number of alternatives that are mutually exclusive ($j = 1, \ldots, J$) at period t will choose the alternative that provides the greatest utility U_{ijt}. The utility component is given by

$$U_{ijt} = V(x_{ijt}, \eta_{ijt}; \beta) + \xi_{ijt}$$

x_{ijt} is the $L \times 1$ vector of observed variables,. ξ_{ijt} is the extreme value error term that is i.i.d.

The deterministic utility is linear in parameters of exogenous variables and the latent variables

$$V_{ijt} = \beta_x^T x_{ijt} + \beta_\eta^T \eta_{ijt}$$

The probability of an individual i choosing an alternative j is given by

$$P_{ijt} \middle| \left(x_{ijt}, \eta_{ijt}; \beta\right) = \frac{e^{V(x_{ijt}, \eta_{ijt}; \beta)}}{\sum_j e^{V(x_{ijt}, \eta_{ijt}; \beta)}}$$

Likelihood Function: The likelihood function is obtained by integrating the joint probability of latent and choice variables over the space range of the latent variables.

$$L = \int_{R_\eta} \prod_i P_{ijt} \middle| \left(x_{ijt}, \eta_{ijt}; \beta\right) \; f_y(y \mid \eta, \Lambda, \Sigma_\varepsilon) f_\eta(\eta \mid x, B, \Gamma, \Sigma_\zeta) d\eta$$

4.3.2 Model Results

The model results show that latent variable indicators are statistically significant with intuitive signs and magnitudes (see Table 4.3). Based on the magnitude of factor loadings, TTR interest and HOT interest are the stronger indicators of attitudes followed by HOV satisfaction and HOT knowledge. The effects of socio-demographics and reliability on the latent variables were not significant and hence not included in the paper.

Table 4.3 Estimates of latent variables

	Estimate	P-Value
Attitudes		
HOV Satisfaction	0.598	<0.0001
HOT Interest	0.884	<0.0001
HOT Knowledge	0.197	0.053
TTR Interest	0.834	<0.0001

The estimates of the coefficients in the utility equation are shown in Table 4.4. All the coefficients in this model are treated as non-random. The GPL alternative is used as the reference category, the utility of which is non-zero with travel time as the explanatory variable.. The direct effect of "attitudes" on utility is significant and positive for both HOT and TTR indicating the decision maker's attitudes towards the concept of HOT and TTR play a significant role in the choice made by them. Higher costs and travel time tend to increase the disutility of a choice in accordance with the expectations. People are more likely to choose HOT and TTR when making longer trips. Lower income categories less than $20k and $30 - $40k have a significant negative impact on the choice of HOT, which is intuitive as they may view the HOT as an additional tax on their pockets. People in the age groups 18-24 and 31-40 are more positive towards the HOT without TTR option. Income and age do not have a significant impact on the choice of TTR.

Table 4.4 Choice estimates

	HOT without TTR		HOT with TTR		GPL	
	Estimate	P-Value	Estimate	P-Value	Estimate	P-Value
Constant	-0.522	0.048	-0.409	0.212	-	-
Attitudes	1.255	0.035	1.927	0.035	-	-
Cost	-0.31	<0.0001	-0.31	<0.0001	-	-
Travel Time	-0.118	0.004	-0.118	0.004	-0.118	0.004
Income						
<$20k	-1.102	0.074	0.231	0.708	-	-
$20k-$30k	-	-	-	-	-	-
$30k-$40k	-1.321	0.011	0.632	0.176	-	-
$40k-$50k	-	-	-	-	-	-
$50k-$75k	-	-	-	-	-	-
$75k-$100k	-	-	-	-	-	-
$100k-$150k	-	-	-	-	-	-
Age						
18-24	1.242	0.049	0.251	0.688	-	-
25-31	-	-	-	-	-	-
31-40	1.164	0.006	-0.08	0.887	-	-
41-54	-	-	-	-	-	-

The model results fairly support three of the four hypotheses propositioned earlier in this chapter. The indicators of the latent variable attitudes are significant in line with proposition 1. Sociodemographic characteristics do not significantly favor proposition 2. Sociodemographics partially affect the choice of HOT and TTR (proposition 3). Higher costs and travel times tend to negatively influence the utility of a choice in line with proposition 4. Among the socio-demographics, income and age are the significant contributors in favor of proposition 3.

4.4 Conclusion

This study provided valuable insights into travellers' attitudes towards priced managed lanes (MLs) by introducing the concept of Travel Time Refund (TTR) through a stated preference (SP) survey in the Phoenix metropolitan area. The preferences of the public among the choices of GPL, HOT with and without TTR are evaluated through the traditional multinomial logit choice models as well as structural equation models with latent variables. The results intuitively indicate that people are less likely to choose the option with higher costs and travel times. Those with a higher interest towards HOT and TTR are more likely to choose the TTR option in comparison to HOT and GPL. Trip purpose seems to influence the choice of TTR with people traveling for commute and work- related trips being more positively interested towards TTR. The majority of the survey respondents are in Arizona, and are not familiar with the concept of HOT. Therefore, their attitudes towards priced lanes along with their understanding and comprehension of the concept of TTR may affect their willingness to pay for TTR. These effects cannot be directly measured and latent variables are incorporated into the choice model. The results indicate that attitudes play a significant role in influencing the choice of the decision maker.

This study is a first step towards exploring the impact of travel time reliability and latent variables representing psychological constructs on the travellers' choice of a new pricing strategy. A positive attitude towards priced MLs can be stimulated by educating the public about their successful implementation elsewhere through social media, stakeholder interviews and focus group discussions. The TTR may receive stronger support when the public becomes more familiar with the concept. This study is constrained by the limited number of measurement indicators available to define the latent variable constructs. In the future, additional insights on the psychological constructs can be obtained by collecting information on the travellers' preferences for flexibility, convenience and safety of priced lanes. Moreover, this study is based on the assumption that the technology required for the implementation of TTR is in place. An analysis of the costs, benefits and operational difficulties of implementation of TTR including the optimum pricing to keep the managed lanes free flowing and a significant increase in the administrative workload with requests and/or arguments from drivers for a refund is worth investigating. It would also be interesting to see the results from a revealed preference study, if any toll facility operator(s) are willing to test the TTR strategy on a less pressured facility.

CHAPTER 5

POTENTIAL APPLICATION OF CONNECTED VEHICLES ON MANAGED LANES

The use of information and communication technologies (ICT) has brought and is continuously bringing innovative approaches to transportation infrastructure ranging from intelligent transportation systems (ITS) to the deployment of connected and automated vehicles (CAVs). Fully automated vehicles are expected to perform all driving activities including making critical safety decisions while connected vehicles enable wireless communication among vehicles, infrastructure and passenger's personal devices (Gasser & Westhoff, 2012; National Highway Traffic Safety Administration, n.d). As the market availability of CAVs is prognosticated by 2020, the potential impact of CAV technologies on effective demand management is worth investigating (Reich, 2013). Priced Managed Lane (ML) facilities have been advocated to effectively mitigate traffic congestion and their number has increased from 14 to 24 in the past five years alone (Perez et al., 2012; Federal Highway Administration, 2017;). MLs include high-occupancy vehicle (HOV) and high-occupancy toll (HOT) lanes, which are dedicated and restricted lanes that operate in a relatively closed and controlled environment suggesting they are promising facilities for early deployment of connected vehicles. The deployment of ICT enables vehicle-to-infrastructure and vehicle-to-vehicle communications and opens various possibilities to information provision and implementing alternative pricing technologies. We envision CV technologies being adopted to provide richer and real-time information about the MLs, such as travel time variability and reliability as well as pricing variability (if applicable), to approaching drivers. Such information would likely affect travelers' propensity of choosing MLs and thus the usage rate and the traffic conditions of the MLs and the general-purpose lanes (GPLs).

This chapter provides a discussion of the implementation issues of TTR and the potential of using CVs to help achieve the vision. Potential implementation issues include information provision to connected and non-connected vehicles, distinction between toll-only and refund customers, measurement of actual travel time, refund calculation and processing and safety and human factors issues. CVs may not be utilized to address all the aforementioned implementation issues but play a significant role in information provision, measurement of travel time and safety and human factors. A comprehensive review of the state of the art practices relevant to the potential implementation issues of TTR is provided in the next section followed by a discussion of the implementation issues of CVs in various stages of toll collection.

5.1 Background

This section provides a discussion of the implementation issues of a new and innovative pricing strategy TTR and the potential of using CVs to help achieve this objective. We envision CVs to enhance our existing information provision capabilities by providing richer real-time information. The feasibility of utilizing existing road infrastructure (traffic signs, toll transponders, tollbooths etc.) to accommodate the new pricing technology is also considered. A brief review of literature in these areas is discussed in the following subsections.

5.1.1 Innovative Pricing Strategies

Congestion pricing is currently implemented in some states in the U.S for effective transportation demand management despite public opposition, double taxation and equity concerns. CAVs provide the tolling agencies the flexibility to explore innovative and alternative pricing strategies such as auction based tolling (Basar & Cetin, 2017), that could potentially alleviate the negative concerns towards tolling and generate higher revenue. In view of this, we propose an alternative pricing strategy via the option of TTR. When choosing to pay for MLs, users are provided an opportunity to purchase an additional TTR, which is a type of insurance that ensures them a certain amount of travel time savings. The cost of TTR is always less than the actual toll. If the users did not experience the "insured" travel time savings due to unforeseen circumstances, they would be refunded the toll amount but not the additional cost of TTR. Our previous study on the exploratory and statistical analyses of a stated preference survey revealed that TTR could make the HOT facilities more appealing (Vadlamani & Lou, 2017a, 2017b).

5.1.2 Connected and Automated Vehicles (CAVs)

Connected and Automated Vehicles (CAVs) are expected to revolutionize our transportation in the very near future with companies like Google, Tesla, Uber etc. already testing their vehicle prototypes. In the last year alone, the number of states that enacted legislations for their testing in the US have increased to 33 from 20 (National Conference of State Legislatures, 2017). Researchers and forecasters prognosticate achieving Level 4 automation by 2045 (Bansal & Kockelman, 2017). Public attitude and perception are crucial for the success of these emerging technologies. Previous research based on surveys across the globe found positive interest from the respondents who are both familiar and unfamiliar with CAV technologies (Schoettle & Sivak, 2014).

Existing literature suggests the deployment of CAVs could potentially support the travel demand management efforts by significantly reducing congestion (Fagnant & Kockelman, 2014; Spieser et al., 2014). The success of CAV technologies to improve traffic conditions depends on the cooperation among all the connected environments and travelers, and their trust in the technology. A recent simulation study demonstrated that the absence of cooperation between travelers and technology led to an increase in traffic congestion (Martinez et al., 2014). More research needs to be done in this area before postulating any theories, but the principles of behavioral economics, cognitive and social psychology and game theory could be implemented in the type of information provided to encourage cooperation among the travelers. Previous studies in behavioral economics revealed that positive framing yields greater cooperation than negative framing (Andreoni, 1995). In addition, social approval (visibility of other people's contributions) encourages cooperation (Rege & Telle, 2004).

5.1.3 Information Provision

The use of CAVs to implement TTR is anticipated to enhance the information provision capabilities through the vehicle-to-vehicle and vehicle-to-infrastructure communications. There is considerable research on *a priori* information about travel time influencing the travelers' propensity of route choice (Tseng et al., 2013; Tsirimpa et al., 2010; Lam & Small, 2001). In addition to the actual content of the information provided, travelers' behavior is also affected by the mere presence of the information. As far as actual content is concerned, studies have shown that the provision of expected travel time alone does not significantly influence the route switching behavior (Avineri & Prashker, 2006). In addition to the expected travel time, including historical information like range and variability (median, standard deviation etc.) of the travel time changes the travelers' choice behavior (Ben-Elia & Shiftan, 2010; Abdel-Aty & Abdalla, 2004). Some studies showed that increased information can produce adverse outcomes (Ben-Akiva et al., 1991; Emmerink et al., 1995a, 1995b; Lindsey et al., 2014; Lu et al., 2014). CV technologies could be used to effectively manage the optimum amount of information as well as the information content provided to the travelers. In the state of practice, traffic information is commonly provided by the roadside Advanced Traveler Information Systems (ATIS), on dynamic message signs, upstream to the ML facility. Information shown by such systems are constrained by the size of the signs and travelers' cognitive abilities to perceive and process the information in passing. These limitations could potentially be overcome by the use of CV technologies by pushing information to the on-board units and presenting the information as visual messages on the in-vehicle display or as auditory messages. The in-vehicle display could present information in various forms that can be easily comprehended by the drivers. The information could also be displayed for a sufficiently long enough time for travelers' to fully process the information. Auditory messages could augment the visual messages and capture the quick attention of the driver without necessarily distracting them.

5.1.4 Real-Time Information

CV technologies can help produce real-time information and increase the accuracy of assessing roadway traffic conditions (Khan et al., 2017). Previous studies have shown that providing information such as travel time variability and reliability as well as pricing variability (if applicable) affects the travel behavior (Ben-Elia & Shiftan, 2010). CV technologies could help provide such relevant information real-time. This real-time information and traffic conditions can effectively be utilized to potentially provide real-time vehicle route guidance systems (Tian et al., 2013).

5.1.5 Road Infrastructure

The feasibility of utilizing existing infrastructure for toll collection and traffic signs without having to necessarily revamp the entire system is worth investigating. Electronic toll collection (ETC) systems are currently in use nationwide with the exception of a few manually operated toll booths on-site that accept either only cash or card payments. These ETC systems eliminate the need for the drivers to stop at the tollbooths and enhance the efficiency of traffic. CV technologies which enable vehicle-to-vehicle and vehicle-to-infrastructure communications open doors to devise innovative but practically feasible toll schemes including but not limited to TTR, auction toll, dynamic toll rates based on network and travel demand attributes and drivers' willingness to pay (Vadlamani & Lou, 2017a, 2017b; Basar & Cetin, 2017; Zangui et al., 2013). Until the full penetration of CAV-enabled vehicles, toll payers are identified using the EZ-tags usually installed on the front windshield of the vehicle. The information exchanged between the EZ-tag installed in the car and a Dedicated Short Range

Communications (DSRC) beacon installed on the overhead signs of the roadway enables the identification of entry and exit points for travel time and toll calculation (Persad et al., 2007).

Although the CAVs are expected to have on-board display and audio units, until their full market penetration, there is still the need for traditional signage on the road to convey messages to the road users. The state of the practice is the use of hybrid signs, which are a combination of the conventional retroreflective static sign and one or more small light emitting diode message panels that display dynamic information like travel time, toll costs, route diversion, accident and other emergency information. The static portion of the sign includes information about the location and the message panels convey varying travel time and toll cost information based on the time of day (Gan et al., 2012).

5.2 TTR Implementation Considerations

While the innovative pricing mechanism of TTR is theoretically very appealing, feasibility and other practical implementation issues cannot be ignored. The existing infrastructure may need to be modified or completely revamped to accommodate the introduction of such new technologies. The type of information provided utilizing the CAV technologies and the distinction between HOT and TTR users are some of the issues that need to be carefully investigated. Potential implementation issues include information provision to both connected and non-connected vehicles, distinction between toll-only and refund customers, measurement of actual travel time, refund calculation and processing and safety and human factors issues. These issues are discussed in detail in the following sections.

5.2.1 Information Provision

Previous studies have shown that the driving behavior is affected by not only the mere provision of information but also the actual content of the information. The state-of-the practice ATIS or dynamic message signs can be used to provide information related to the refund pricing to the travelers. Hybrid signs which are a combination of static and dynamic message signs can be used to provide information about travel time and toll cost (HOT and TTR) to the drivers as shown in Figure 5.1.

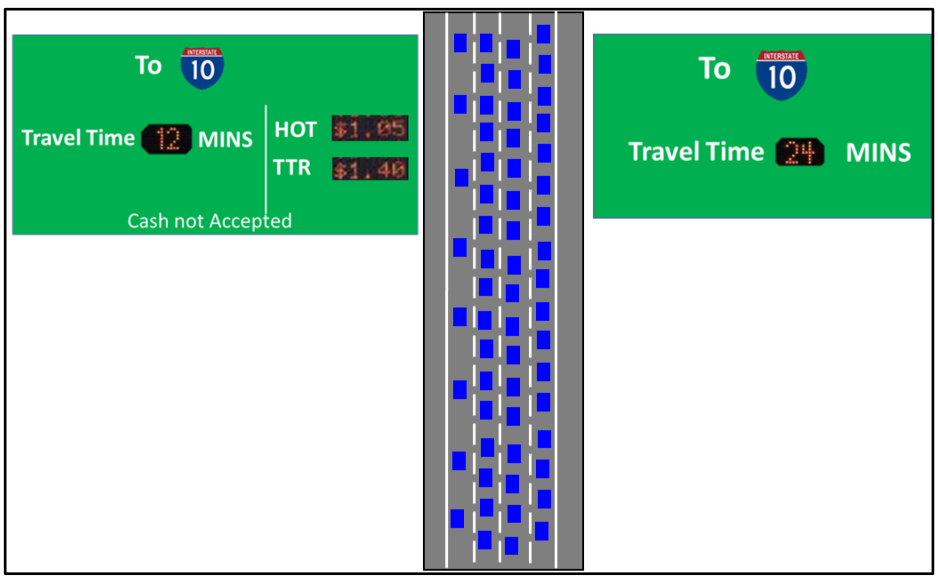


Figure 5.1 Sample Layout of Road Network with Signage for Refund Option

The travel time displayed on these signs is estimated using the information obtained from loop detectors, Bluetooth and Wi-Fi enabled technologies etc. as described in section 5.2.3. This travel time is updated at a certain time interval (2 minutes, 5 minutes etc.) based on the agency standards. The amount of information displayed on the signs is constrained by their size and the driver's cognitive abilities to comprehend it in passing. On the other hand, CAVs are not necessarily subject to this limitation as they are expected to be able to receive, process, and display more diverse and more relevant information in a real-time manner. The following are some of the potential types of information that can be displayed on-board an equipped CV:

1. *Travel time and savings of other CVs:* Real time information of travel time and potential savings in time of other CVs can be provided to motivate the drivers to purchase the TTR in accordance with the previous research on social learning (Andreoni, 1995; Rege & Telle, 2004).
2. *Return of Investment:* The provision of the travel time and the toll cost alone does not mean anything to the travelers unless they are familiar with the value for their money. The on-board messages can be used to provide information about the return of investment or benefit to cost ratio, which is expected to be a motivator to consider the HOT and TTR options.
3. *Recommended action and the confidence level:* Previous studies have shown that learning and experience affect the travel behavior. The travelers may be hesitant to invest in the new pricing strategy and providing some recommended information on purchasing the HOT/TTR option may be encouraging. This will relieve them from second-guessing that is not uncommon when they are left on their own to decide. Airline tickets purchase site Kayak provides a forecast of how likely the ticket prices are to go up or down over the next seven days for a given destination and dates (Kayak Flight Search, n.d.). It also provides a

recommendation of whether to buy the ticket now or wait along with a confidence level (number or percentage of statistical accuracy). Similarly, the CVs could provide a percentage indicator of how likely it is for the drivers to stay within the estimated travel time. A recommendation of whether to choose the HOT/TTR option along with a confidence level can also be included.

The above information can be presented using a combination of auditory and visual messages to ensure both the comprehension and safety of the drivers.

5.2.2 Toll Collection Technologies

In the proposed refund strategy, the traveler has the option of using the toll road without choosing to pay the additional premium for the TTR. There should be a way to differentiate the HOT and TTR users. For CVs, this could be a choice made by the click of a button through an application enabled by the on-board units. For non-connected vehicles, this can be achieved by making minor modifications to the existing transponder technology.

Figure 5.2 Illustration of EZ-Pass for Refund Strategy (Source: https://www.ezpassva.com/EZPages/New-Flex.aspx).

A toll transponder with a switchable feature called EZ-Pass Flex currently being used on the I-95/495 Express Lanes in Virginia (Virginia Department of Transportation E-Z Pass, n.d.) is shown in Figure 6.1. This transponder lets a traveler utilize the HOV discount if there are more than two or three people in the car by sliding the transponder switch to one side to indicate the “HOV ON” status. If there is only one person in the car, the switch is moved the other way to indicate travel at the posted toll rate. The same technology could be utilized to indicate whether the traveler wishes to use the HOT or the TTR option. If they wish to pay the additional premium, they will switch the transponder switch to TTR and if not they leave it at the default HOT. The transponder will work as the standard EZ-Pass on toll roads, which necessarily do not have a TTR option irrespective of the switch position.

5.2.3 Measurement of Actual Travel Time

Historically, the travel time was measured using license plate matching, attaching mechanical devices to odometers or using GPS recording devices (Turner et al., 1998; Taylor, 2000; Hunter, 2006; J, 2004). Probe vehicles, which drive through the network at various times, are also in use despite the accuracy concerns with a relatively low sample size. With the advent and wide spread use of Automatic Vehicle Identification (AVI) systems, travel times are now measured using toll tags and Bluetooth technology (Persad et al., 2007). AVI systems use radio-frequency identification (RFID) technology to enable communication between the in-vehicle transponder and roadside unit for travel time or toll calculations. These systems cannot be used when there are no toll roads or the existing infrastructure does not support the technology. Most of the transportation agencies use the traditional inductive loop detectors, which are typically installed per mile in every lane of the freeway and collect speed, volume and occupancy information. The data is gathered at a pre-determined frequency (for example every 20 seconds) and can be aggregated into 5, 15 or 60 minutes based on the requirements of the individual agency. The travel time between stations is calculated based on speed and distance, where missing data is often imputed by statistical means, spatial interpolation or trajectory methods. Loop detectors are the primary source of the travel time displayed on the physical hybrid signs and includes information from all the vehicles passing through them.

A toll tag transponder is required for toll collection and identification until the full penetration of CVs. Upon complete market penetration, CVs can choose their HOT/TTR option on-board without the need of a transponder. For vehicles (both CV and non-CVs) equipped with a toll tag transponder, the toll tag reader (installed on the overhead sign gantry or the side of the road) receives the signal from the transponder and the travel time between two roadside units is estimated based on the time difference and distance between them. The processing and estimation of travel time happens at the back end and the current travel time of other CVs within a pre-defined vicinity is displayed on the on-board units of CVs real-time. The transponder-equipped vehicles can also help gather travel time information for the general-purpose lanes. This may only require the additional installation of toll tag readers over the general-purpose lanes.

The information from vehicles equipped with Dedicated Short Range Communication (DSRC) technologies can also be used to calculate travel time for general-purpose lanes. For vehicles not equipped with toll tags or DSRC technologies, Bluetooth sensors can also be used for travel time measurements. A portable Bluetooth sensor installed on the overhead gantry detects the MACID of the personal mobile devices and the time of detection. Similar to toll tag transponders, the travel time is estimated based on the time difference and distance between the Bluetooth sensors.

The information collected from the transponder, Bluetooth and DSRC technologies can be integrated with that obtained from the loop detectors to generate more accurate travel time estimates. This fusion helps in improving the bias in the estimates (if any) from loop detectors due to missing data imputation and help in providing richer information.

5.2.4 Calculation and Processing of Refund

The determination of the TTR cost, the refund amount and how the refund is processed plays a crucial role in the successful implementation of TTR pricing strategy. The refund could be a full or a partial refund and can potentially be determined based on risk, similar to the insurance rates or premiums for home or auto insurance. Risk is defined as the potential (probability) that someone will make a claim. The insurance rates or premiums are determined based on the premise that the greater the risk, the higher the premium and the lower the risk, the lower the premium. This is likely to maximize revenue generation but may not realistically achieve the operational objective of maintaining free-flow traffic on the toll lanes while maximizing the throughput of the freeway (combined toll and GP lanes). This can be achieved by dynamically varying the toll rate in response to changing traffic conditions over time (Chu, 1995; Liua, 1999;

Yang, 1997; Kuwahara, 2001). For example, the toll rates on I-394 HOT lanes in Minnesota, I-15 in San Diego and Katy Freeway in Houston among others are adjusted based on the observed traffic density to be able to maintain free flow traffic conditions. Recent studies have suggested iteratively adjusting the pricing of toll lanes in real-time based on lane occupancy and the motorist's willingness to pay through a reactive self-learning approach (Lou et al., 2011; Yin & Lou, 2009). Various innovative pricing schemes based on anticipated or predicted congestion (Dong et al., 2011), variation in space (Rouhani & Niemeier, 2014), travel characteristics or attributes (Zangui et al., 2013) have also been proposed. More research needs to be done in this area to formulate a pricing strategy for the TTR option based on current practice and proposed techniques. The auto insurance premiums are typically determined based on the driver demographics, driving record, vehicle make, model and its safety features (Desyllas & Sako, 2013). Similarly, the refund rates can potentially be determined based on historic travel times, congestion levels, crash history and weather.

The calculation and processing of refund will potentially be automatic at the back end with the use of technology. Unlike the current practice in majority of insurance- and consumer- related claims, the users need not go through the strenuous process of manually filing a claim and communicating with multiple agents until its final resolution, which may take up to several days if not months or more. The transponder has the toll location information, from which the recorded experienced travel time can be compared with that displayed on the VMS signs or through on-board units to determine the refund eligibility based on the position of the transponder switch. The refund can either be posted to the credit card/debit card /bank account on file for the transponder account consistent with the current practice in the retail or consumer industry. If chosen by the user, it can also be posted as a credit on the transponder account, which could be used for future transactions.

5.2.5 Safety and Human Factors

CVs and fully automated vehicles result in a reduced driver workload allowing them to involve in secondary tasks like in-vehicle entertainment, work etc. Although the degree of this involvement depends on the level of automation, it poses a potential safety hazard when there is a vehicle automation failure. Although existing literature based on simulated studies showed decreased attention to the road ahead due to secondary tasks, they proved that drivers paid increased attention if the situation demanded like heavy traffic (Merat et al., 2012; Jamson et al., 2013). Another study determined that age does not impact the switch from automated to manual driving control when evading an obstacle indicating older drivers are able to handle maneuver changes as well as younger drivers (Korber et al., 2016).

The information provided should be legible and easily comprehensible by a driver in a moving vehicle and not negatively influence the driver behavior. The connected vehicles with their onboard display units support the selection of sensory modalities (visual or auditory) for information provision. Research suggests the use of visual messages for presenting complex information that does not call for immediate attention and is not safety-critical. Auditory messages are used for short messages that require quick or immediate action from the driver. Previous research suggests improved operator/driver performance when information is presented using a combination of visual auditory and haptic messages (Campbell et al., 2016). This combination can be utilized to provide travel time, statistical confidence and information about the potential return on investment or benefit–cost ratio of using MLs to the drivers. The auditory messages could reveal the magnitude of the potential savings while symbolic messages that vary in size with the magnitude of the savings can be displayed on the on-board unit. The potential saving information is a little complex that cannot be presented using simple tones, earcons or auditory icons and would require the use of speech messages for greater legibility and faster comprehension. Haptic messages provide information to the end user utilizing the sense of touch in a user interface and this technology is currently being tested by one leading vehicle manufacturer (Etherington, n.d.). The timing that this information is provided could play a significant role in safety and human factors that needs to be further investigated.

The introduction of managed lanes involves reducing the width of the median, left or right shoulder or eliminating them altogether due to space constraints. The type of barrier used determines the width of the buffer required for the separation of managed lanes from general-purpose lanes. The barrier could be physical (pylons or concrete) with or without intermediate access points or a non-physical painted stripes or solid double-white lines with or without enforced access. Existing safety studies on HOT and HOV lanes suggest fewer crashes are associated with wider lanes and buffer widths. Higher number of access points are associated with increasing crashes due to excessive weaving between the managed and general-purpose lanes (Fitzpatrick & Avelar, 2016s). The addition of new managed lanes should comply with the geometric design criterion while considering the safety tradeoffs.

5.3 Conclusion

This chapter provides some insights into the implementation considerations of an innovative pricing scheme for managed lanes, namely the travel time refund option and the potential of using connected vehicles for such implementation. The TTR provides an additional incentive to the drivers to pay for MLs by insuring their travel time and refunds their toll cost if they do not arrive at their destination within the specified travel time savings. Exploratory and statistical analyses of the responses from a stated preference survey found that travelers are interested in the refund option. Discussions on 1) information provision, 2) toll collection, 3) measurement of actual travel time, 4) refund calculation and processing, and 5) safety and human factors are provided in this chapter. CVs can potentially be applied to provide richer real-time information including travel time savings and return on investment that motivate the travelers to choose HOT and TTR options. This study revealed that HOT lanes with a refund option are technically feasible to implement using the existing toll tag transponder technologies. Additional investigation is needed on formulating a robust pricing strategy to determine the actual toll costs. Existing refund processing practices from the retail and consumer industry can be applied to process the refunds. Highly automated driving does not potentially have a detrimental effect on driver performance and safety. With CVs, a combination of visual, audio and haptic messages can be utilized for information provision without affecting the driver behavior. Future research includes investigating the calculation of the actual refund by analyzing the various factors that could possibly influence the risk potential. The impact of the refund option on toll rate and generated toll revenue should also be evaluated. The financial feasibility and implications of deploying the TTR option needs to be explored.

