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An End To End V.M.T Framework With Controlled V.M.T Tax Rate Using Optimal Feedback Control Technique

Pratik Verma

University of Nevada, Las Vegas

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AN END TO END V.M.T FRAMEWORK WITH CONTROLLED V.M.T TAX
RATE USING OPTIMAL FEEDBACK CONTROLS TECHNIQUE

by

PRATIK VERMA

Bachelor of Technology
Indian Institute of Technology(Banaras Hindu University), Varanasi, India
2008

A thesis submitted in partial fulfillment
of the requirements for the

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**Department of Electrical and Computer Engineering
Howard R. Hughes College of Engineering
The Graduate College**

**University of Nevada, Las Vegas
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Master of Science in Electrical Engineering

Department of Electrical and Computer Engineering

Pushkin Kachroo, Ph.D., Committee Chair

Yingtao Jiang, Ph.D., Committee Member

Emma Regentova, Ph.D., Committee Member

Robyn Raschke, Ph.D., Graduate College Representative

Tom Piechota, Ph.D., Interim Vice President for Research &
Dean of the Graduate College

December 2012

ABSTRACT

An End To End V.M.T Framework With Controlled V.M.T Tax Rate

Using Optimal Feedback Control Technique

by

Pratik Verma

⟨Dr. Pushkin Kachroo⟩, Examination Committee Chair
Professor of Electrical and Computer Engineering
University of Nevada, Las Vegas

Vehicle Mile Travel (VMT) is a study related to available alternatives for the road revenue collection system. As per the demand, the existing Gas/Fuel tax based revenue collection system is not found an appropriate option in the longer run. Due to existing system constraints like: no effective tax process for vehicles based on alternative fuel (e.g. electric vehicles), no effective changes in tax due to economical inflation, and more highway expenditure than generated revenue, an alternative revenue collection mechanism is required. Hence, the objective is to study an alternative option in detail, which can address the gaps between required revenue and generated revenue in existing collection system. In Nevada, Phase1 of the study was completed in 2010, which included: 1) Design of a GPS based mileage fee system, 2) To conduct comprehensive public outreach, identify concerns, educate the public about the shortfalls and limitations of the current fuel tax, 3) Assessment and evaluation of potential

privacy impacts, 4) Analyses of institutional, policy, legislative, and legal aspects, and 5) Developing economic models to assess and recommend equitable VMT fee. As part of this work, the main objective is to study the Vehicle Mile Traveled (VMT) tax based revenue collection system solution over existing gas tax based revenue collection system. Objective also consists of small-scale field test that needs to be conducted with 25 participants to assess the feasibility of the VMT system. Other components of thesis include: identifying the technical details in order to have complete VMT infrastructure, data analysis, qualitative analysis of reviews collected during phase 1 and phase 2 in order to compare the “privacy concern” in both the phases, analyzing the Department of Motor Vehicles (DMV) database to assess the approximate VMT tax rate. An optimal control model has also been developed to control rate per mile to optimize the generated revenue based on VMT tax.

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CHAPTER 1

FRAMEWORK

1.1 Summary

This chapter discusses the over all problem statement and solution to each problem described in various chapters. It also provides a high level skeleton of the work presented in this document. This would help reader to have the better understanding of the bigger picture of the overall framework.

1.2 Problem Statement

Various studies have shown that the existing road revenue system based on gas tax is not sufficient to fulfill the needs to the current road infrastructure [4]. Due to various reasons such as political influence, gas tax is more or less constant since the last decade, which has resulted in less revenue generation. To address this gap between generated revenue and required revenue, a new tax collection system VMT (Vehicle Miles Traveled) is proposed. In this mechanism the tax charged is based on the number of miles driven on the road and not on the amount of fuel consumed. VMT can provide a transparent system directly proportional to caused road damage. VMT is insensitive to the factors having potential loss in revenue such as fuel effi-

ciency.

1.2.1 Key Factors in VMT Implementation

There are many key factors which need to be considered while designing the infrastructure for VMT. The proposed system must be technically as robust as the existing system and should have public acceptance. The Following key factors must be answered in order to have VMT implementation:

1. Advantages and limitations of VMT over the existing revenue system.
2. Other studies and their conclusions in terms of VMT.
3. Required Technical Infrastructure and Field Test to ensure feasibility.
4. Quantitative, Qualitative and Historical Data Analysis.
5. Mathematical modeling of VMT tax rate.
6. Conclusion in terms of revenue improvement with the proposed Model of VMT.

1.3 Framework

All of the the above mentioned key factors are studied in various chapters of this document. Below is the brief description of each chapter addressing the key factors:

Advantages and limitations of VMT over existing revenue system

Chapter 2: Introduction describes the problem statement in detail. It provides the advantages and limitations of both the proposed (VMT based) and old (Gas Tax based) tax systems. It provides historic data and factors regarding existing gas tax based revenue system. Nevada's contribution in the area of VMT study has also been described in the chapter.

Studies and their conclusions in terms of VMT

After justifying the requirement of a new tax collection system for road revenue, **Chapter 3: Literature Review** describes the major work done in the recent years in area of VMT. It describes the technology used/proposed by other states in order to achieve objectives of their corresponding VMT study. Major concerns/issues identified during these studies are also listed in this chapter.

Required Technical Infrastructure and Field Test to ensure feasibility

Considering various conclusions drawn in the previous studies described in the previous chapter, **Chapter 4: Field Test Setup** of this document describes the complete hardware and software solution used in field test. Field test was done with 25 participants. It describes the pro's and con's of one technical solution vs other. Algorithms used in order to design the software solutions are also presented in this chapter. It describes the design which incorporates major public concerns of "primacy". In conclusion it assures the technical feasibility of VMT infrastructure.

Quantitative, Qualitative and Historical Data Analysis

Once the feasibility of technical VMT infrastructure is assured in previous chapter, **Chapter 5: Data Analysis** is divided into three major categories of analysis. In quantitative analysis data collected during the field test is analyzed. While in qualitative analysis conclusions have been drawn by analysis of reviews/comments collected from participants in phase 1 and phase 2 of VMT study in Nevada. DMV data of past various years are analyzed in order to identify approximate VMT tax rate based on total number of miles driven and estimated fuel consumed. In conclusion it shows the significant drop in major public concern of "privacy" during phase 1 and phase 2. Payment plan to collect approximate VMT tax is proposed in this chapter.

Mathematical modeling of VMT tax rate

Based on feasibility and data analysis in previous chapters, the question arises What VMT tax rate per mile should be charged? **Chapter 6: Model for Optimal Control** proposes a model based on optimal control feedback theory in order to have optimum balance between VMT tax rate and generated revenue based on the this rate. Using technique of optimal control, final HJB (Hamilton-Jacobi-Bellman) is derived. We analyze the steady state solution in this chapter. We propose the rate in term of VMT in order to have maximum revenue.

Conclusion in terms of revenue improvement with the proposed Model of VMT

Once we have the steady solution of VMT tax rate r in terms of VMT from previous chapter, we use the value of r in VMT dynamics order to steady VMT behavior.

Chapter 7: Results and Conclusion describes the various methods to estimate r based on past data. Yearly VMT data for Nevada, available in reports from NDOT and monthly data of VMT from FHWA (Federal Highway Administration) are used to predict r (VMT tax rate dollar per mile) for the previous years. Based on the estimated r and actual VMT, revenue for previous years is estimated. In conclusion estimated revenue of this technique is compared with the estimated required revenue for improving the existing infrastructure of other studies.

CHAPTER 2

INTRODUCTION

2.1 Summary

This chapter discusses the advantages and limitations of the current road revenue system, which is based on fuel taxes. This chapter also discusses the need for an alternative road revenue system and gives an overview of the Vehicle Miles Traveled (VMT) study. The advantages and transparency of VMT tax system over current fuel-tax-based revenue system are described. Finally, the contribution of the State of Nevada in the VMT study is highlighted.

2.2 Introduction

The current road revenue system is based purely upon the fuel tax. Due to various reasons, such as political influence, the fuel tax has not increased to meet the demand to maintain the existing highway infrastructure. According to economic studies and projections, revenue generated by current fuel-tax-based system is neither sufficient to improve the transportation infrastructure nor to maintain the existing one. Therefore, various alternatives were evaluated to address the problems with the existing road revenue system. In addition, new alternatives to address such major traffic issues as

congestion are explored. In particular, an alternative known as Vehicle Miles Traveled (VMT) would be an indirect approach to reduce congestion on roads in order to have better flow of traffic. VMT helps to maximize the usage of existing system and allow an even distribution of traffic.

2.3 Need for Alternatives

It is becoming challenging to maintain and develop the highway infrastructure of United States with the currently generated road revenue. Traditionally, a major portion of highway development funds come from revenue generated by the fuel tax. However, the past trend regarding the fuel tax demonstrates that tax has remained more or less the same from 1994 until 2004 [1]. Any revenue growth from the fuel tax has been impacted due to increase in the percentage of alternative-fuel vehicles, such as electric vehicles. In addition, the increase in the total number of vehicles on the road has caused more road damage, which adds to the cost. a. In a report by the American Association of State Highway and Transportation Officials (AASHTO, 2007d), information was presented on future revenue requirements for the highway and transportation infrastructures in the U.S. for the years from 2005 to 2021 [4]. This report analyzed and forecasted funding requirements to maintain existing systems and to improve the infrastructures, based on future needs. These estimates are based on an assumption that the historic split between the federal and state/local share of capital costs for surface transportation is maintained. Since the analysis horizon for this study is for the year 2025, the values obtained from the American Association

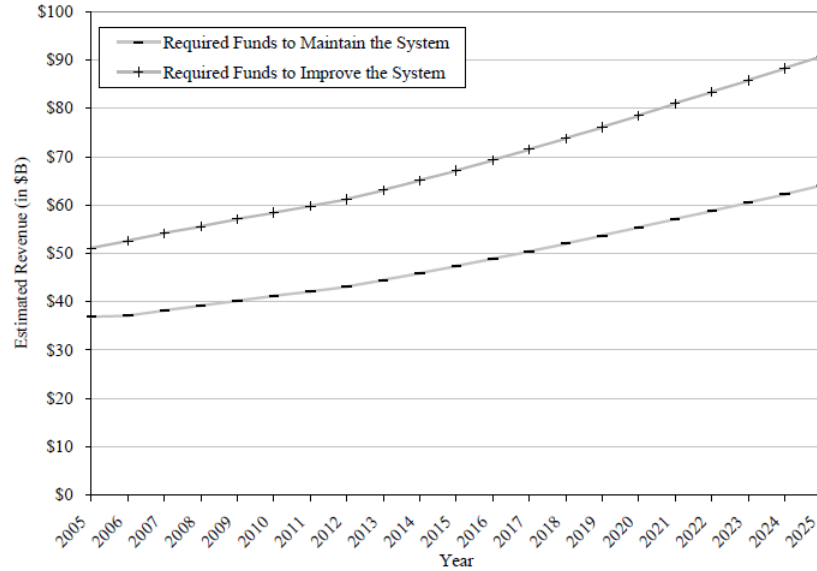


Figure 2.1: Funding required from fuel taxes for future transportation needs (Source: Policy for highway financing: Gasoline taxes and other Alternatives, Vinod Vasudevan, 2008)

of State Highway and Transportation Officials (AASHTO) are projected to the year 2025 [4].

2.4 Current Road Revenue System

The current road revenue system is based upon the tax related to the consumption of gas. In this system, the amount of tax one pays is directly proportional to the amount of gas consumed by the vehicle being used. This system is completely insensitive towards fuel efficiency of the vehicle. Vehicles having high fuel efficiencies consume less gas, resulting in less tax collected in contrast to vehicles with lower fuel efficiencies; however, but road damage and infrastructure usage is same for both types

of vehicles.

2.5 Advantages to the Existing System

The current system has been proven robust enough for working in the past, and significant development in transportation has taken place due to the revenue collected by this system. There are some very useful advantages of the existing road revenue system. Some of these are:

1. **Low Administration cost:** Because the fuel tax is collected directly by wholesale sellers and not by individual consumers, the system involves less administrative costs.
2. **Less Fraud Potential:** There is no revenue loss in collection of fuel taxes due to corruption. A certain type of colored dye is added to the fuel to differentiate between fuel that is taxed and not taxed.
3. **Reliability:** The current system has been running smoothly for decades.
4. **Transparent to the Public:** As this tax is directly proportional to the individuals fuel consumption. It is a system with high transparency to the public.

2.6 Problems in the Current System

There are many such issues that are not handled properly in the existing system. Regarding the impact of inflation, the existing fuel tax system is more or less insensitive to inflation. During the last few decades, the fuel tax has not increased

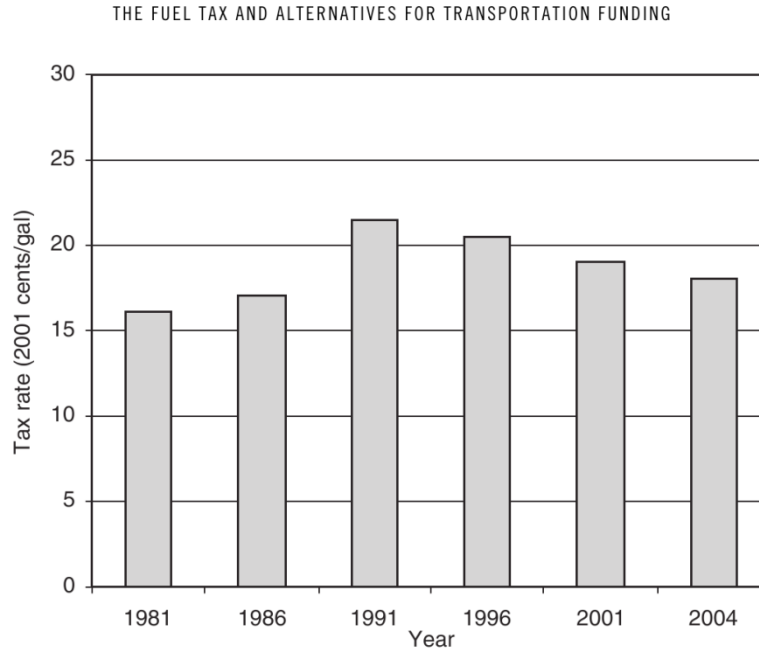


Figure 2.2: Sales-weighted constant-dollar average state gasoline tax rate (Source: FHWA 1987; FHWA 1997; FHWA 2005a) [1]

sufficiently to address the gaps between generated revenue and required revenue. Figure 2.2 shows the variation in the fuel tax rate (cents/gal) from 1981 to 2004 [1], and Figure 2.3 shows the fuel price trend from Nov-1994 to Nov 2011 [2]. Fuel prices have changed over these past years while fuel tax has not changed over this period of time. As can be seen from this figure 2.3, the federal gas tax has not been increased since 1993. All other taxes for example, income tax, sales tax, and property tax all are regularly updated with inflation.

Figure 2.3 shows the fuel price trend from Nov-1994 to Nov 2011

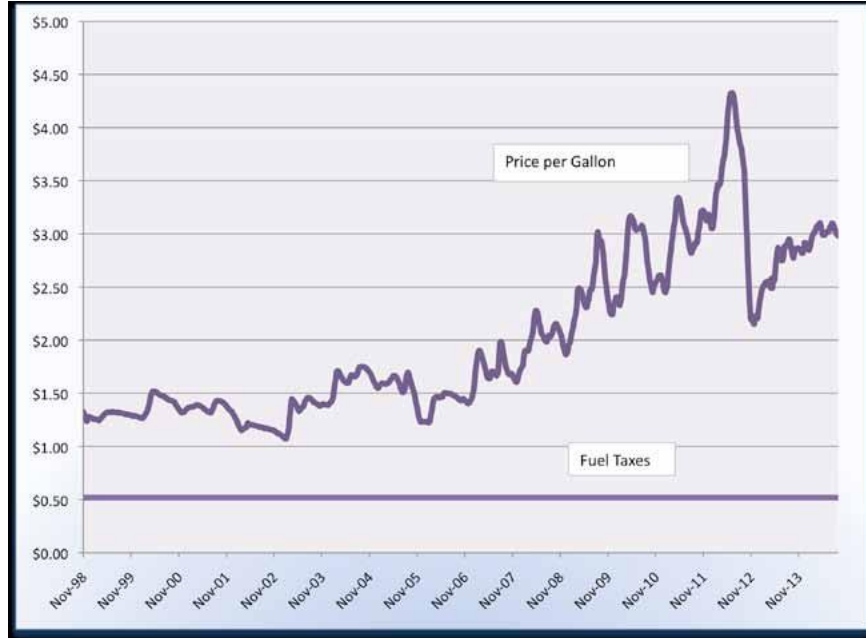


Figure 2.3: The fuel price trend from Nov-1994 to Nov 2011. (Source: NDOT 2011) [2]

Impact of Increasing Fuel Efficiency

Due to technical advances, automotive fuel efficiency has increased to a large extent. Increased fuel efficiency has reduced the operating cost of a vehicle. Reduced operating cost is an encouraging factor in the increment of vehicle sales. Hence increase in number of vehicles on road results more road damage which requires more funds to maintain the same road. Figure 2.4 represents the upcoming trend of an increase in fuel efficiency. In a report by the U.S. Energy Information Administration (EIA, 2005a), an increase in fuel efficiency is estimated from 1951 to 2021 [1]. The estimate shows increase in fuel efficiency for all types of vehicles. For most vehicles, efficiency is predicted to be approximately 29 miles per gallon in 2021 [1]. This increased fuel

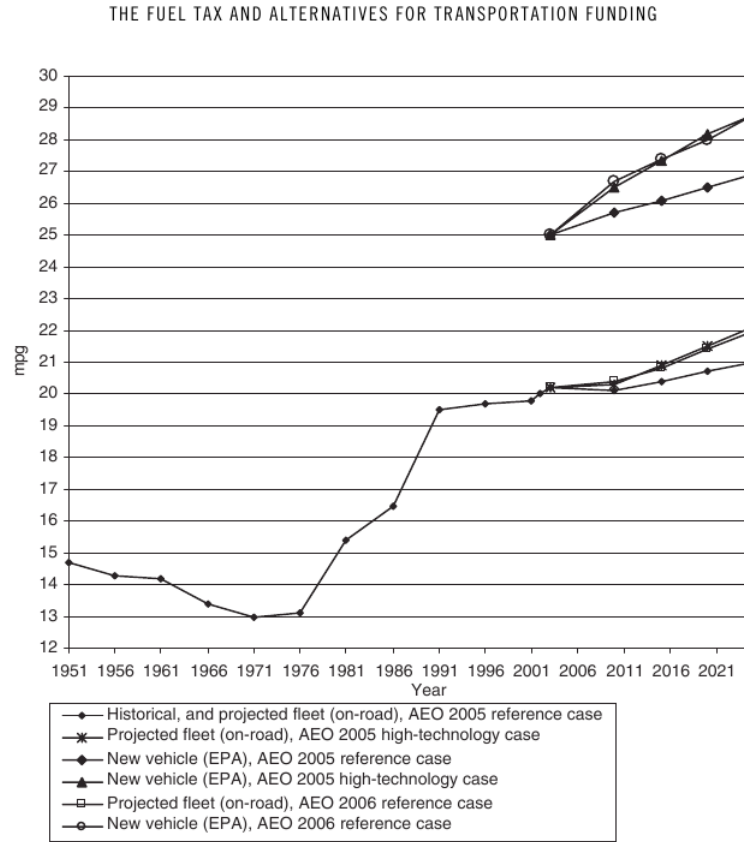


Figure 2.4: The upcoming trend of an increase in fuel efficiency (Sources: U.S. Energy Information Administration (EIA, 2005a; EIA, 2005b)[1]

efficiency would have a severe impact on amount of fuel tax collected, if under the current system.