CHAPTER 6

SIMULATION ANALYSIS

The previous chapters have indicated a positive attitude of the respondents' towards the refund option. A better understanding of the refund option and the potential of using connected vehicles can be obtained by evaluating the system performance through simulation analysis. The premise is that connected vehicles have the provision of obtaining real-time information whereas the non-connected vehicles obtain the aggregated information through the dynamic message signs. The simulation analysis is intended to test the hypotheses (1) connected and non-connected vehicles display different choice behaviors due to the information difference and (2) traffic operators make use of connected vehicles to encourage HOV/HOT usage. This chapter discusses the proposed simulation that will be performed on a hypothetical network based on the MNL models described in the previous chapters.

6.1 Simulation Environment

There are wide ranges of commercially available simulation tools to choose from for analysis purposes like VISSIM, DTALite etc. However, none of the existing tools can integrate behavioral models with the traffic flow models as intended in this study. A simulation tool is developed using MATLAB, which is typically used to perform a wide array of analyses including data analytics, simulation & algorithm development and creating models. The simulation performed using MATLAB is elaborated in the following sections.

6.2 Traffic Flow Models

6.2.1 Background

The simulation involves generating vehicles and moving them through a transportation network. The flow of traffic is described using macroscopic, microscopic or mesoscopic models. The macroscopic models describe the properties of traffic stream at an aggregated level using continuum fluid representation of flow and density. The seminal kinematic wave theory by Lighthill and Whitham (1955) and Richards (1956) and its simplified version by Newell (1993a; 1993b; 1993c) are examples of macroscopic theories. The LWR theory is based on the assumptions of a well-defined relationship between flow and density and the first-order conservation law which is given by

$$\frac{\partial k(t,x)}{\partial t} + \frac{\partial q(t,x)}{\partial x} = 0$$

where k and q are density and flow at time t and location x. The flow conservation law represents that “the rates of variation of flow and density in space and time are consistent with the no entering/leaving traffic hypothesis” (Daganzo 1997). According to the theory, a disturbance in traffic stream signaling a change in traffic state propagates in space as a kinematic wave (also termed as a shock wave) whose speed is given by the slope of the segment joining the two points on the flow-density relationship as shown in Figure 6.1.

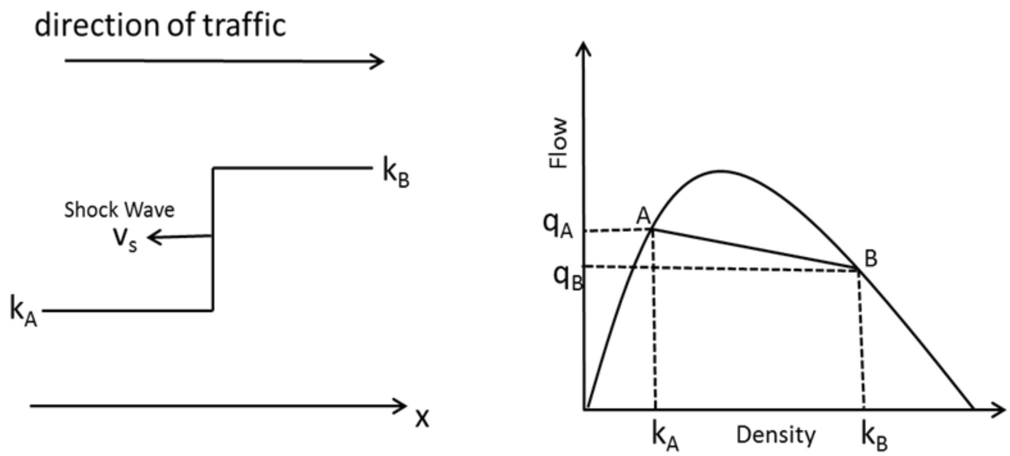


Figure 6.1 Illustration of Flow-Density relation from LWR Theory

Newell's simplified kinematic theory assumes a triangular flow-density relationship as shown in Figure 6.2 to evade the mathematical nuisances that arise from the non-linear LWR model.

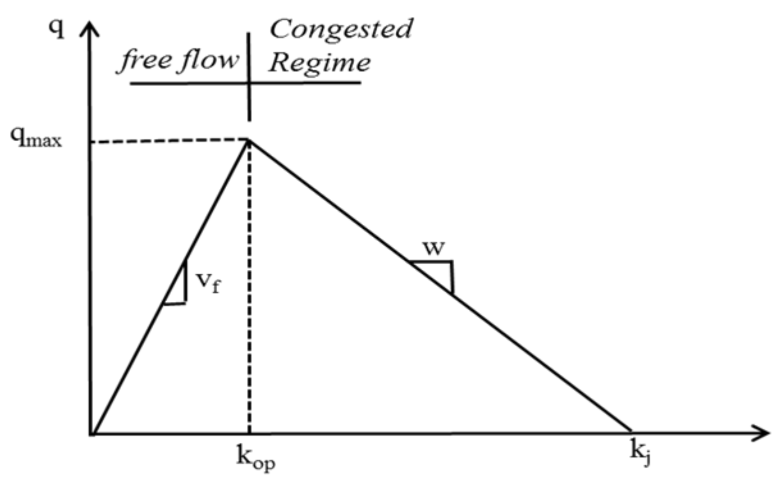


Figure 6.2 Illustration of Fundamental Diagram from Newell's Model

Points on the triangular flow-density diagram in Figure 6.2 represent possible (steady) traffic states. The left branch corresponds to uncongested traffic regimes, where an increase in flow is accompanied by an increase in density. In contrast, the right branch represents congested regimes, where an increase in density is accompanied by a decrease in flow (i.e., restricted flow). The mathematical representation of this model is shown below

$$q_{max} = v_f k_{op}$$

$$w = \frac{v_f k_{op}}{k_j - k_{op}}$$

$$q(k) = \min(v_f k, w(k - k_j)) = \min(v_f k, -\frac{v_f k_{op}}{k_j - k_{op}} (k - k_j))$$

Where

q_{max}= Maximum flow

v_f = Free flow speed

k_{op}= Optimum density

k_j = Jam density (where flow is zero)

w= negative velocity during congestion

The microscopic models describe the interaction between individual pairs of vehicles relying on car following and lane changing models. These models include car following models developed by Pipes (1953), General Motors Research lab (Chandler et al. 1958, Herman et al. 1959), Kometani and Sasaki (1959), Gipps (1981) and Newell (2002). Newell's simplified car following model (2002) establishes a connection between the macroscopic and microscopic traffic features. A mesoscopic model takes into account the origin, destination, departure time and route of individual vehicles and moves them in relation to the macroscopic traffic flow parameters.

The flow conservation constraints are achieved by the FIFO process and the traffic congestion at typical bottlenecks like tollbooths, lane drop, merging and weaving segments) is captured by integrating the seminal kinematic theory with flow conservation principles. The queue formation, spillback and dissipation are typically modeled using a variety of queuing models like point queue, spatial queue and Newell's kinematic wave model. In this study, point queue model, which is the most simple amongst all the existing queueing models, is employed and is elaborated in the following section.

6.2.2 Point-Queue Model

This model was first proposed in the seminal work by Vickrey (1969) and aims to capture the effect of traffic congestion at major bottlenecks. The model imposes a single outflow capacity constraint, which implies there is only one road between the origin and destination with a bottleneck of fixed capacity. The queue is modeled as a vertical stack as if it does not occupy any physical space along the roadway as shown in Figure 6.3.

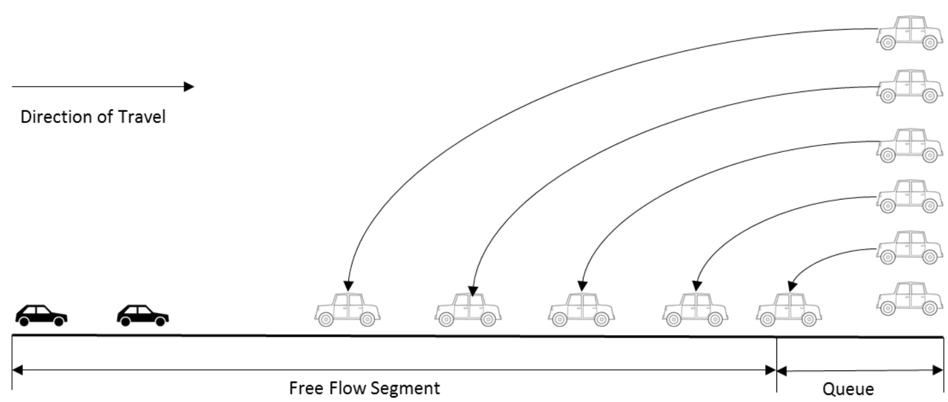


Figure 6.3 Illustration of Point Queue Model as Vertical Stack Queue

The model assumes that the vehicles travel at free flow speed until they arrive at the end of the queue and are then discharged from the queue at a certain rate. This discharge rate is assumed exponential in the present analysis. The average travel time during a time interval t is the sum of free-flow time and the average queueing delay at the end of the segment calculated as

$$C(t) = C_0 + \frac{N(t-1) + N(t)}{2S}$$

Where

$C(t)$ = Average travel time during interval t

C_0 = Free-flow travel time

$N(t-1)$ *and* $N(t)$ = Number of queueing vehicles at the end of time intervals t-1 and t respectively.

S = Saturation flow in vehicles/time interval

6.4 Simulation Architecture

The simulation architecture consists of integrating the behavioural model estimated in the previous chapter with the traffic flow model and the information provision for CVs and non CVs as shown in Figure 6.4

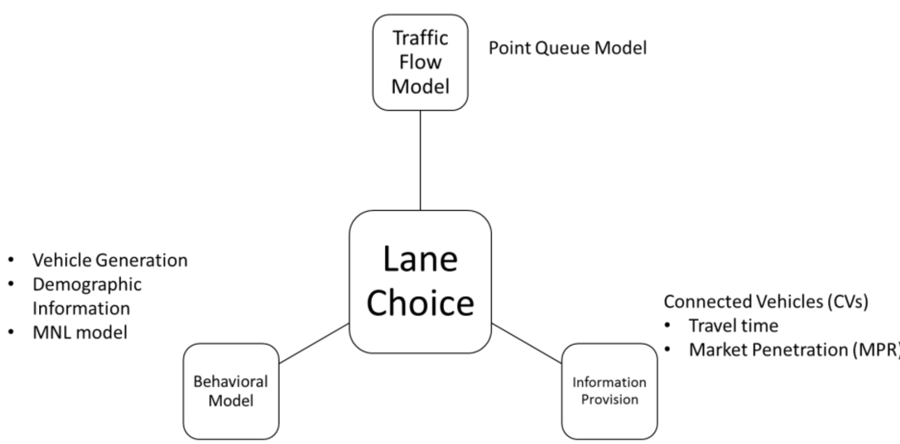


Figure 6.4 Illustration of Simulation Architecture

6.4 Simulation Set Up and Data Generation

A simulation study area of length 15 miles with a free flow travel speed of 60 mph is assumed. Based on the assumptions of length and free flow speed, the free flow travel time of the simulated site is 15 minutes. The length of each simulation interval is assumed 60 seconds. A hundred simulation intervals are carried out and hence the total simulation time in our analysis is 100 minutes (6000 seconds).

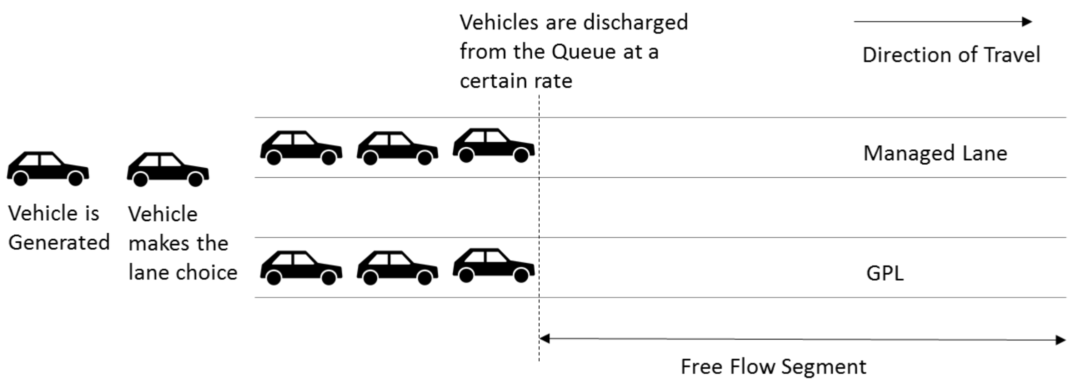


Figure 6.5 Depiction of Simulation Process

The simulation process is depicted in Figure 6.5. Vehicles are generated for each simulation interval with an assumed exponential distribution. A generated vehicle is randomly assigned the socio demographic characteristics including the age, gender and income of the driver, their knowledge of and interest towards HOT lanes and their interest towards the TTR option. The vehicles then make a lane choice between the GPL and the ML lanes using the coefficients of the MNL model estimated in chapter 4. A point-queue model described in the previous section is used to discharge the vehicles and determine their travel time. The queue in Figure 6.5 is for illustration purposes only and the point-queue model actually assumes the vehicles are vertically stacked instead of the horizontal stack depicted in the figure. Initially, when there is no congestion, free flow travel time is displayed to the approaching drivers. As the vehicles begin to arrive, the displayed travel time is updated for every time interval using the point queue model described in the previous section. The queue discharge is assumed normally distributed. The total travel time of the vehicle is the free flow travel time plus the time spent in queue. The downstream capacity is fixed at 1800 vph for both the lanes. The vehicles are assumed to arrive at the discharge capacity for the first 25 minutes, 1.25 times the discharge capacity for the next 25 minutes and at one-half the discharge capacity for the last 50 minutes of the simulation as shown in Table 6.1

Table 6.1 Arrival Pattern of Vehicles

Time Interval	Arrival Pattern (vph)
1-25	3600
25-50	4500
50-100	1800

The toll cost is varied from 20 to 100 cents per mile with 20-cent increments. The HOT lanes are congested when the toll costs are less than 20 cents and hence those costs are not included in the analysis. The market penetration levels for connected vehicles (CVs) are varied from 10 – 100 percent.

6.5 Design of Experiments

6.5.1 Information Provision

As mentioned in Chapter 5, connected vehicles can be utilized by provide richer information to the travelers and thus may help in their decision-making. The CVs can display not only travel time information but also a wide array of other information like return on investment, benefit cost ratio, recommended action, confidence level for purchasing the refund option etc. Previous studies have shown that the driving behavior is affected by not only the mere provision of information but also the actual content of the information. In addition, social learning and experience affect the travel behavior. The statistical models estimated in chapter 4 only includes travel time and reliability but nothing about return on investment, benefit cost ratio or confidence level for the purchase of refund option. Hence sensitivity analyses on the travel behavior of CVs and non-CVs to the difference in information provision is only included in the present study.

In current practice, the travel time information displayed on the dynamic message is calculated from the information gathered from loop detectors. This displayed information is updated every 2-5 minutes depending on the agency. This analysis assumes the travel time information on the dynamic message signs is updated every 5 minutes. CVs are able to communicate with the infrastructure and with each other and are capable of receiving information at a finer resolution compared to the dynamic message signs. CVs are assumed to receive updated information every 1 minute. Non-CVs can only receive information from the dynamic message signs that is updated every 5 minutes. Reliability is calculated based on the number of vehicles that left the system during the respective intervals.

6.5.2 Calculation of Refund

The level of guarantee and the difference in the estimated and actual travel time determine the number of people getting a refund. The travelers falling outside the window of a predetermined percentage of the estimated travel time window, which is the promised level of guarantee, will get a refund. The optimum percentage is ideally determined using optimization techniques such that HOT lane objectives are achieved and simultaneously the operator is not incurring losses. While this is beyond the scope of the current study, 10 and 15 percent are used for analysis purposes in this study. The travelers are eligible for a refund if the actual travel time exceeds the estimated travel time by 10 or 15 percent.

6.6 Simulation Results

The simulation was run for various toll costs ranging from 20 to 100 cents in increments of 20 cents. The MPR for CVs varied from 10 to 100 percent. The refund cost was fixed at 10 percent of the toll cost for all the simulation scenarios. The simulation was run 100 times and average of the key outputs like the proportion of ML and GPL users among both CVs and non-CVs, proportion of CVs receiving a refund etc. were calculated.

6.6.1 Proportion of ML and GPL

The average proportion of ML and GPL users among CVs and non-CVs for various costs across all the MPR's is given in Table 6.2.

Table 6.2 Average Choice Split between ML and GPL

Cost(cents)	CV		Non-CV	
	ML	GPL	ML	GPL
20	48.10	51.90	48.63	51.37
40	41.97	58.03	44.46	55.54
60	37.45	62.55	41.25	58.75
80	34.23	65.77	38.33	61.67
100	31.44	68.56	36.24	63.76

Intuitively, the proportion of ML users decreases with increasing. At lower cost of 20 cents, there is most nearly an equal split between MLs and GPLs. The gap between the ML and GPL split increases with increase in cost.

The arrival rates are not the same throughout the simulation period and hence the average of the choice split across all the simulation intervals is not very meaningful. The variation of the choice across each simulation interval for various costs at a particular MPR is shown in Figures 6.6 to 6.10 respectively.

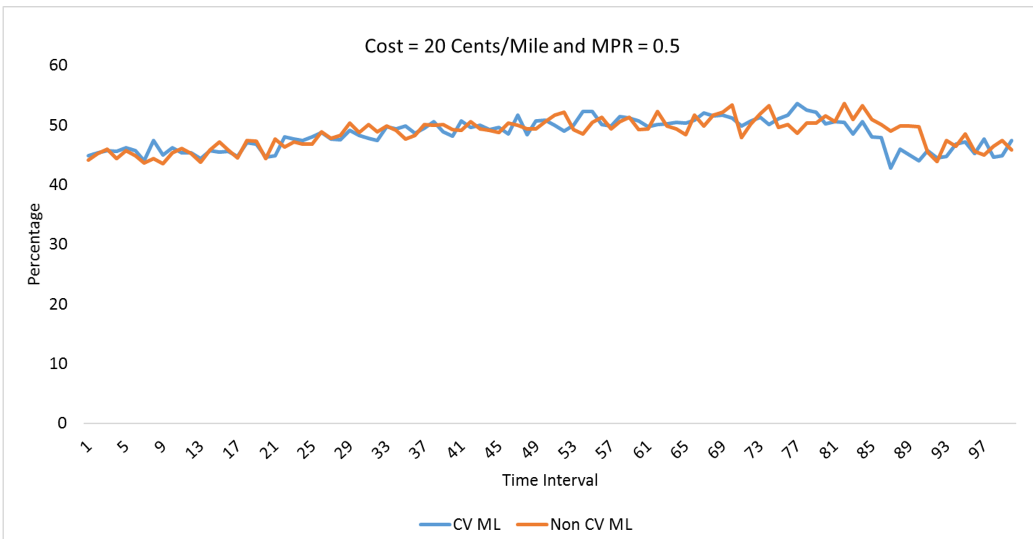


Figure 6.6 Time Varying ML Choice for CVs and Non CVs at 20 Cents

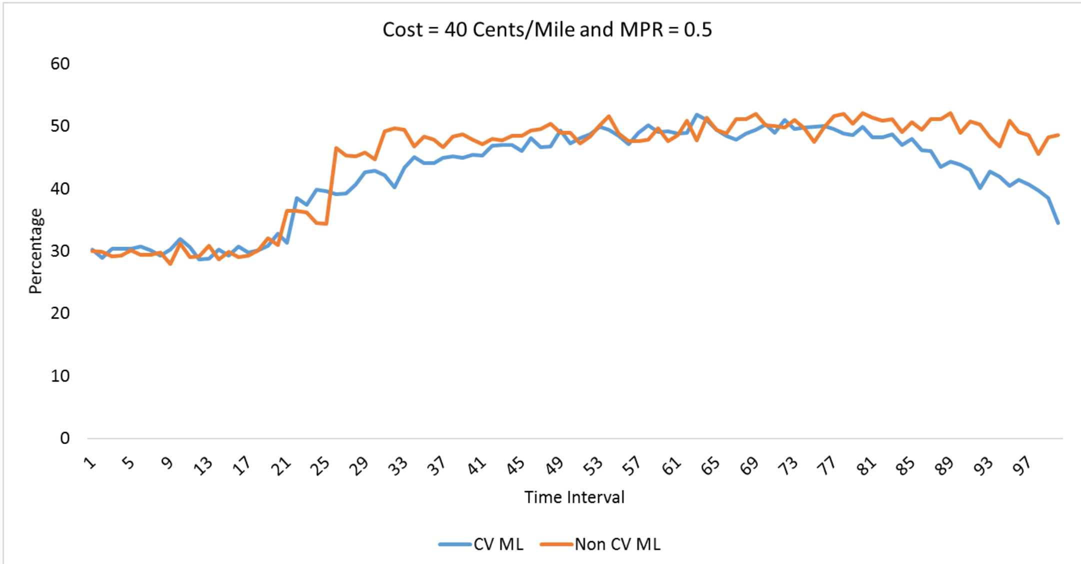


Figure 6.7 Time Varying ML Choice for CVs and Non CVs at 40 Cents

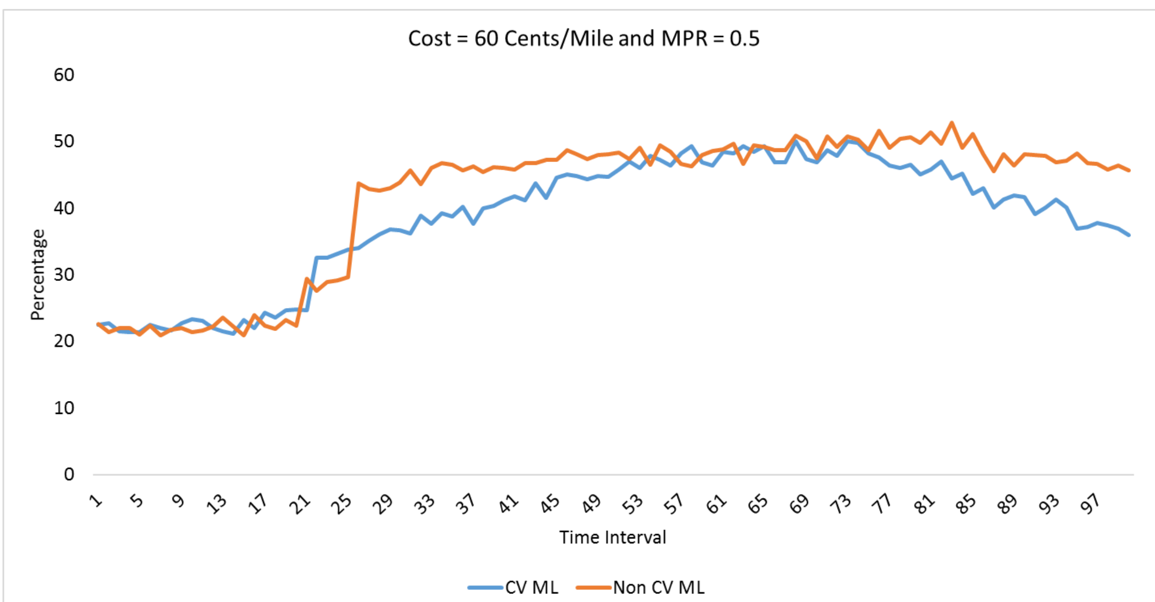


Figure 6.8 Time Varying ML Choice for CVs and Non CVs at 60 Cents

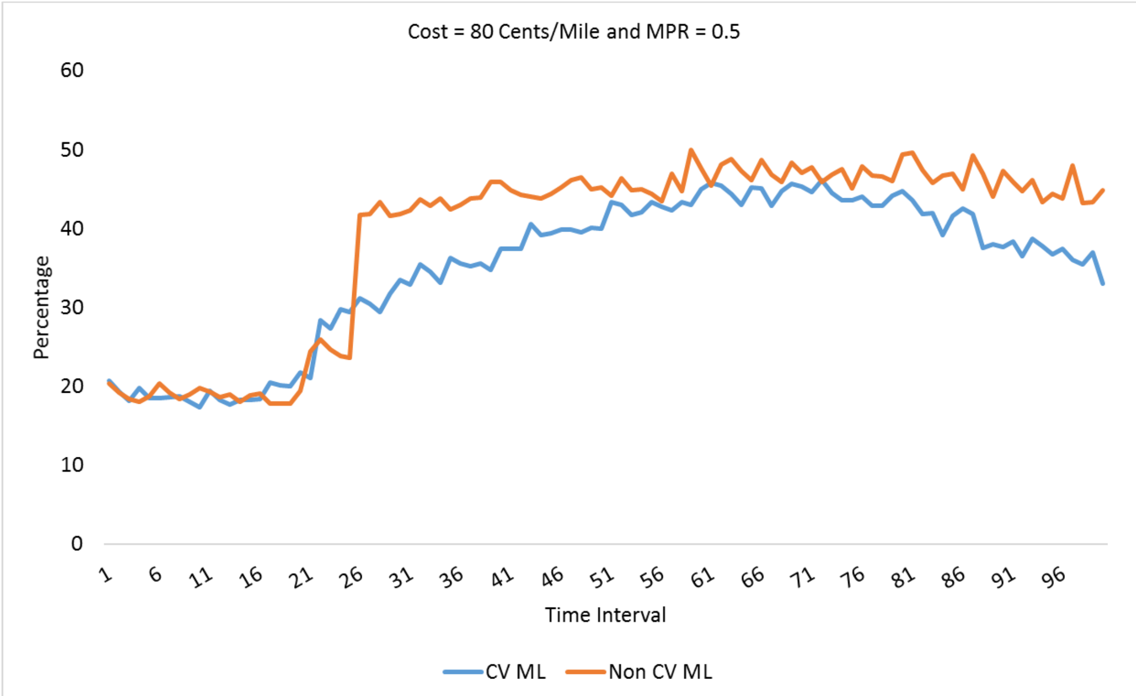


Figure 6.9 Time Varying ML Choice for CVs and Non CVs at 80 Cents

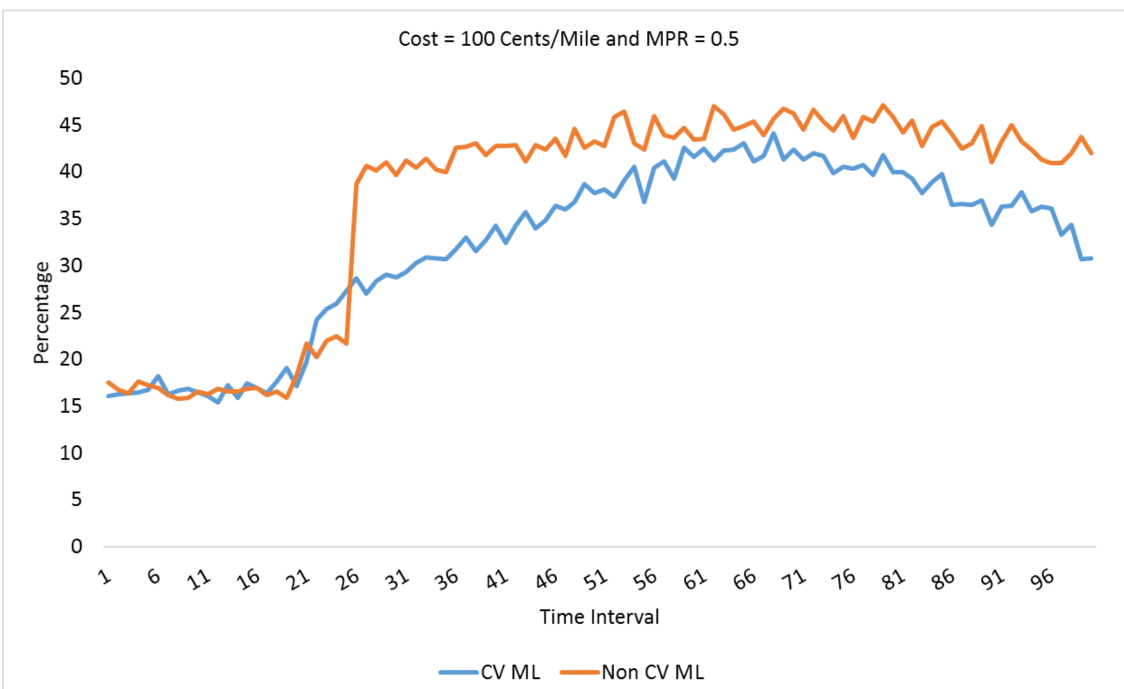


Figure 6.10 Time Varying ML Choice for CVs and Non CVs at 100 Cents

6.6.2 Refund

The toll payers receive a refund if their actual travel time is greater than a certain percentage of the estimated travel time. Two scenarios of 10% and 15% are used to estimate the percentage of toll payers receiving a refund. These percentages are calculated based on the total number of vehicles actually leaving the system and not actually those who enter the system. Tables 6.3 and 6.4 presents the percentage of vehicles receiving a refund for various costs and MPR levels when the cut off is at 15% and 10% respectively.

Table 6.3 Percentage of Vehicles Receiving a Refund (15% Cut-Off)

MPR	20		40		60		80		100	
	CV	N-CV	CV	N-CV	CV	N-CV	CV	N-CV	CV	N-CV
10	12.04	12.06	9.71	10.36	5.74	6.54	3.08	3.57	1.38	1.73
20	12.11	12.02	8.03	8.33	5.21	5.86	2.36	2.84	1.19	1.62
30	12.96	13.21	8.36	8.81	4.61	5.17	1.66	1.91	0.48	0.58
40	12.28	12.31	8.43	8.7	4.15	4.56	0.81	0.99	0.29	0.35
50	11.49	11.64	7.19	7.56	2.61	2.87	0.54	0.61	0.23	0.3
60	12.01	12	6.92	7.38	2.14	2.26	0.31	0.36	0.026	0.047
70	12.57	12.87	6.28	6.64	2.3	2.58	0.16	0.18	0.04	0.05
80	12.04	12.19	5.38	5.52	1.21	1.32	0.15	0.15	0.027	0.037
90	12.63	12.35	5.13	5.55	0.81	0.84	0.12	0.16	0	0
100	11.72	NA	4.99	NA	0.72	NA	0.19	NA	0.01	NA

CV: Connected Vehicle, N-CV: Non-Connected Vehicle

At the lowest cost, the percentage of vehicles receiving a refund is constant across varying MPR. However, as the cost increases, the percentage of vehicles receiving a refund decreases with increasing MPR. When the vehicles are all connected, they have the most up to date information about the travel time (1 min vs 5 min aggregated) and hence are able to make a better informed decisions. This supports the fact that connected vehicles can potentially be used for encouraging the HOT lane usage. The percentage refund for 10% refund is similar and is shown in Table 6.4.

Table 6.4 Percentage of Vehicles Receiving a Refund (10% Cut-Off)

MPR	20		40		60		80		100	
	CV	N-CV	CV	N-CV	CV	N-CV	CV	N-CV	CV	N-CV
10	15.62	15.67	12.61	13.45	9.01	10.22	6.27	7.49	3.76	5.02
20	15.53	15.46	12.54	13.4	7.35	8.27	4.47	5.08	2.85	3.71
30	15.11	15.06	11.77	12.43	7.54	8.61	4.07	4.81	2.02	2.59
40	16.03	16.14	12.03	12.81	7.69	8.55	3.58	4.24	1.39	1.73
50	16.26	16.31	11.04	11.53	5.55	6.12	2.2	2.59	0.79	0.96
60	14.66	14.87	11.55	12.05	5.55	6.21	1.44	1.71	0.58	0.69
70	16.05	16.35	11.06	11.68	3.85	4.24	0.91	1.05	0.26	0.34
80	16.05	16.35	9.22	9.58	3.33	3.57	1.12	1.23	0.16	0.21
90	15.59	15.42	10.26	10.78	2.69	2.79	0.74	0.84	0.056	0.079
100	15.82	NA	8.78	NA	3.13	NA	0.42	NA	0.15	NA

CV: Connected Vehicle, N-CV: Non-Connected Vehicle

6.7 Conclusion

This chapter evaluates the system performance and the potential of using connected vehicles through simulation. A hypothetical road network is simulated in MATLAB and the multinomial logit models estimated in the previous chapters were used to determine the lane choice of the travelers. Point queue model is used to determine the total travel time of the vehicles. The potential of utilizing connected vehicles to achieve the objectives of managed lanes is tested through simulation. The results indicate that the percentage of vehicles receiving a refund decreases with increase in the market penetration of connected vehicles. Hence, connected vehicles can potentially encourage the use of managed lanes through the refund option.

CHAPTER 7

FUTURE RESEARCH DIRECTIONS

This study provided valuable insights into the attitudes of the public towards priced managed lanes by introducing the concept of travel time refund (TTR) through a stated preference survey mainly deployed in the Phoenix metropolitan area. The TTR concept explored provides an additional incentive to the drivers to pay for MLs by insuring their travel time and refunds their toll cost if they do not arrive at their destination with the specified travel time savings. The perceived benefits of TTR include changing the negative attitudes towards priced MLs, increase in underutilized HOV/HOT lanes, overall congestion mitigation and additional funding for the transportation agencies.

The results of the empirical analysis make a strong base to conjecture a new and innovative pricing scheme for managed lanes and High Occupancy Toll Lanes. A better understanding of the attitudes of the people towards the refund option has implications on convincing the transportation authorities and the public for introducing toll lanes in Arizona in the future to meet the growing demands of traffic and congestion. This study is a very first step towards exploring TTR, as a new pricing strategy for MLs and involves a preliminary empirical analysis to investigate the attitudes of the people toward the refund option. Future research involves further analysis using optimization techniques to determine the optimum toll and refund costs that would simultaneously achieve the objectives of improving capacity and utilizing the throughput of the managed lanes while generating revenue to the toll operator.

The survey consisted a set of questions on the last trip on I-10, opinions on priced managed lanes, demographics and hypothetical scenarios involving the TTR option. 2274 responses were obtained via newsletters of ASU, ITE and ITS chapters of AZ and social media platforms. The data distribution indicated sample bias with lack of representative diversity, which is addressed by sample weighting based on the most recent American Community Survey (ACS) information. Ordered probit models were estimated to determine the factors that affect the user interest in HOT and TTR. Both the exploratory and statistical analysis of the data revealed negative interest towards HOT and TTR options in accordance with the expectations and previous studies. However, it was observed that users are less negative about TTR than HOT, supporting the idea that TTR could make HOT facilities more appealing.

The preferences of the public among the choices of GPL, HOT with and without TTR are evaluated through the traditional multinomial logit choice models as well as structural equation models with latent variables. The results intuitively indicate that people are less likely to choose the option with higher costs and travel times. Those with a higher interest towards HOT and TTR are more likely to choose the TTR option in comparison to HOT and GPL. Trip purpose seems to influence the choice of TTR with people traveling for commute and work- related trips being more positively interested towards TTR. The majority of the survey respondents are in Arizona, and are not familiar with the concept of HOT. Therefore, their attitudes towards priced lanes along with their understanding and comprehension of the concept of TTR may affect their willingness to pay for TTR. These effects cannot be directly measured and latent variables are incorporated into the choice model. The results indicate that attitudes play a significant role in influencing the choice of the decision maker. A positive interest towards MLs could be stimulated by enhancing the awareness and knowledge of the public by communicating through social media, stakeholder interviews and focus group discussions. Moreover, TTR may receive higher support when the public becomes more familiar with the concept.

This study also provides some insights into the implementation considerations of an innovative pricing scheme for managed lanes, namely the travel time refund option and the potential of using connected vehicles for such implementation. Simulation analysis on a hypothetical road network revealed that connected vehicles can encourage and enhance the use of managed lanes.

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APPENDIX A

SURVEY QUESTIONNAIRE

Page 1: Pre-Survey

Refund Option for Toll Lanes
Conducted by Researchers at Arizona State University

Thank you for your interest in partaking in the following survey. This survey, conducted by graduate student, Melissa Archer, under the direction of Dr. Lou at Arizona State University, is about freeway managed lanes. Freeway managed lanes are designated lanes on a freeway where demand and available capacity are controlled. Participation in this survey includes answering questions regarding your reactions to various traffic scenarios. Your responses will be used in research to understand community reactions to freeway managed lanes and pricing strategies.

The survey is voluntary. The questions are optional and your responses will remain anonymous. You may opt out at any time. The results may be used in reports, presentations, or publications in aggregate form. If you choose to complete the survey, your total time commitment will be approximately 10 to 15 minutes.

Upon completion of the survey, you have the opportunity to enter your information into raffle prizes drawings as an appreciation of your participation. Two Kindles and a Fitbit will be given away following the closing of the survey on December 1st. If you complete the survey by October 31st, you will be entered into an additional drawing for a second Fitbit. Winners of the drawings will be notified by November 15, 2014 for the first selection and by December 15, 2014 for the overall selection. The raffle prizes are purchased and given away by Arizona State University. Amazon and Fitbit are not sponsors of this survey.

If you have any questions concerning the research study, please contact the research team at: melissa.archer@asu.edu or yingyan.lou@asu.edu. If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788.
* = Required
* By checking the box below, you verify that you are 18 years or older and give consent to contribute your answers to research purposes.

☐ Yes, I certify that I am 18 years or older and agree to participate in this research.

Page 2: I-10 Trip or No I-10 Trip

In Arizona, Interstate 10 (or I-10) is a major east-west highway that connects Phoenix to the major cities of Los Angeles, CA and Tucson, AZ.

Image taken from http://www.I10phoenix.com/

* Have you taken a trip that included the I-10 in the Phoenix-metro area within the past year?

O Yes
O No

How often do you travel the I-10?

O □5-7 Days a week
O □2-4 Days a week
O □Once a week
O □Occasionally

What is your primary trip purpose when using the I-10?

- ○ Commuting to/from work
- ○ Work related (other than to and from home or work)
- ○ To attend class at a school or educational institute
- ○ Recreational / Social / Entertainment
- ○ Shopping / Personal errands
- ○ Other, please specify... ________

Page 3: Most Recent I-10 Trip

Last Trip on I-10

The next questions refer to the last trip you took on the I-10 in the Phoenix area, as indicated on the previous page. If you do not remember the answer to a question asked, you may skip it.

What was the purpose of the trip?

- ○ Commuting to/from work
- ○ Work related (other than to and from home or work)
- ○ To attend class at a school or educational institute
- ○ Recreational / Social / Entertainment
- ○ Shopping / Personal errands
- ○ Other, please specify... ________

What day of the week did your last trip take place?

- ○ Weekday
- ○ Weekend

Approximately what time did you start your trip?
Time ________

What is the zip code of where the trip started?
____

What is the zip code of where the trip ended?
____

Did you use the high occupancy vehicle (HOV) lane during this trip?

- ○ Yes
- ○ No

What type of vehicle did you use?

- ○ Passenger car / SUV / Pick-up truck
- ○ Motorcycle
- ○ Bus
- ○ Other, please specify... ________

How many people, other than yourself, were in the vehicle with you?

- ○ 0
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ Greater than 4

* Where did you get ON the I-10 on your last trip?

- ◊ An exit east of Loop 202 (Santan Fwy) / Pecos Rd
- ◊ Loop 202 (Santan Fwy) / Pecos Rd
- ◊ Chandler Blvd
- ◊ Ray Rd
- ◊ Warner Rd
- ◊ Elliot Rd
- ◊ US 60 (Superstition Fwy)
- ◊ Broadway Rd
- ◊ SR 143 (Hohokam Expy)
- ◊ 40th St
- ◊ 32nd St / University Dr
- ◊ 24th St
- ◊ I-17 / US-60 (Maricopa Fwy)
- ◊ Buckeye Rd
- ◊ Jefferson St / Washington St
- ◊ SR 51 (Piestewa Fwy) / Loop 202 (Red Mountain Fwy)
- ◊ 16th St
- ◊ 7th St
- ◊ 7th Ave
- ◊ 19th Ave
- ◊ I-17 (Black Canyon Fwy)
- ◊ 27th Ave
- ◊ 35th Ave
- ◊ 43rd Ave
- ◊ 51st Ave
- ◊ 59th Ave
- ◊ 67th Ave

◊ 75th Ave
◊ 83rd Ave
◊ 91st Ave
◊ Loop 101 (Agua Fria Fwy)
◊ An exit west of the Loop 101 (Agua Fria Fwy)

* Where did you get OFF the I-10 on your last trip?

◊ An exit east of Loop 202 (Santan Fwy) / Pecos Rd)
◊ Loop 202 (Santan Fwy) / Pecos Rd
◊ Chandler Blvd
◊ Ray Rd
◊ Warner Rd
◊ Elliot Rd
◊ US 60 (Superstition Fwy)
◊ Broadway Rd
◊ SR 143 (Hohokam Expy)
◊ 40th St
◊ 32nd St / University Dr
◊ 24th St
◊ I-17 / US-60 (Maricopa Fwy)
◊ Buckeye Rd
◊ Jefferson St / Washington St
◊ SR 51 (Piestewa Fwy) / Loop 202 (Red Mountain Fwy)
◊ 16th St
◊ 7th St
◊ 7th Ave
◊ 19th Ave
◊ I-17 (Black Canyon Fwy)
◊ 27th Ave
◊ 35th Ave
◊ 43rd Ave
◊ 51st Ave
◊ 59th Ave
◊ 67th Ave
◊ 75th Ave
◊ 83rd Ave
◊ 91st Ave
◊ Loop 101 (Agua Fria Fwy)
◊ An exit west of the Loop 101 (Agua Fria Fwy)

Estimate your total travel time (in minutes) on the I-10 on your last trip.

____

Page 4: General Preference Questions

* Do you know what a High Occupancy Vehicle (HOV) lane is?

○ □Yes
○ □No

Images taken from http://phoenix.about.com/od/highwaysroads/a/HOV.htm and http://blogs.kcrw.com/shortcuts/soon-solo-drivers-will-be-able-to-drive-in-car-pool-lanes-no-hybrid-required

An HOV lane is a freeway or expressway lane restricted to vehicles with the required occupancy, typically two or more people, during specified peak hours of the day. HOV lanes are a type of freeway managed lane.

How often do you use an HOV lane?

○ □Daily
○ □2-3 times a week
○ □2-3 times a month
○ □Very rarely
○ □Never

How satisfied were you with the HOV lane?

0 1 2 3 4 5 6 7 8 9 10

Not Satisfied ... Very Satisfied

* Do you know what a High Occupancy Toll (HOT) lane is?

○ □Yes
○ □No

Images taken from http://www.mnpass.org/ and http://www.theolympian.com/2013/10/20/2784942/how-will-we-toll-for-new-roads.html

An HOT lane is a freeway or expressway lane that charges tolls to regulate access while maintaining travel speed and reliability. Typically, HOVs are allowed access to HOT lanes at a discounted rate or free of charge. Like HOV lanes, HOT lanes are also a type of freeway managed lane.

Have you ever used an HOT lane?

○ Yes
○ No

How interested are you in using an HOT lane?

0 1 2 3 4 5 6 7 8 9 10

Not Satisfied — Very Satisfied

Some freeways display a time window that allows you to estimate when you will arrive at a specific destination, such as an exiting ramp to another freeway.

An example of a dynamic message sign time window in Oregon.
(http://otrec.us/news/entry/report_travel_time_data_lacking_at_key_spots_on_portland_area_freeways)

Imagine an HOT exists that provides similar time window displays as seen above.

Additionally, imagine the HOT lane includes an option to buy a travel time refund (TTR) or "insurance". The TTR allows HOT users to pay an additional cost, or premium, on top of the toll amount to insure their travel time will be within the time window. The TTR will always cost less than the toll amount. If you do not arrive to your exit ramp within the provided time window, the toll amount will be refunded but not the TTR cost.

Assume all technologies required for implementing HOT with a TTR exist.

If there was a refund option, how interested would you be in purchasing it?

0 1 2 3 4 5 6 7 8 9 10
Not Interested Very Interested

Page 5: Stated Preference – Most Recent Trip

For the hypothetical scenario below, the HOT lane includes an option to buy a travel time refund (TTR), or “insurance”.

This cost of the TTR, or "insurance", will always be less than the toll. When the TTR is bought and you do not arrive to your exiting ramp within the provided time window, the toll will be refunded but not the TTR amount. Assume all technologies necessary to use the HOT lane with TTR (such as vehicle tag readers) exist.

Refund, travel time refund, and TTR are synonymous in the following examples.

Scenario: You are taking the same **25.5** mile trip from an exit east of Loop 202 (Santan Fwy) / Pecos Rd to an exit west of the Loop 101 (Agua Fria Fwy) on the I-10 freeway. Which option would you choose?

1. **GPL (Total Cost $0.00):** Drive in the general purpose lanes for free. The general purpose lanes appear heavily congested.

2. HOT no refund (Total Cost $1.28): Drive in the HOT lane for **$1.28** and do not purchase a travel time refund. The average travel time can vary between **25** and **31** minutes.

3. HOT with refund (Total Cost $1.59): Drive in the HOT lane for **$1.28** and purchase the travel time refund at **$0.32.** The average travel time can vary anywhere between **25** and **31** minutes.

○ □Option 1: GPL
○ □Option 2: HOT no refund
○ □Option 3: HOT with refund

Part 2: Now imagine the same scenario as in the previous question, however the travel time refund cost is lower. Which option would you choose?

1. GPL (Total Cost $0.00): Drive in the general purpose lanes for free. The general purpose lanes appear heavily congested.

2. HOT no refund (Total Cost $1.28): Drive in the HOT lane for **$1.28** and do not purchase a travel time refund. The average travel time can vary between **25** and **31** minutes.

3. HOT with refund (Total Cost $1.40): Drive in the HOT lane for **$1.28** and purchase the travel time refund at **$0.13.** The average travel time can vary anywhere between **25** and **31** minutes.

○ Option 1: GPL
○ Option 2: HOT no refund
○ Option 3: HOT with refund

Page 6: Stated Preference – Scenario 1

For the hypothetical scenario below, the HOT lane includes an option to buy a travel time refund (TTR), or "insurance".

This cost of the TTR, or "insurance", will always be less than the toll. When the TTR is bought and you do not arrive to your exiting ramp within the provided time window, the toll will be refunded but not the TTR amount. Assume all technologies necessary to use the HOT lane with TTR (such as vehicle tag readers) exist.

Refund, travel time refund, and TTR are synonymous in the following examples.

Scenario 1: You are taking a **10 mile** trip on the I-10 freeway during the **PM** rush hour in the peak direction. Which option would you choose?

1. GPL (Total Cost $0.00): Drive in the general purpose lanes for free. The general purpose lanes appear heavily congested.

2. HOT no refund (Total Cost $2.00): Drive in the HOT lane for **$2.00** and do not purchase a travel time refund. The average travel time can vary between **10** and **12** minutes.

3. HOT with refund (Total Cost $2.50): Drive in the HOT lane for **$2.00** and purchase the travel time refund at **$0.50**. The average travel time can vary anywhere between **10** and **12** minutes.

○ Option 1: GPL
○ Option 2: HOT no refund
○ Option 3: HOT with refund

Scenario 1, Part 2: Now imagine the same scenario as in the previous question, however the travel time refund cost is higher. Which option would you choose?

1. GPL (Total Cost $0.00): Drive in the general purpose lanes for free. The general purpose lanes appear heavily congested.

2. HOT no refund (Total Cost $2.00): Drive in the HOT lane for **$2.00** and do not purchase a travel time refund. The average travel time can vary between **10** and **12** minutes.

3. HOT with refund (Total Cost $3.00): Drive in the HOT lane for **$2.00** and purchase the travel time refund at **$1.00**. The average travel time can vary anywhere between **10** and **12** minutes.

- ○ Option 1: GPL
- ○ Option 2: HOT no refund
- ○ Option 3: HOT with refund

Page 7: Stated Preference – Scenario 2

For the hypothetical scenario below, the HOT lane includes an option to buy a travel time refund (TTR), or "insurance".

This cost of the TTR, or "insurance", will always be less than the toll. When the TTR is bought and you do not arrive to your exiting ramp within the provided time window, the toll will be refunded but not the TTR amount. Assume all technologies necessary to use the HOT lane with TTR (such as vehicle tag readers) exist.

Refund, travel time refund, and TTR are synonymous in the following examples.

Scenario 2: You are taking a **15 mile** trip on the I-10 freeway during the **AM** rush hour in the peak direction. Which option would you choose?

1. GPL (Total Cost $0.00): Drive in the general purpose lanes for free. The average travel time can vary between **17** and **26** minutes.

2. HOT no refund (Total Cost $5.25): Drive in the HOT lane for **$5.25** and do not purchase a travel time refund. The average travel time can vary between **17** and **20** minutes.

3. HOT with refund (Total Cost $6.56): Drive in the HOT lane for **$5.25** and purchase the travel time refund at **$1.31**. The average travel time can vary anywhere between **17** and **20** minutes.

○ Option 1: GPL
○ Option 2: HOT no refund
○ Option 3: HOT with refund

Scenario 2, Part 2: Now imagine the same scenario as in the previous question, however the travel time refund cost is lower. Which option would you choose?

1. GPL (Total Cost $0.00): Drive in the general purpose lanes for free. The average travel time can vary between **17** and **26** minutes.

2. HOT no refund (Total Cost $5.25): Drive in the HOT lane for **$5.25** and do not purchase a travel time refund. The average travel time can vary between **17** and **20** minutes.

3. HOT with refund (Total Cost $5.78): Drive in the HOT lane for **$5.25** and purchase the travel time refund at **$0.53**. The average travel time can vary anywhere between **17** and **20** minutes.

- ○ Option 1: GPL
- ○ Option 2: HOT no refund
- ○ Option 3: HOT with refund

Page 8: Stated Preference – Scenario 3

For the hypothetical scenario below, the HOT lane includes an option to buy a travel time refund (TTR), or “insurance”.

This cost of the TTR, or "insurance", will always be less than the toll. When the TTR is bought and you do not arrive to your exiting ramp within the provided time window, the toll will be refunded but not the TTR amount. Assume all technologies necessary to use the HOT lane with TTR (such as vehicle tag readers) exist.

Refund, travel time refund, and TTR are synonymous in the following examples.

Scenario 3: You are taking a **25 mile** trip on the I-10 freeway during the **PM** rush hour in the peak direction. Which option would you choose?

1. GPL (Total Cost $0.00): Drive in the general purpose lanes for free. The average travel time can vary between **31** and **46** minutes.

2. HOT no refund (Total Cost $8.75): Drive in the HOT lane for **$8.75** and do not purchase a travel time refund. The average travel time can vary between **25** and **30** minutes.

3. HOT with refund (Total Cost $10.94): Drive in the HOT lane for **$8.75** and purchase the travel time refund at **$2.19**. The average travel time can vary anywhere between **25** and **30** minutes.

○ Option 1: GPL
○ Option 2: HOT no refund
○ Option 3: HOT with refund

Scenario 3, Part 2: Now imagine the same scenario as in the previous question, however the travel time refund cost is lower. Which option would you choose?

1. GPL (Total Cost $0.00): Drive in the general purpose lanes for free. The average travel time can vary between **31** and **46** minutes.

2. HOT no refund (Total Cost $8.75): Drive in the HOT lane for **$8.75** and do not purchase a travel time refund. The average travel time can vary between **25** and **30** minutes.

3. HOT with refund (Total Cost $9.63): Drive in the HOT lane for **$8.75** and purchase the travel time refund at **$0.88**. The average travel time can vary anywhere between **25** and **30** minutes.

○ Option 1: GPL
○ Option 2: HOT no refund
○ Option 3: HOT with refund

Page 9: General Preference – After Scenarios

Now that you have completed all of the scenarios, if there was a refund option, how interested would you be in purchasing it?

0	1	2	3	4	5	6	7	8	9	10

Not Interested — Very Interested

Under what circumstances are you most likely to use the following:
HOT without TTR ________
HOT with TTR ________

If you have any additional comments, please add them below.

____

Page 10: Demographics

You may skip any question you prefer not to answer.

What is your age?

____

What is your gender?

- ○ Male
- ○ Female
- ○ Prefer Not to Answer

What is your ethnicity?

- ○ White / Caucasian
- ○ Spanish / Hispanic / Latino
- ○ Black / African American
- ○ Asian
- ○ Pacific Islander
- ○ Native American
- ○ Other
- ○ Prefer Not to Answer

What is the highest level of education you have completed?

- ○ Some High School or Less
- ○ High School Diploma / GED
- ○ Some College
- ○ 4-Year College Degree (Bachelor's)
- ○ Master's Degree
- ○ Doctoral Degree
- ○ Professional Degree (MD, JD)

Including yourself, how many people are in your household?

____

How many vehicles are in your household?

____

Estimate your gross annual household income in 2013.