Impact of Alternative Fuel Vehicles

Nowadays, vehicles based on alternative fuel options such as, electric vehicles and hydrogen-powered vehicles are becoming popular choices. These vehicles do not consume fuel directly in proportion to the distance travelled on the road. However, these

types of vehicles cause the same road damage and congestion as other less fuel-efficient vehicles. Hence, an increase in the number of alternative-fuel vehicles also results in loss of road revenue loss.

State and Federal Roles and Responsibilities

Some portion of state government highway programs is funded by state-imposed user fees, including fuel tax as well as registration and licensing fees. The rest of the funding comes from federal aid, based on federal user fees. Local governments use property and sales taxes, mainly, to pay for transportation programs. Since there is no certain funding methodology to fund projects, the division of roles and responsibilities between local and federal government is unclear. In United States, there is no consistent trend regarding local governments expenditures for highways, as shown in Figure 2.5.

Impact of Accidents, Emission, and Congestion

Figure 2.6 shows the highway user fee revenue and highway expenditures from 1961 to 2004 [1]. In the current road revenue system, revenue loss associated with accidents, emissions, and congestion are not taken into consideration. In U.S., approximately 40,000 people are killed every year in road accidents. With every such accident, there is cost associated with it for example cost of insurance, hospitalization, time of clearance etc. Similarly, increased congestion results in extended travel time, which directly impacts productivity. This loss of productivity has costs associated with it.

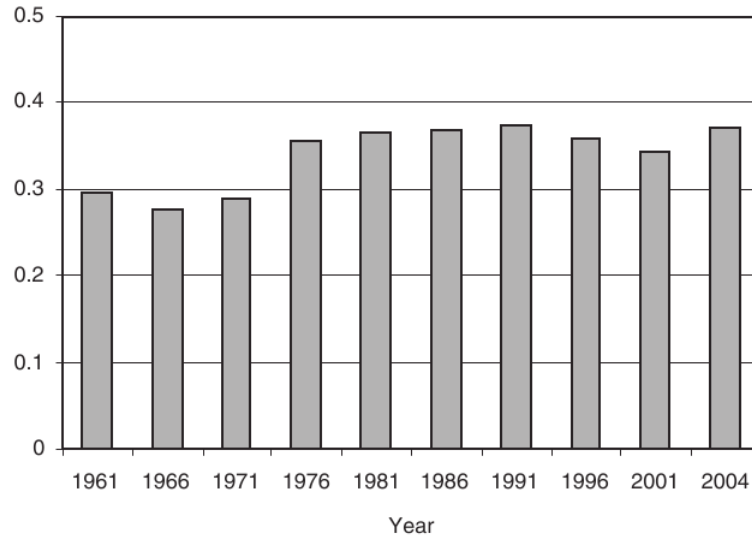


Figure 2.5: Trend regarding local government expenditures for highways (Source: FHWA) [1]

More vehicles on the roads cause more damage to the environment as well as to the road infrastructure. All such issues are not taken into consideration in the existing road revenue system.

2.7 Proposed Solution: Road Revenue Based On Vehicle Miles Traveled

The Vehicle Miles Traveled (VMT) study evaluates the available alternatives for the road revenue collection system. The existing revenue collection system based on a fuel tax is not an appropriate option in the long run, due to existing system constraints, including:

1. No effective tax procedure for alternative-fuel vehicles, such as electric vehicles;

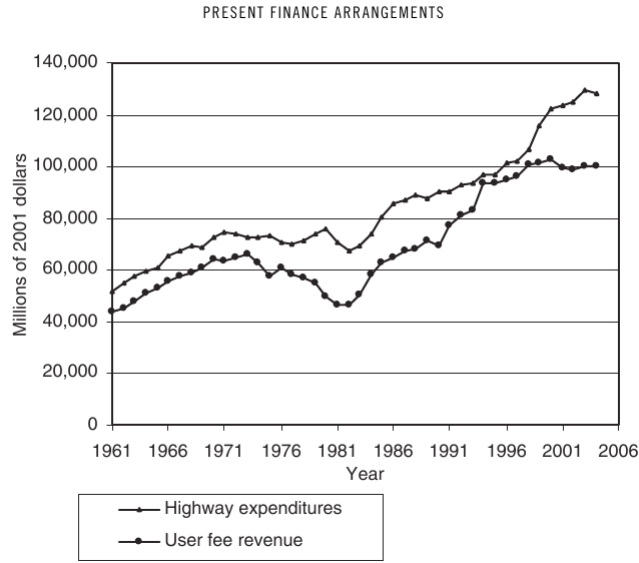


Figure 2.6: The highway user fee revenue and highway expenditures from 1961 to 2004. (Source: FHWA) [1]

2. No effective changes in the fuel tax to reflect inflation over the years; and
3. Greater highway expenditures than generated revenue.

Hence the objective of this study is to evaluate alternative in detail. In particular, this study will address the gaps between required revenue and the existing collection system. The main goal of the VMT study is to evaluate how best to collect road tax based upon road usage of a vehicle instead of fuel usage. With the VMT system, the tax imposed on a vehicle will be directly proportional to the distance traveled by vehicle. In this way, vehicles with different fuel efficiencies would pay the same amount of tax based upon their road usage. This type of system is even more transparent than the current system. The VMT study also has the potential to incorporate the concept of congestion pricing. Various states and universities have identified VMT as

one of the several potential solutions to replace the current gas tax system. Studies conducted by other universities will be discussed in detail in Chapter 2, Literature Review, of this report.

Advantage of VMT (Vehicle Mile Traveled)

VMT has many advantages over the existing road revenue system based on a fuel tax. It would help address the gap between required and generated revenue to maintain the current infrastructure. It is also independent of vehicle fuel efficiency. Some of the major advantages of VMT are:

1. Greater transparency to users/public than any other service, for example, electric or phone utilities.
2. Vehicles will be taxed based upon their travel distances, independent of fuel type.
3. Varying VMT charges, for example, during peak-hour congestion, will result in reduced congestion.
4. Peak-hour congestion charges will encourage the public to use transit services.
5. State and local government will be given greater ownership of projects.
6. The expenditure for highway projects will be directly associated with revenue generated by their usage.
7. Inflation can be taken into account in VMT fee calculations.

2.8 Contribution of Nevada in the National VMT Study

State of Nevada has planned the VMT study in three phases. Phase 1 of the VMT study already has been conducted in 2009 and completed in 2010 [2]. Currently, the study is in Phase 2, during which a system has been developed to capture miles travelled to system; this system has been tested with 25 participants. Phase 3 of the study will test the VMT infrastructure on larger scale.

Phase 1

Phase 1 of VMT field test has been done by the University of Nevada, Reno (UNR) in collaboration with the Nevada Department of Transportation (NDOT). This study was conducted in 2009 and completed in 2010 —[2]. The major objectives of this study were to assess the feasibility of a collection and payment method for the VMT fee. As part of this study, a proactive public outreach program was designed to educate the public, elected officials, and various stake holders about the advantages and disadvantages of the VMT system. Some major goals identified as part of this phase are:

1. Conduct a comprehensive literature review.
2. Conduct comprehensive public outreach and educate all stakeholders about VMT.
3. Evaluate the impact of VMT implementation regarding privacy issues.
4. Design a pilot program protocol.

5. Develop economic models to build the VMT fee structure.

Feedback was collected regarding the various concerns about VMT implementation. As the result of the feedback collected in these workshops, the four major public concerns[2] are:

1. Privacy
2. Policies
3. Administrative issues
4. Technical issues

Phase 2

Phase 2 of the VMT study involves a collaborative effort among NDOT, the University of Nevada, Las Vegas (UNLV) and UNR. The main objective of Phase 2 is to implement and test the system, using volunteers selected randomly from different educational backgrounds, ethnicity, age groups etc. Implementation of the test unit will be followed by data collection, using vehicles of the volunteers, and data analysis. The actual pilot test for Phase 2 was conducted with 25 participants in July 2011, and completed in September 2011. The main objectives of Phase 2 are:

1. Conduct VMT field tests with 25 participants.
2. Collect odometer data without the use of a global positioning system (GPS).
3. Data analysis, using data from the Nevada Division of Motor Vehicles (NDMV).

4. Qualitative data analysis of public comments regarding the VMT system.
5. Evaluation of a prepaid payment plan for VMT fees.

Phase 3

Phase 3 of the VMT is planned for the future. The main objective of Phase 3 of the VMT study is to test the complete system at the state level. Suitable hardware and software, identified in Phase 2, will be developed further in order to be used on a larger scale. The goal of VMT Phase 3 is to test the complete infrastructure of VMT with approximately 1,000 participants.

2.9 Conclusion

Vehicle Miles Traveled is one of the most promising systems to replace the current road revenue system. It is more transparent and fair in terms of payment per usage than the current system. It also has the potential to incorporate such concepts as congestion pricing. Various state and universities have identified VMT as one of the potential solutions that could replace the current fuel tax system.

CHAPTER 3

LITERATURE REVIEW

3.1 Summary

This chapter discusses the major contributions of various universities and states regarding the Vehicle Miles Traveled (VMT) study. Many universities are studying several of aspects of usage based the tax revenue system. For example, Oregon is one of the leading states in VMT research. In addition, this chapter looks at various technical solutions used by various universities in order to capture the distance traveled by a vehicle. Finally, privacy is one of the major issues identified in all the related studies discussed in this chapter.

3.2 2007 Study Conducted in Oregon

To date, Oregon has contributed most in the research related to the VMT-based revenue collection system. In 2007, Oregon completed two phases of VMT field test, using 280 participants [3]. Phase 1 of the field test was conducted for five months for the data collection as the control phase. Based on the results from the control phase, participants were divided into two groups for the second phase: an experimental group and a control group. Field test, based on implementation of technology in

Phase 2, was followed by data analysis [3]. In the field test, an on-vehicle electronic device was installed in order to calculate the total number of miles driven based on geographic zones. The mileage information captured using the on-vehicle device was transmitted to the gas station wirelessly. A receipt with VMT tax information was generated based on the miles driven. The Oregon study also identified and examined major issues in order to implement VMT on a large scale. Major issues included public acceptance, privacy protection, cost, and technology reliability

3.2.1 Systems Architecture for Oregon's VMT Revenue Collection System [3]

Oregon designed an on-vehicle electronic device based on a global positioning system (GPS). This device was equipped with a display and GPS receiver antenna. During the field test, data transfer was done over a wireless communication link. Below are the main technical components used by Oregon[3] in the field test:

1. A device for VMT data collection based on a GPS receiver was used. The on-vehicle device included a dashboard display, a GPS receiver, and an antenna.
2. Data transmission was done by short-range wireless communication technology.
3. The captured data was stored in a central database for each vehicle.

The below figure 3.1 presents the high-level architecture of the design used in the study conducted by Oregon. Once the data related to travelled distance was captured, it was transmitted to a central server over a wireless communication link. All the

central servers were connected to a central database system so that all the data was stored in one place. Privacy[3] is one of the major concerns identified during Oregon field test. As on-vehicle device in this study was based on GPS (Global positioning system) which can cause potential invasion to privacy of participants. Here are some of the main issues identified during field test:

1. Public acceptance issue.
2. Privacy policy
3. Rate equity.
4. Accuracy related technical issues.

3.3 University of Iowa Study (1999–2009)

In below section phase one and phase two of the study are discussed. In field test of the Iowa study, distance travelled by a vehicle was calculated using GPS and geographic information system (GIS) data files[5]. The GIS is used to track the location of a particular vehicle. In order to transmit the data to the server, a cellular wireless transmitter receiver system was used.

3.3.1 Phase 1 (1999-2003)[5]

Since 1999, the University of Iowa conducted a national study that evaluated of tax systems based on miles traveled. Various issues regarding implementation of a

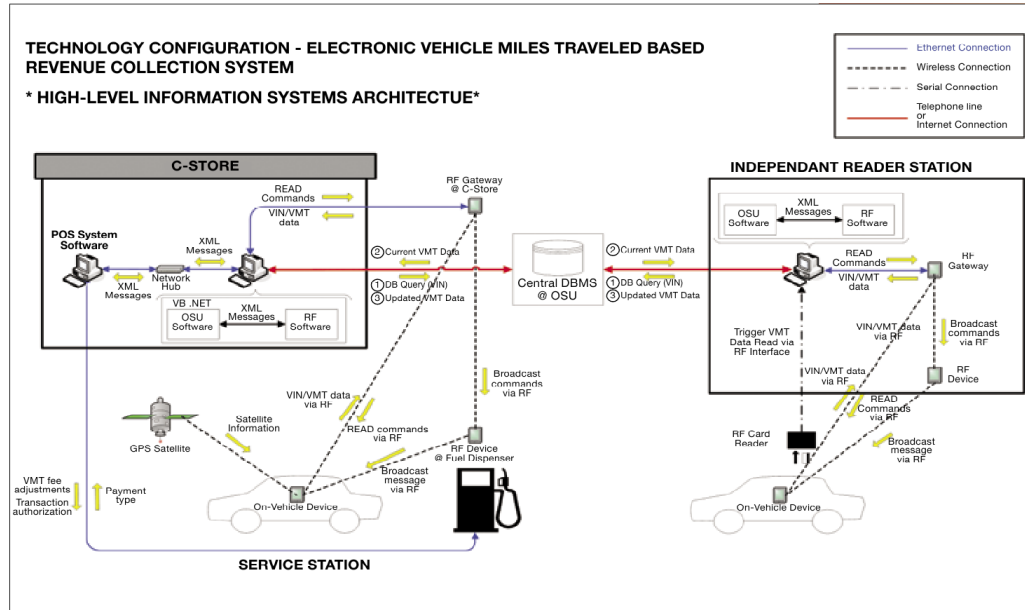


Figure 3.1: The high-level architecture of the design used in the study conducted by Oregon. (Source: Oregon's Mileage Fee Concept and Road User Fee Pilot Program (Oregon Department of Transportation, November 2007)[3]. Attached with permission

mileage-based fee were studied, and the basic architecture of a mileage-based road user charge system was developed. This study mainly was funded by the U.S. Federal Highway Administration (FHWA).

3.3.2 Phase 2 (2005-2009)[5]

Phase 2 of this study was funded by the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (Public Law 109-59; SAFETEA-LU). Its objective was to evaluate a prototype of a mileage-based user charge system at the national level. During evaluation, the main focus was on identifying the major issues in terms of public acceptance. Technological feasibility was also evaluated.

During the first year of Phase 2, approximately 1,200 participants were chosen from 6 sites nationwide[5]. Main components used in this field test[5] were:

1. A GPS receiver.
2. A GIS data file.
3. An onboard computer system.
4. A cellular wireless transmitter-receiver.

The system architecture used in the Iowa study is shown in Figure 3.2. In this diagram, the overall skeleton is presented to track position of vehicle from GPS (Global positioning system) and track its distance using OBD based speedometer. Once the location and odometer reading is calculated, it is transmitted to a central database over a wireless link. Mechanism to identify heavy vehicles using on-board vehicle weighing system is also proposed. Due to using a GPS-based onboard device, and also location tracking by means of a GIS data file, this study identified privacy as one of the major issues. Below are the major public concerns identified during the study[5]:

1. Privacy issues.
2. Public acceptance.

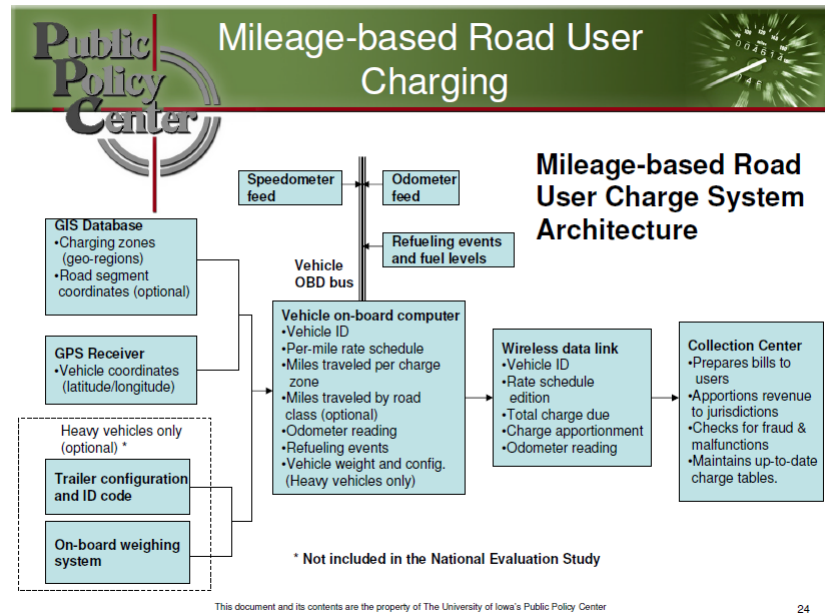


Figure 3.2: The system architecture used in the Iowa study. (Source: National Evaluation of a Mileage-based Road User Charge by Jon G. Kuhl and Paul Hanley (Public Policy Center the University of Iowa)[5]. Attached with permission.)