- ○ Under $20,000
- ○ $20,000 - $30,000
- ○ $30,000 - $40,000
- ○ $40,000 - $50,000

- $50,000 - $75,000
- $75,000 - $100,000
- $100,000 - $150,000
- $150,000 or more
- Prefer Not to Answer

APPENDIX B

DESCRIPTIVES

Table B-1 Person Demographics

	Count	Percent
Gender		
Male	591	34
Female	1118	64
Total	1709	
Age		
18-24	402	25
25-30	270	17
31-40	361	22
41-54	366	22
55 and Older	231	14
Total	1630	
Ethnicity		
White/Caucasian	1248	72
Spanish/Hispanic/Latino	167	10
Black/African American	41	2
Asian	117	7
Pacific Islander	6	0.34
Native American	23	1
Other	37	2
Prefer Not to Answer	92	5
Total	1731	
Education		
Some High School or Less	1	0
High School Diploma/GED	49	3
Some College	477	27
4-Year College Degree (Bachelor's)	535	31
Master's Degree	487	28
Doctoral Degree	154	9
Professional Degree (MD,JD)	32	2
Total	1735	

Table B-2 Household Demographics

	Count	Percent
Total Number of People in household		
1	302	18
2	554	33
3	306	18
4	307	19
5 or More	187	11
Total	1656	
Total Number of Vehicles in Household		
0	22	1
1	397	24
2	722	43
3	352	21
4	133	8
5 or More	56	3
Total	1682	
Estimated Gross Yearly Household Income		
Under $30,000	173	12
$30,000-$50,000	255	17
$50,000-$75,000	224	15
$75,000-$100,000	273	18
$100,000-$150,000	265	18
$150,000 or More	155	10
Prefer Not to Answer	159	11
Total	1504	

Table B-3 Characteristics of Last Trip on I-10

	Count	Percent
Purpose of Last I-10 Trip		
Commuting to/from work	370	20
Work related (other than to and from home or work)	200	11
To attend class at a school or educational institute	157	9
Recreational/Social/Entertainment	739	40
Shopping/Personal errands	208	11
Other	170	9
Total	1844	
Day of the Week Last I-10 Trip Occurred		
Weekday	1092	59
Weekend	756	41
Total	1848	
HOV Use During Last I-10 Trip		
Used HOV Lane	686	37
Did Not Use HOV Lane	1149	63
Total	1835	
Travel Mode		
Passenger car/SUV/Pick-up truck	1771	95
Motorcycle	14	1
Bus	43	2
Other	30	2
Total	1858	
Vehicle Occupancy		
1	743	40
2	552	30
3	256	14
4	142	8
5	74	4
Greater than 5	86	5
Total	1853	

APPENDIX C

CROSSTABULATIONS

Age vs HOT Familiarity

Table C-1 Age vs. HOT Familiarity

Age Categories	HOT Familiarity			
		Yes	No	Total
Missing	Count	151	175	326
	% within Age	46.30%	53.70%	100.00%
	% within HOT Familiarity	16.30%	17.00%	16.70%
	% of Total	7.70%	8.90%	16.70%
18-24	Count	140	262	402
	% within Age	34.80%	65.20%	100.00%
	% within HOT Familiarity	15.10%	25.50%	20.60%
	% of Total	7.20%	13.40%	20.60%
25-30	Count	114	156	270
	% within Age	42.20%	57.80%	100.00%
	% within HOT Familiarity	12.30%	15.20%	13.80%
	% of Total	5.80%	8.00%	13.80%
31-40	Count	164	197	361
	% within Age	45.40%	54.60%	100.00%
	% within HOT Familiarity	17.70%	19.10%	18.50%
	% of Total	8.40%	10.10%	18.50%
41-54	Count	210	156	366
	% within Age	57.40%	42.60%	100.00%
	% within HOT Familiarity	22.70%	15.20%	18.70%
	% of Total	10.70%	8.00%	18.70%
>=55	Count	148	83	231
	% within Age	64.10%	35.90%	100.00%
	% within HOT Familiarity	16.00%	8.10%	11.80%
	% of Total	7.60%	4.20%	11.80%
Total	Count	927	1029	1956
	% within Age	47.40%	52.60%	100.00%
	% within HOT Familiarity	100.00%	100.00%	100.00%
	% of Total	47.40%	52.60%	100.00%

Age vs TTR Interest Before

Table C-2 Age vs TTR Interest Before

Age		TTR Interest (TTR)							
		0	1	2	3	4	5	6	Total
18-24	Count	86	42	48	52	75	55	42	400
	% within Age	21.50%	10.50%	12.00%	13.00%	18.80%	13.80%	10.50%	100.00%
	% within TTR	18.00%	14.30%	22.20%	18.10%	27.30%	25.30%	24.40%	20.60%
	% of Total	4.40%	2.20%	2.50%	2.70%	3.90%	2.80%	2.20%	20.60%
25-30	Count	64	43	25	38	41	28	27	266
	% within Age	24.10%	16.20%	9.40%	14.30%	15.40%	10.50%	10.20%	100.00%
	% within TTR	13.40%	14.70%	11.60%	13.20%	14.90%	12.90%	15.70%	13.70%
	% of Total	3.30%	2.20%	1.30%	2.00%	2.10%	1.40%	1.40%	13.70%
31-40	Count	75	58	37	56	50	44	38	358
	% within Age	20.90%	16.20%	10.30%	15.60%	14.00%	12.30%	10.60%	100.00%
	% within TTR	15.70%	19.80%	17.10%	19.40%	18.20%	20.30%	22.10%	18.50%
	% of Total	3.90%	3.00%	1.90%	2.90%	2.60%	2.30%	2.00%	18.50%
41-54	Count	100	67	35	58	39	37	28	364
	% within Age	27.50%	18.40%	9.60%	15.90%	10.70%	10.20%	7.70%	100.00%
	% within TTR	21.00%	22.90%	16.20%	20.10%	14.20%	17.10%	16.30%	18.80%
	% of Total	5.20%	3.50%	1.80%	3.00%	2.00%	1.90%	1.40%	18.80%
55 and Over	Count	71	34	26	38	23	23	16	231
	% within Age	30.70%	14.70%	11.30%	16.50%	10.00%	10.00%	6.90%	100.00%
	% within TTR	14.90%	11.60%	12.00%	13.20%	8.40%	10.60%	9.30%	11.90%
	% of Total	3.70%	1.80%	1.30%	2.00%	1.20%	1.20%	0.80%	11.90%
Total	Count	477	293	216	288	275	217	172	1938
	% within Age	24.60%	15.10%	11.10%	14.90%	14.20%	11.20%	8.90%	100.00%
	% within TTR	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
	% of Total	24.60%	15.10%	11.10%	14.90%	14.20%	11.20%	8.90%	100.00%

Gender vs. HOV Use

Table C-3 Gender vs. HOV Use

Gender		HOV Use					
		Daily	2-3 times a week	2-3 times a month	Very rarely	Never	Total
Male	Count	65	99	152	230	44	590
	% within Gender	11.00%	16.80%	25.80%	39.00%	7.50%	100.00%
	% within HOV Use	44.50%	36.70%	33.90%	30.70%	33.60%	33.80%
	% of Total	3.70%	5.70%	8.70%	13.20%	2.50%	33.80%
Female	Count	78	163	287	505	83	1116
	% within Gender	7.00%	14.60%	25.70%	45.30%	7.40%	100.00%
	% within HOV Use	53.40%	60.40%	63.90%	67.40%	63.40%	64.00%
	% of Total	4.50%	9.30%	16.40%	28.90%	4.80%	64.00%
Prefer Not to Answer	Count	3	8	10	14	4	39
	% within Gender	7.70%	20.50%	25.60%	35.90%	10.30%	100.00%
	% within HOV Use	2.10%	3.00%	2.20%	1.90%	3.10%	2.20%
	% of Total	0.20%	0.50%	0.60%	0.80%	0.20%	2.20%
Total	Count	146	270	449	749	131	1745
	% within Gender	8.40%	15.50%	25.70%	42.90%	7.50%	100.00%
	% within HOV Use	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
	% of Total	8.40%	15.50%	25.70%	42.90%	7.50%	100.00%

Gender vs. HOT Knowledge

Table C-4 Gender vs. HOT Knowledge

Gender		HOT Knowledge		
		Yes	No	Total
Male	Count	327	264	591
	% within Gender	55.30%	44.70%	100.00%
	% within HOT Knowledge	39.50%	28.70%	33.80%
	% of Total	18.70%	15.10%	33.80%
Female	Count	475	643	1118
	% within Gender	42.50%	57.50%	100.00%
	% within HOT Knowledge	57.40%	69.80%	64.00%
	% of Total	27.20%	36.80%	64.00%
Prefer Not to Answer	Count	25	14	39
	% within Gender	64.10%	35.90%	100.00%
	% within HOT Knowledge	3.00%	1.50%	2.20%
	% of Total	1.40%	0.80%	2.20%
Total	Count	827	921	1748
	% within Gender	47.30%	52.70%	100.00%
	% within HOT Knowledge	100.00%	100.00%	100.00%
	% of Total	47.30%	52.70%	100.00%

Gender vs. TTR Before

Table C-5 Gender vs. TTR Interest Before

Gender		TTRbefore (TTRB4)						
		0	1	2	4	5	6	Total
Male	Count	156	84	50	91	139	66	586
	% within Gender	26.60%	14.30%	8.50%	15.50%	23.70%	11.30%	100.00%
	% within TTRB4	36.30%	31.90%	26.20%	37.80%	30.80%	41.00%	33.70%
	% of Total	9.00%	4.80%	2.90%	5.20%	8.00%	3.80%	33.70%
Female	Count	259	174	137	148	301	93	1112
	% within Gender	23.30%	15.60%	12.30%	13.30%	27.10%	8.40%	100.00%
	% within TTRB4	60.20%	66.20%	71.70%	61.40%	66.70%	57.80%	64.00%
	% of Total	14.90%	10.00%	7.90%	8.50%	17.30%	5.40%	64.00%
Prefer Not to Answer	Count	15	5	4	2	11	2	39
	% within Gender	38.50%	12.80%	10.30%	5.10%	28.20%	5.10%	100.00%
	% within TTRB4	3.50%	1.90%	2.10%	0.80%	2.40%	1.20%	2.20%
	% of Total	0.90%	0.30%	0.20%	0.10%	0.60%	0.10%	2.20%
Total	Count	430	263	191	241	451	161	1737
	% within Gender	24.80%	15.10%	11.00%	13.90%	26.00%	9.30%	100.00%
	% within TTRB4	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
	% of Total	24.80%	15.10%	11.00%	13.90%	26.00%	9.30%	100.00%

Gender vs. TTR After

Table C-6 Gender vs. TTR Interest After

Gender		TTRAfter (TTRAF)						
		0	1	2	4	5	6	Total
Male	Count	186	84	61	88	135	31	585
	% within Gender	31.80%	14.40%	10.40%	15.00%	23.10%	5.30%	100.00%
	% within TTRAF	37.10%	26.90%	27.70%	35.50%	36.20%	38.80%	33.70%
	% of Total	10.70%	4.80%	3.50%	5.10%	7.80%	1.80%	33.70%
Female	Count	301	216	158	157	231	47	1110
	% within Gender	27.10%	19.50%	14.20%	14.10%	20.80%	4.20%	100.00%
	% within TTRAF	60.10%	69.20%	71.80%	63.30%	61.90%	58.80%	64.00%
	% of Total	17.40%	12.50%	9.10%	9.10%	13.30%	2.70%	64.00%
Prefer Not to Answer	Count	14	12	1	3	7	2	39
	% within Gender	35.90%	30.80%	2.60%	7.70%	17.90%	5.10%	100.00%
	% within TTRAF	2.80%	3.80%	0.50%	1.20%	1.90%	2.50%	2.20%
	% of Total	0.80%	0.70%	0.10%	0.20%	0.40%	0.10%	2.20%
Total	Count	501	312	220	248	373	80	1734
	% within Gender	28.90%	18.00%	12.70%	14.30%	21.50%	4.60%	100.00%
	% within TTRAF	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
	% of Total	28.90%	18.00%	12.70%	14.30%	21.50%	4.60%	100.00%

Education vs. HOT Knowledge

Table C-7 Education Level vs. HOT Knowledge

Education Level	HOT Knowledge			
		Yes	No	Total
Some High School or Less	Count	1	0	1
	% of Education	100.00%	0.00%	100.00%
	% of HOT Knowledge	0.10%	0.00%	0.10%
	% of Total	0.10%	0.00%	0.10%
High School Diploma / GED	Count	20	29	49
	% of Education	40.80%	59.20%	100.00%
	% of HOT Knowledge	2.40%	3.20%	2.80%
	% of Total	1.20%	1.70%	2.80%
Some College	Count	183	294	477
	% of Education	38.40%	61.60%	100.00%
	% of HOT Knowledge	22.30%	32.20%	27.50%
	% of Total	10.50%	16.90%	27.50%
4-Year College Degree (Bachelor's)	Count	253	282	535
	% of Education	47.30%	52.70%	100.00%
	% of HOT Knowledge	30.80%	30.90%	30.80%
	% of Total	14.60%	16.30%	30.80%
Master's Degree	Count	261	226	487
	% of Education	53.60%	46.40%	100.00%
	% of HOT Knowledge	31.80%	24.80%	28.10%
	% of Total	15.00%	13.00%	28.10%
Doctoral Degree	Count	85	69	154
	% of Education	55.20%	44.80%	100.00%
	% of HOT Knowledge	10.30%	7.60%	8.90%
	% of Total	4.90%	4.00%	8.90%
Professional Degree (MD, JD)	Count	19	13	32
	% of Education	59.40%	40.60%	100.00%
	% of HOT Knowledge	2.30%	1.40%	1.80%
	% of Total	1.10%	0.70%	1.80%
Total	Count	822	913	1735
	% of Education	47.40%	52.60%	100.00%
	% of HOT Knowledge	100.00%	100.00%	100.00%
	% of Total	47.40%	52.60%	100.00%

Education vs. TTR Before

Table C-8 Education Level vs. TTR Interest Before

Education Level		TTRbefore (TTRB4) 0	1	2	4	5	6	Total
Some High School or Less	Count	1	0	0	0	0	0	1
	% within Education	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	% within TTRB4	0.20%	0.00%	0.00%	0.00%	0.00%	0.00%	0.10%
	% of Total	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%	0.10%
High School Diploma / GED	Count	8	11	5	9	10	6	49
	% within Education	16.30%	22.40%	10.20%	18.40%	20.40%	12.20%	100.00%
	% within TTRB4	1.90%	4.30%	2.60%	3.70%	2.20%	3.70%	2.80%
	% of Total	0.50%	0.60%	0.30%	0.50%	0.60%	0.30%	2.80%
Some College	Count	113	62	55	73	126	44	473
	% within Education	23.90%	13.10%	11.60%	15.40%	26.60%	9.30%	100.00%
	% within TTRB4	26.70%	24.10%	28.80%	30.30%	28.00%	27.30%	27.40%
	% of Total	6.60%	3.60%	3.20%	4.20%	7.30%	2.60%	27.40%
4-Year College Degree (Bachelor's)	Count	140	78	57	84	129	45	533
	% within Education	26.30%	14.60%	10.70%	15.80%	24.20%	8.40%	100.00%
	% within TTRB4	33.00%	30.40%	29.80%	34.90%	28.70%	28.00%	30.90%
	% of Total	8.10%	4.50%	3.30%	4.90%	7.50%	2.60%	30.90%
Master's Degree	Count	114	67	53	60	133	55	482
	% within Education	23.70%	13.90%	11.00%	12.40%	27.60%	11.40%	100.00%
	% within TTRB4	26.90%	26.10%	27.70%	24.90%	29.60%	34.20%	28.00%
	% of Total	6.60%	3.90%	3.10%	3.50%	7.70%	3.20%	28.00%
Doctoral Degree	Count	39	31	18	11	45	10	154
	% within Education	25.30%	20.10%	11.70%	7.10%	29.20%	6.50%	100.00%
	% within TTRB4	9.20%	12.10%	9.40%	4.60%	10.00%	6.20%	8.90%
	% of Total	2.30%	1.80%	1.00%	0.60%	2.60%	0.60%	8.90%
Professional Degree (MD, JD)	Count	9	8	3	4	7	1	32
	% within Education	28.10%	25.00%	9.40%	12.50%	21.90%	3.10%	100.00%
	% within TTRB4	2.10%	3.10%	1.60%	1.70%	1.60%	0.60%	1.90%
	% of Total	0.50%	0.50%	0.20%	0.20%	0.40%	0.10%	1.90%
Total	Count	424	257	191	241	450	161	1724
	% within Education	24.60%	14.90%	11.10%	14.00%	26.10%	9.30%	100.00%
	% within TTRB4	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
	% of Total	24.60%	14.90%	11.10%	14.00%	26.10%	9.30%	100.00%

Education vs. TTR After

Table C-9 Education Level vs. TTR Interest Before

Education Level		TTRAfter (TTRAF) 0	1	2	4	5	6	Total
Some High School or Less	Count	0	1	0	0	0	0	1
	% within Education	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	100.00%
	% within TTRAF	0.00%	0.30%	0.00%	0.00%	0.00%	0.00%	0.10%
	% of Total	0.00%	0.10%	0.00%	0.00%	0.00%	0.00%	0.10%
High School Diploma / GED	Count	9	7	8	13	11	1	49
	% within Education	18.40%	14.30%	16.30%	26.50%	22.40%	2.00%	100.00%
	% within TTRAF	1.80%	2.30%	3.60%	5.20%	3.00%	1.30%	2.80%
	% of Total	0.50%	0.40%	0.50%	0.80%	0.60%	0.10%	2.80%
Some College	Count	135	75	67	70	104	25	476
	% within Education	28.40%	15.80%	14.10%	14.70%	21.80%	5.30%	100.00%
	% within TTRAF	27.40%	24.10%	30.30%	28.00%	28.50%	31.30%	27.70%
	% of Total	7.80%	4.40%	3.90%	4.10%	6.00%	1.50%	27.70%
4-Year College Degree (Bachelor's)	Count	162	101	59	80	104	24	530
	% within Education	30.60%	19.10%	11.10%	15.10%	19.60%	4.50%	100.00%
	% within TTRAF	32.90%	32.50%	26.70%	32.00%	28.50%	30.00%	30.80%
	% of Total	9.40%	5.90%	3.40%	4.70%	6.00%	1.40%	30.80%
Master's Degree	Count	134	86	62	70	104	25	481
	% within Education	27.90%	17.90%	12.90%	14.60%	21.60%	5.20%	100.00%
	% within TTRAF	27.20%	27.70%	28.10%	28.00%	28.50%	31.30%	28.00%
	% of Total	7.80%	5.00%	3.60%	4.10%	6.00%	1.50%	28.00%
Doctoral Degree	Count	43	33	20	14	38	4	152
	% within Education	28.30%	21.70%	13.20%	9.20%	25.00%	2.60%	100.00%
	% within TTRAF	8.70%	10.60%	9.00%	5.60%	10.40%	5.00%	8.80%
	% of Total	2.50%	1.90%	1.20%	0.80%	2.20%	0.20%	8.80%
Professional Degree (MD, JD)	Count	10	8	5	3	4	1	31
	% within Education	32.30%	25.80%	16.10%	9.70%	12.90%	3.20%	100.00%
	% within TTRAF	2.00%	2.60%	2.30%	1.20%	1.10%	1.30%	1.80%
	% of Total	0.60%	0.50%	0.30%	0.20%	0.20%	0.10%	1.80%
Total	Count	493	311	221	250	365	80	1720
	% within Education	28.70%	18.10%	12.80%	14.50%	21.20%	4.70%	100.00%
	% within TTRAF	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
	% of Total	28.70%	18.10%	12.80%	14.50%	21.20%	4.70%	100.00%

Income vs. HOT Use

Table C-10 Income vs. HOT Use

Income Categories		HOT lane Use		
		Yes	No	Total
Under $20,000	Count	19	77	96
	% of Income	19.80%	80.20%	100.00%
	% of HOT Use	6.20%	6.50%	6.40%
	% of Total	1.30%	5.10%	6.40%
$20,000 - $30,000	Count	7	67	74
	% of Income	9.50%	90.50%	100.00%
	% of HOT Use	2.30%	5.60%	4.90%
	% of Total	0.50%	4.50%	4.90%
$30,000 - $40,000	Count	27	97	124
	% of Income	21.80%	78.20%	100.00%
	% of HOT Use	8.80%	8.10%	8.30%
	% of Total	1.80%	6.50%	8.30%
$40,000 - $50,000	Count	21	109	130
	% of Income	16.20%	83.80%	100.00%
	% of HOT Use	6.90%	9.20%	8.70%
	% of Total	1.40%	7.30%	8.70%
$50,000 - $75,000	Count	49	174	223
	% of Income	22.00%	78.00%	100.00%
	% of HOT Use	16.00%	14.60%	14.90%
	% of Total	3.30%	11.60%	14.90%
$75,000 - $100,000	Count	56	216	272
	% of Income	20.60%	79.40%	100.00%
	% of HOT Use	18.30%	18.10%	18.20%
	% of Total	3.70%	14.40%	18.20%
$100,000 - $150,000	Count	52	213	265
	% of Income	19.60%	80.40%	100.00%
	% of HOT Use	17.00%	17.90%	17.70%
	% of Total	3.50%	14.20%	17.70%
$150,000 or more	Count	45	110	155
	% of Income	29.00%	71.00%	100.00%
	% of HOT Use	14.70%	9.20%	10.40%
	% of Total	3.00%	7.30%	10.40%
Prefer Not to Answer	Count	30	128	158
	% of Income	19.00%	81.00%	100.00%
	% of HOT Use	9.80%	10.70%	10.60%
	% of Total	2.00%	8.60%	10.60%
Total	Count	306	1191	1497
	% of Income	20.40%	79.60%	100.00%
	% of HOT Use	100.00%	100.00%	100.00%
	% of Total	20.40%	79.60%	100.00%

Income vs. HOT Interest

Table C-11 Income vs. HOT Interest

Income Categories		HOT Interest							
		0	1	2	3	4	5	6	Total
Under $20,000	Count	34	18	10	14	9	9	4	98
	% of Income	34.70%	18.40%	10.20%	14.30%	9.20%	9.20%	4.10%	100.00%
	% of HOT Interest	6.60%	7.10%	6.40%	6.80%	5.90%	7.70%	4.20%	6.60%
	% of Total	2.30%	1.20%	0.70%	0.90%	0.60%	0.60%	0.30%	6.60%
$20,000 - $30,000	Count	30	10	10	7	10	4	2	73
	% of Income	41.10%	13.70%	13.70%	9.60%	13.70%	5.50%	2.70%	100.00%
	% of HOT Interest	5.80%	4.00%	6.40%	3.40%	6.60%	3.40%	2.10%	4.90%
	% of Total	2.00%	0.70%	0.70%	0.50%	0.70%	0.30%	0.10%	4.90%
$30,000 - $40,000	Count	50	16	16	14	12	9	5	122
	% of Income	41.00%	13.10%	13.10%	11.50%	9.80%	7.40%	4.10%	100.00%
	% of HOT Interest	9.70%	6.30%	10.30%	6.80%	7.90%	7.70%	5.20%	8.20%
	% of Total	3.40%	1.10%	1.10%	0.90%	0.80%	0.60%	0.30%	8.20%
$40,000 - $50,000	Count	34	26	13	24	16	10	7	130
	% of Income	26.20%	20.00%	10.00%	18.50%	12.30%	7.70%	5.40%	100.00%
	% of HOT Interest	6.60%	10.30%	8.30%	11.70%	10.50%	8.50%	7.30%	8.70%
	% of Total	2.30%	1.70%	0.90%	1.60%	1.10%	0.70%	0.50%	8.70%
$50,000 - $75,000	Count	79	38	29	30	15	17	14	222
	% of Income	35.60%	17.10%	13.10%	13.50%	6.80%	7.70%	6.30%	100.00%
	% of HOT Interest	15.40%	15.10%	18.60%	14.60%	9.90%	14.50%	14.60%	14.90%
	% of Total	5.30%	2.50%	1.90%	2.00%	1.00%	1.10%	0.90%	14.90%
$75,000 - $100,000	Count	89	54	26	42	23	18	21	273
	% of Income	32.60%	19.80%	9.50%	15.40%	8.40%	6.60%	7.70%	100.00%
	% of HOT Interest	17.30%	21.40%	16.70%	20.40%	15.10%	15.40%	21.90%	18.30%
	% of Total	6.00%	3.60%	1.70%	2.80%	1.50%	1.20%	1.40%	18.30%
$100,000 - $150,000	Count	86	51	28	31	24	24	19	263
	% of Income	32.70%	19.40%	10.60%	11.80%	9.10%	9.10%	7.20%	100.00%
	% of HOT Interest	16.80%	20.20%	17.90%	15.00%	15.80%	20.50%	19.80%	17.60%
	% of Total	5.80%	3.40%	1.90%	2.10%	1.60%	1.60%	1.30%	17.60%
$150,000 or more	Count	43	19	9	17	27	22	18	155
	% of Income	27.70%	12.30%	5.80%	11.00%	17.40%	14.20%	11.60%	100.00%
	% of HOT Interest	8.40%	7.50%	5.80%	8.30%	17.80%	18.80%	18.80%	10.40%
	% of Total	2.90%	1.30%	0.60%	1.10%	1.80%	1.50%	1.20%	10.40%
Prefer Not to Answer	Count	68	20	15	27	16	4	6	156
	% of Income	43.60%	12.80%	9.60%	17.30%	10.30%	2.60%	3.80%	100.00%
	% of HOT Interest	13.30%	7.90%	9.60%	13.10%	10.50%	3.40%	6.30%	10.50%
	% of Total	4.60%	1.30%	1.00%	1.80%	1.10%	0.30%	0.40%	10.50%
Total	Count	513	252	156	206	152	117	96	1492
	% of Income	34.40%	16.90%	10.50%	13.80%	10.20%	7.80%	6.40%	100.00%
	% of HOT Interest	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
	% of Total	34.40%	16.90%	10.50%	13.80%	10.20%	7.80%	6.40%	100.00%

Income vs. TTR After

Table C-12 Income vs. TTR Interest After

Income Levels		TTR Interest After (TTRAF)							
		0	1	2	3	4	5	6	Total
Under $20,000	Count	21	11	17	13	15	15	7	99
	% of Income	21.20%	11.10%	17.20%	13.10%	15.20%	15.20%	7.10%	100.00%
	% of TTRAF	4.90%	4.10%	8.90%	7.50%	7.00%	10.60%	9.00%	6.60%
	% of Total	1.40%	0.70%	1.10%	0.90%	1.00%	1.00%	0.50%	6.60%
$20,000 - $30,000	Count	16	12	12	10	7	11	6	74
	% of Income	21.60%	16.20%	16.20%	13.50%	9.50%	14.90%	8.10%	100.00%
	% of TTRAF	3.70%	4.50%	6.30%	5.80%	3.30%	7.80%	7.70%	4.90%
	% of Total	1.10%	0.80%	0.80%	0.70%	0.50%	0.70%	0.40%	4.90%
$30,000 - $40,000	Count	35	25	13	17	17	12	5	124
	% of Income	28.20%	20.20%	10.50%	13.70%	13.70%	9.70%	4.00%	100.00%
	% of TTRAF	8.10%	9.40%	6.80%	9.80%	8.00%	8.50%	6.40%	8.30%
	% of Total	2.30%	1.70%	0.90%	1.10%	1.10%	0.80%	0.30%	8.30%
$40,000 - $50,000	Count	31	27	20	10	24	11	6	129
	% of Income	24.00%	20.90%	15.50%	7.80%	18.60%	8.50%	4.70%	100.00%
	% of TTRAF	7.20%	10.10%	10.50%	5.80%	11.30%	7.80%	7.70%	8.60%
	% of Total	2.10%	1.80%	1.30%	0.70%	1.60%	0.70%	0.40%	8.60%
$50,000 - $75,000	Count	80	42	22	19	28	23	9	223
	% of Income	35.90%	18.80%	9.90%	8.50%	12.60%	10.30%	4.00%	100.00%
	% of TTRAF	18.50%	15.70%	11.50%	11.00%	13.10%	16.30%	11.50%	14.90%
	% of Total	5.40%	2.80%	1.50%	1.30%	1.90%	1.50%	0.60%	14.90%
$75,000 - $100,000	Count	74	49	36	40	35	22	14	270
	% of Income	27.40%	18.10%	13.30%	14.80%	13.00%	8.10%	5.20%	100.00%
	% of TTRAF	17.10%	18.40%	18.80%	23.10%	16.40%	15.60%	17.90%	18.10%
	% of Total	4.90%	3.30%	2.40%	2.70%	2.30%	1.50%	0.90%	18.10%
$100,000 - $150,000	Count	82	53	29	30	31	24	15	264
	% of Income	31.10%	20.10%	11.00%	11.40%	11.70%	9.10%	5.70%	100.00%
	% of TTRAF	19.00%	19.90%	15.20%	17.30%	14.60%	17.00%	19.20%	17.70%
	% of Total	5.50%	3.50%	1.90%	2.00%	2.10%	1.60%	1.00%	17.70%
$150,000 or more	Count	38	22	20	20	27	15	12	154
	% of Income	24.70%	14.30%	13.00%	13.00%	17.50%	9.70%	7.80%	100.00%
	% of TTRAF	8.80%	8.20%	10.50%	11.60%	12.70%	10.60%	15.40%	10.30%
	% of Total	2.50%	1.50%	1.30%	1.30%	1.80%	1.00%	0.80%	10.30%
Prefer Not to Answer	Count	55	26	22	14	29	8	4	158
	% of Income	34.80%	16.50%	13.90%	8.90%	18.40%	5.10%	2.50%	100.00%
	% of TTRAF	12.70%	9.70%	11.50%	8.10%	13.60%	5.70%	5.10%	10.60%
	% of Total	3.70%	1.70%	1.50%	0.90%	1.90%	0.50%	0.30%	10.60%
Total	Count	432	267	191	173	213	141	78	1495
	% of Income	28.90%	17.90%	12.80%	11.60%	14.20%	9.40%	5.20%	100.00%
	% of TTRAF	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
	% of Total	28.90%	17.90%	12.80%	11.60%	14.20%	9.40%	5.20%	100.00%

Number of People in Household vs. HOV Use

Table C-13 Household Size vs. HOV Use

Household Size		HOV Use					
		Daily	2-3 times a week	2-3 times a month	Very rarely	Never	Total
1	Count	22	28	58	154	39	301
	% within Household Size	7.30%	9.30%	19.30%	51.20%	13.00%	100.00%
	% within HOV Use	13.40%	9.50%	11.70%	18.10%	26.70%	15.40%
	% of Total	1.10%	1.40%	3.00%	7.90%	2.00%	15.40%
2	Count	46	67	133	271	36	553
	% within Household Size	8.30%	12.10%	24.10%	49.00%	6.50%	100.00%
	% within HOV Use	28.00%	22.80%	26.80%	31.90%	24.70%	28.30%
	% of Total	2.40%	3.40%	6.80%	13.90%	1.80%	28.30%
3	Count	29	50	96	115	15	305
	% within Household Size	9.50%	16.40%	31.50%	37.70%	4.90%	100.00%
	% within HOV Use	17.70%	17.00%	19.30%	13.50%	10.30%	15.60%
	% of Total	1.50%	2.60%	4.90%	5.90%	0.80%	15.60%
4	Count	25	74	82	111	15	307
	% within Household Size	8.10%	24.10%	26.70%	36.20%	4.90%	100.00%
	% within HOV Use	15.20%	25.20%	16.50%	13.10%	10.30%	15.70%
	% of Total	1.30%	3.80%	4.20%	5.70%	0.80%	15.70%
≥ 5	Count	16	41	56	60	14	187
	% within Household Size	8.60%	21.90%	29.90%	32.10%	7.50%	100.00%
	% within HOV Use	9.80%	13.90%	11.30%	7.10%	9.60%	9.60%
	% of Total	0.80%	2.10%	2.90%	3.10%	0.70%	9.60%
Missing	Count	26	34	72	139	27	298
	% within Household Size	8.70%	11.40%	24.20%	46.60%	9.10%	100.00%
	% within HOV Use	15.90%	11.60%	14.50%	16.40%	18.50%	15.30%
	% of Total	1.30%	1.70%	3.70%	7.10%	1.40%	15.30%
Total	Count	164	294	497	850	146	1951
	% within Household Size	8.40%	15.10%	25.50%	43.60%	7.50%	100.00%
	% within HOV Use	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
	% of Total	8.40%	15.10%	25.50%	43.60%	7.50%	100.00%

Number of People in Household vs. HOT Use

Table C-14 Household Size vs. HOT Use

Household Size		HOT use		
		Yes	No	Total
1	Count	56	242	298
	% within Household Size	18.80%	81.20%	100.00%
	% within HOT Use	13.80%	15.70%	15.30%
	% of Total	2.90%	12.40%	15.30%
2	Count	114	438	552
	% within Household Size	20.70%	79.30%	100.00%
	% within HOT Use	28.10%	28.40%	28.40%
	% of Total	5.90%	22.50%	28.40%
3	Count	53	253	306
	% within Household Size	17.30%	82.70%	100.00%
	% within HOT Use	13.10%	16.40%	15.70%
	% of Total	2.70%	13.00%	15.70%
4	Count	75	231	306
	% within Household Size	24.50%	75.50%	100.00%
	% within HOT Use	18.50%	15.00%	15.70%
	% of Total	3.90%	11.90%	15.70%
≥ 5	Count	49	138	187
	% within Household Size	26.20%	73.80%	100.00%
	% within HOT Use	12.10%	9.00%	9.60%
	% of Total	2.50%	7.10%	9.60%
Missing	Count	59	239	298
	% within Household Size	19.80%	80.20%	100.00%
	% within HOT Use	14.50%	15.50%	15.30%
	% of Total	3.00%	12.30%	15.30%
Total	Count	406	1541	1947
	% within Household Size	20.90%	79.10%	100.00%
	% within HOT Use	100.00%	100.00%	100.00%
	% of Total	20.90%	79.10%	100.00%

Education vs. HOT Knowledge

Table C-15 Education vs. HOT Knowledge

Education level		HOT Knowledge		
		Yes	No	Total
Some High School or Less	Count	1	0	1
	% of Education	100.00%	0.00%	100.00%
	% of HOT Knowledge	0.10%	0.00%	0.10%
	% of Total	0.10%	0.00%	0.10%
High School Diploma / GED	Count	20	29	49
	% of Education	40.80%	59.20%	100.00%
	% of HOT Knowledge	2.40%	3.20%	2.80%
	% of Total	1.20%	1.70%	2.80%
Some College	Count	183	294	477
	% of Education	38.40%	61.60%	100.00%
	% of HOT Knowledge	22.30%	32.20%	27.50%
	% of Total	10.50%	16.90%	27.50%
4-Year College Degree (Bachelor's)	Count	253	282	535
	% of Education	47.30%	52.70%	100.00%
	% of HOT Knowledge	30.80%	30.90%	30.80%
	% of Total	14.60%	16.30%	30.80%
Master's Degree	Count	261	226	487
	% of Education	53.60%	46.40%	100.00%
	% of HOT Knowledge	31.80%	24.80%	28.10%
	% of Total	15.00%	13.00%	28.10%
Doctoral Degree	Count	85	69	154
	% of Education	55.20%	44.80%	100.00%
	% of HOT Knowledge	10.30%	7.60%	8.90%
	% of Total	4.90%	4.00%	8.90%
Professional Degree (MD, JD)	Count	19	13	32
	% of Education	59.40%	40.60%	100.00%
	% of HOT Knowledge	2.30%	1.40%	1.80%
	% of Total	1.10%	0.70%	1.80%
Total	Count	822	913	1735
	% of Education	47.40%	52.60%	100.00%
	% of HOT Knowledge	100.00%	100.00%	100.00%
	% of Total	47.40%	52.60%	100.00%