3.4 Study by Puget Sound Regional Council

In 2008, the Puget Sound Regional Council in Washington State conducted a study entitled: “A Global Positioning System Based Pricing Pilot Project: Evaluating Traveler Response to Variable Road Tolling through a Sample of Volunteer Participants”.

In this study, there were 450 volunteer drivers with vehicles from over 275 households[6].

The study was carried out for approximately 18 months. During this time, a driving routine was developed to incorporate congestion pricing in that volunteers were charged a toll for accessing selected roadway facilities at particular time periods during the day. This study concluded that congestion pricing might reduce traffic congestion

and raise road revenues. The system developed as part of this study was based on global positioning system. Collected data was transferred over a GSM communication link[6]. The main technical components and overall architecture of developed system[6] is described below:

1. GPS receiver.
2. Global System for Mobile Communications (GSM).

The overall design used in this study is shown in Figure 3.3. Once the information related to distance travelled is captured in a vehicle by using GPS, it is transmitted to a central server by means of a GSM network. All central servers are connected to each other over wireless communications. These servers also connect to the terminals. Due to involvement of a global positioning system, the system design has potential threat to the privacy of the user. Hence, privacy was one of the major concerns identified in this study as well. Congestion pricing, also studied as part of this project, added complexity to policy issues. Below are the major public concerns identified during the study[6]:

1. Privacy issues.
2. Policy issues.

3.5 “Pay-As-You-Drive” Minnesota Research (2004)

The Minnesota Department of Transportation (MnDOT) conducted a study in 2004 whose main objectives were to simulate the variable cost alternatives of trans-

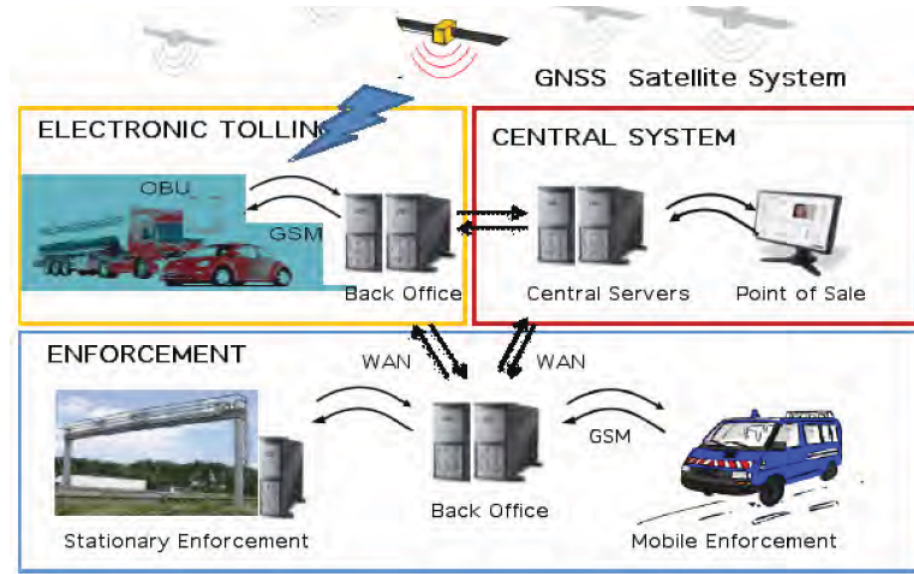


Figure 3.3: System architecture used in the Washington State study. (Source: Traffic Choices Study Summary Report (Puget Sound Regional Council, April 2008)[6]. Attached with permission)

portation and to develop a deep understanding of public behavior towards a fee based on road usage. As part of this study, an electronic device called CarChip, developed by Davis Instruments Corp., was installed in the participants vehicles[7]. This device recorded information related to every trip made by the participants. At the end of the field test, all the CarChip devices were collected in order to retrieve the recorded data. Data was collected during three periods: March-May 2004, May-August 2004, and November 2004-February 2005[7]. As part of this study, 130 households were recruited from the eight counties of the Minneapolis/St. Paul metropolitan area. All participants were requested to fill out an exit survey regarding their attitudes and opinions. The CarChip, an off-the-shelf product developed by Davis Instruments Corp., was used in this study to collect the data. Once the CarChip device was in-

stalled in system, it recorded the distance travelled by the vehicle for each trip. There was no provision for wireless transmission of the data in this study. All the CarChip devices were collected at the end of study, and the data was transferred manually to the database. The main technical component of this study was CarChip, based on the onboard diagnostic system OBD II. During this study, there was no use of a GPS or GSM, even though the main issue identified was privacy. Distance travelled in each trip of a vehicle was that measurement captured[7]. Figure 3.4 shows the overall flowchart followed in the “Pay-As-You-Drive” field study. The study was broadly classified into two categories: market survey and field experiment. The market survey was further categorized into a general market survey and a vehicle lessor survey. The field experiment had two sub-phases: data collection and the participants survey.

3.6 European Commission Study on ARMAS

This study was conducted by a European commission from 2003 to 2008. The study examined pricing based on road usage for greater responsibility, efficiency, and sustainability in European cities. This project was conducted in eight European cities: Bristol, Copenhagen, Edinburgh, Genoa, Gothenburg, Helsinki, Rome, and Trondheim[8]. During Phase 1 of this study, the major objective was to come to a definition of the Active Road Management Assisted by Satellite (ARMAS) prototype. This included the evaluation of institutional, legal, and safety aspects. During Phase 2, live demonstrations were conducted of the concepts inherent to the ARMAS project in terms of road safety, traffic management, and virtual tolling. Phase 3, scheduled

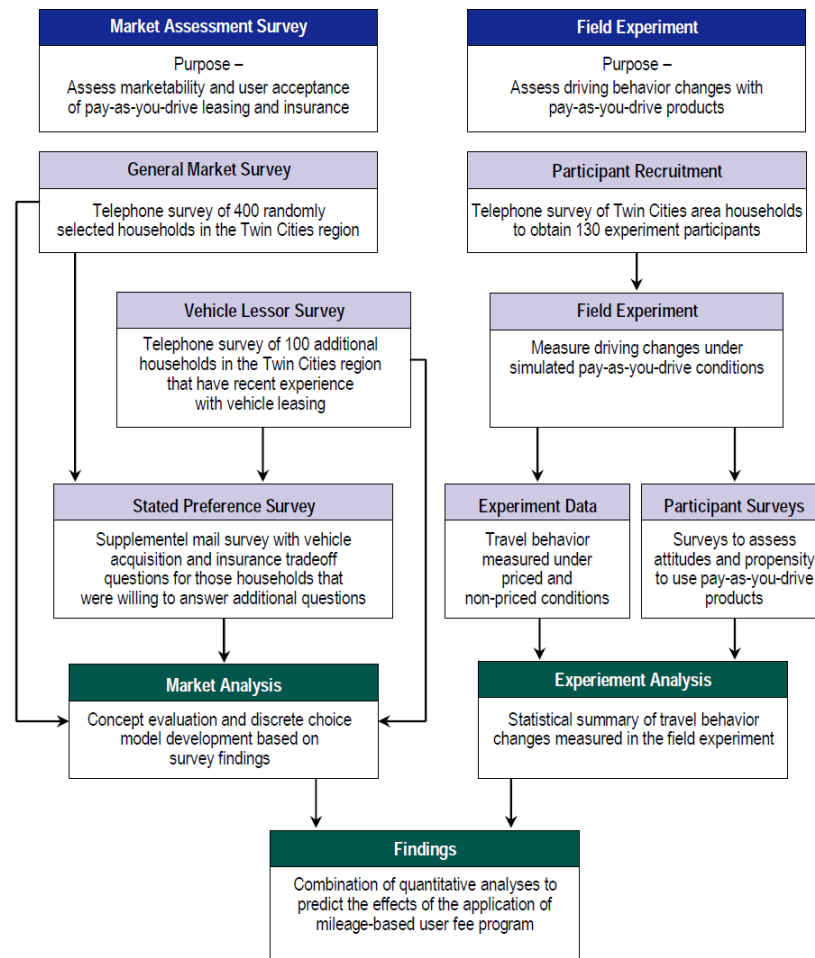


Figure 3.4: The overall flowchart followed in the “Pay-As-You-Drive” field study. (Source: Mileage-Based User Fee Demonstration Project by the Minnesota Department of Transportation (2004)[7]. Attached with permission.)

from August 2006 to December 2007, brought ARMAS to the commercial market[8]. As part of this study, automatic number plate recognition was used in order to identify vehicles. The data were transferred over a short-range communication link. Some of the main components used as part of the study were:

1. Short range communication.
2. Automatic number plate recognition.
3. A global positioning system

3.7 Netherlands, “MobiMiles” Project (2001)

“MobiMiles” was proposed by the Ministry of Transport, Public Works, and Water Management of the Netherlands in 2001[10]. As part of this study, a new road pricing system was introduced for charging a user fee based on the vehicle location. This system incorporated the impact to the environment caused by vehicles. In this program, both location-based congestion pricing and time-based congestion pricing were taken into account. According to Pieper and Prins (2001), “The “MobiMiles” proposal received extremely broad support both within the market and amongst political parties and activist groups”. Location tracking was done using a GPS to study the details of location-based congestion pricing and time-based congestion pricing. Some of the main components used as part of the study were[10]:

1. GSM standard development process.
2. A global positioning system.

3.8 “LKW-MAUT” Study in Germany (2005)

In 2005, “LKW-MAUT” short for the German term, “Lastkraftwagen-Maut”, which literally means ‘truck-toll’ was introduced by German autobahns for trucks weighing more than 12 tons. This toll system was developed to perform automatic tax collection from all heavy vehicles based on the distance driven, the number of axles, and exhaust emissions. This system is capable of providing three options for payment. First, each vehicle was equipped with an onboard unit and GPS receiver, and payment transactions were done over a wireless communication link[13]. This payment mode was based on advance payment of their taxes by entering their journey information at the toll payment terminals. This option was related to advance payment of taxes over Internet. In order to calculate the distance travelled by a particular vehicle, an on-board GPS-based device was used[13]. Distance calculated was transferred to the server over a wireless communication link[13]. Main technical components used as part of this study were:

1. Vehicles equipped with onboard units that included a GPS.
2. A wireless communication link.
3. Taxes that could be paid by the Internet for people who are willing to pay by that method.

3.9 Nevada Vehicle-Miles-Traveled Study, Phase 1

Phase 1 of the VMT field test was conducted by the University of Nevada, Reno (UNR) in collaboration with the Nevada Department of Transportation (NDOT) [2]. This study was conducted in 2009 and completed in 2010. The major objectives of this study were to assess the feasibility of a VMT fee collection and payment method. As part of this study, a proactive public outreach program was designed to educate public, elected officials, and various stake holders about advantages and disadvantages of a VMT system. Some major goals identified as part of this phase[2] include:

1. Conduct a comprehensive literature review.
2. Conduct a comprehensive public outreach and educate all stakeholders about VMT.
3. Evaluate the impact of VMT implementation on privacy.
4. Design a protocol for a pilot program.
5. Develop economic models to build a VMT fee structure.

3.9.1 Phase 1: Survey

During Phase 1 of this study, VMT workshops were conducted in Reno on May 9, 2009, and in Las Vegas on August 19, 2009[2]. There were approximately 20 invitees in each workshop[2]. Participants were divided equally into four groups in order to collect feedback about various concerns regarding implementation of a VMT system.

Ranking	Issues from Reno workshop	Issues from Las Vegas workshop
1	Policy	Policy
2	Privacy	Privacy
3	Technical Issues	Administrative Issues.
4	Administrative Issues.	Technical Issues

Table 3.1: Issues Identified during Phase 1[2]

As a result of the feedback collected in these workshops, the major public concerns are:

1. Privacy issues.
2. Policy issues.
3. Administrative issues.
4. Technical issues.

In addition to these workshops, there were two public meetings in Reno and Clark County, respectively. The first meeting was held on March 30, 2010 in Reno, and the second was held on April 29, 2010 in Clark County. A total of 75 participants attended these meetings[2]. During these meetings, people were made aware of the VMT study and also the reasons for the study. At the end of each meeting, participants were surveyed for feedback. In this survey, participants reported that privacy issues and policy issues were major concerns, as shown in Table 1. The findings from the public meetings were exactly same as those of the earlier workshops. Only half of participants in Phase 1 were willing to participate in Phase 2, the VMT pilot program.

Major concerns identified based upon public comments during in the workshops for Reno and Las Vegas are as follows:

1. All funds collected should be used according to transportation needs.
2. User identification must be only related to the number of miles traveled.
3. Technology that is used must be secure.
4. NO use of GPS.
5. VMT rates are to be tied to vehicle classification.
6. There is low credibility regarding government guarantees of privacy.
7. The system should be similar to that existing at pump stations.

3.10 Conclusion

In most of the studies involved in distance-based tax systems, privacy, policy and public acceptance were identified as some of the major issues in their implementation. For a VMT system in Nevada, a complete system design needs to be developed that can fulfill the desired goal of having a distance-based tax system and also addresses these issues at the same time. The design must not use a GPS component to avoid any potential breach in user privacy. The system that is developed must be easy to use and similar to the existing tax payment system in terms of operation.

CHAPTER 4

FIELD TEST SETUP

4.1 Summary

This chapter discusses the high-level overview for the Phase 2 of the VMT study in Nevada, during which the field test was conducted. Complete development of the architecture for the field test was based on input received in public meetings during Phase 1. In this chapter, the business requirements as per demand and their corresponding solutions are analyzed. The system was redesigned to eliminate one of the major concerns regarding “privacy”, which was raised during Phase 1. The architecture of the system was designed to incorporate triple redundancy. Each of the developed/selected tools was tested thoroughly during unit testing and regression testing. An OBD II-based off-the-shelf product, “CarChip, developed by Davis Instruments Corp” was used to capture the distance traveled by vehicles. Software related to the data display and user interface was also developed. A complete software development lifecycle was followed during the development of the software for this project.

4.2 Introduction

In order to implement the concept of road tax system based on VMT, A complete infrastructure design needs to be developed on top of the existing, working gas station infrastructure. The developed infrastructure must also satisfy the given technical specification in the below section and must be user friendly at the same time.

4.2.1 Requirement Specifications

Team members of NDOT and UNLV decided the specifications of infrastructure taking various constraints into consideration. These constraints have been identified during the literature review of previous studies as well as from Phase 1 of Nevada's VMT program. The key features and constraints that must be present in the developed hardware are as follows:

1. In terms of ease of operation, the developed infrastructure must not deviate much from the existing "payment at the gas station" infrastructure.
2. Minimum modifications to vehicles should be required to install the system.
3. The system must be independent of car models.
4. The system should only record distance traveled by the vehicle.
5. There should be no involvement of a GPS device at all.
6. The wireless transmission of recorded data from the car to the server at a gas station must be set up.

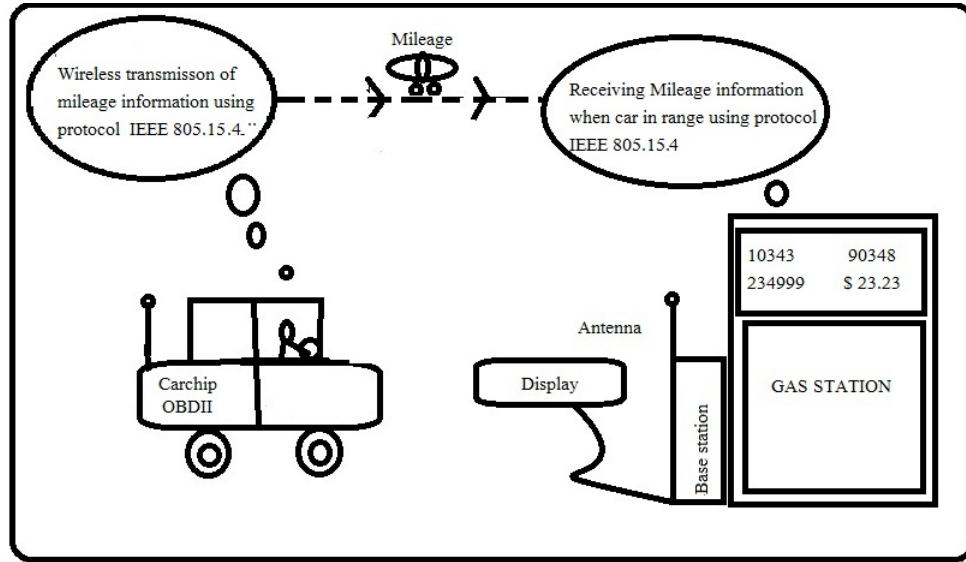


Figure 4.1: Basic architecture for a VMT system.

7. A receipt, comparing a VMT tax and the current fuel tax, must be generated.

Figure 4.1 describes the overall structure of the proposed VMT system. In this system, distance traveled by a vehicle is captured using an on-vehicle device. A receiver is kept on the gas station. Whenever a vehicle goes to a gas station, VMT data captured from the vehicle is transferred to the gas station over a wireless communication link.

4.2.2 Complete Architecture of the Developed System

Based on the constraints and specifications mentioned above, a system with triple redundancy has been developed. The complete system architecture consists of various products developed by UNLV team members as well as various commercial products available on the market. To record the travel data, a product was used based on an

OBD-II port CarChip Fleet Pro, developed by Davis Instrument Corp. This device records the distance travelled by a vehicle during each trip. CarChip has been selected for VMT Phase 2 pilot tests specifically because it does not use a global positioning system to calculate the travel distance. This device provides a functionality to transmit all the recorded data to a server over a communication link whenever in range.