APPENDIX D

TIME VARYING ML CHOICE FOR CVS AND NON CVS

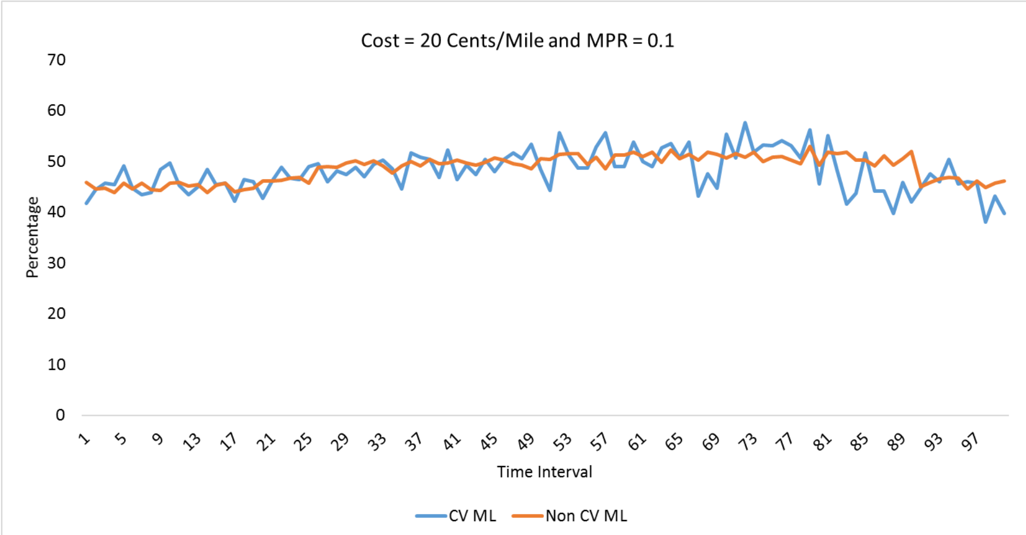

Figure D-1 ML Choice for CVs and Non CVs at 20 Cents and 10% MPR

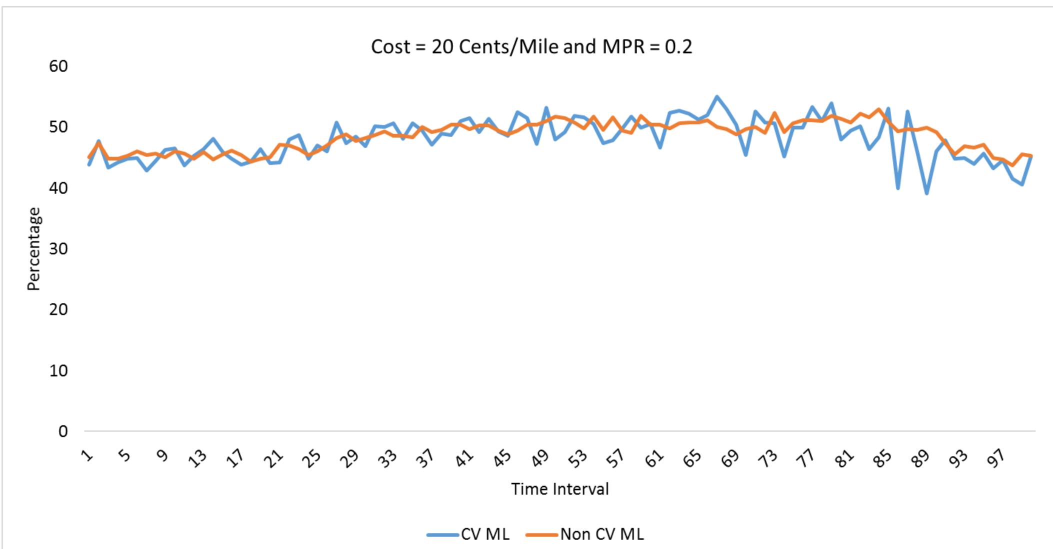

Figure D-2 ML Choice for CVs and Non CVs at 20 Cents and 20% MPR

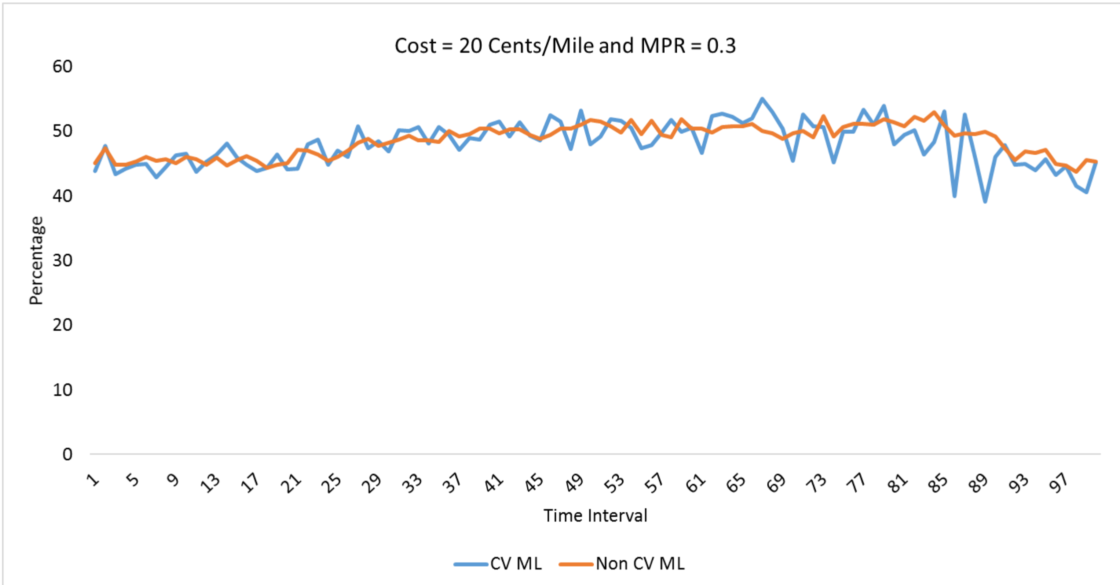

Figure D-3 ML Choice for CVs and Non CVs at 20 Cents and 30% MPR

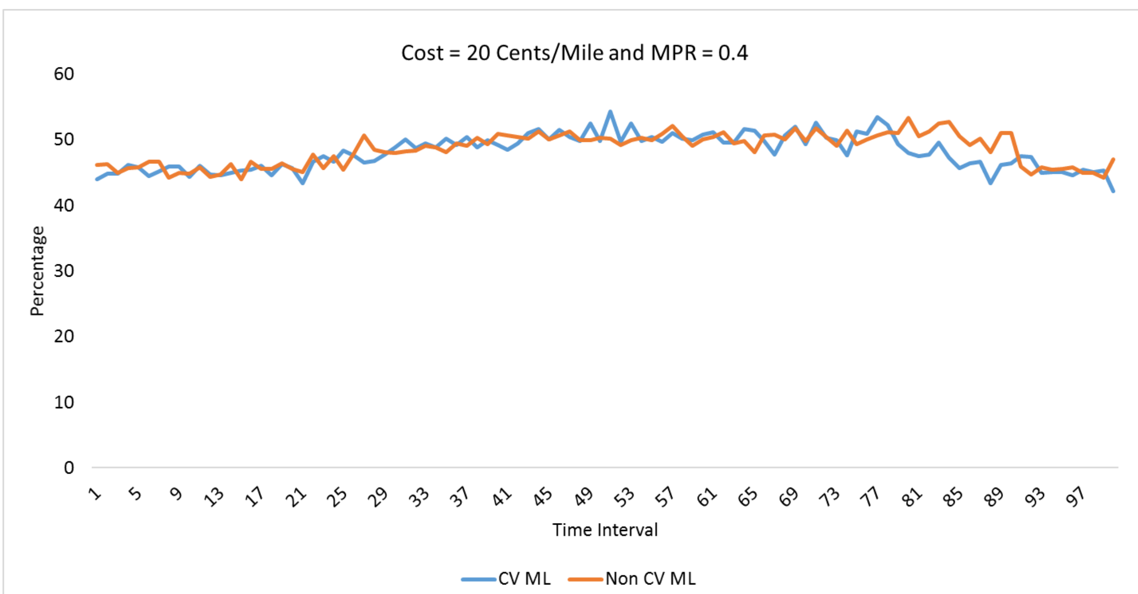

Figure D-4 ML Choice for CVs and Non CVs at 20 Cents and 40% MPR

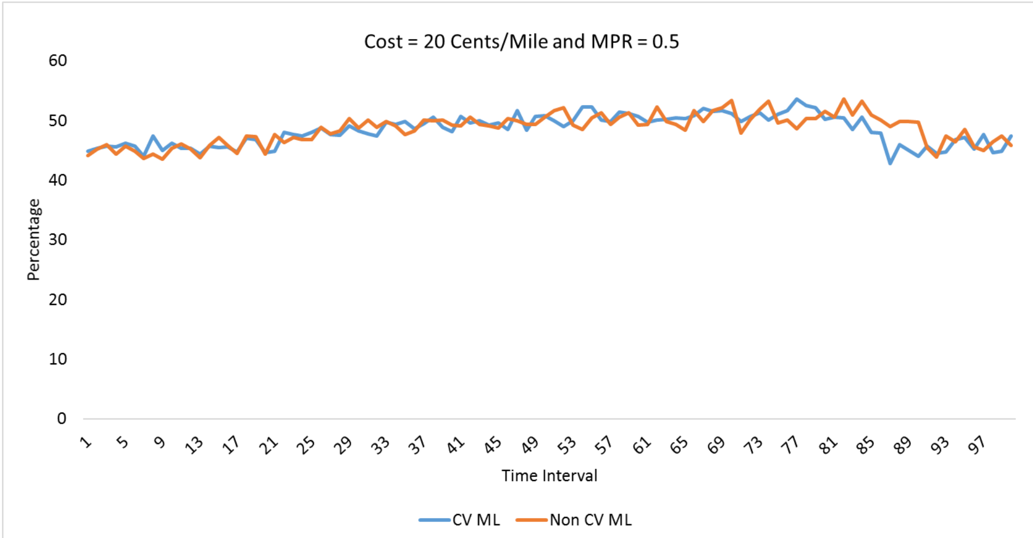

Figure D-5 ML Choice for CVs and Non CVs at 20 Cents and 50% MPR

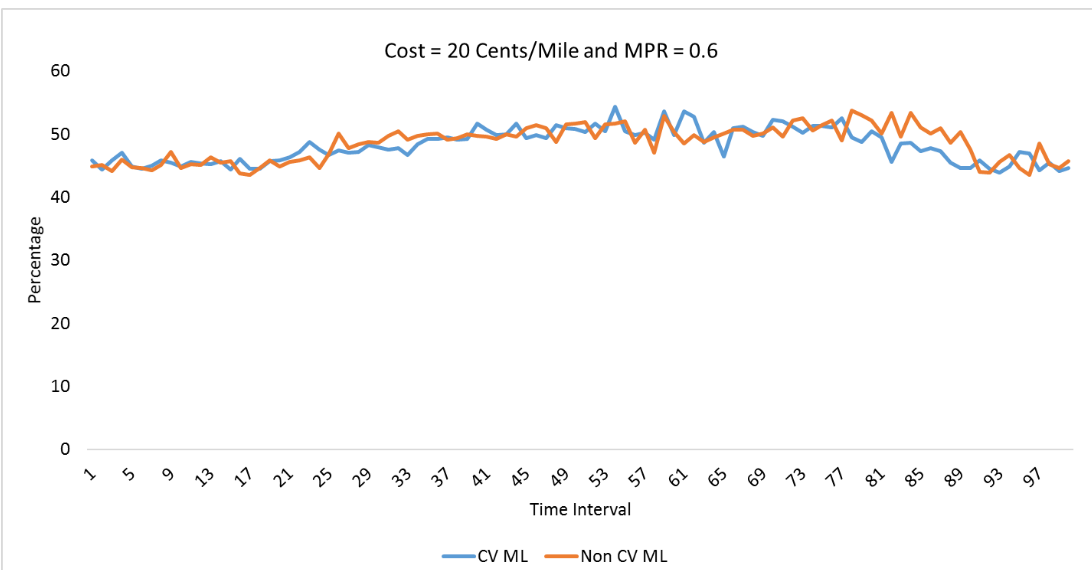

Figure D-6 ML Choice for CVs and Non CVs at 20 Cents and 60% MPR

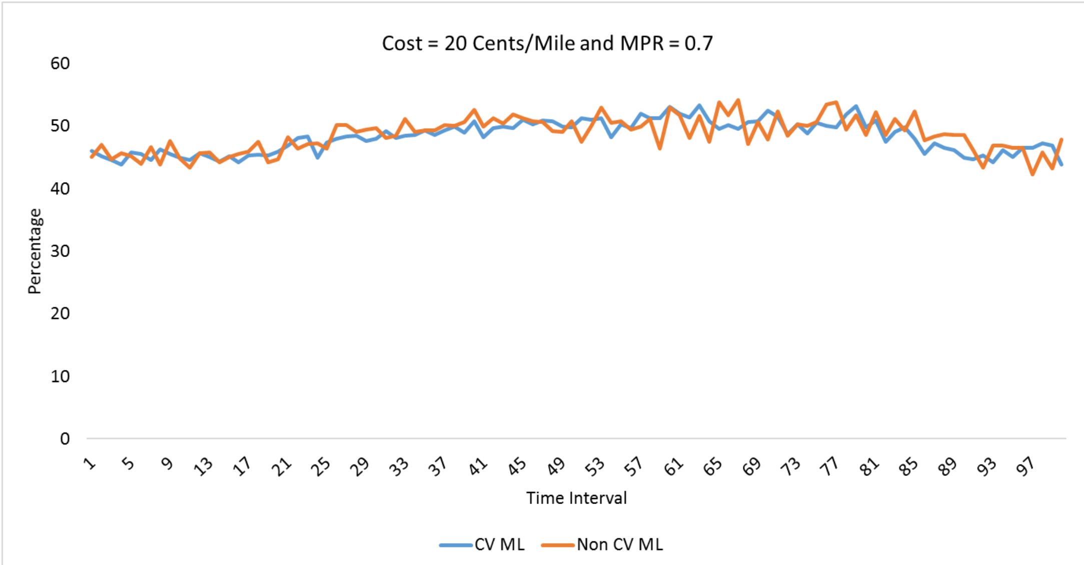

Figure D-7 ML Choice for CVs and Non CVs at 20 Cents and 70% MPR

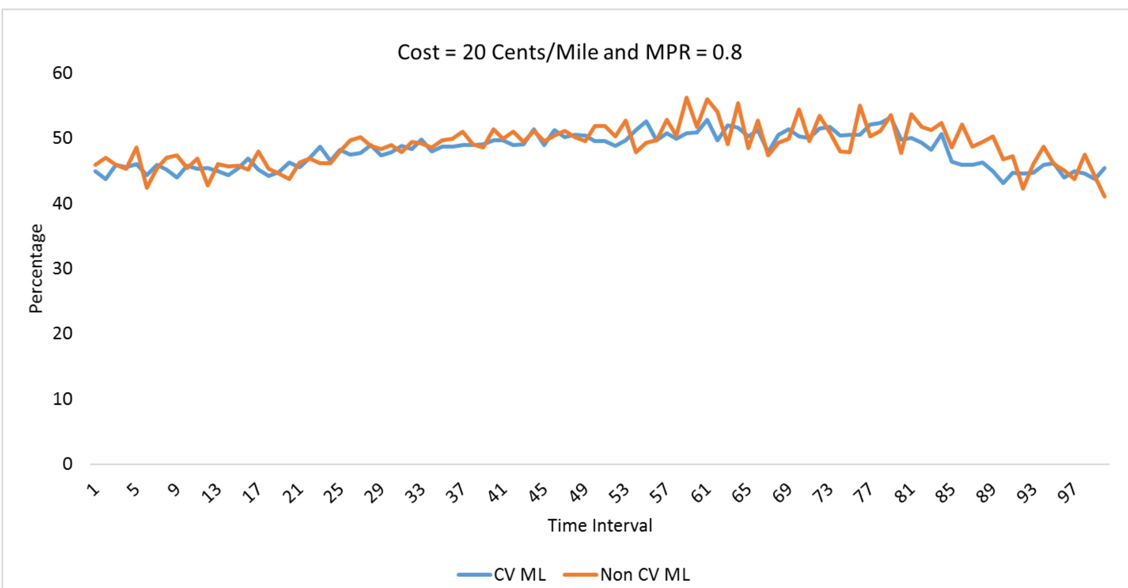

Figure D-8 ML Choice for CVs and Non CVs at 20 Cents and 80% MPR

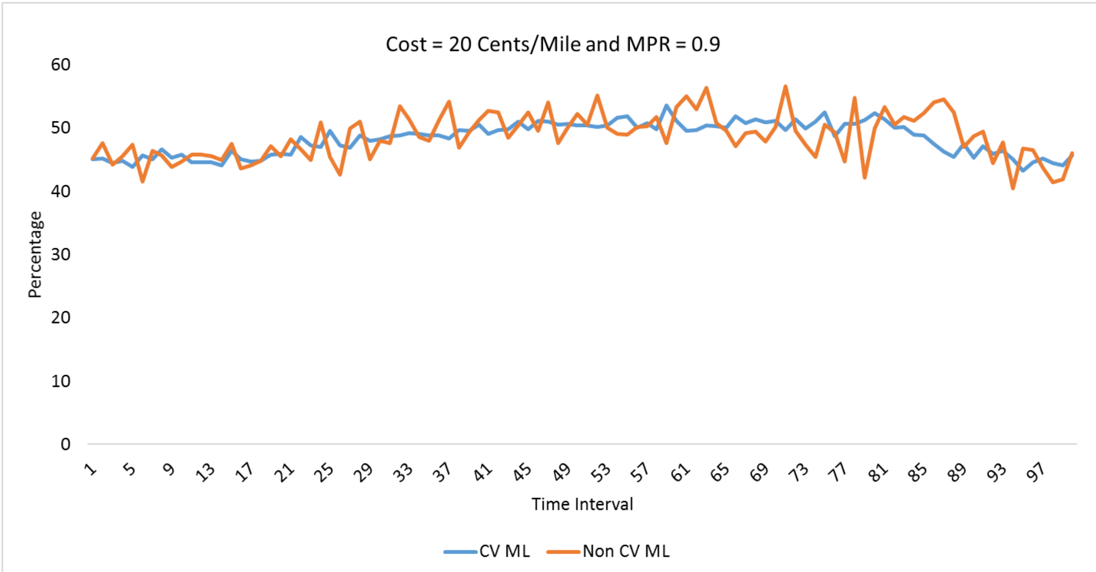

Figure D-9 ML Choice for CVs and Non CVs at 20 Cents and 90% MPR

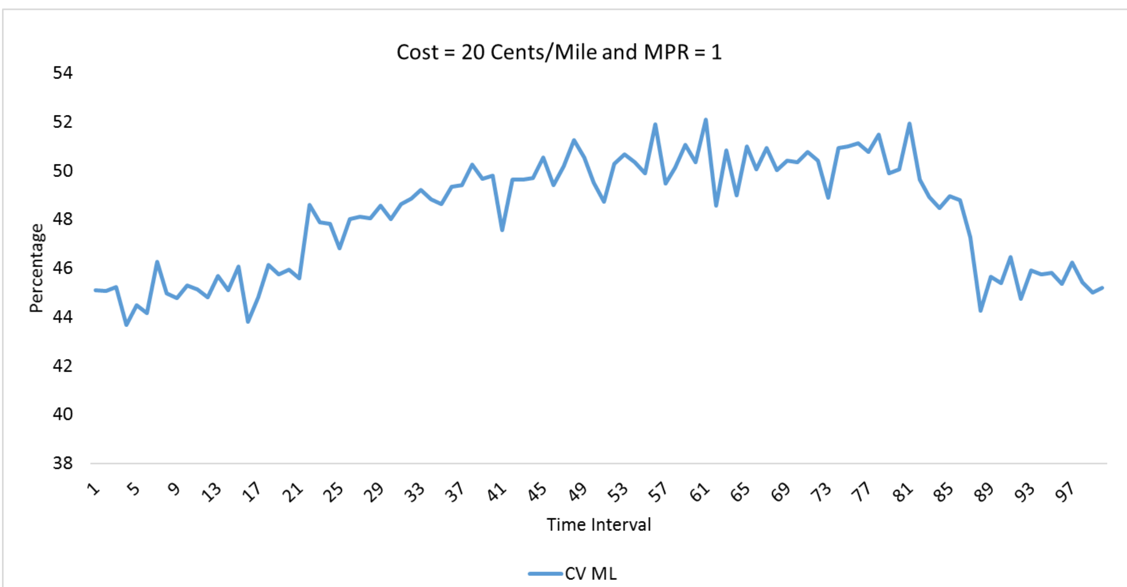

Figure D-10 ML Choice for CVs and Non CVs at 20 Cents and 100% MPR

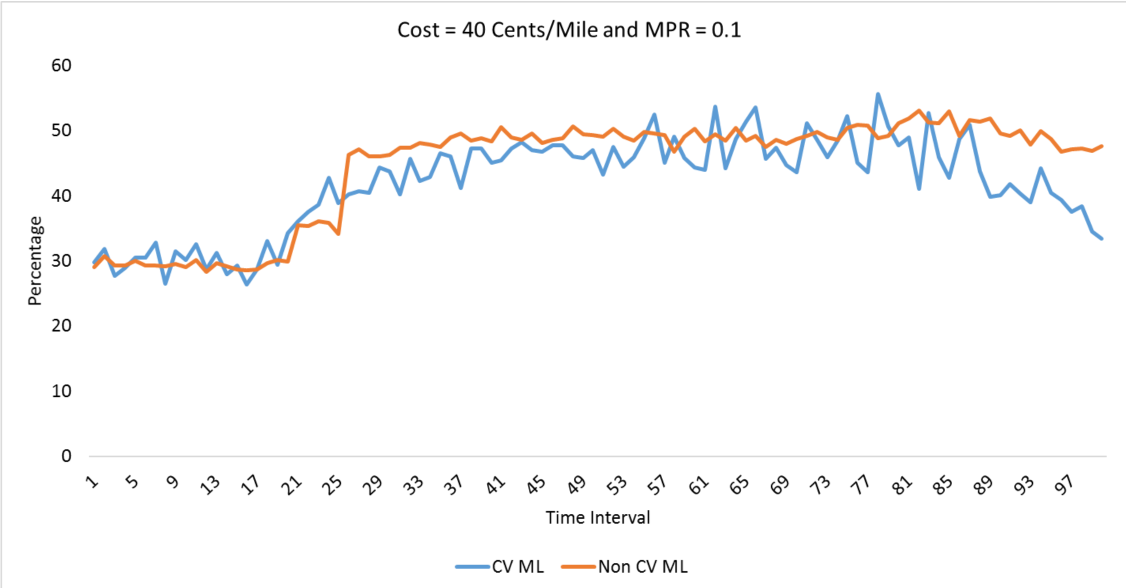

Figure D-11 ML Choice for CVs and Non CVs at 40 Cents and 10% MPR

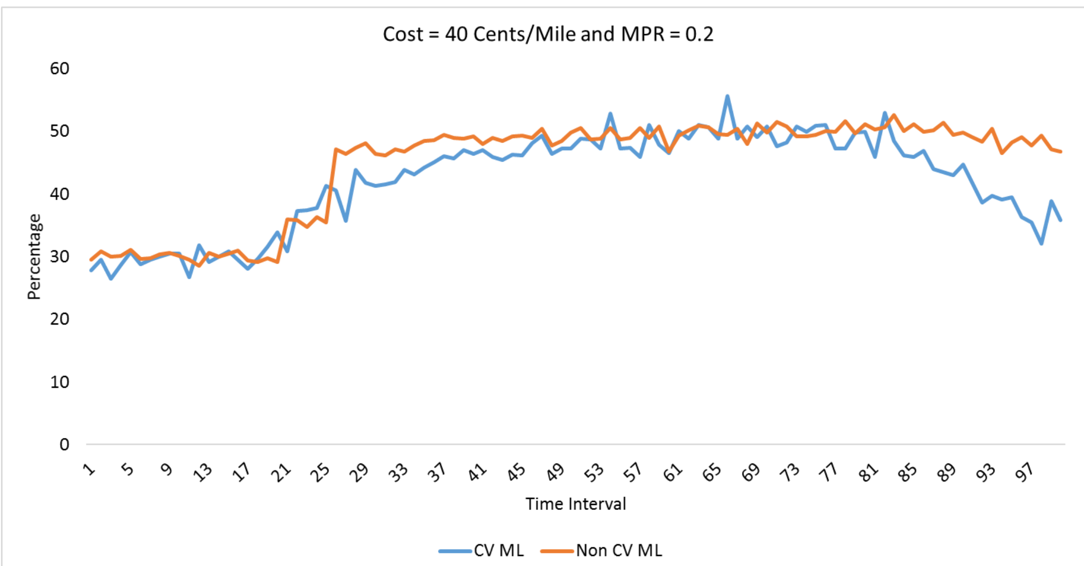

Figure D-12 ML Choice for CVs and Non CVs at 40 Cents and 20% MPR

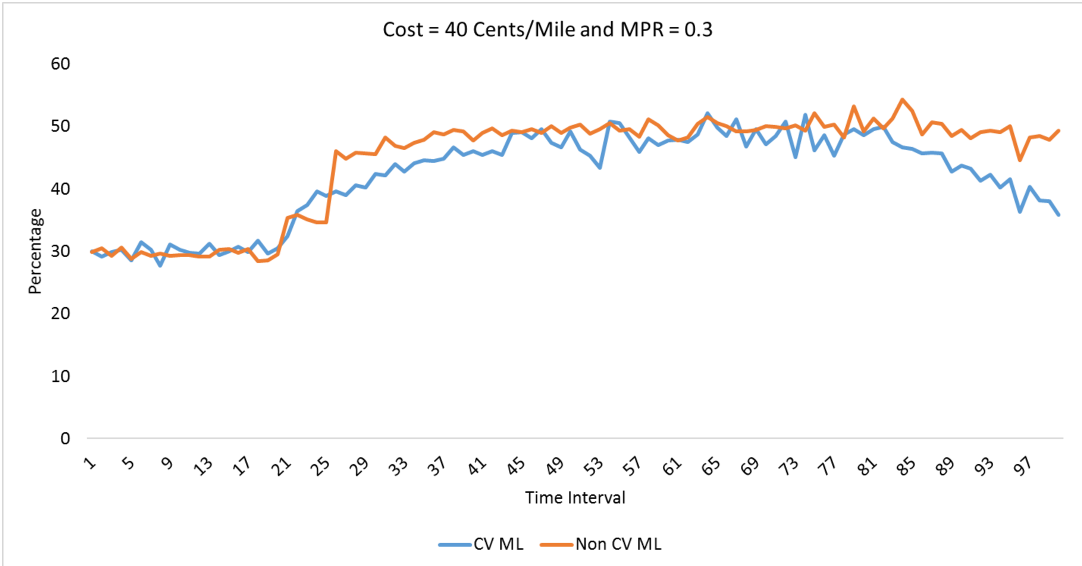

Figure D-13 ML Choice for CVs and Non CVs at 40 Cents and 30% MPR

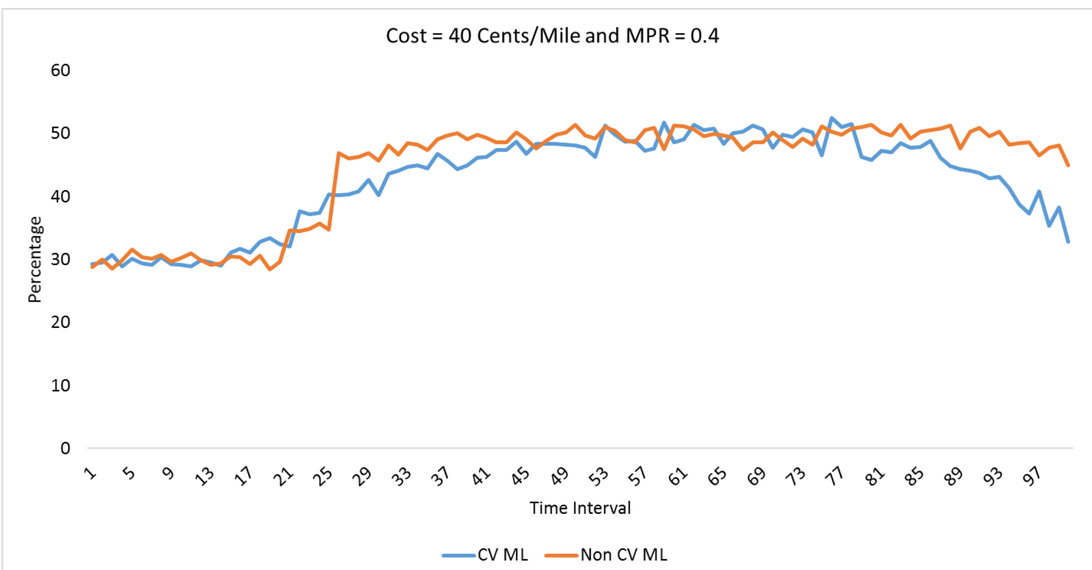

Figure D-14 ML Choice for CVs and Non CVs at 40 Cents and 40% MPR

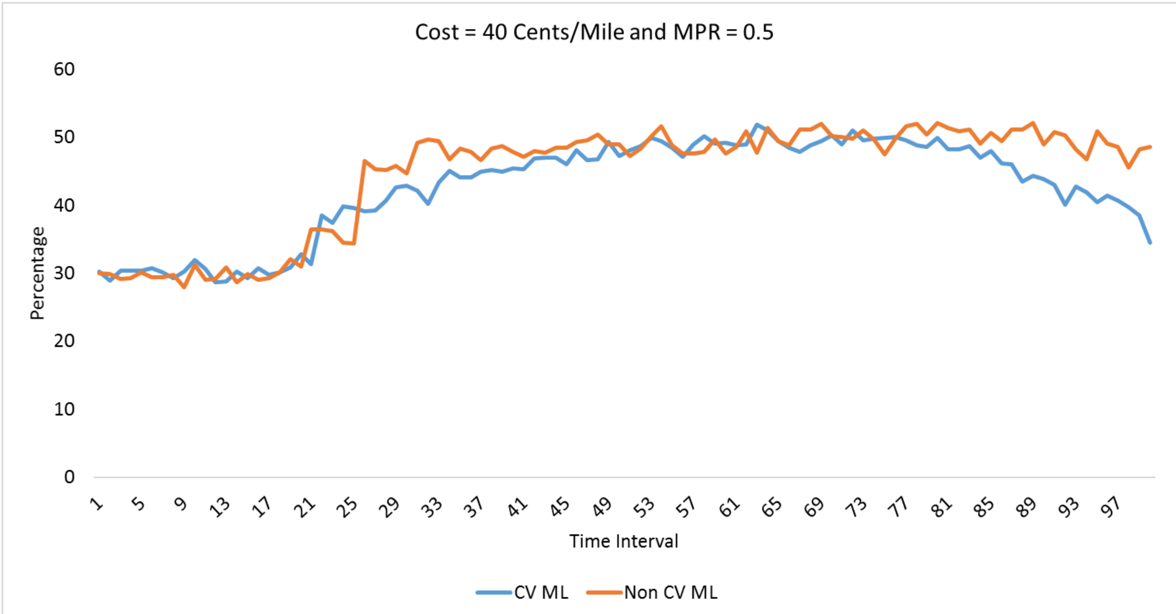

Figure D-15 ML Choice for CVs and Non CVs at 40 Cents and 50% MPR

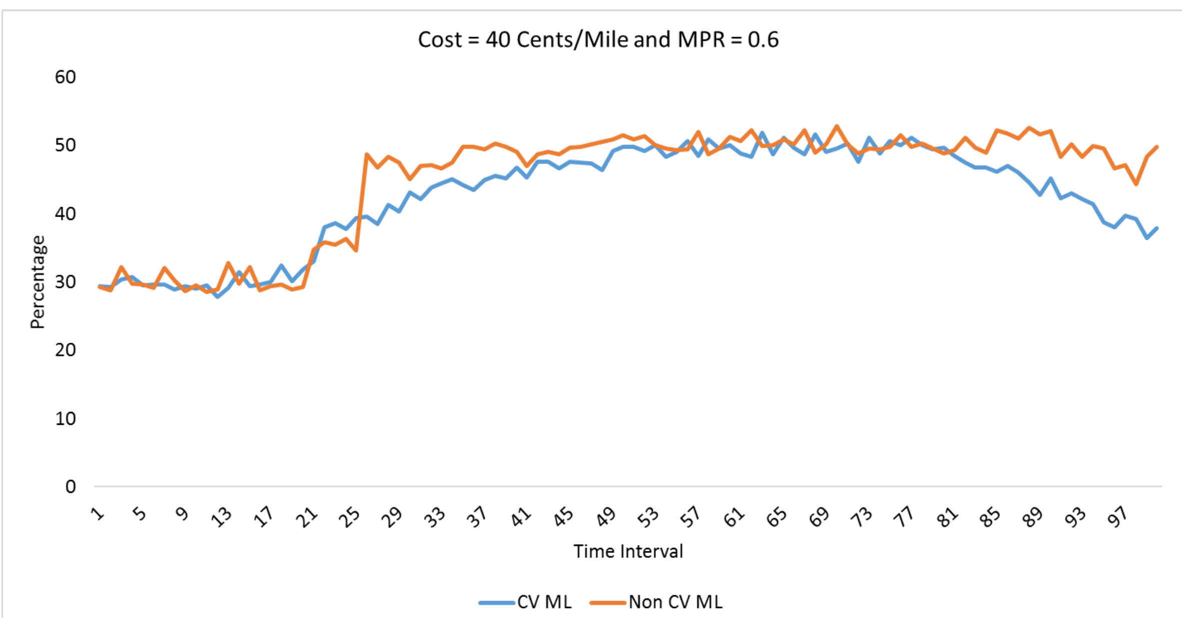

Figure D-16 ML Choice for CVs and Non CVs at 40 Cents and 60% MPR

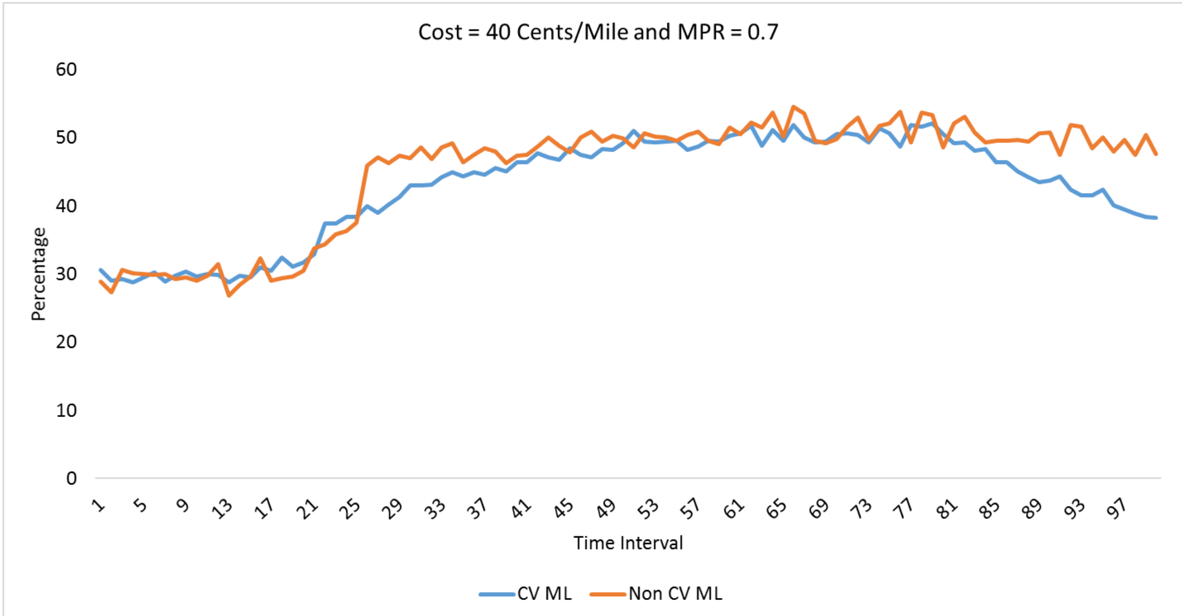

Figure D-17 ML Choice for CVs and Non CVs at 40 Cents and 70% MPR

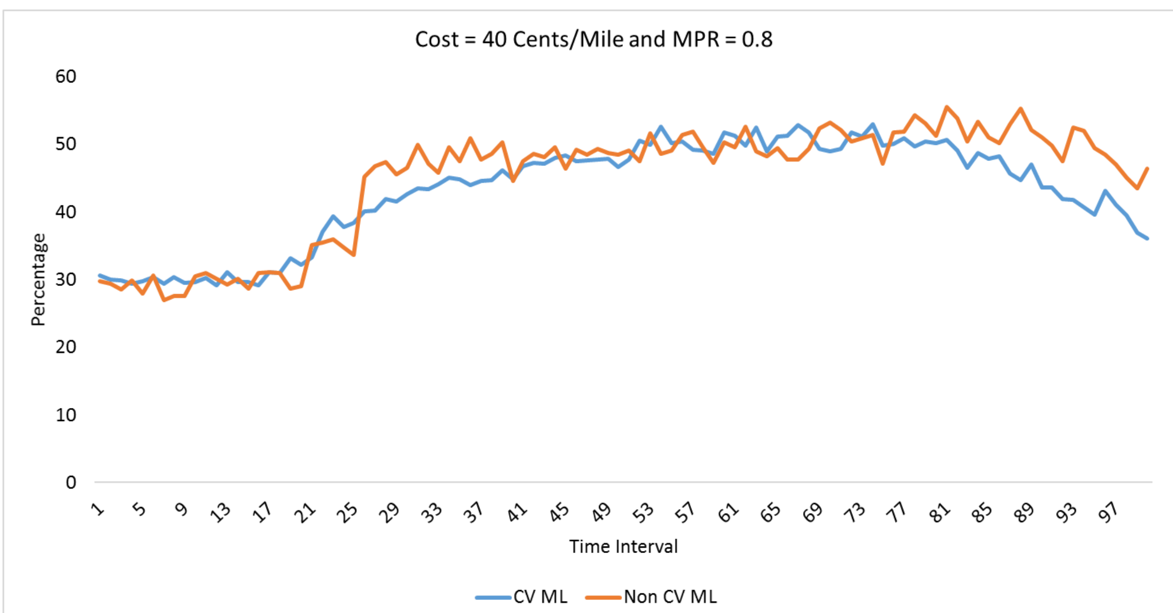

Figure D-18 ML Choice for CVs and Non CVs at 40 Cents and 80% MPR

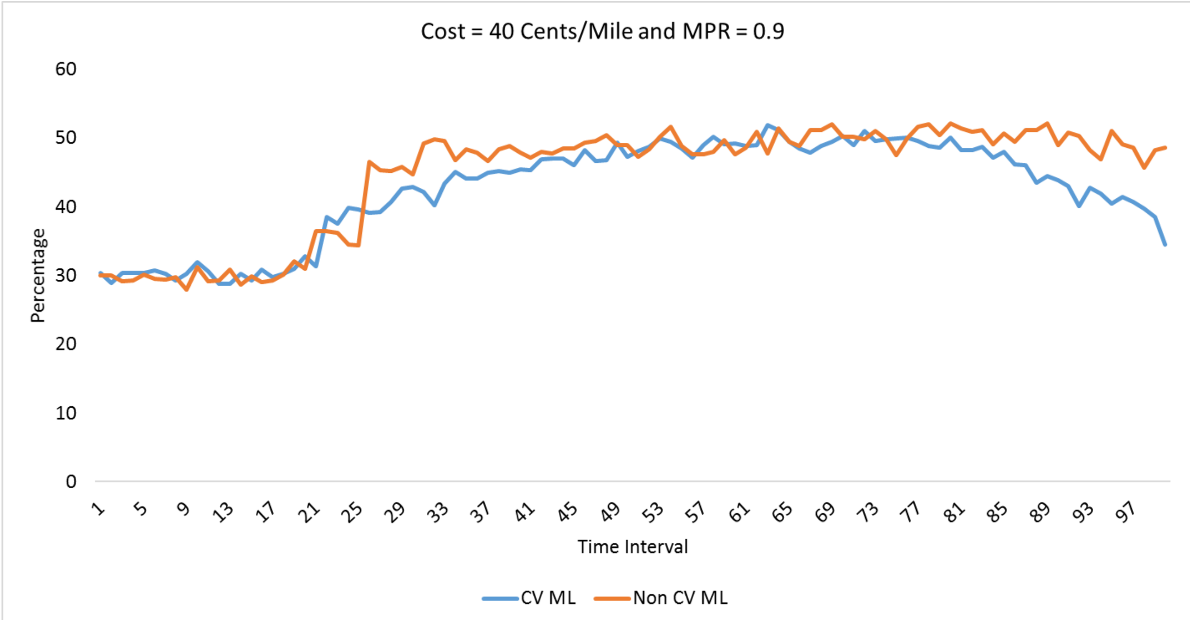

Figure D-19 ML Choice for CVs and Non CVs at 40 Cents and 90% MPR

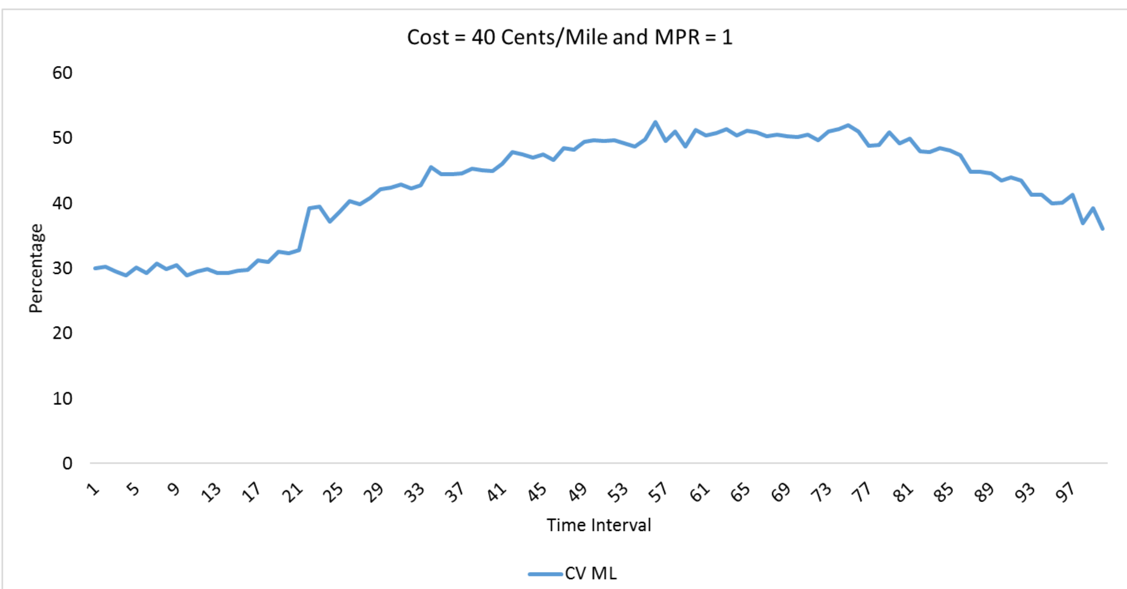

Figure D-20 ML Choice for CVs and Non CVs at 40 Cents and 100% MPR

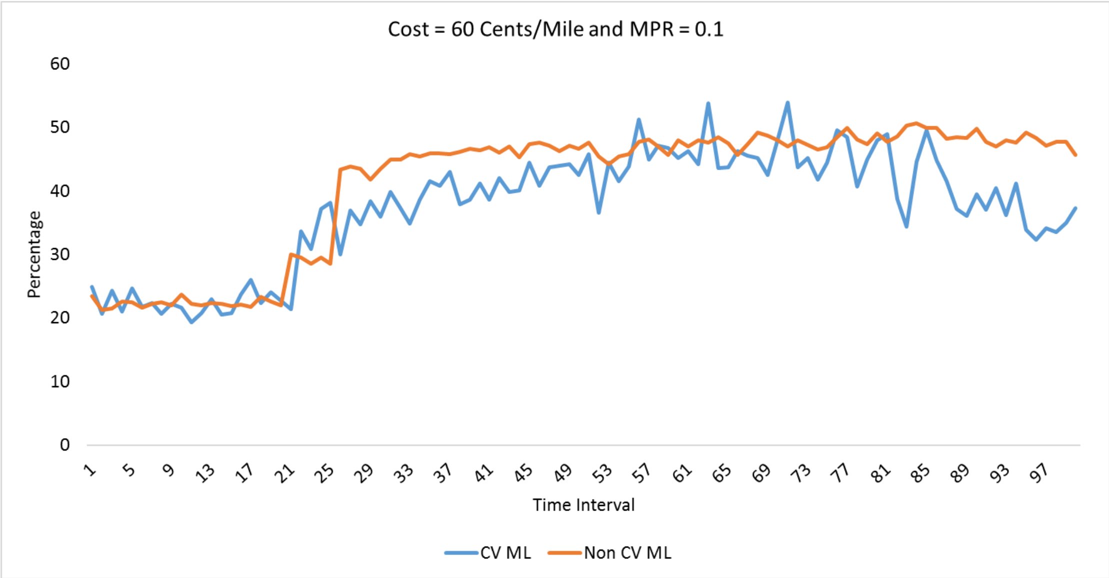

Figure D-21 ML Choice for CVs and Non CVs at 60 Cents and 10% MPR

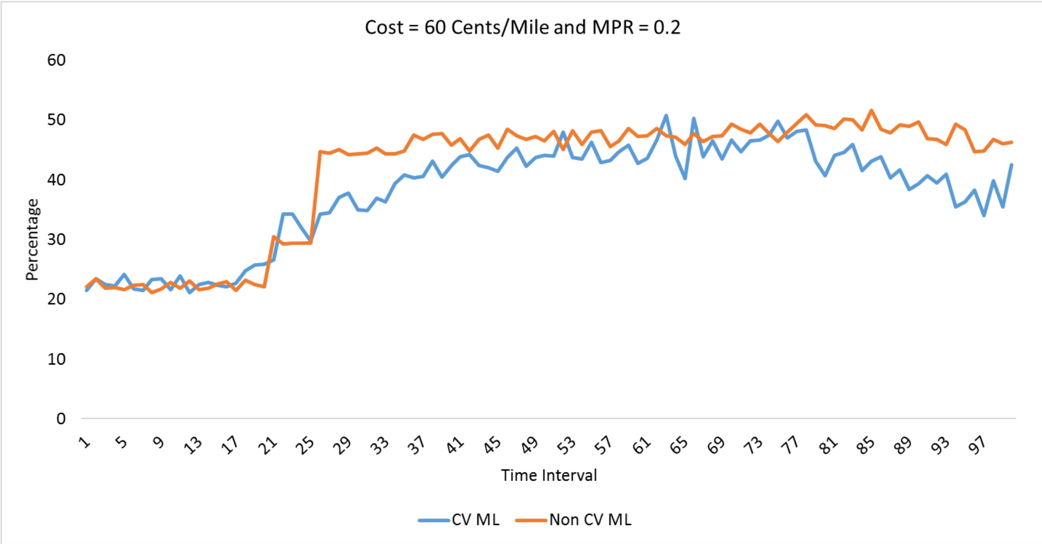

Figure D-22 ML Choice for CVs and Non CVs at 60 Cents and 20% MPR

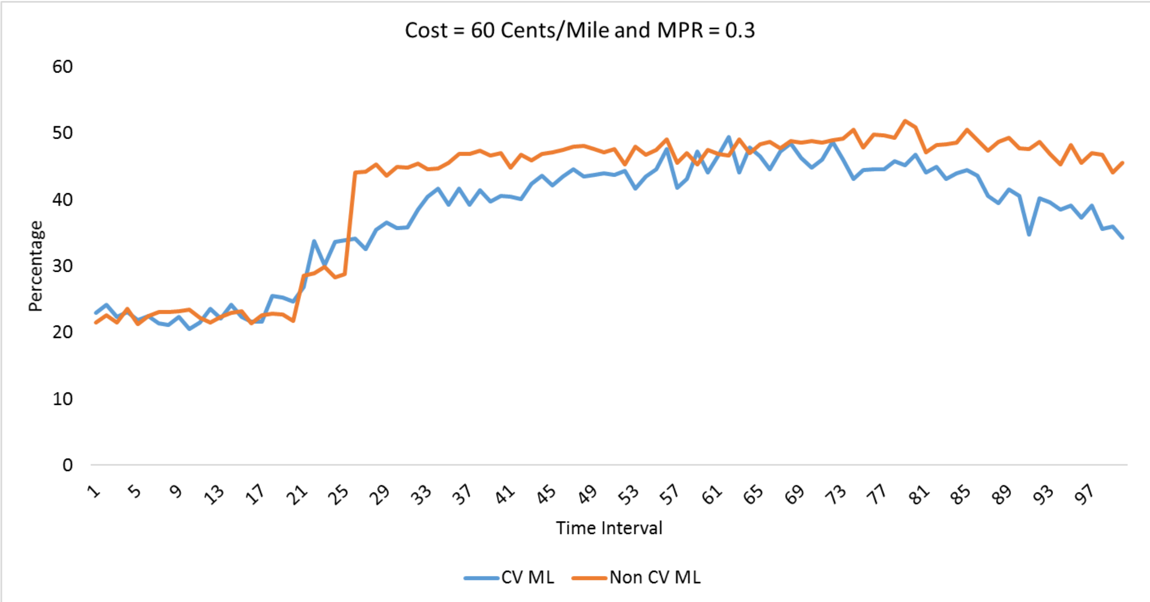

Figure D-23 ML Choice for CVs and Non CVs at 60 Cents and 30% MPR

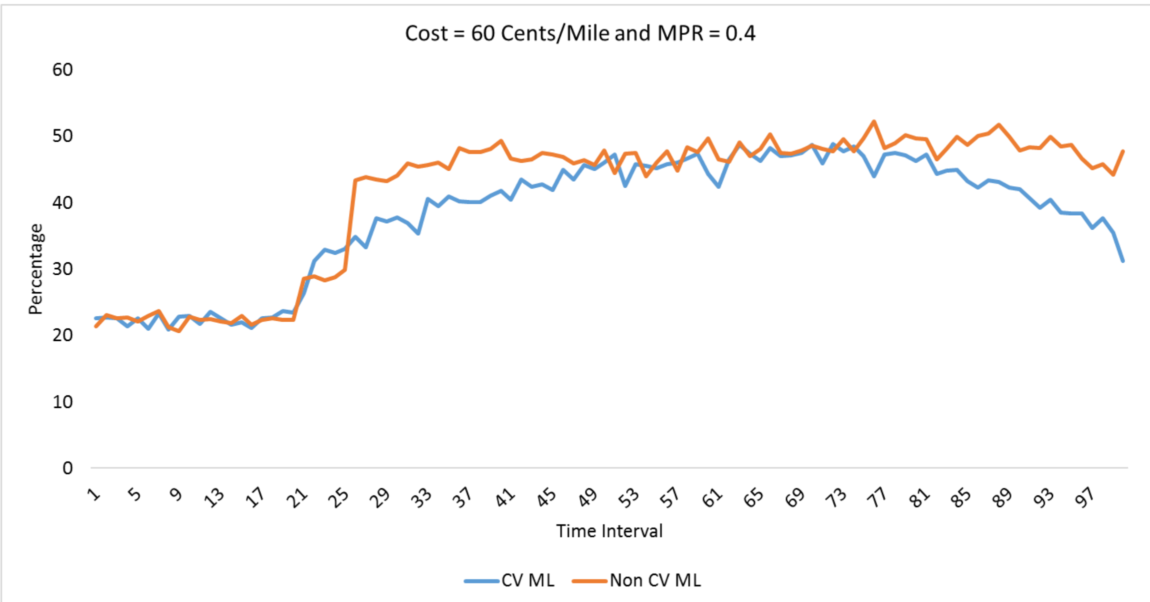

Figure D-24 ML Choice for CVs and Non CVs at 60 Cents and 40% MPR

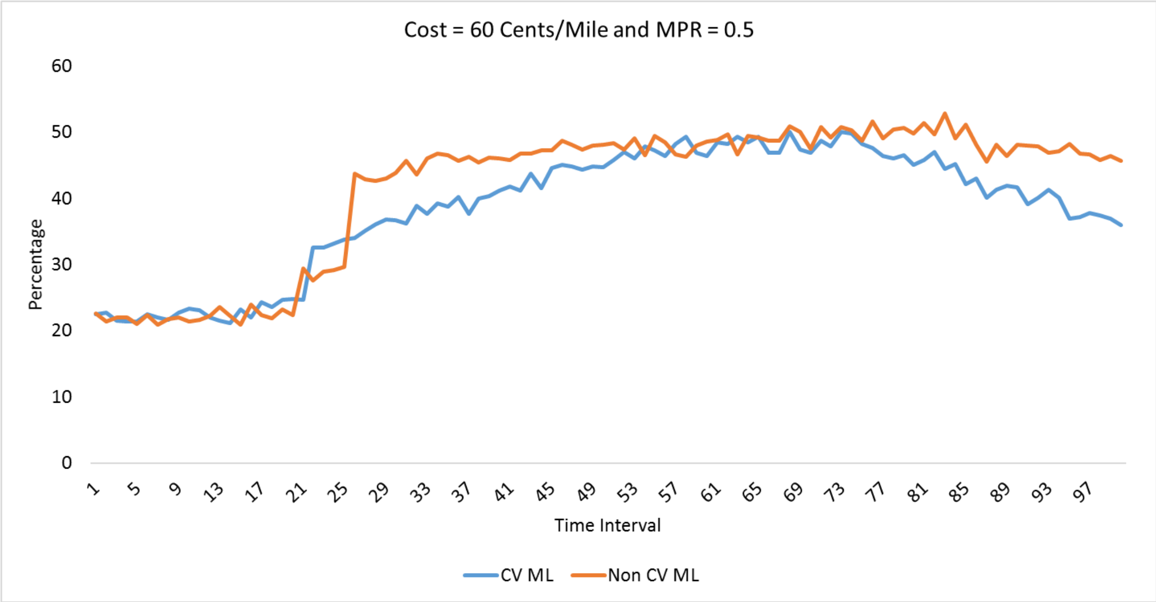

Figure D-25 ML Choice for CVs and Non CVs at 60 Cents and 50% MPR

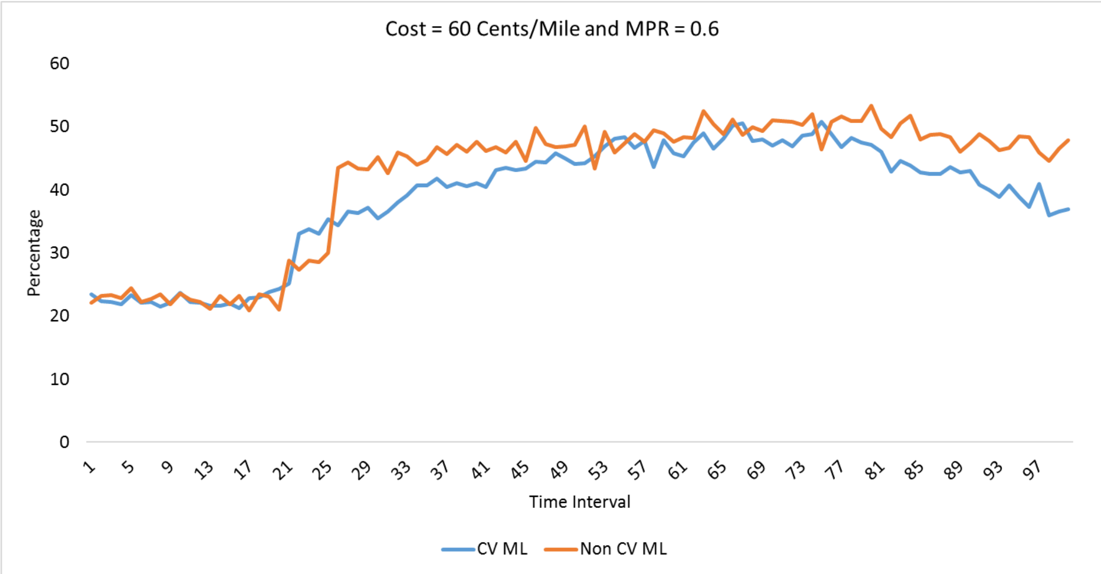

Figure D-26 ML Choice for CVs and Non CVs at 60 Cents and 60% MPR

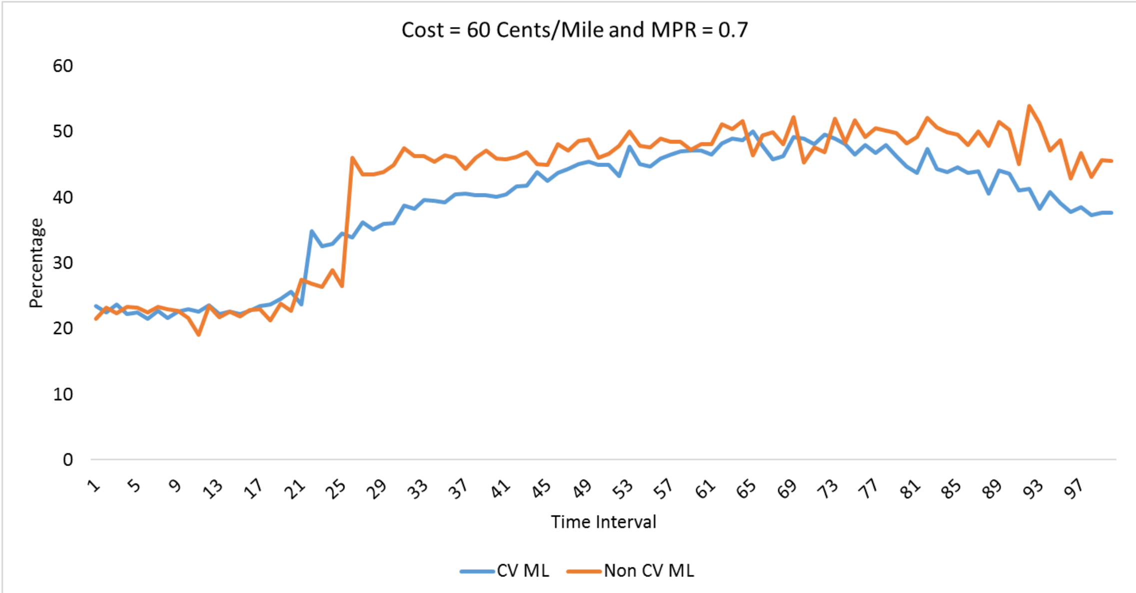

Figure D-27 ML Choice for CVs and Non CVs at 60 Cents and 70% MPR

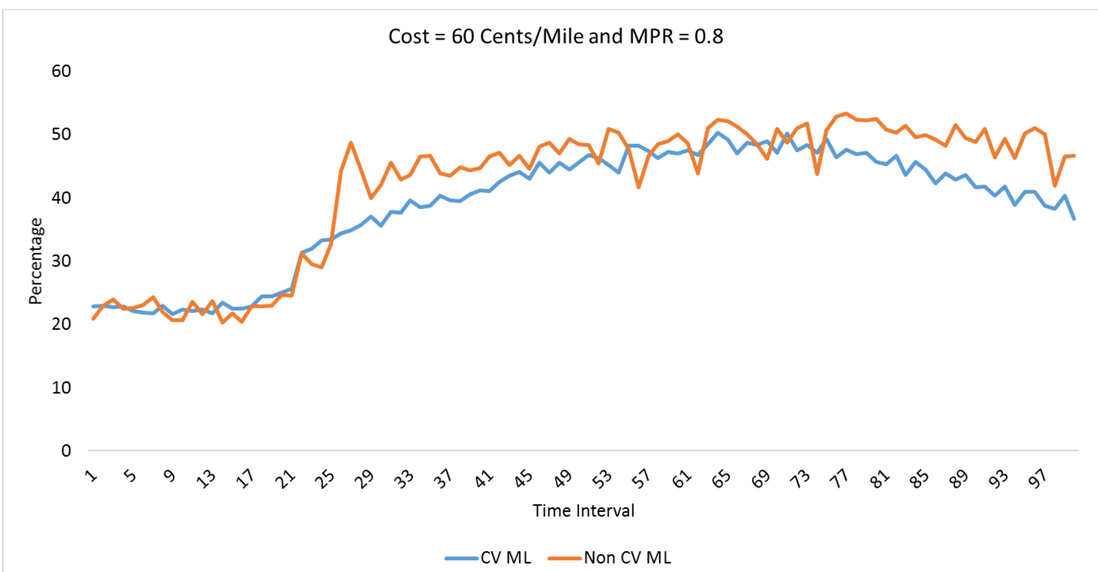

Figure D-28 ML Choice for CVs and Non CVs at 60 Cents and 80% MPR

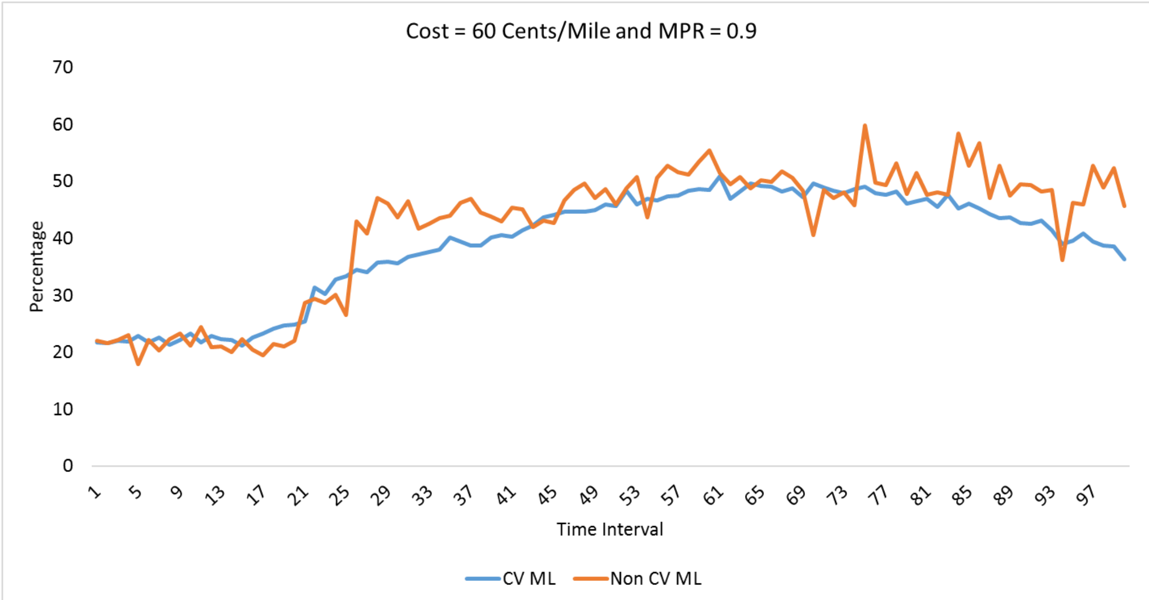

Figure D-29 ML Choice for CVs and Non CVs at 60 Cents and 90% MPR

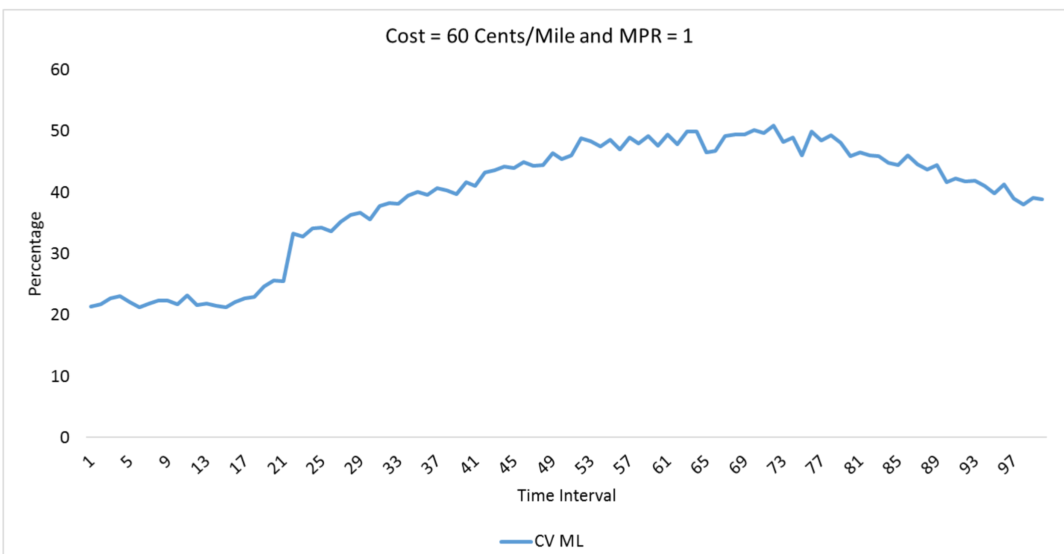

Figure D-30 ML Choice for CVs and Non CVs at 60 Cents and 100% MPR

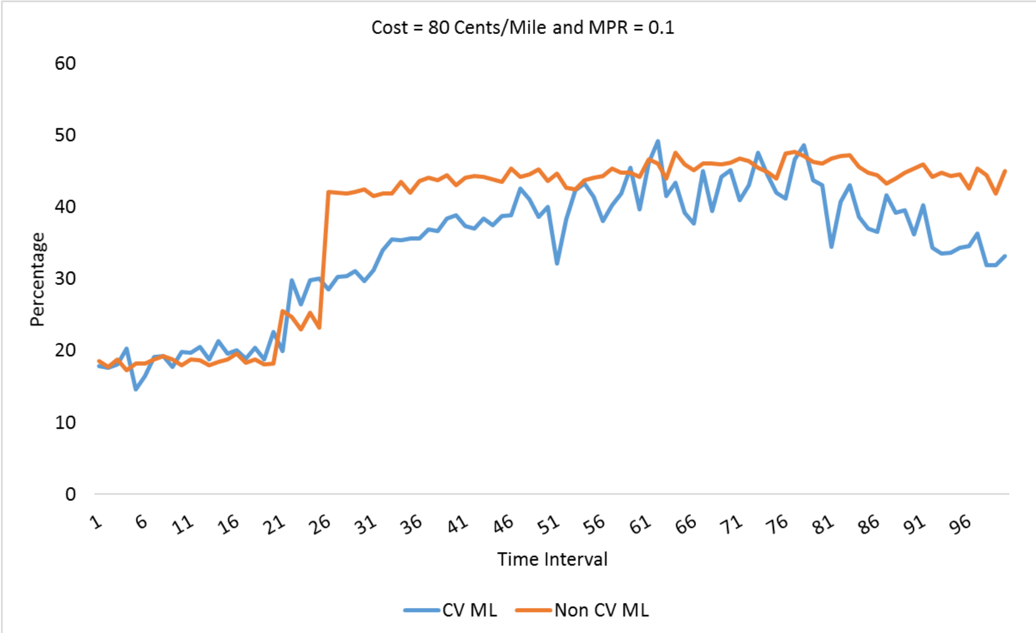

Figure D-31 ML Choice for CVs and Non CVs at 80 Cents and 10% MPR

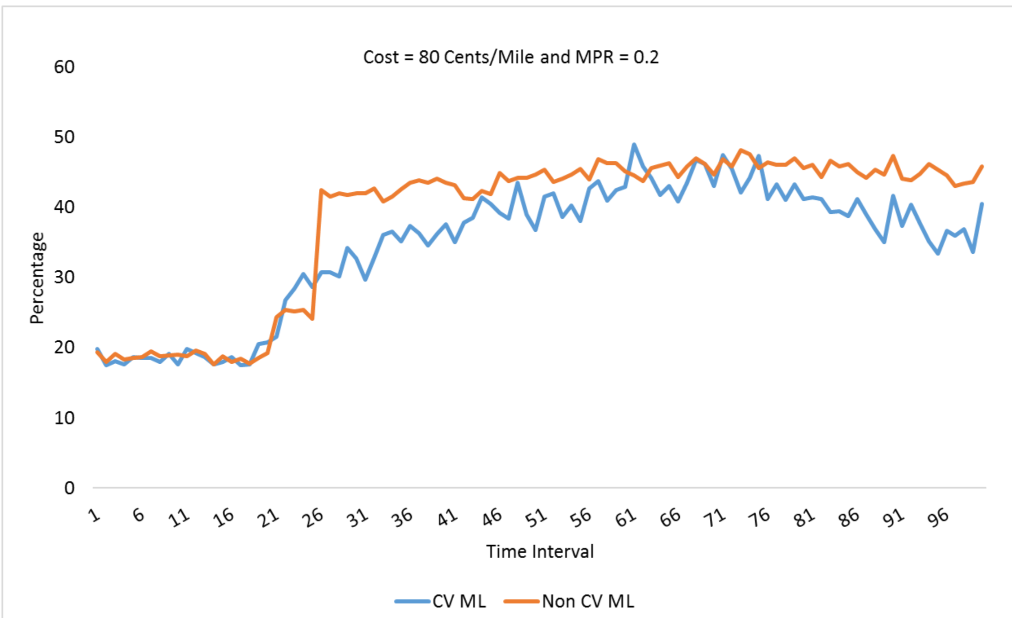

Figure D-32 ML Choice for CVs and Non CVs at 80 Cents and 20% MPR

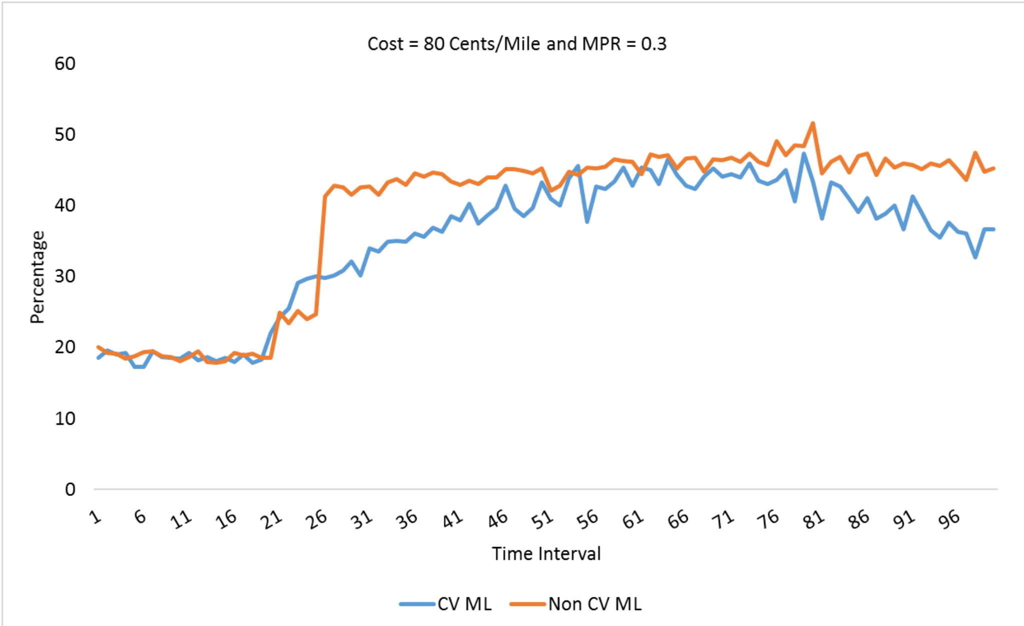

Figure D-33 ML Choice for CVs and Non CVs at 80 Cents and 30% MPR

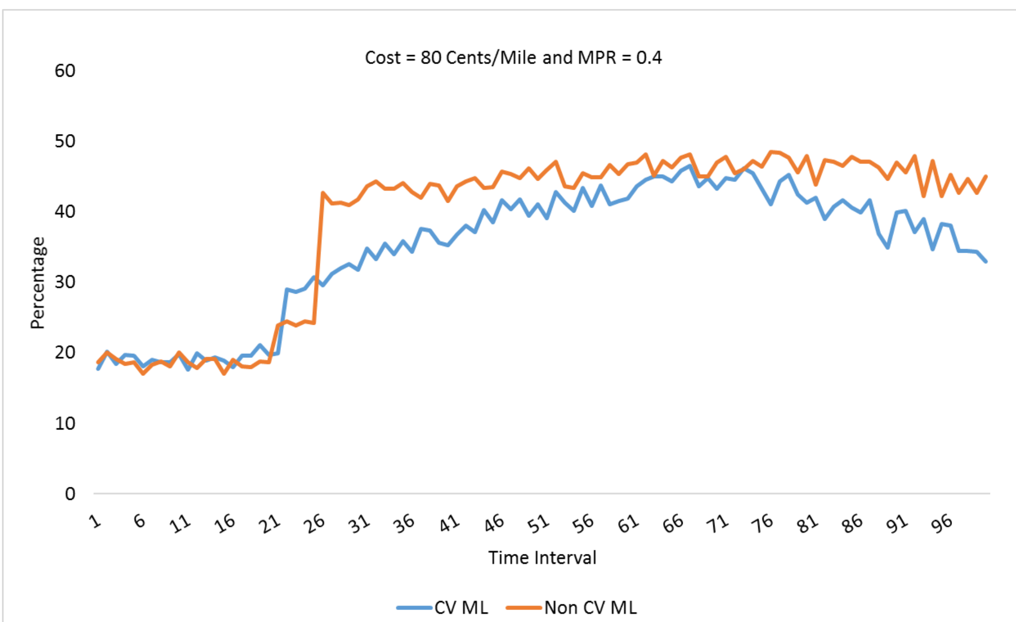