Figure 4.2 below shows the architecture of the server at a gas station. Once the car enters into the gas station, receiver of the CarChip base station detects presence of the car and starts downloading the recorded data. As soon as data is transferred, it is stored in a Microsoft Access database. Using free commercial software, Allway Sync, two local backups are created of updated database. First copy of the backup data is used to interact with a user interface based on Visual Basic, developed at UNLV. This script is interfaced with a printer and scanner. The user interface is equipped with functionality to login and logout. During Phase 2, after successfully logging in, the participants were asked to enter the approximate amount of gas to be purchased. Participants were also requested to scan their receipt generated from gas station as well as drop them in a box. A receipt, which compares the VMT tax and the current fuel tax, is generated by the user interface for the participant. The second copy of the backup is synchronized in Dropbox, which is free software for sharing files up to 2 GB in size. Using Dropbox, the database copy is immediately updated on various computers of team members at UNLV. An internet connection is required to use Dropbox. In this study, a Sprint wireless connection was used to provide internet

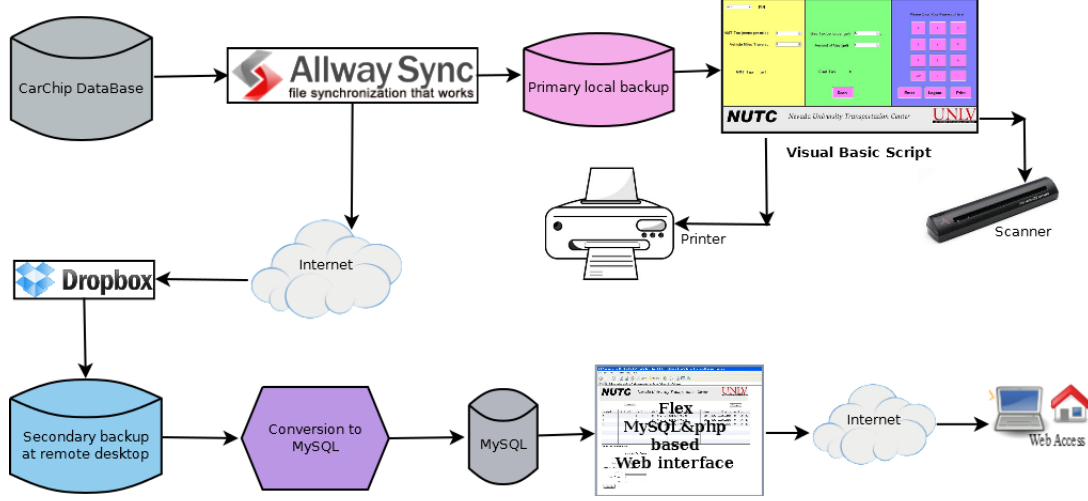


Figure 4.2: Architecture of server at a gas station.

access to the server at the gas station during Phase 2. The MS Access database that is received is manually converted to a MySQL database. Once that was done, a Flex-PHP-based website was hosted on the server. Participants could check their basic trip information using the website. Every participant was provided with unique ID and pin to login into website.

4.3 Hardware Details

Hardware details includes a) the hardware used to capture the traveled distance within the car; b) the hardware used to transmit data and receive captured data; c) hardware to run the user interface and scan the gas receipt; and d) hardware to generate the tax receipt. Hardware can be broadly classified into two categories: that which is installed inside the car and the setup at the gas station.

4.3.1 Hardware Installed Inside the Car

These days, most of the cars support an onboard diagnostic version 2 (OBD-II) port. Basic health information of the car can be captured using this OBD-II port. CarChip is one of the many products available that provides an interface to record the distance traveled by the vehicle using its vehicle speed sensor (VSS). We selected CarChip for the purpose of this study as it also provides an interface to transmit the collected data over a wireless communication link using Zigbee wireless standard protocol. It provides a wireless onboard module that transmits the data from CarChip by using an interface module. Below are the details of components installed inside the car:

1. CarChip Fleet Pro
2. Wireless onboard module
3. Interface module

Figure 4.3 below illustrates the complete setup of the hardware inside the car. CarChip Fleet Pro was connected to the OBD-II port of the car. At the same time, it also was connected to the wireless onboard module by way of an interface module.

4.3.2 Hardware Setup at the Gas Station

During our study, a base station (receiver unit) from CarChip was placed at the gas station to retrieve the captured data. This receiver was interfaced with a computer to store the data into an MS Access database. Once the data was captured, multiple

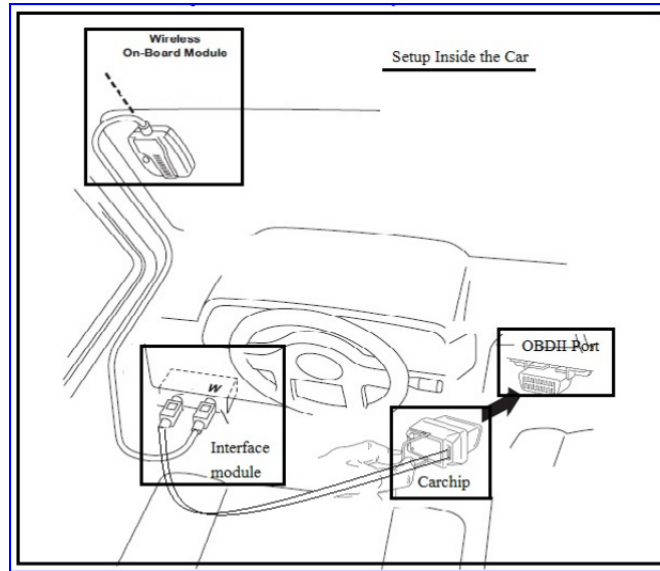


Figure 4.3: CarChip interface inside the car (Setup inside the car is based on the CarChip Fleet Pro installation manual).

backup copies were made. A user interface was designed to interact with the database to calculate the VMT tax. Below are the hardware details at the gas station:

1. The base station
2. A computer central processing unit
3. A scanner
4. A printer
5. A touchscreen monitor

A receiver is placed at the gas station to capture the transmitted mileage information.

This transmission takes place over a wireless communication link. Whenever the

car is in the range of receiver, a communication link is automatically established to download the data.

4.4 Software Details

This section discusses the complete details of the software development. The software was designed following the complete software development life cycle (SDLC). First, the business needs for each part of software was analyzed, based on input received from various sources. As part of Phase 2 of the VMT study, a user interface was developed to give easy access to the data and to generate tax receipts that compared proposed VMT tax and the actual fuel tax. Software was also designed to automatically detect the presence of a car based upon the data entry and also to generate the VMT tax receipt. A website for the display of data was created to provide user access to the captured data over the internet. Finally, the high level algorithm used to develop the software, and other useful technical details, will be discussed. We have used Visual Basic (VB) 2008 to design the user interface, the front-end screen. Some open source software was integrated with the VB script to achieve the complete required functionality of the product. Such issues as data loss, error handling, and exception handling have been addressed in the design. The “software development life cycle” (SDLC) process was followed in order to develop a good quality and robust product.

4.4.1 User Interface Details

As soon as the car enters into the gas station, the base station unit of CarChip detects the presence of the car. Once the car is identified, a communication link is established between the base station and the car. After establishing the communication link, it starts downloading data. Meanwhile, user goes to the gas pump and fills the car with gas. Participants in the study were requested to take their gas receipts to the VMT setup. Following are the basic steps that the users were requested to follow:

1. Users were requested to fill their car with gas by means of the normal process and get their gas receipts.
2. They were asked to take their gas receipts to the VMT setup at the gas station.
3. They logged into the VMT user interface with a user-id and PIN.
4. After login, they scanned their gas receipt, using user interface.
5. They entered the amount of gas in gallons they pumped at that time.
6. Finally, they took the printed receipt that had the VMT tax and fuel tax.

Figures 4.4 below displays the touch-screen user interface designed by team members at UNLV. The user interface has basic functionalities to display the captured data and to print a receipt.

Figure 4.4: User interface design for Phase 2 of the VMT study.

4.4.2 User Interface Design

As part of Phase 2 of the VMT study, the field test phase, there was a need for a user interface similar to the existing user interface at the gas station. This user interface was required to provide user access to the recorded data. The main objective of the user interface was to design a simple and user-friendly interface that can be used by people of to all educational backgrounds and age groups.

Business Requirements

A user interface must exist to provide the users with basic useful information related to the VMT tax. It must incorporate the basic data security features. It must have the provision to login and logout. Finally, it must generate a receipt that compares the VMT tax and the existing fuel tax.

Functional Requirements

Functional requirements are the basic common functionalities of the user interface. As a result, the business requirements were analyzed, and list of basic functionalities that must be present in the user interface was developed. Once all the functionalities were identified, a technical specification document was prepared. All main functional requirements of the user interface are mentioned as follows:

1. An integrated system needs to be developed on top of the database of the Fleet Management Software (FMS), developed by Davis Instruments, that can be used by users to check their VMT information.
2. It also must provide users with a generated receipt so that they can compare their fuel tax and the VMT tax.
3. Users also must be able to record their fuel information using the same system.
4. The system should have the functionality to scan the gas receipt generated by the gas station and to store it.
5. It must be protected with a User ID and PIN to ensure data security.
6. The system should have login and logout features to address privacy issues.
7. It must be user-friendly and easy to use.

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Search Refresh

locationID	driveRightID	driverID	startDateTime	endDateTime	tripTime	distance	startOdometer	endOdometer
1	1	1	2011-02-24 16:2	2011-02-24 16:3	15	91.6637573242	98968.6015625	98977.703125
1	1	1	2011-02-24 16:2	2011-02-24 16:3	15	91.6637573242	98968.6015625	98977.703125
1	1	1	2011-02-24 16:2	2011-02-24 16:3	15	91.6637573242	98968.6015625	98977.703125

All the Distance are in KM

Insert new Fuel Record

First Name

Last Name

Date(YYYY-MM-DD)

DriverID

Fuel Amount

cost

Figure 4.5: Web interface for user access to captured data.

4.4.3 Website for Data Visualization

A web interface was developed using Adobe Flex programming language with a PHP and MySQL database. The database was automatically synchronized on the developers machine, and was manually converted into the MySQL database. A website hosted on the server was made accessible to all the users. Users could search their trip information using their user-id. They also could enter their gas receipt information using this website. Figure 4.5 below shows the website that was developed.

4.5 Software Architecture and Algorithm

Software architecture is one of the highest level architectures of the entire user interface. In this system, all the main technical components were identified, based

on functional requirements and technical specifications. Six main components were identified that must be integrated with the user interface to provide complete functionality:

1. A VB script for the user interface.
2. A scanner to provide the functionality to scan actual gas receipt.
3. A printer to provide the functionality to automatically print the generated receipt,.
4. The commercial software Allway Sync to create multiple backup copies of captured data.
5. A Microsoft Access database to provide data to user interface.
6. A Windows file system to store scanned receipts, generated receipts etc.

4.5.1 Technical Specifications for the Software

This section discusses the major technical components used to develop the desired product. Technical components were chosen such that all the functionalities that were identified in the functional requirements section are achieved. Basic technical specifications are as follows:

1. The front end of user interface is based on Visual Basic 2008.
2. The user interface is integrated with an MS Access database.

3. VB script of the scanner is integrated with a TWAIN driver.
4. VB script is integrated with PrintFile to add the receipt printing functionality.
5. The VB script must store the scanned file with the proper naming convention.
6. The VB script must take the backup of all the generated receipts.
7. The VB script must be independent of the existing Fleet Management System.

4.5.2 Flow Chart of the Software Developed

Figure 4.6 illustrates the basic algorithm used in the software. According to the algorithm of the script, a user logs into the system using a unique User ID and PIN. Meanwhile, the data recorded in the CarChip is transferred to the server and stored in the database. Based on the current data, the Vehicle Miles Traveled of that particular vehicle is calculated and displayed on the user interface screen. At that point, the user is requested to scan the gas receipt generated at the gas station and enter the approximate amount of gas purchased. Once the user enters the amount of gas purchased, a receipt comparing the current fuel tax and the VMT tax is generated by the system. A step-by-step algorithm of developed interface is described in the diagram below.

4.5.3 Alternate Design

In an alternate design, a code was developed for automatic receipt printing of the VMT tax. This VB script monitors the database to identify the presence of a new

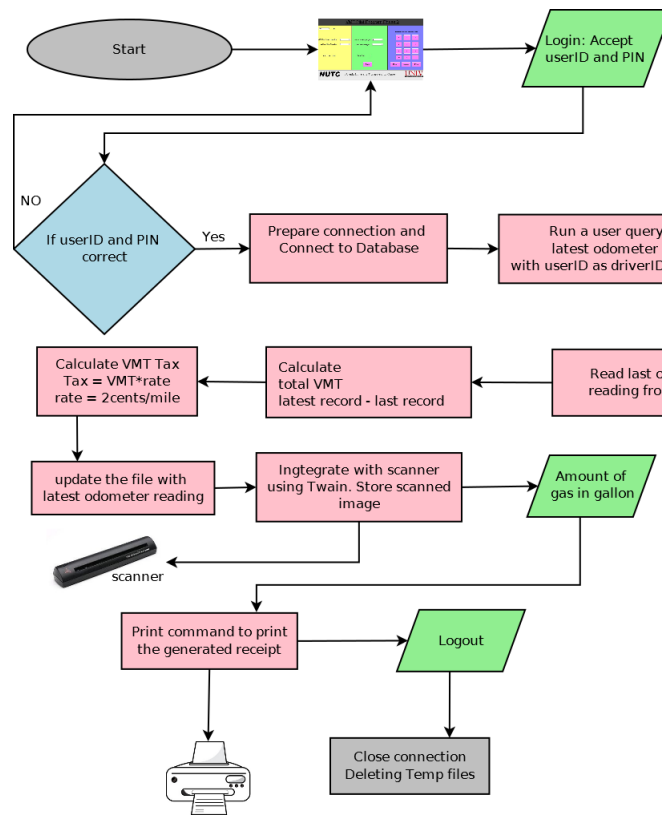


Figure 4.6: Flowchart of the algorithm for the user interface.

record corresponding to the recent arrival of a car. As soon as the record for a new car is identified, it calculates the distance traveled and the VMT tax based on the same. It generates a receipt, prints it by means of a printer.

Limitations of the Alternate Design

As compared to the design with a user interface, the alternate design was developed so that no user input is required. As soon as the presence of a car is detected, CarChip automatically transfers the data to the database. The script calculates the recent miles traveled and the fuel tax, based upon the recent data entry in the database. Some of the limitations of this user interface are:

1. There is no provision to integrate the scanner in this script.
2. The database has to be checked continuously after some time interval, which in turn needs the process to run in an infinite loop.
3. No user input is required in this script.
4. There is no provision to compare the fuel tax and a VMT tax.

Advantages of the Alternate Design

This design also has some advantages over the user interface that was developed. In this design, user input is not required, which makes it perfect for people with a wide range of educational backgrounds. Some of the main advantages of this design are:

1. There is no basic computer knowledge needed on part of the users, as no user input is required.
2. An automatic receipt gets generated after data download.
3. As this design is based on the latest car arrival, there are no issues related to data security and data privacy.
4. This design is similar to the existing system design at gas pumps.
5. In this design, all the processes run in the back end.

4.5.4 Flowchart of the Alternate Design

Figure 4.7 below presents the step-by-step process of the alternate design. In this design, as soon as the car enters into the gas station, the base station component of CarChip identifies the presence of the car and starts downloading the data. Once the complete data is downloaded and stored in the database, the VB script keeps track of the new data entries in the database at regular intervals. It identifies the newest data and the vehicle ID (assigned to user) based on the recent information. For this particular vehicle, the net distance traveled and the tax based upon the distance is calculated. Once the VMT tax information is ready, it generates the tax receipt for the user.

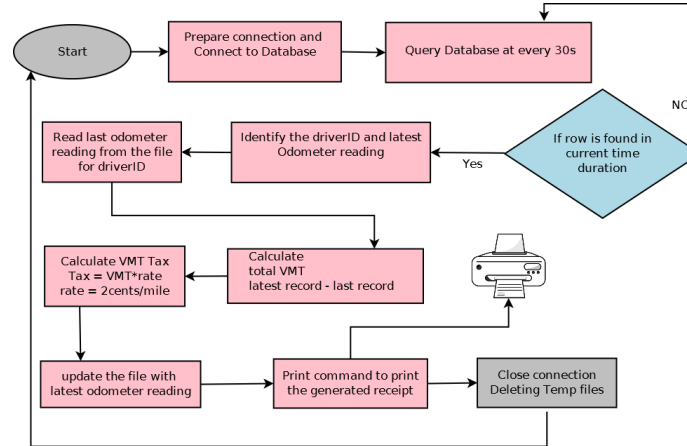


Figure 4.7: Flowchart of algorithm of alternate design.

4.5.5 Web-based User Interface for Data Display

A website was developed for the display of collected data. This website was based on the Adobe Flex 4 language, which has a hypertext preprocessor (PHP) on top of a MySQL database. As the data was being collected in the MS Access database, the data in the MS Access database had to be converted into the MySQL database in order to run the Adobe Flex website with that information. The conversion from MS Access to MySQL was achieved using the software Access To MySQL (3.0.0.148). This website also was developed according to complete software development life cycle procedures.

Business Requirements

Users must have easy access to their recorded data so that they can view their own data for easy reference. This website also must provide the user functionality to input fuel data.

Functional Requirements

Functional requirements are the basic common functionalities of the website. The business requirements were analyzed, and a list of basic functionalities was developed that must be present in the web-based user interface. Once all the functionalities were identified, a technical specification document was prepared. All the main functional requirements of the website are as follows:

1. A website is required to display the recorded data.
2. The website must have a search option to identify data of the specific user.
3. The website also must provide functionality to the users to record their fuel information.
4. The website must display such important information as the trip information, using a corresponding user ID, and start as well as end odometer readings.
5. Entered fuel information must be saved in the database table.
6. Appropriate messages must be displayed to all users.
7. The website must be stable, with proper error/exception handling functionality.

4.5.6 Basic Architecture of Website

Front-end user interface was developed using Adobe Flash Builder 4, using Adobe Flex 4 language. It interacts with an amfPHP module, using remote object and calls

functions written in a PHP file. The PHP file at the back end interacts with MySQL database. First, the PHP file prepares the database connection and then executes the appropriate SQL query in the database. Once it retrieves the data from the database, it is sent back to Adobe Flex module, using a remote object. As soon as Adobe Flex language retrieves the data, it uses it for display purposes, using such various components as data grids and charts.

Technical Specifications

This section identifies the major technical components that can be used to develop the desired product. Technical components were chosen such that all the functionalities identified in the functional requirements section were achieved. Basic technical specifications are as follows. The website must have:

1. A search box in order to enter the User ID.
2. A search button to click in order to search the data related to specific User ID.
3. A data grid to display the retrieved data from the database.
4. A submission form must be present to submit fuel information.
5. A PHP file to create functions that retrieve specific data.
6. SQL queries designed to retrieve specific data, using the 'where' clause.
7. Action script files to handle the data between amfPHP and the Adobe Flex module.

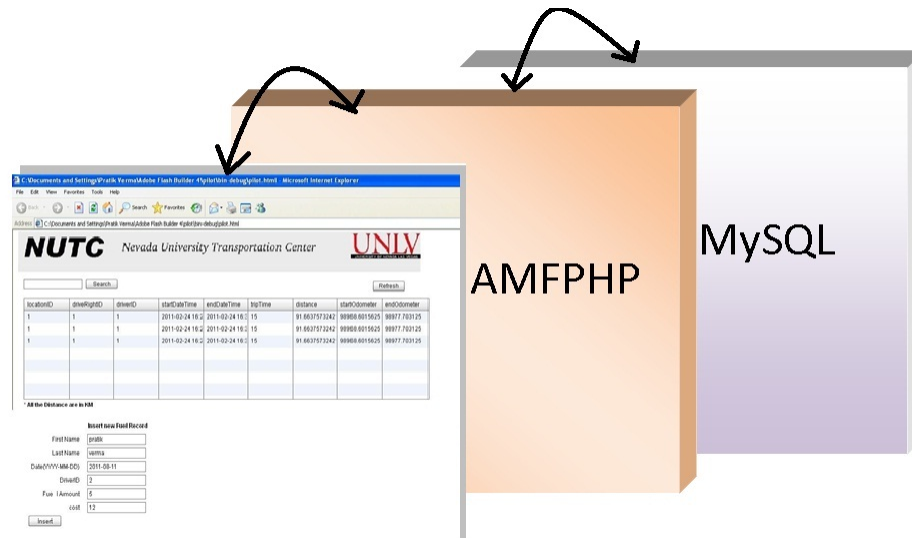


Figure 4.8: High-level overview of front-end and back-end technical layers.

Web User Interface

Figure 4.9 below shows the main algorithm used in web user interface. It is based mainly upon the following three components:

1. A request generated using the front-end.
2. A PHP function request to MySQL, based on the user interface.
3. A data retrieval and data display system.

Once the user provides his or her User ID in the search box, the program then takes that User ID to the PHP function. The PHP function prepares a MySQL query based upon the type of request, retrieves the data from the MySQL, and hands it over to the user interface. The user interface displays the retrieved data in a data grid.

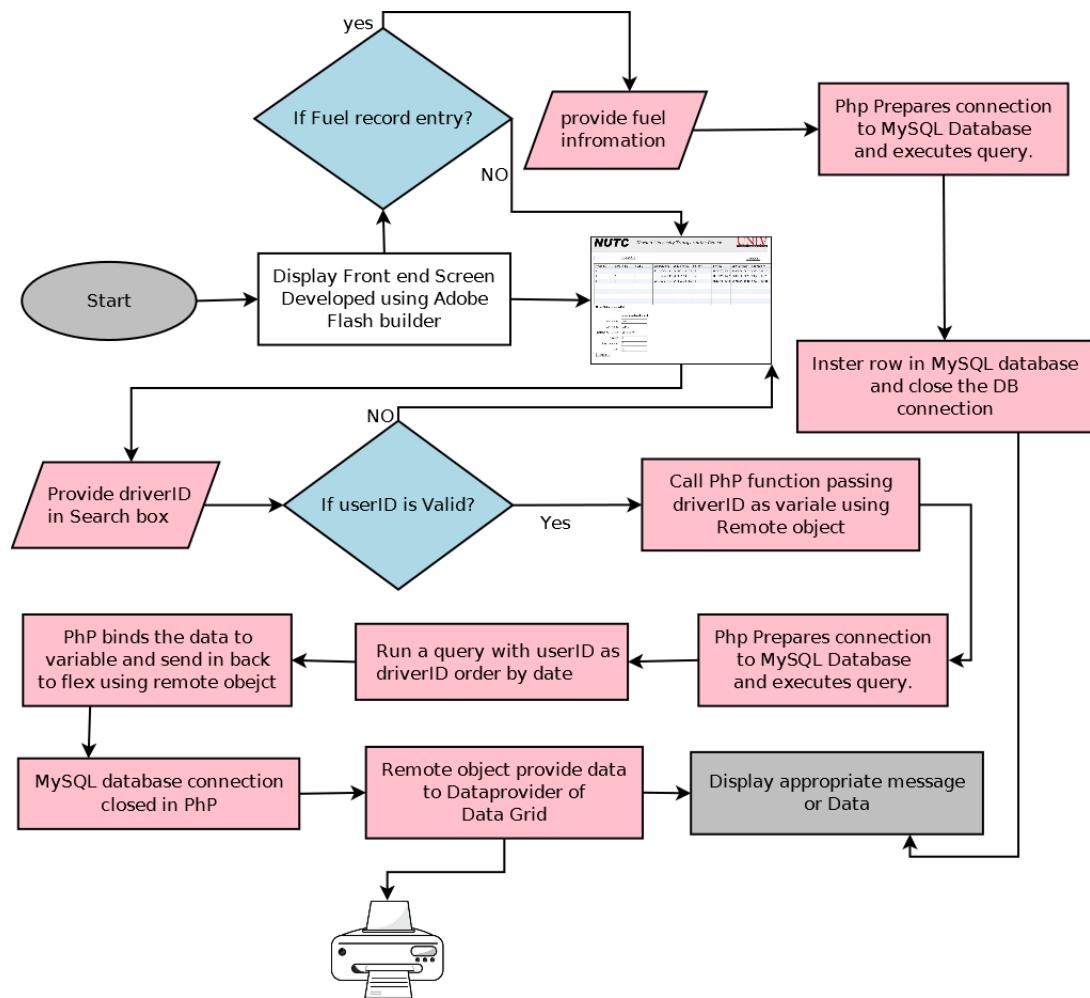


Figure 4.9: Flowchart of the algorithm used in web user interface.

4.6 Conclusion

In conclusion of this chapter, feasibility of VMT has been assured in technical aspect. An integrated system with various independent components can be developed in order to achieve the the required functionality. However, If the CarChip is used to record the distance traveled, a user interface and website for data display must be used to interact with the centralized database of CarChip. As drivers come from all age groups and educational backgrounds, a very user-friendly user interface and website needs to be developed, which must be similar to the existing user interface at gas stations. The user interface that was developed in this study can be used in large-scale multiple terminals to interact with the single database, after slight modifications. The complete system must be robust and reliable to be used on a large scale.

CHAPTER 5

DATA ANALYSIS

5.1 Summary

In this chapter, data has been analysed broadly into three categories: quantitative analysis, qualitative analysis and DMV data analysis. In quantitative analysis, data collected during field test has been analysed in various aspects. In qualitative analysis section, reviews collected phase 1 and phase 2 are analysed and compared in order to analyse major public concerns. DMV data has been also used to analyze to estimate the approximate VMT tax rate.

5.2 Quantitative Data Analysis

In this section data captured during VMT phase 2 will be analyzed. This data has been collected during 3 months period from 10th July 2011 to 20th Oct 2011. Collected data can be broadly classified into two categories of trip data and fuel data. Trip data consists of information regarding all trips of a vehicle. It includes data odometer reading, date, time, distance traveled etc. Fuel data is the data regarding amount of gas purchased by each vehicle. It also consists of number of trips to gas station of each vehicle. Yearly revenue generated by VMT tax based on the

captured data has been estimated. A prepaid payment plan for VMT tax has also been proposed in this chapter.

5.2.1 Introduction

In VMT phase odometer data has been captured using a commercial product “CarChip Flee pr” developed by Davis instruments. This data has been collected during 3 months period from 10th July 2011 to 20th Oct 2011. Data regarding each trip of vehicle has been captured using “Carchip” based on OBD II port of vehicle. A receiver (“Base station” component of ”Carchip” setup) used to download the captured data from “Carchip” installed in the vehicle. This downloaded data is stored MS-Access data base using Fleet management software (FMS). As part of the field test participants were requested to key in amount of gas purchased every time come to gas station. They were also requested to drop all their gas receipts in box during the study. This data has been manually keyed in from all the receipts. We have captured mainly there parameters User ID; Date when gas was filled; and Amount of gas purchased from the receipts . It also consists of number of trips to gas station of each vehicle.

5.2.2 Data preparation

As the data captured by CarChip was stored in MS-Access database. This data was manually converted into MySQL data base. This data had three main tables Driver Table; Vehicle Table; and Trips Table. Driver table consist all relevant in-

formation about driver for example driver name, driver ID, vehicle ID etc. Whereas vehicle table contains all the relevant information about vehicle for example color of vehicle, model year, fuel type etc. We have configured all the CarChip assuming that a unique driver owns a unique vehicle. No driver owns more than one vehicle and No vehicle is driven by more than one driver. For data analysis, Trips table of the data base has been focused upon. It has information related to all the trips made by a particular vehicle. Each time between vehicle engines being ON to OFF is considered as one trip. It contains important parameters like travel time, distance traveled, idle time, driver ID, start odometer reading, end odometer reading etc. We have extracted eight most important parameters for the analysis. The sample data used in basic data analysis contains all the eight parameters (e.g.: travel time, distance traveled, idle time, driver ID, start odometer reading, end odometer reading etc.). This data describes the trip time in minutes while the distance is KM*10. Hence we have converted the data into miles for analysis purpose. As part of the field test participants were requested to key in amount of gas purchased every time come to gas station. We have captured mainly there parameters from the receipts. The sample data entered using fuel receipts of participants consists of User ID; Date when gas was filled; and Amount of gas purchased in gallons.

5.2.3 Data Analysis

The basic data analysis has been done using data analysis software “The R Project for Statistical Computing” in Linux. Data was fed in CSV format into the software

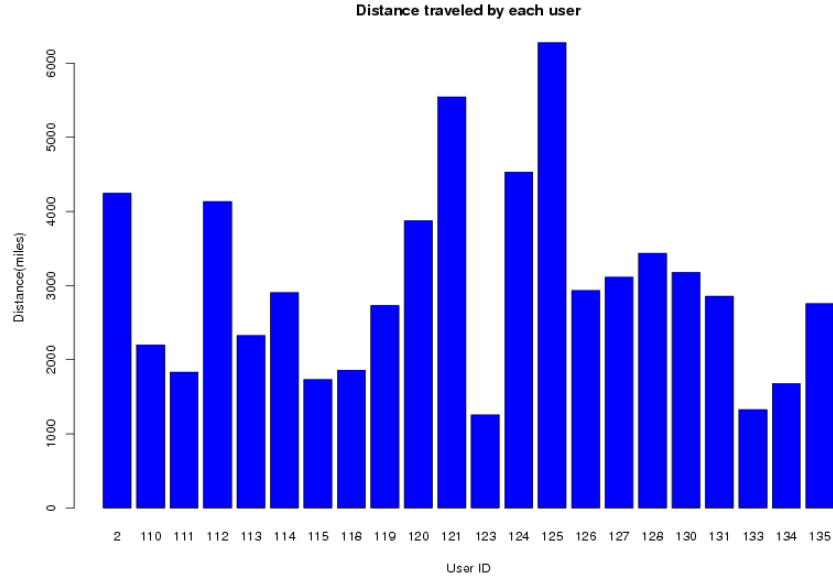


Figure 5.1: Distance traveled by Each User.

and basic frequency analysis was done.

Distance Traveled by Each user:

The data has details regarding all the trips made by every user during the period of study. We have come estimated total distance traveled by each user during the period of study. Average VMT per user can be estimated using this analysis results. Below figure 5.1 describes the approximate distance (in miles) traveled by each user over a period of 90 days. Though we have data of approximately 100 days from 10h July 2011 up to 20th Oct 2011 but we kept the duration of study as 90 days for data analysis. This Assumption nullifies the effect of error induced due to time consumed in installation and uninstallation of devices (“CarChip”) in the cars.

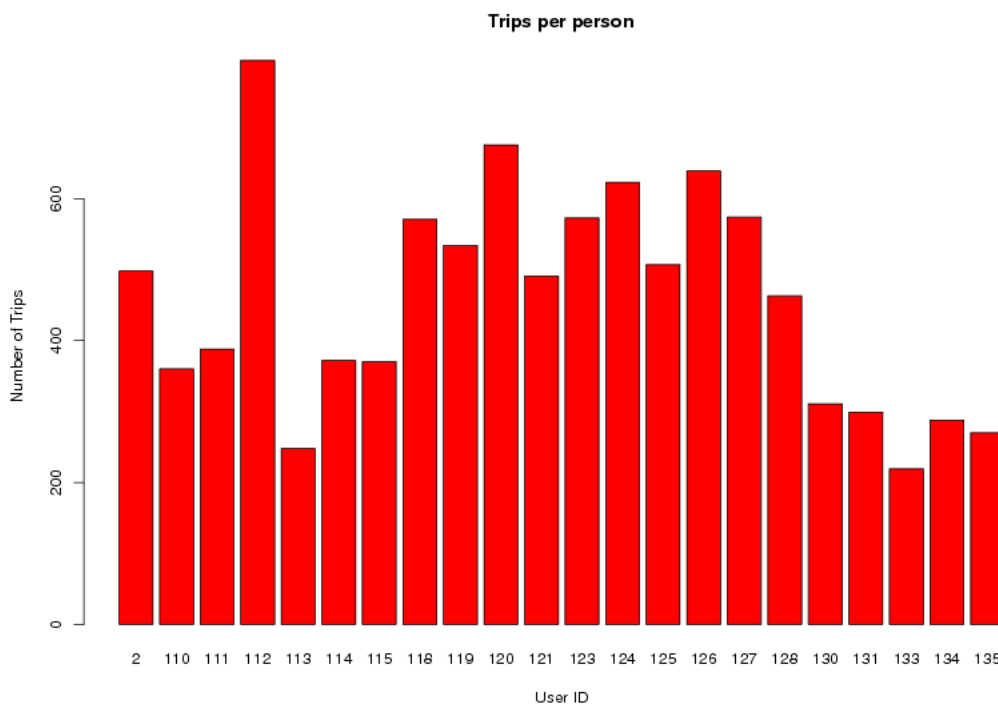


Figure 5.2: Trips per person.

The distance mentioned in the above figure 5.3 is the distance traveled by each user in multiple trips we have estimate approximate number of trips by each user over the period of 90 days. We have also estimate average number of trips per user per day. Below figure 5.2 shows the total number of trips by each user over a period of 90 days.

From the above analysis we have estimated 4 trips per user per day. Now the distance traveled in each trip needs to be estimate. We have identified the the distance travelled by each user in one trip. Below figure 5.3 shows the distance (in miles) traveled in one trip by each user. Based on the above analysis we have estimated the

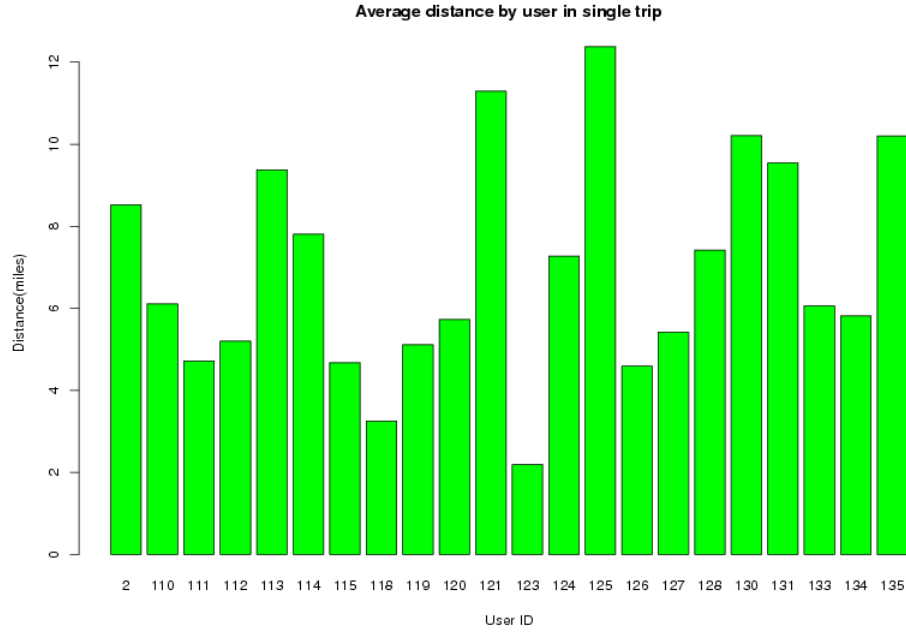


Figure 5.3: Average distance.

average distance of 7.5 miles is traveled by user in one trip.

Note: User 116 dropped out from field study and there were hardware issue identified for user 117 and 132. Hence data for user ids 116,117,132 was not included in analysis.

Estimation of VMT Tax per year

We have assumed certain parameters to come up with a simple and basic design to estimate the VMT tax per year. These assumptions depend upon the availability of relevant information, simplicity of the design, linear extrapolation and parameters with potential impact on cost estimate. Change in any of the assumptions may have

a significant potential impact on the estimated cost.

Basic Assumptions

1. People from age group 18-65 have one vehicle per person.
2. One Driver owns a single vehicle.
3. A unique vehicle is assigned to unique Driver.
4. VMT tax rate has been assumed 2cents per miles.

Population has been estimated based on <http://www.census.gov/>. Population in Nevada = 2,643,085 Of the total population, 74.1 percent people fall in the above 18 years category and 11.3 percent people fall in the below 65 years category. So people between 18 years old and 65 years old constitute $74.1 - 11.3 = 62.8$ percent of the population.