Figure D-34 ML Choice for CVs and Non CVs at 80 Cents and 40% MPR

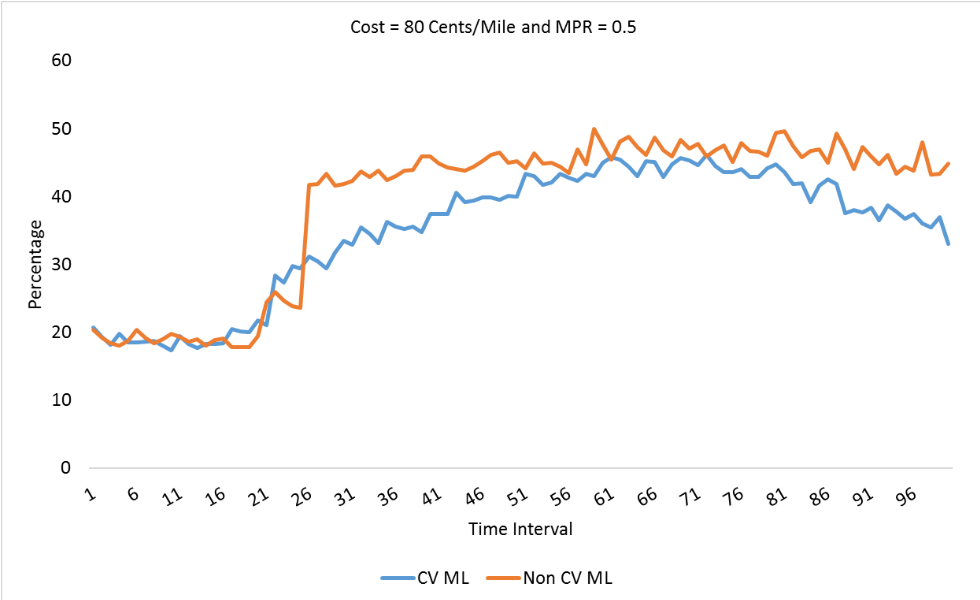

Figure D-35 ML Choice for CVs and Non CVs at 80 Cents and 50% MPR

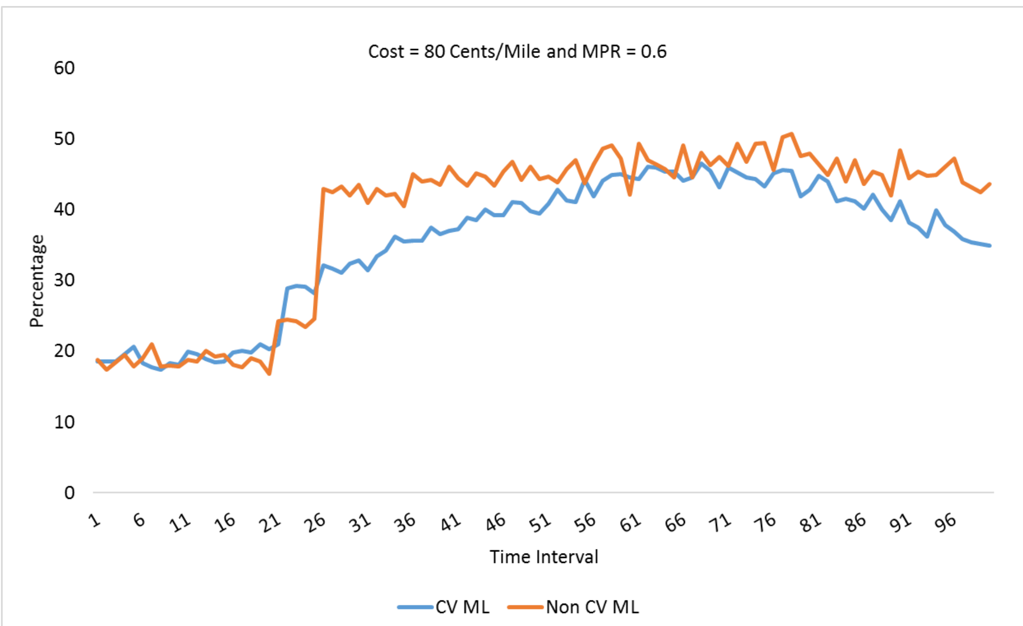

Figure D-36 ML Choice for CVs and Non CVs at 80 Cents and 60% MPR

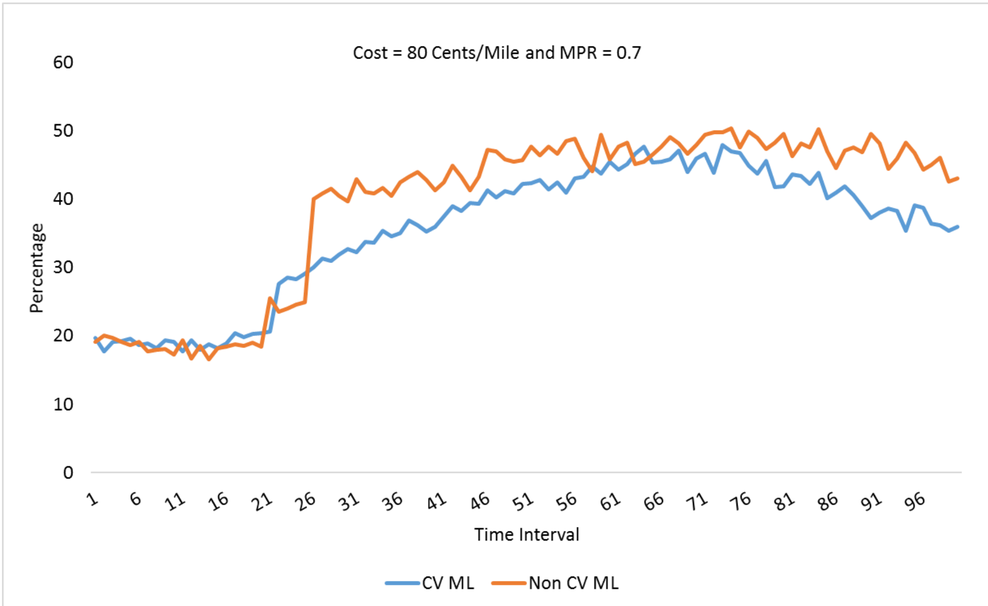

Figure D-37 ML Choice for CVs and Non CVs at 80 Cents and 70% MPR

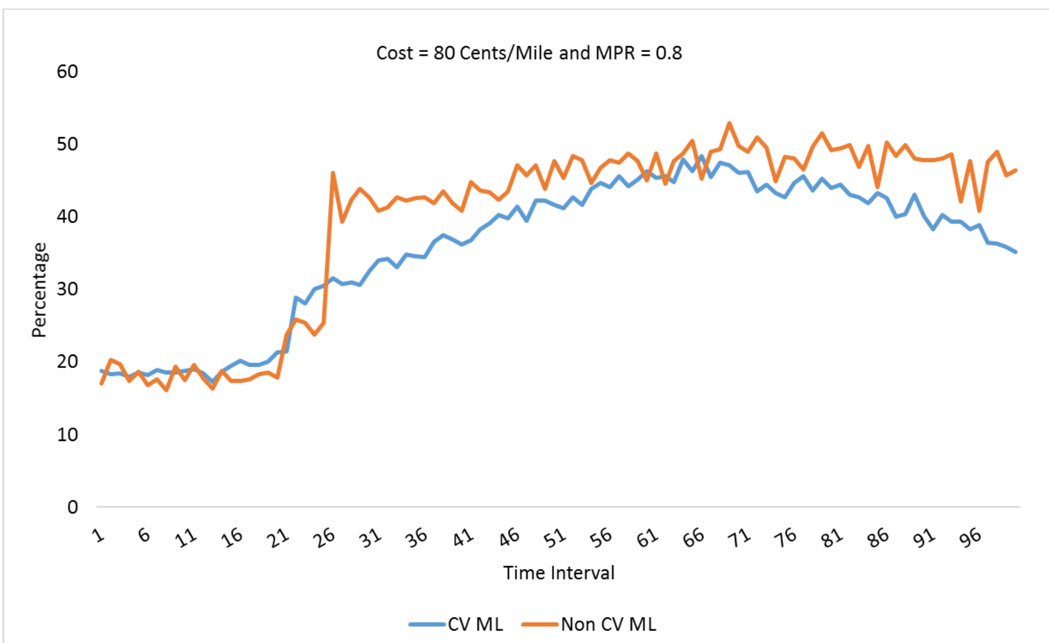

Figure D-38 ML Choice for CVs and Non CVs at 80 Cents and 80% MPR

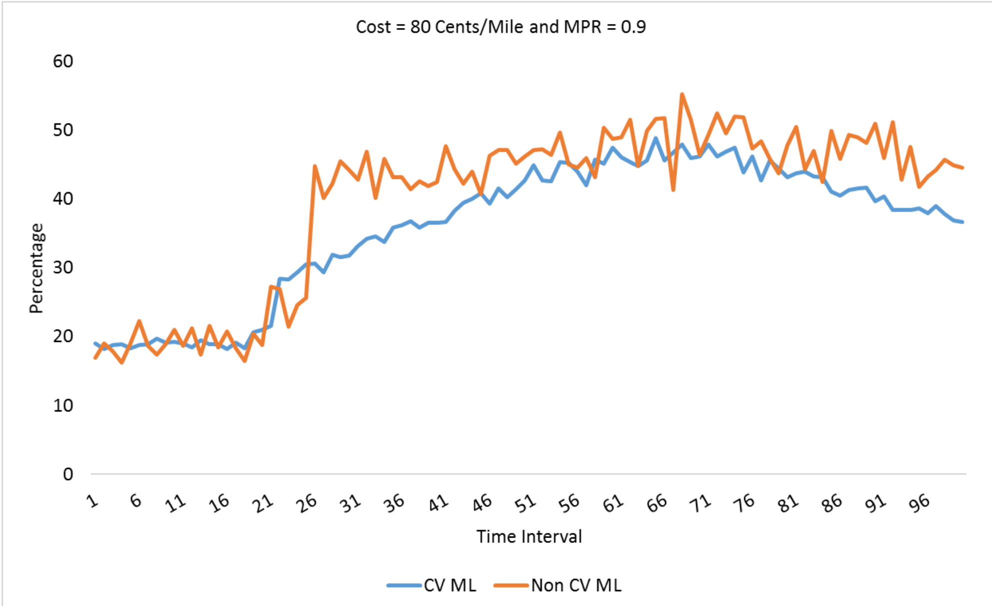

Figure D-39 ML Choice for CVs and Non CVs at 80 Cents and 90% MPR

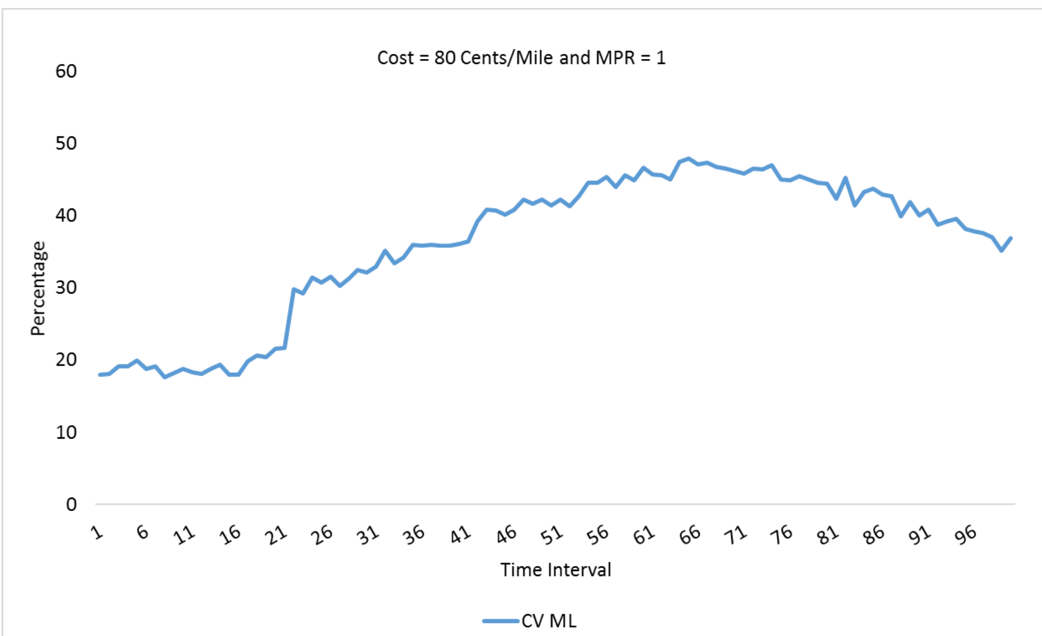

Figure D-40 ML Choice for CVs and Non CVs at 80 Cents and 100% MPR

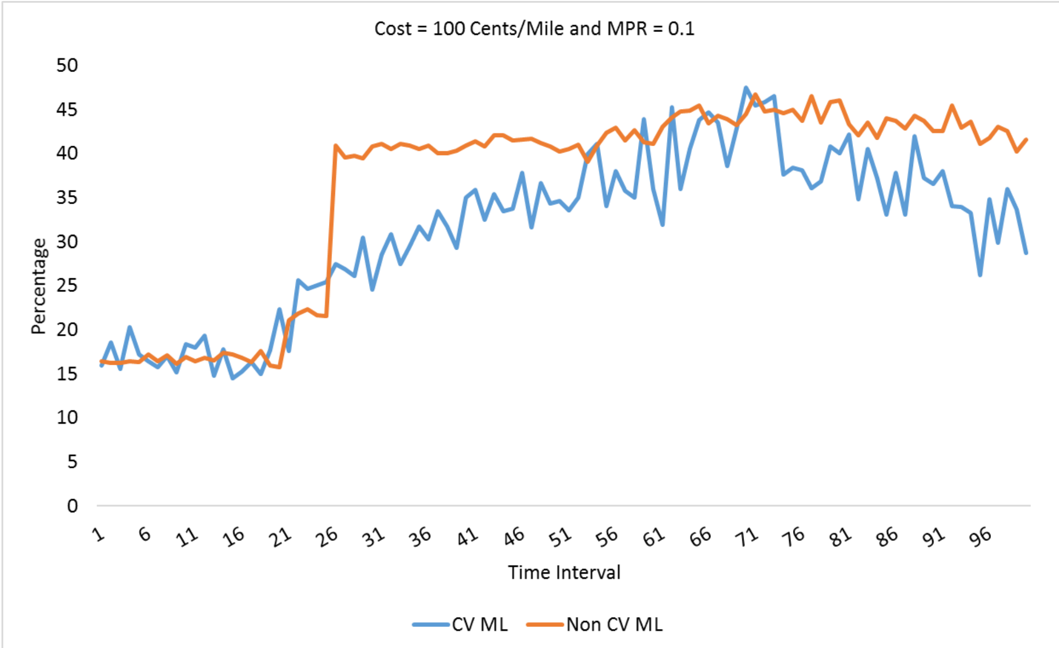

Figure D-41 ML Choice for CVs and Non CVs at 100 Cents and 10% MPR

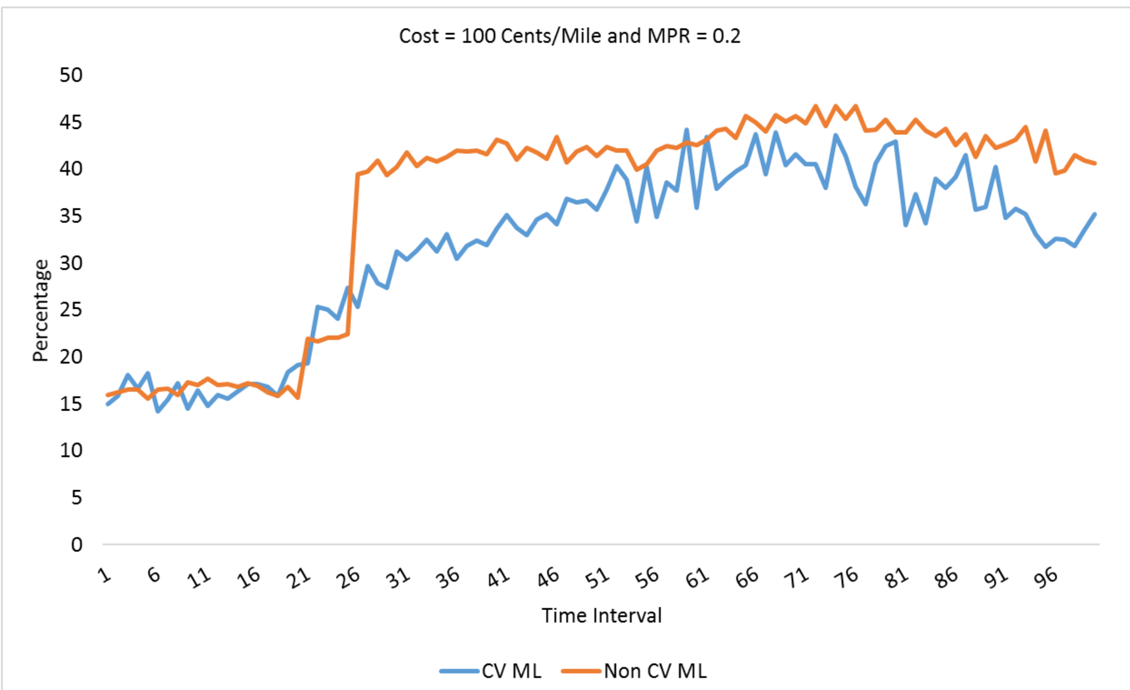

Figure D-42 ML Choice for CVs and Non CVs at 100 Cents and 20% MPR

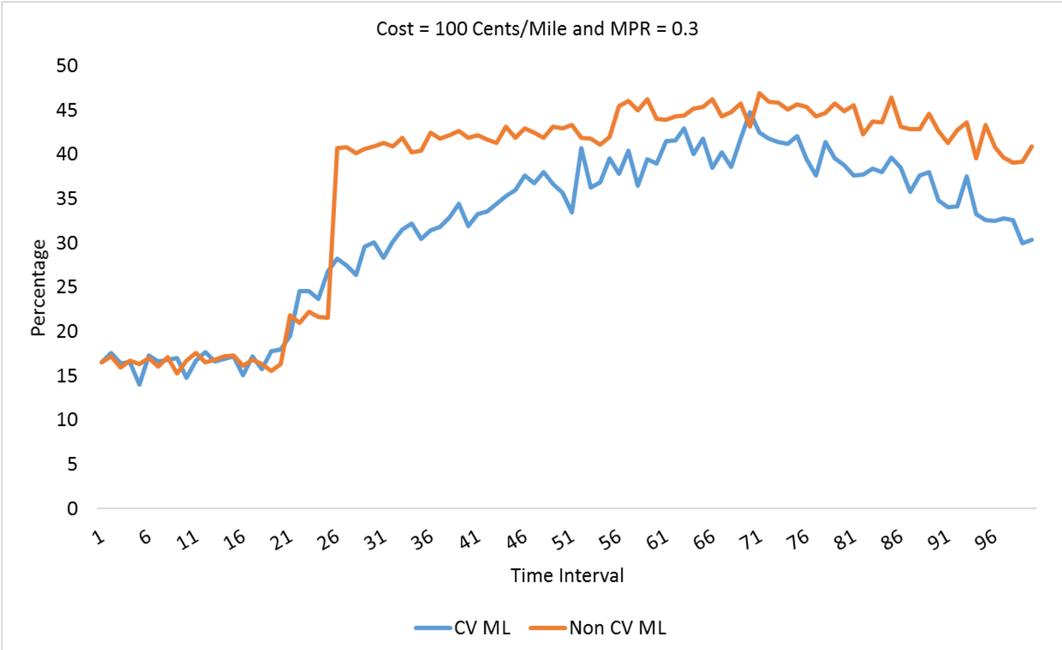

Figure D-43 ML Choice for CVs and Non CVs at 100 Cents and 30% MPR

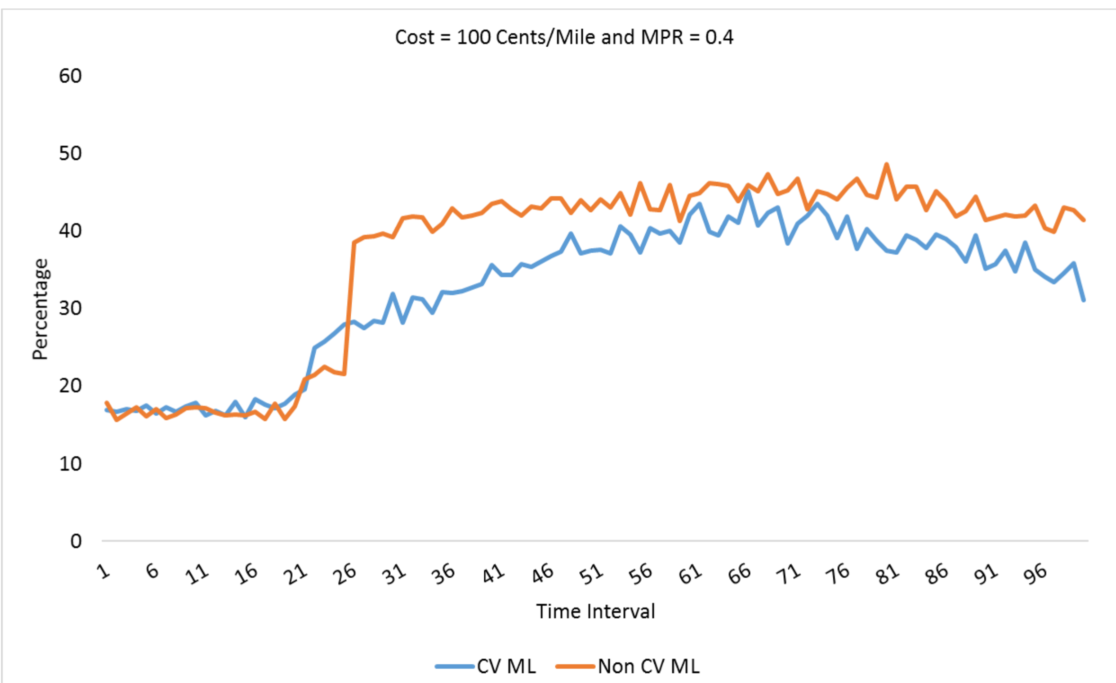

Figure D-44 ML Choice for CVs and Non CVs at 100 Cents and 40% MPR

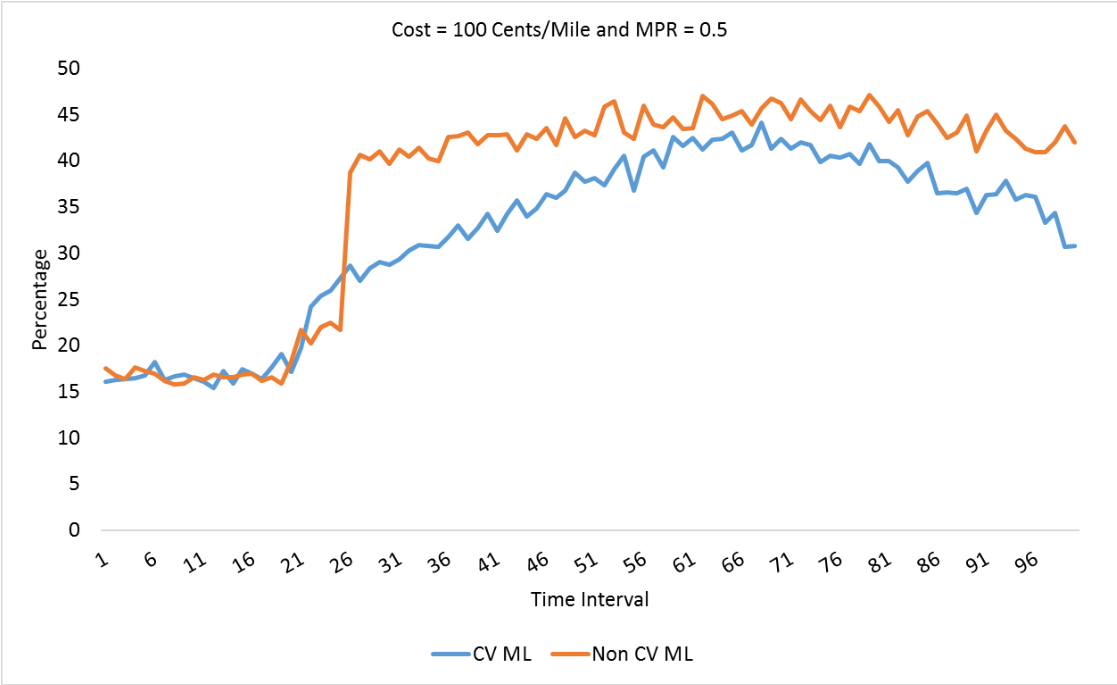

Figure D-45 ML Choice for CVs and Non CVs at 100 Cents and 50% MPR

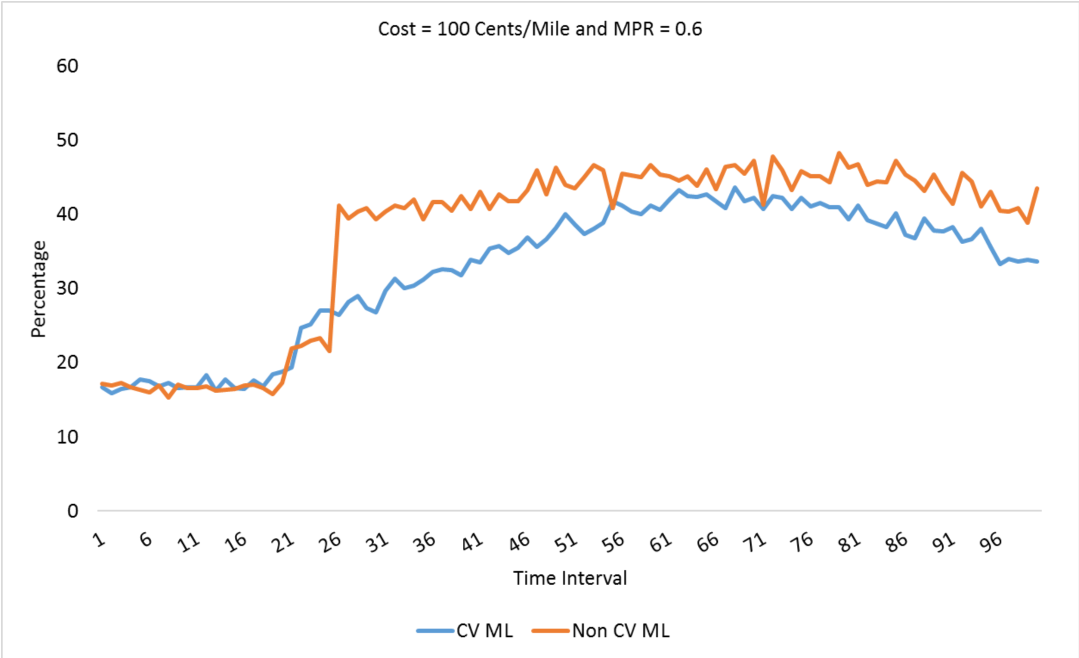

Figure D-46 ML Choice for CVs and Non CVs at 100 Cents and 60% MPR

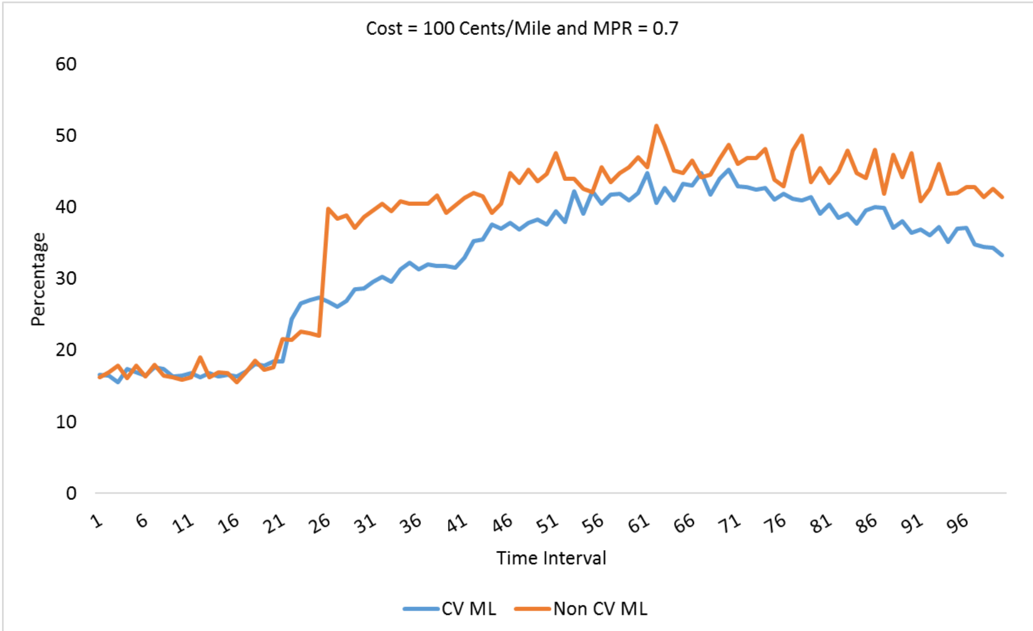

Figure D-47 ML Choice for CVs and Non CVs at 100 Cents and 70% MPR

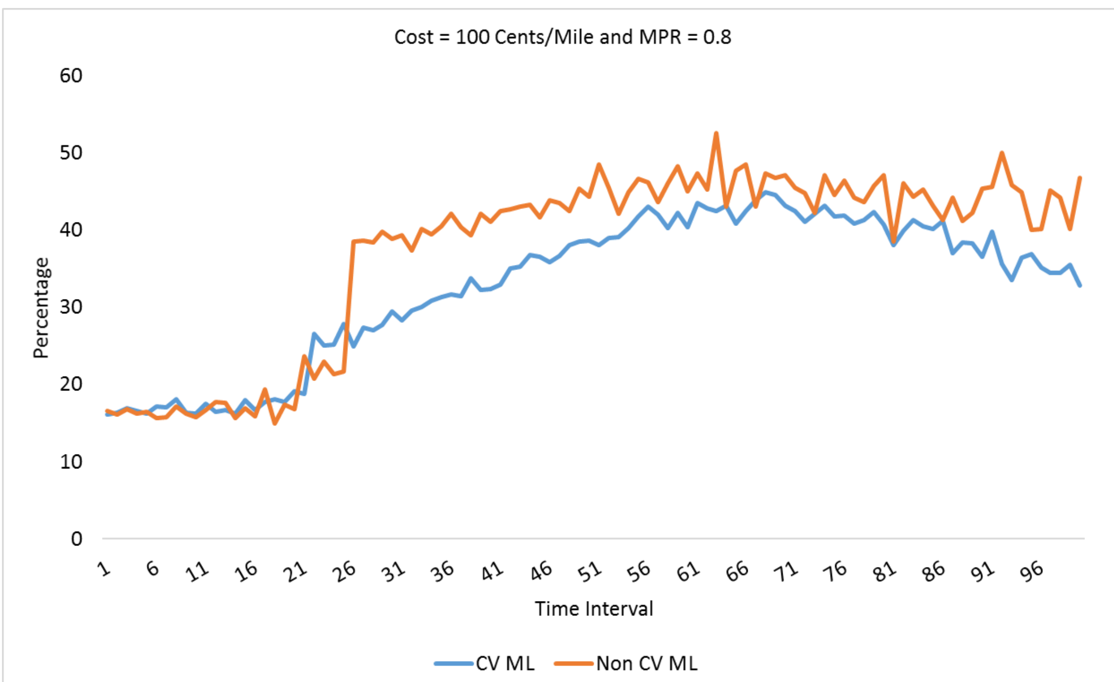

Figure D-48 ML Choice for CVs and Non CVs at 100 Cents and 80% MPR

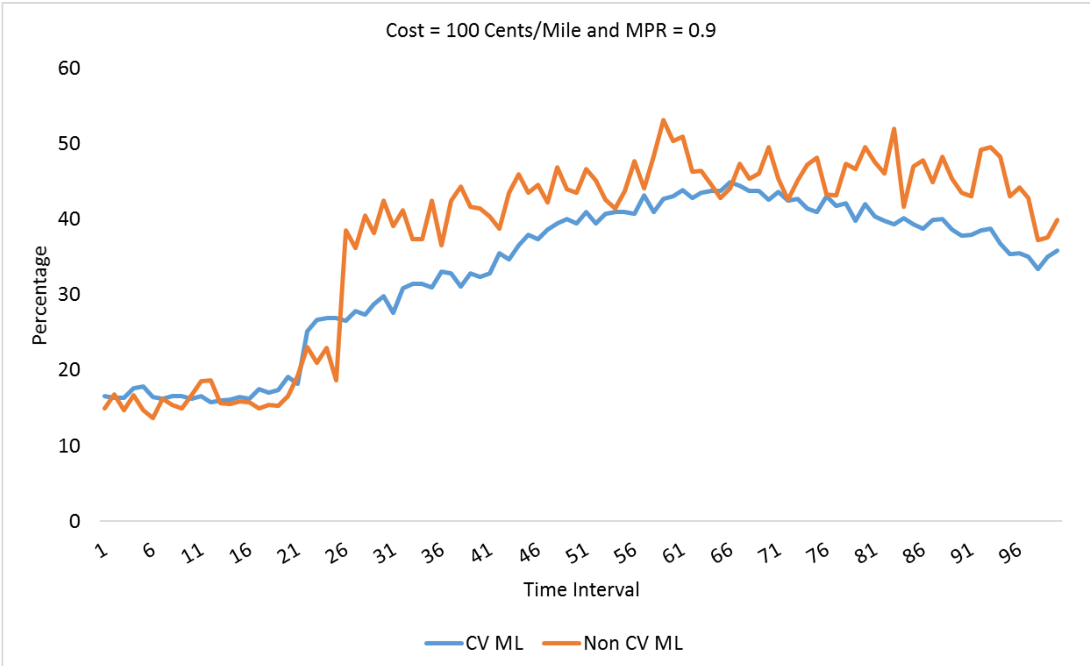

Figure D-49 ML Choice for CVs and Non CVs at 100 Cents and 90% MPR

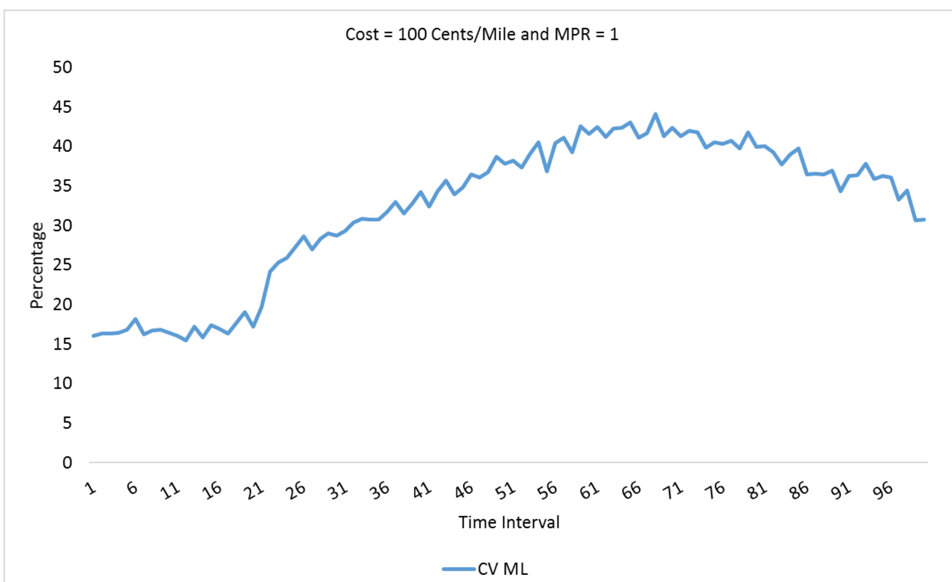

Figure D-50 ML Choice for CVs and Non CVs at 100 Cents and 100% MPR