Total population in Nevada	2,643,085
People above 18 and below 65	62.8%
Estimate of number of users	1,659,857
Average number of trips per user per day	5
Average distance (in miles) traveled by user per trip	6.9
Distance traveled (in miles) per day per user	34.5
Distance (in miles) traveled per user per year	12,592.5
Average VMT per user per year	12,592.5
Total number of estimated users	1,659,857
Average VMT in state of Nevada	20,901,749,272.5 (Miles)
VMT tax rate (\$/mile)	0.02
Total VMT tax per year in Nevada	418,034,985.45 \$0.418 billion

Table 5.1: VMT Tax Estimation

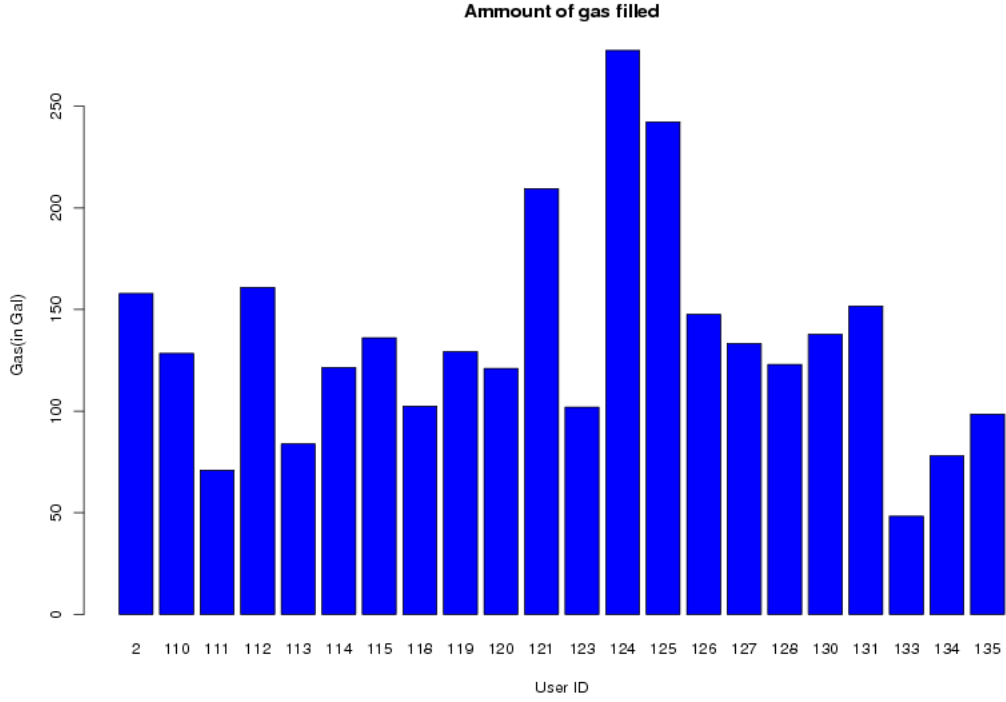


Figure 5.4: Amount of Gas filled.

5.2.4 Gas Data Analysis

As we have the data regarding each trip to gas station of each participant. We have estimated the total amount of gas filled by each of user during period of 90 days. Below figure 5.4 shows the total amount of gas filled by each participant. This contains data of participants filing big amount of gas and also data of the participants who have bought less of amount of gas during this period. We have also estimated the no of trips to the gas station of participants. By number of trips to the gas station and amount the total amount of gas taken we have calculated the average number of trips to the gas station and average amount of gas filled by single participant.

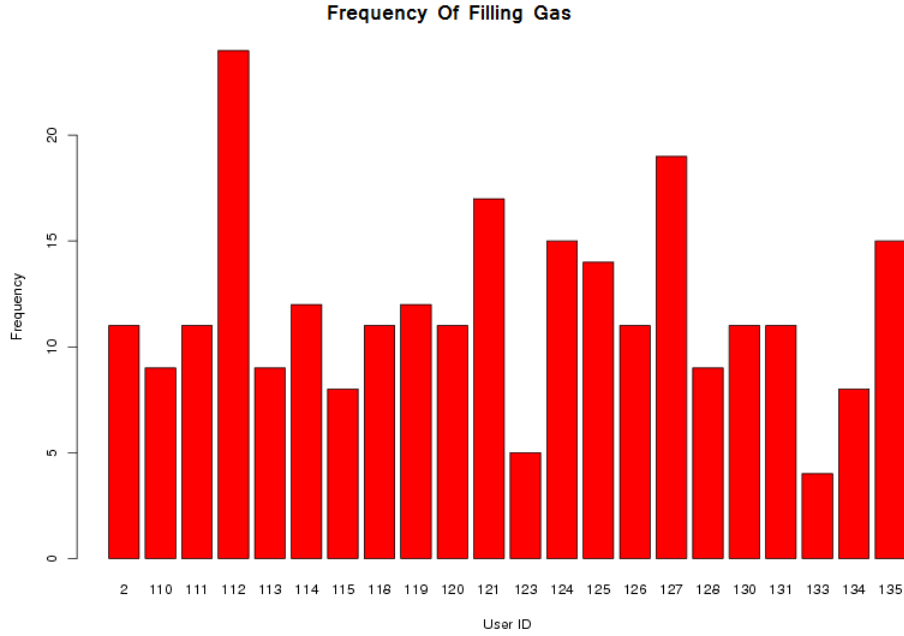


Figure 5.5: Frequency of filling Gas.

The total number of trips to the gas station is reflected in the figure 5.5 below. It reflect the number time participant has filled gas during this period.

Note: Some of the fuel data has been imputed for users (user ID 111,121,125,135) based upon their frequency of filling the gas. For these users, there was a large amount of traveled miles were recorded on certain dates with no corresponding fuel receipts. The missing fuel data has been estimated based on the average fuel efficiency estimated based on the available data. User 116 dropped out from field study and there were hardware issue identified for user 117 and 132. Hence data for user ids 116,117,132 was not included in analysis.

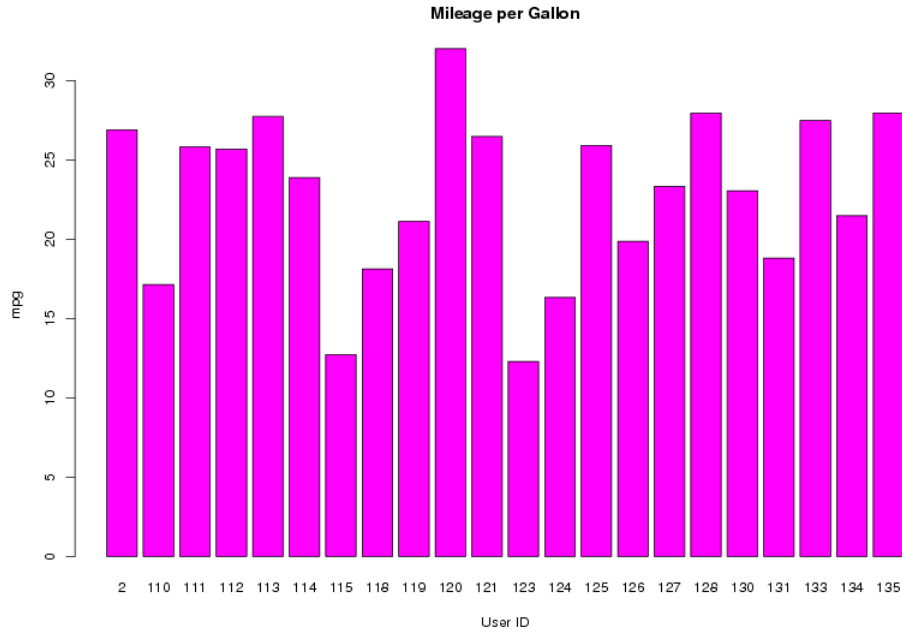


Figure 5.6: Fuel Efficiency.

5.2.5 Fuel Efficiency

Based on the above data, fuel efficiency has been estimated for each individual vehicle. Figure 5.5 below shows the estimated fuel efficiency of each vehicle. The fuel purchased in every trip to gas station is for future requirement while the travel data recorded represents the past travel history. Keeping this constraint in mind, approximate fuel efficiency for each vehicle has been estimated based upon their driving behavior and amount of gas filled during the study. Average fuel efficiency of 22.8 miles per gallon has been estimated based on the available data.

5.2.6 Estimation of GAS Tax per year:

We have assumed certain to estimate the fuel tax per year. These assumptions depend upon the availability of relevant information, simplicity of the design, linear extrapolation and parameters with potential impact on cost estimate. Change in any of the assumptions may have a significant potential impact on the estimated cost.

Basic Assumptions

1. People from age group 18-65 have one vehicle per person.
2. One Driver owns a single vehicle.
3. A unique vehicle is assigned to unique Driver.
4. fuel tax rate has been assumed 52cents per gallon

Total population in Nevada	2,643,085
Total Population of nevada	2,643,085
Estimate of number of users	1,659,857
Average number of gallons filled per user in 90 days (in gallons)	150.46
Amount of gas purchased in 365 days (in gallons)	610.19
Total amount of gas purchased (in gallons)	1,012,828,142.83
Gas tax rate in \$ per gallon	0.52
Net amount of gas tax generated per year	\$ B 0.527

Table 5.2: GAS Tax Estimation

5.3 Prepaid Plan of VMT tax payment based upon estimate

As of now the plan of VMT tax payment is based on actual vehicle miles travelled. In current plan whenever a vehicle goes to station to fill the gas, it is required to pay its VMT tax based upon its previous distance travelled whereas the amount of gas filled will be according to future estimate. So if a user fills less amount of gas during this time still he has to pay the complete tax based upon his previous distance travelled. So we need a payment plan which can estimate the future VMT tax based upon the amount of gas filled at a time.

5.3.1 Proposed Solution:

In this plan VMT (vehicle mile travel) will be estimated based upon the amount of gas filled (Gal) and average estimated value of mileage of vehicle (Miles per Gal). This amount of Tax will be collected along with the gas price. When vehicle goes to gas station next time and fills the gas, actual VMT tax will be calculated based upon actual distance travelled. Variation would be calculated in estimated and actual value of VMT tax. Again this time future VMT tax would be the estimated based on the amount of gas filled and mileage of vehicle but it would also adjust the variation in Tax amount from previous time. This repetitive process would help in collective estimated VMT tax on every trip to gas station based on the amount of fuel taken and fuel efficiency of vehicle. This would help consumer in paying VMT tax in multiple installments rather than paying whole amount of tax in single installment.

5.3.2 Prepaid payment model

First Trip to gas station

$$M = G.Mp$$

$$VTes = M.r$$

$$VTac = Vac.r$$

$$VTer = VTac - VTes$$

Next trip onwards at Gas Station:

$$VTes = M.r + VTer$$

where

Mp = Mileage in miles/gal, M = Total number of miles, G = Amount of gas in gal,
 r = VMT Tax rate in dollar per mile, $VTes$ = Estimated VMT Tax, $VTac$ = Actual
VMT Tax, $VTer$ = Variance in Tax, Vac = Actual VMT.

5.3.3 Prepaid Payment plan using Actual Data:

Here we have analyzed the data for the prepaid payment plan for a particular user. We have estimated the distance traveled based upon the amount of fuel purchased and mileage information. This information has been estimated from the fuel data collected during phase 2 of the study.

5.3.4 Actual Payment plan:

Actual VMT tax has been estimated from the data captured using CarChip. Amount of VMT tax has been calculated for all the trips to gas station. Below is the figure 5.8 represents the estimated VMT and estimated VMT tax and the actual VMT and actual VMT tax. We have calculated payment installments based on the following assumptions:

1. Mileage of car has been assumed 23 miles per gallon.
2. During first trip to gas station amount of gas in the car is NOT taken into account.
3. VMT tax rate has been assumed 2 cents per mile.

Figure 5.7 below describes the estimated VMT and estimated VMT tax based upon amount of fuel purchased and mileage.

As per model, the basic parameter values are mentioned below for second transaction.

Variables: Estimated Mileage of Vehicle = 23 miles/gal Amount of gas = 6.96 gal
VMT Tax rate= \$ 0.02 /mile Estimated VMT Tax = 160.08 Actual VMT Tax = 179.4 Variance in Tax = \$ 0.94

Due to big difference in the amount of payment in each trip, we have come up with plans to regulate the amount of payment in each trip to the gas station. This would help in reducing extra burden from user. Instead of paying big amount in some of trips and small amount in some of the trips, user would be paying an approximately uniform amount in each trip. Though amount of tax collected is nearly uniform in these plans but net amount of tax payment will be same.

ID	Trip to Gas Station	Amount of Gas Purchased gal	Assumed Fuel Efficiency	Estimated VMT	Estimated VMT Tax	Actual VMT	Actual VMT Tax	Error	Final Tax
112	8/6/2011	7.14	23.00	164.31	3.29	0.00	0.00	-3.29	3.29
112	8/9/2011	6.96	23.00	160.08	3.20	117.00	2.34	0.95	2.26
112	8/11/2011	7.80	23.00	179.40	3.59	149.00	2.98	-0.72	4.31
112	8/13/2011	7.14	23.00	164.22	3.28	89.00	1.78	2.53	0.75
112	8/18/2011	7.18	23.00	165.14	3.30	222.60	4.45	-3.70	7.00
112	8/19/2011	7.19	23.00	165.37	3.31	59.00	1.18	5.82	-2.52
112	8/23/2011	7.19	23.00	165.37	3.31	208.00	4.16	-6.68	9.98
112	8/25/2011	6.88	23.00	158.24	3.16	150.20	3.00	6.98	-3.81
112	8/27/2011	6.96	23.00	160.08	3.20	96.00	1.92	-5.73	8.94
112	9/5/2011	6.46	23.00	148.58	2.97	413.00	8.26	0.68	2.30
112	9/7/2011	8.36	23.00	192.28	3.85	83.80	1.68	0.62	3.23
112	9/9/2011	6.50	23.00	149.50	2.99	127.00	2.54	0.69	2.30
112	9/17/2011	6.76	23.00	155.43	3.11	391.00	7.82	-5.52	8.62
112	9/22/2011	6.81	23.00	156.63	3.13	251.70	5.03	3.59	-0.46
112	9/24/2011	6.81	23.00	156.63	3.13	163.70	3.27	-3.73	6.86
112	9/26/2011	6.79	23.00	156.17	3.12	128.30	2.57	4.30	-1.18
112	9/29/2011	6.85	23.00	157.57	3.15	201.90	4.04	-5.21	8.36
112	10/2/2011	6.85	23.00	157.57	3.15	89.70	1.79	6.57	-3.42
112	10/8/2011	6.95	23.00	159.76	3.20	361.40	7.23	-10.65	13.84
112	10/11/2011	6.83	23.00	157.09	3.14	113.00	2.26	11.58	-8.44
					64.59				
	Total Gas Purchased	140.41		Total Distance Traveled		3415.30	68.31		
						Total VMT Tax Paid			62.23

Figure 5.7: Actual Payment Plan.

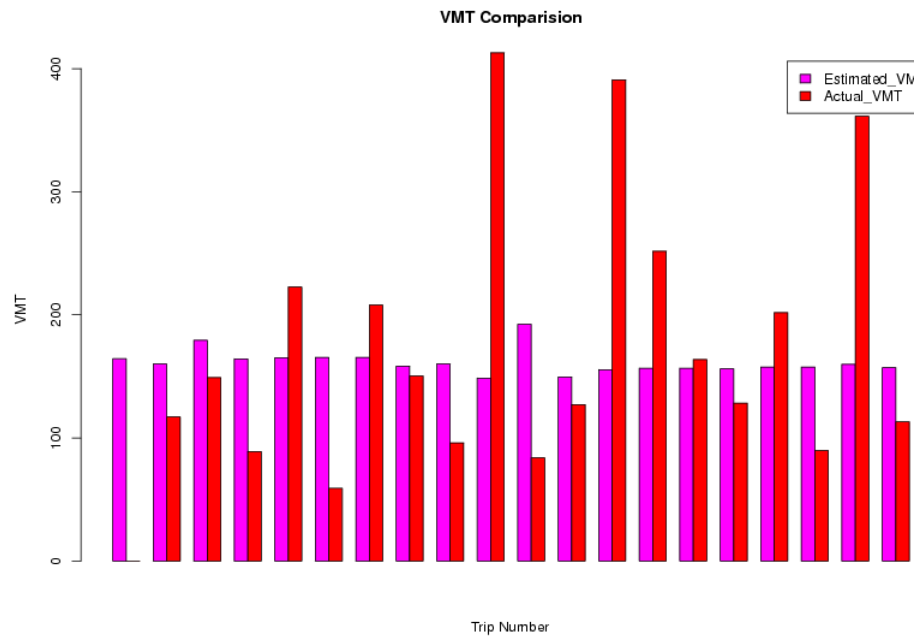


Figure 5.8: Estimated Vs Actual VMT.

5.3.5 50% Payment Plan

The main feature of this plan is that user has to pay only half of the amount in any trip to gas station. The other half of the payment would be adjusted during his next visit to the gas station. Once the total amount of tax has been estimated as in case of previous plan, User only pays half of his final payment and rest half would be treated as pending payment. This pending payment is added to final payment of the next visit and again user pays only half this payment. Figure 5.9 below shows the comparison between the final amount and the paid amount. The yellow column named Final tax shows the amount of tax in \$, calculated in the previous plan based upon the Actual payment while the column named 50% paid displays the amount of payment after plan implementation. Note: It has been assumed that user pays his first installment in full.

Below figure 5.10 displays that after implementing this payment plan peaks of payment went down in each trip to gas station. This shows that a uniform payment amount is charged in all the trips place of big amounts in some of the trips.

5.3.6 Plan1 (Simple Moving Average at 3):

In this plan we have used the methodology of simple moving average over the amount of 3 trips. This way a user pays the actual amount during his first trip. During his second trip to the gas station he pays the average amount of actual tax during first two trips. Third time onwards, user is charged only an average amount of the payment due in this trip to gas station and the payment of last two trips.

ID	Trip to Gas Station	Amount of	Estimated VMT	Estimated VMT Tax	Actual VMT	Actual Tax	Final Tax	50% Paid	50% Pending
		Gas Purchased							
		gal							
112	8/6/2011	7.14	164.31	3.29	0.00	0.00	3.29	3.29	0.00
112	8/9/2011	6.96	160.08	3.20	117.00	2.34	2.26	1.13	1.13
112	8/11/2011	7.80	179.40	3.59	149.00	2.98	4.31	2.72	2.72
112	8/13/2011	7.14	164.22	3.28	89.00	1.78	0.75	1.74	1.74
112	8/18/2011	7.18	165.14	3.30	222.60	4.45	7.00	4.37	4.37
112	8/19/2011	7.19	165.37	3.31	59.00	1.18	-2.52	0.93	0.93
112	8/23/2011	7.19	165.37	3.31	208.00	4.16	9.98	5.45	5.45
112	8/25/2011	6.88	158.24	3.16	150.20	3.00	-3.81	0.82	0.82
112	8/27/2011	6.96	160.08	3.20	96.00	1.92	8.94	4.88	4.88
112	9/5/2011	6.46	148.58	2.97	413.00	8.26	2.30	3.59	3.59
112	9/7/2011	8.36	192.28	3.85	83.80	1.68	3.23	3.41	3.41
112	9/9/2011	6.50	149.50	2.99	127.00	2.54	2.30	2.86	2.86
112	9/17/2011	6.76	155.43	3.11	391.00	7.82	8.62	5.74	5.74
112	9/22/2011	6.81	156.63	3.13	251.70	5.03	-0.46	2.64	2.64
112	9/24/2011	6.81	156.63	3.13	163.70	3.27	6.86	4.75	4.75
112	9/26/2011	6.79	156.17	3.12	128.30	2.57	-1.18	1.79	1.79
112	9/29/2011	6.85	157.57	3.15	201.90	4.04	8.36	5.08	5.08
112	10/2/2011	6.85	157.57	3.15	89.70	1.79	-3.42	0.83	0.83
112	10/8/2011	6.95	159.76	3.20	361.40	7.23	13.84	7.34	7.34
112	10/11/2011	6.83	157.09	3.14	113.00	2.26	-8.44	-0.55	-0.55
								62.78	
	Total Gas Purchased	140.41	Total Distance Traveled		3415.3				
					Total VMT Tax Paid		62.23		

Figure 5.9: 50 percent payment plan.

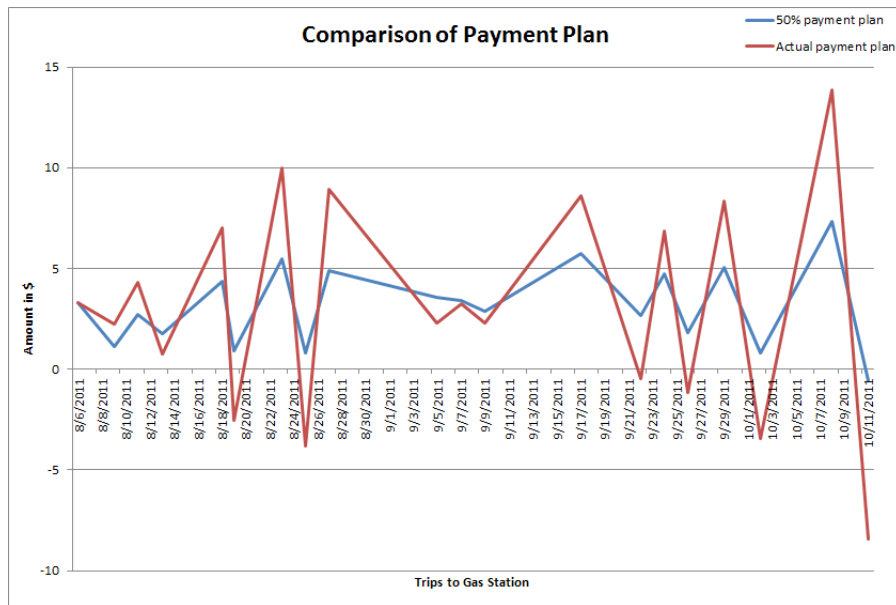


Figure 5.10: Actual Payment Plan Vs 50 percent Payment Plan.

ID	Trip to Gas Station	Amount of Gas Purchased gal	Estimated VMT	Estimated VMT tax	Actual VMT	Actual Tax	Final tax	Payment at Gas Station (moving avg at 3)	Pending Payment (moving avg at 3)
112	8/6/2011	7.14	164.31	3.29	0.00	0.00	3.29	3.29	0.00
112	8/9/2011	6.96	160.08	3.20	117.00	2.34	2.26	2.77	-0.52
112	8/11/2011	7.80	179.40	3.59	149.00	2.98	4.31	3.28	1.03
112	8/13/2011	7.14	164.22	3.28	89.00	1.78	0.75	2.44	-1.69
112	8/18/2011	7.18	165.14	3.30	222.60	4.45	7.00	4.02	2.98
112	8/19/2011	7.19	165.37	3.31	59.00	1.18	-2.52	1.75	-4.26
112	8/23/2011	7.19	165.37	3.31	208.00	4.16	9.98	4.82	5.16
112	8/25/2011	6.88	158.24	3.16	150.20	3.00	-3.81	1.22	-5.03
112	8/27/2011	6.96	160.08	3.20	96.00	1.92	8.94	5.03	3.90
112	9/5/2011	6.46	148.58	2.97	413.00	8.26	2.30	2.47	-0.18
112	9/7/2011	8.36	192.28	3.85	83.80	1.68	3.23	4.82	-1.59
112	9/9/2011	6.50	149.50	2.99	127.00	2.54	2.30	2.61	-0.30
112	9/17/2011	6.76	155.43	3.11	391.00	7.82	8.62	4.72	3.91
112	9/22/2011	6.81	156.63	3.13	251.70	5.03	-0.46	3.49	-3.95
112	9/24/2011	6.81	156.63	3.13	163.70	3.27	6.86	5.01	1.85
112	9/26/2011	6.79	156.17	3.12	128.30	2.57	-1.18	1.74	-2.92
112	9/29/2011	6.85	157.57	3.15	201.90	4.04	8.36	4.68	3.68
112	10/2/2011	6.85	157.57	3.15	89.70	1.79	-3.42	1.26	-4.68
112	10/8/2011	6.95	159.76	3.20	361.40	7.23	13.84	6.26	7.58
112	10/11/2011	6.83	157.09	3.14	113.00	2.26	-8.44	0.66	-9.10
							Net Amount	66.35	
	Total Gas Purchased	140.41	Total Distance Traveled	3415.30			Net Error	-4.13	
					Total VMT Tax Paid	62.23			

Figure 5.11: SMA at 3 Payment Plan.

Payment due during i th trip $= p_i$

Amount charged during first trip $T_1 = p_1$

Amount charged during second trip $T_2 = (p_1 + p_2)/2$

Amount charged during third trip $T_3 = (p_1 + p_2 + p_3)/3$

Next time onwards amount charged $T_i = (p_i + p_{i-1} + p_{i-2})/3 ; i \geq 3$

Below figure 5.12 shows the difference between the 50% payment plan and the plan with moving average at 3. This way we could have more uniform fee even in comparison to the 50% payment plan. At the end of the 20th trip the net amount charged is \$ 66.35 and the net error is\$ 4.12 which is nearly same the amount of final tax of 62.27 \$. Peak payment went down up to\$ 6.26 in this plan whereas in case of

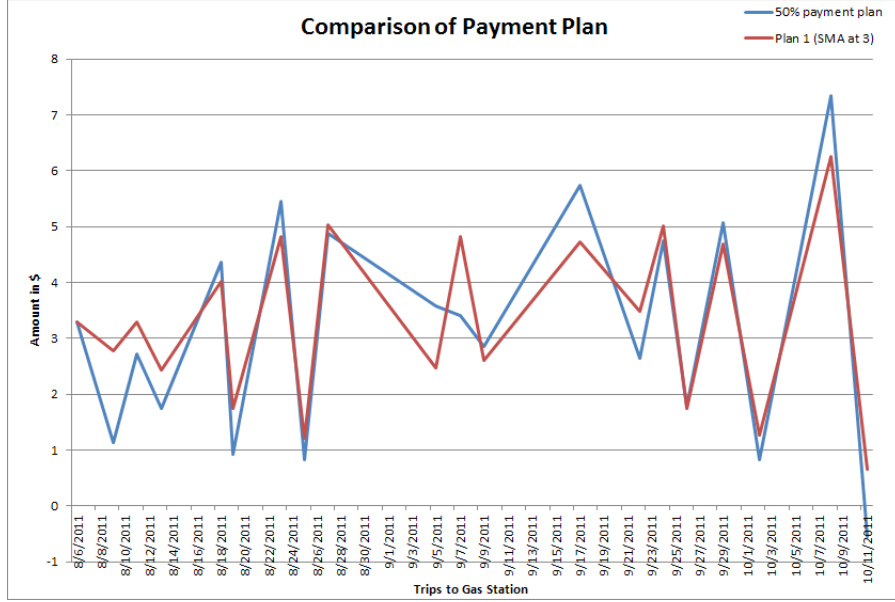


Figure 5.12: SMA at 3 Payment Plan Vs 50 Percent Payment Plan.

50% payment plan peak value was \$ 7.33

5.3.7 Plan 2 (Simple Moving Average at 5):

In this plan we have used the methodology of simple moving average over the amount of 5 trips. This way a user pays the actual amount during his first trip. During his second trip to the gas station he pays the average amount of actual tax during first two trips. This way average amount of last trips was charged till the fifth trip. Fifth trip onwards, the average amount of the current trip and last forth trips is charged.

Payment due during i th trip = p_i

Amount charged during first trip $T_1 = p_1$

Amount charged during second trip $T_2 = (p_1 + p_2)/2$

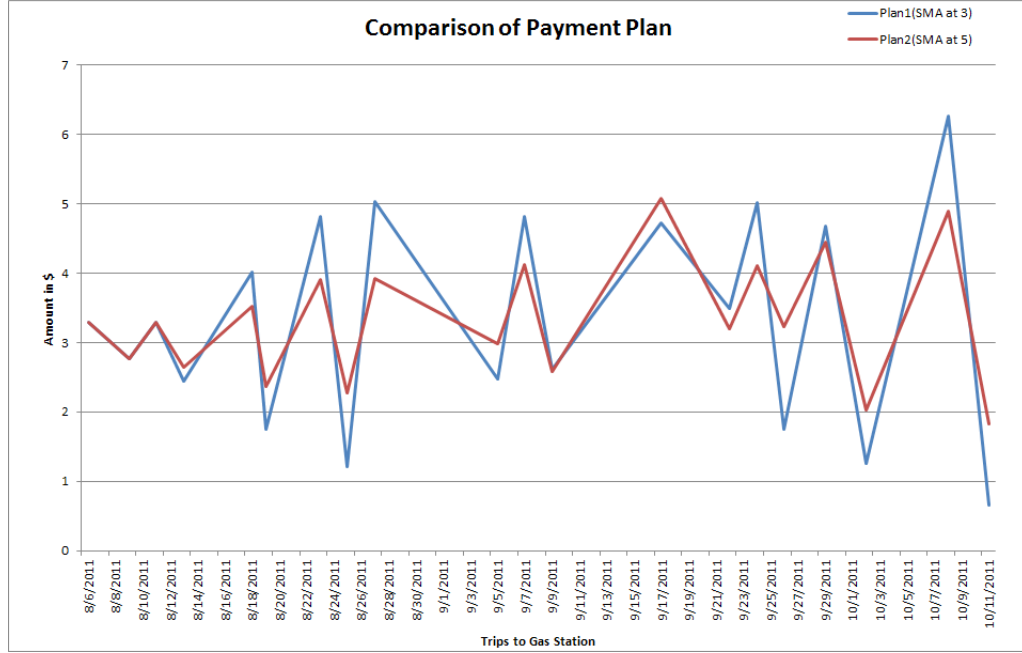


Figure 5.13: SMA at 3 Payment Plan Vs SMA at 5 Payment Plan.

Amount charged during third trip $T_3 = (p_1 + p_2 + p_3)/3$

Amount charged during forth trip $T_3 = (p_1 + p_2 + p_3 + p_4)/4$

Next time onwards amount charged $Ti = (p_i + p_{i-1} + p_{i-2} + p_{i-3} + p_{i-4})/5; i \geq 5$

Below figure 5.13 shows the difference in amount charged between Plan 1 (SMA at 3) and the plan 2 (SMA at 5). This way we could have more uniform fee charged at every trip. At the end of 20th trip the net amount charged is \$ 66.50 and the net error is 4.27 \$ which is nearly same as the net amount of final tax of \$ 62.27. Peak payment went down up to \$ 5.01 in this plan whereas in case of Plan1 (SMA at 3) peak value was \$ 6.26.

5.3.8 Conclusion

Above data analysis show the fuel tax generated based on the data collected per year is approximately \$ B 0.527 per year in Nevada whereas if VMT is collected at the rate of 2 cents per mile the amount of tax collected would be \$ B 0.418. Based on the above analysis if VMT tax rate is kept 2.5 cents per mile, Amount of VMT tax collected would match the amount of gas tax. Using prepaid plan we can provide flexibility and transparency to the user in paying tax in multiple installments.

5.4 Qualitative Data Analysis

In this section the data related to public opinion, comments regarding VMT have analyzed. As part of the VMT fee study NDOT (Nevada Department of Transportation) has conducted several public meetings and workshops in order to bring awareness about VMT in several groups. These public meetings and workshops have been conducted in both phase 1 and phase 2 of the study. The comparison between data of phase 1 and phase 2 helps us to draw significant conclusion in order to cross check that up to what extent issues raised in phase 1 have been addressed in Phase2. It also shows change in public perspective towards VMT in Phase 1 and phase2. It helps us in giving concrete input to policymakers and other stakeholders. Qualitative analysis has been done using commercial software “Leximancer”. As result of this comparison we have seen that privacy concern has significantly gone down in phase 2 as compared to phase 1. In phase 2, public is much interested in knowing the technicality of system rather than having concern about “privacy”. People are more

concerned about road damage in phase 2 where as in phase 1, administration was one of the major concerns.

5.4.1 Introduction

In Phase 1 of VMT field test, NDOT has conducted two public meetings in Las Vegas and Reno and two workshops. The main objectives of these workshops and public meetings were to bring awareness about VMT and to collect public feedback on the same. As result of the feedback collected during these meetings major public concerns were identified. These public concerns were targeted to be addressed in next phase (i.e. phase 2) of VMT. After incorporating public comments, NDOT has conducted public meetings and workshops in Phase 2 as well to get public feedback based upon their experience in phase 2. During these meetings and workshops were participants were requested to provide their comments, concerns in feedback forms. Various people belonging to different groups submitted their input via email. Hence we have analyzed the collected set of data in both the phases and compared the results of analysis.

5.4.2 Technical Details

As comments received in both the phases were in form of unstructured text. We required a stronger analytical tool which can analyze unstructured data and provide us with results/conclusion of analysis. We were in need of a technical tool which can go through the unstructured data and analyze the data and public option based

on defined algorithm. After considering multiple options for qualitative we have narrowed down to software Leximancer (<https://www.leximancer.com/>). Leximancer is the data mining software based on machine learning technique to develop concept maps and themes. Leximancer has been used by various marketing and advertising agencies in order to analyze data for efficient decision making. Its algorithm is based on Bayesian theory. Advantages of using Leximancer of plain text data as follows:

1. It can be used on large set of data.
2. Its algorithm automatically identifies the words and concept map around them.
3. It accepts data as pdf/text without data formatting.
4. It is having very user friendly interface to manage the data.
5. It does not require data coding before extraction of concept maps.
6. User defined concept maps can be drawn.
7. Correlation between different seeds can be studied.
8. It displays extracted information visually.

5.4.3 Content Analysis

Content analysis is a research methodology which is used to analyze the data content in text or speech. It helps in determining the physiological state of speaker or writer. It is used in identifying different import words or concepts used in text. In this

methodology the text is divided into broad categories for further analysis. Content analysis techniques can be used over various set of data (i.e. political speech, survey comments etc.) in order to have better understanding. This technique can be used majorly in following areas:-

1. Content analysis regarding political speeches.
2. Determine various propaganda
3. In surveys that have comments and feedback
4. Understanding physiological state of participants.

Content analysis can be broadly classified into two of the following categories:

Conceptual Content Analysis:

In concept analysis strength of a concept is measured based upon the frequency of a particular word or concept. In this case if a word is being used multiple times in in the given text it adds to the strength of a concept. Many words which are related or infer the same meaning in some context could be also linked in one single concept. These concepts can be single words, phrases sentences or collection of words representing one concept. Leximancer has a good functionality of combining multiple words of same context in a single concept. It has its own thesaurus for each map. This functionality reduces user coding effort significantly.

Relational Content Analysis:

n this case, instead of studying relationship of concept map relation with each other co-occurrence of different concepts in the documents are identified. Leximancer automatically identifies such information and provides a visual display of comparison between different concept maps. It displays the main relationship between different concept maps.

Concept Map:

The co-occurrence measure of different concepts is used in generation of concept maps. In Leximancer, concept is a collection of words which are used closely in the whole input text. Each term is weighed based on their occurrence in a sentence and frequency of occurrence in the whole text. These sentences are tagged based on containment of a concept.

Concept seed words:

As per Leximancer, concept seed words are starting point on any concept map. Many of concept seed words are automatically identified from the input text. Each concept can contain one or more seeds. During learning the text software me add more words around the seeds to the definition of concept map. Though Leximancer automatically identifies the main seeds from text but it also provides functionality to user to define seeds manually. A concept map would be generated around these user defined seeds if there are words found in relation with the defined seed. Some major points to

understand the generated concept map by Leximancer.

1. Significance of the color of label: Green: Proper names. White: Locations/actions etc.
2. The brightness of concepts label reflects the frequency of concept in the text.
3. The colored circles on the map are theme of circle. They represents grouping of cluster of concepts.
4. The distance between the two concepts shows the correlation between starting and ending concept via connected nodes.

5.4.4 Data preparation:

In order to prepare data to feed into Leximancer, data has been classified into two major categories.

Pre Data set:

Pre data set is the dataset generated by combining all the relevant comments gathered in phase 1. VMT workshops were conducted in Reno on May 9, 2009 and in Las Vegas on August 19, 2009. There were approximately 20 invitees in each workshop. Participants were divided equally in four groups to collect feedback about various concerns about VMT implementation. In addition to workshops, there were two public meetings in Reno and Clark County. First meeting was held on March 30, 2010 in Reno while the second one was on April 29, 2010 with 75 participants. In

these meetings people were made aware of VMT and reasons for the study. At the end of each meeting a survey was collected from participants for feedback. This feedback data was combined with the data collected from online feedback given by public.

Post Data set:

The post data set consists of the feedback and comments received during phase 2 of VMT study. During phase 2 various people belonging to different groups have provided their comments to stakeholders via email and online form. There were hand written comments also submitted to NDOT. We have manually converted the hand written comments into text. Also, some of the discussion during public meetings was recorded. This recorded data was also converted into text manually. All these data sets we have combined all the comments received in emails and a consolidated document was produced.

One audio recording of VMT public meeting was also available for analysis. Audio file was manually converted into text file with all the comments of participants. The data in this text file was also consolidated with the above data received in emails.

5.4.5 Procedure of Qualitative analysis:

Here we are presenting the major steps of qualitative analysis using Leximancer. First we have to prepare the data to feed it into Leximancer. Then we create a new project and load the prepared data. Two tags Pre_data and Post_data were defined for the data comparison. Then manually some more seeds were inserted in

order to identify the concept map around them. Similar words (e.g. 1. road, roads 2 vehicle, vehicles, cars etc) were combined together to have efficient analysis. These are different steps needs to be followed in order to generate qualitative analysis results.

1. Data preparation.
2. Creating one project in Leximancer.
3. Load the data.
4. Define tags with the name of Datasets.
5. Preprocess data in Leximancer.
6. Manually insert user define seeds.
7. Combine similar words.
8. Generate outputs from leximancer.

5.4.6 Results:

Efficiency of efforts made in phase 2 can be validated based on results of qualitative analysis. As discussed earlier the major concern in case of phase 1 public meetings was privacy. We have identified that now privacy is no more major concern. In phase 2 people are much more concerned about system and road damage. As output, Leximancer generates output as concept map showing connection between various words and concepts. It also show how different words have impact on each other

and correlated to each other. In case of our analysis data has been divided into two categories of phase 1 and phase 2 so concept map has been generated around these tags. Leximancer also provides a functionality to find the correlation coefficient based on the pathway distance of two concepts. Below is the correlation coefficient of different concepts in phase1 and phase 2.

Correlation between Leximancer:

Correlation in Leximancer is based upon the pathway distance between two concepts. Pathway between two concepts describes an indirect relationship between the two concepts. In conceptual space, it is the most likely path via various related concepts from starting concept to the ending concept. First we have to click the starting concept on the concept map in Leximancer it shows all the direct links between starting concepts and other concepts. As soon as the second or end concept is selected in the concept map, a pathway is designed between the starting and the ending concept connecting various other related concepts in between. It also shows the correlation coefficient and the detailed connection between starting and ending concept. Contribution mentioned in front of the each term is based on the weightage of each word to provide an appropriate evidence for the presence of a concept.

Phase 1 correlation with Privacy:

Pathway between the starting concept tag of Phase_one_data to the end concept Privacy. The calculated correlation factor between phase_one_data and privacy based



Figure 5.15: correlation factor.

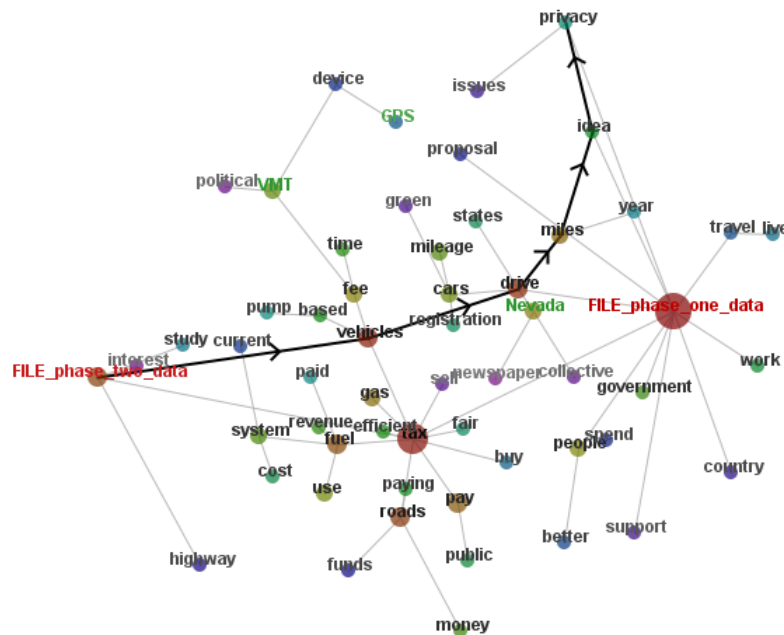


Figure 5.16: pathway between Phase two data to Privacy.

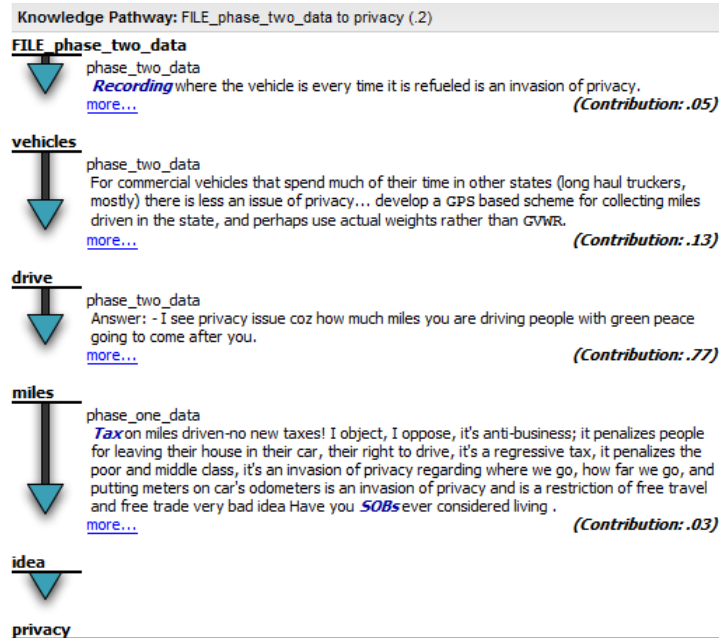


Figure 5.17: correlation factor.

from the phase 1 one data which show comparatively low correlation between phase 2 data and privacy concept. Using the similar methodology below are main correlations between different concepts (like privacy, cost, issues, tax etc.) have been estimated with both the sets of data. Leximancer extracts the various concepts based on textual data in terms of words. Software generates concept maps around these words in order to have better visualization. In our analysis we have identified that above mentioned six different concepts were import in case of both the phases. Concept map can also be interpreted in order to have better understanding of interrelation of various concepts.

5.5 DMV Data Analysis

In this section we are going to discuss our findings from DMV data. We have DMV data for almost three years (2009 to 2011). Many useful parameters are present in this data for the analysis of VMT. We have converted the complete DMV data into MySQL database for basic frequency analysis. There were approximately 1.9 million entries present in this database. We identified different car models from this DMV data and their corresponding odometer reading from the database. Mileage of these car models were also estimated based on information on different internet forums. For each particular car model, gas consumption was estimated based upon the mileage and odometer reading. This gas consumption resulted in estimation of corresponding fuel tax. Hence considering the assumption the current gas tax is equal to VMT tax, VMT tax rate per mile has been estimated.

5.5.1 Introduction

As part of the regular DMV registration process, certain parameters are being recorded by DMV for every vehicle which includes parameters such as odometer read-

Correlation between concepts	Phase1	Phase2
Privacy	. 58	.21
Cost	.73	.41
Issues	.60	.35
Tax	.60	.56
Interest	.26	.90
Government	.88	.25

Table 5.3: Correlation Factor Comparison between Phase 1 and Phase 2

ing, fuel type, inspection data etc. Each vehicle entry can be uniquely identified by a unique VIN number. Vehicle model and vehicle make year are being also recorded.

Parameters Recorded in DMV data:-

Field	Data
1. VIN	1FTNX21P4EB95813
Inspection-Date	2010-08-19
INSPECTION-ZIP-CODE	89434
STATION-COUNTY	WA
ODOMETER-READING	139701
MODEL-YEAR	2004
IVEH-MAKE-CD	FORD
VEH-MODEL	F250 SUPER DUTY
VEH-BODY-STYLE-CD	TC
VEH-NO-OF-CYLS	0008
VEH-FUEL-TYPE	D
VIR-NUM	91
OVERALL-INSPECTION-RESULT	P

Table 5.4: Sample Record of DMV data

DMV data has records of vehicle models starting from 1968 to 2011. We have done basic frequency analysis of number of records related to a particular type of vehicle model year. We observed an expected increase in number of rows of vehicle up to year 2008. There are not many records present in year 2010 and 2011 as these model years are significantly close to our date of data analysis. Query executed: “select count(*), ‘MODEL-YEAR’ from DMVDATA group by ‘MODEL-YEAR’ order by count(*)”

There are two distinct fuel type vehicles present in the DMV data. A) D (diesel) and B) G (Gas). We have identified number of rows present corresponding to each

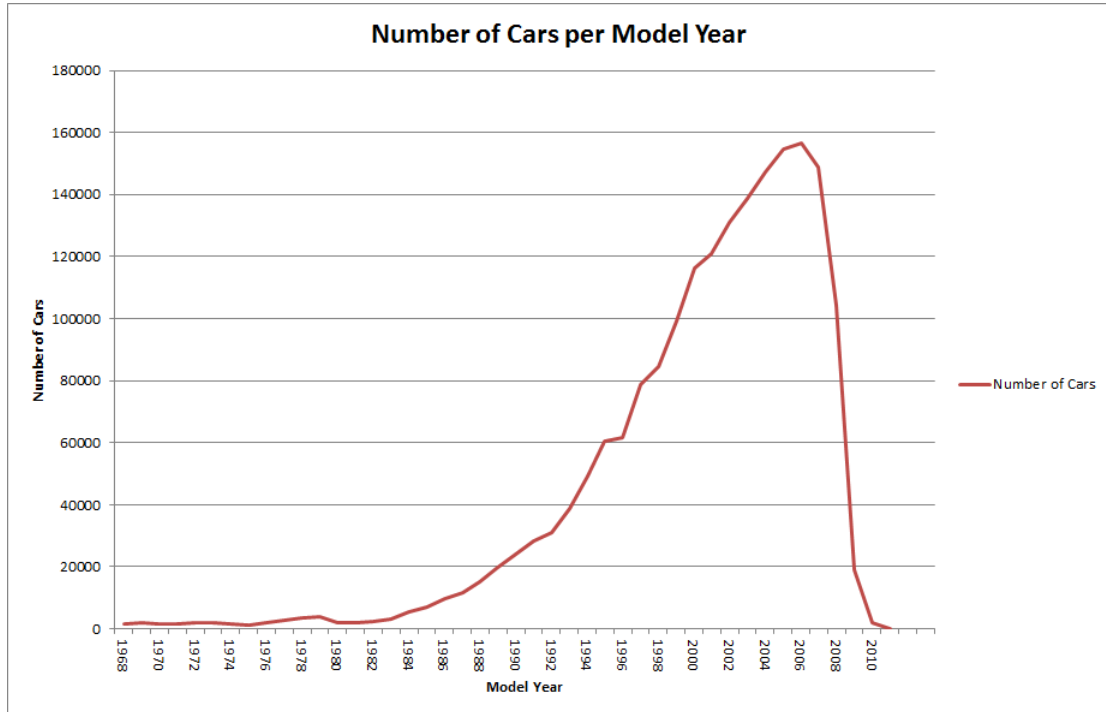


Figure 5.18: No of Cars per Model year.

fuel type in database.

Query executed

“select count(*), ‘VEH-FUEL-TYPE’ from DMVDATA group by ‘VEH-FUEL-TYPE’
”

Field	Data
No. of Vehicles	Fuel Ttype
1881862	G
18138	D

Table 5.5: No. of Vehicles per Fuel Type

We have identified all distinct vehicle models available in this data and selected

14 of them with the maximum number of rows. For these selected vehicle models we estimated their corresponding mileages in MPG (miles per gallon) from various internet forums. Then we evaluated approximate distance Traveled by each type of these models. Once we have approximate mileage in MPG and total number of miles Traveled by each type of vehicle model, we estimated the total amount of gas consumed by each model. Net gas tax was estimated based on the amount of fuel consumed.

5.5.2 Vehicle model selection for Analysis:

There were data entries corresponding to 6889 distinct vehicle models in DMV data. In these distinct vehicle models different versions of same model are considered as different car models e.g. CIVIC LX and CIVIC EX are two different models. There was minimum single data entry for the each model and max 41085 entries for F150 car model. Due to huge number of distinct car models we have selected only those vehicle models for analysis that have more than 10000 entries in DMV data corresponding to them. Below is the list of vehicle models selected for data analysis and data entries corresponding to them in DMV data.

5.5.3 Fuel Efficiency estimation:

For the above selected models we have estimated their mileage in MPG (Miles per gallon) via various internet forums. We have used average of mileage information given in cities/highways. Combined mileage information was also used for some of

the car models. Below is the list of estimated mileage (in MPG) used in analysis corresponding each of the selected vehicle model.

Vehicle Model	Number of entries in data base
F150	41085
RANGER	24886
ACCORD EX	19088
COROLLA CE/LE/S	18080
C1500 SILVERADO	17743
EXPLORER	15031
ACCORD LX	14410
CIVIC LX	13453
MUSTANG	12717
CIVIC EX	12394
F150 SUPERCREW	12361
S10	12268
CAMRY LE/XLE/SE	12049
RAM 1500 QUAD ST/SLT	10651

Table 5.6: Vehicles Selected for Analysis

Vehicle Model	"Efficiency in MPG (Miles per Gallon)"
F150	16
RANGER	17
ACCORD EX	18
COROLLA CE/LE/S	29
C1500 SILVERADO	16
EXPLORER	16
ACCORD LX	23
CIVIC LX	28
MUSTANG	22
CIVIC EX	28
F150 SUPERCREW	13
S10	19
CAMRY LE/XLE/SE	21
RAM 1500 QUAD ST/SLT	14

Table 5.7: Estimated Fuel Efficiency for Each Vehicle Model

5.5.4 Distance Estimation:

Once we estimated the mileage information, we calculated the total distance Traveled by each car of particular vehicle model type. Maximum distance traveled by each unique car of particular model type was fetched from database. Net distance Traveled by cars of particular model was the sum of all these maximum values of odometer reading of particular vin number. These max values were added to get the net distance Traveled by each vehicle model. Below is the table representing net distance Traveled by each type of vehicle:

Vehicle Model	Total Distance
F150	2764380057
RANGER	1591011134
ACCORD EX	1265514908
COROLLA CE/LE/S	797296682
C1500 SILVERADO	1000408958
EXPLORER	1217315859
ACCORD LX	1095737109
CIVIC LX	861206140
MUSTANG	696963027
CIVIC EX	696963027
F150 SUPERCREW	624833836
S10	966861787
CAMRY LE/XLE/SE	578742405
RAM 1500 QUAD ST/SLT	463157192

Table 5.8: Net VMT Estimate for Each Model from DMV Data

5.5.5 Fuel Estimation:

Once we have the total distance Traveled by each type of model and mileage in miles per gallon corresponding to them, we have estimated the total amount of fuel consumed by each type on model in travelling corresponding distance. We have calculated the amount of fuel in gallons assuming linear relationship between distance Traveled and fuel consumed. Following is the amount of fuel in gallons consumed by each type of vehicle in travelling corresponding distance.

Model	Distance(Miles)	Efficiency(MPG)	Fuel(GAL)
F150	2764380057	16	172773753
RANGER	1591011134	17	93588890
ACCORD EX	1265514908	18	70306383
COROLLA CE/LE/S	797296682	29	27492989
C1500 SILVERADO	1000408958	16	62525559
EXPLORER	1217315859	16	76082241
ACCORD LX	1095737109	23	47640743
CIVIC LX	861206140	28	30757362
MUSTANG	696963027	22	31680137
CIVIC EX	696963027	28	24891536
F150 SUPERCREW	624833836	13	48064141
S10	966861787	19	50887462
CAMRY LE/XLE/SE	578742405	21	27559162
RAM 1500 QUAD ST/SLT	463157192	14	33082656

Table 5.9: Fuel Estimation for Each Vehicle Model

5.5.6 Fuel Tax Estimation:

After estimating the net fuel consumed by each type of vehicle models we have calculated the corresponding gas tax associated with each type of vehicle model. We have assumed gas tax to be approximately 52 cents/gallon. Below is the corresponding fuel tax based on fuel consumption of each vehicle model with fuel tax rate 52 cents/gal.

Model	Fuel(GAL)	GasTax rate(\$/mile)	Fuel Tax(\$)
F150	172773753	0.52	89842351.56
RANGER	93588890	0.52	48666222.8
ACCORD EX	70306383	0.52	36559319.16
COROLLA CE/LE/S	27492989	0.52	14296354.28
C1500 SILVERADO	62525559	0.52	32513290.68
EXPLORER	76082241	0.52	39562765.32
ACCORD LX	47640743	0.52	24773186.36
CIVIC LX	30757362	0.52	15993828.24
MUSTANG	31680137	0.52	16473671.24
CIVIC EX	24891536	0.52	12943598.72
F150 SUPERCREW	48064141	0.52	24993353.32
S10	50887462	0.52	26461480.24
CAMRY LE/XLE/SE	27559162	0.52	14330764.24
RAM 1500 QUAD ST/SLT	33082656	0.52	17202981.12

Table 5.10: Fuel Estimation for Each Vehicle Model

5.5.7 VMT Tax Rate Estimation:

Once we have the corresponding fuel tax we have calculated the VMT tax rate (in cents/mile) in order to generate the same amount VMT tax (as fuel tax) correspond-

ing to the same distance Traveled. We have assumed linear relationship between VMT gas tax rate and VMT tax. In this analysis we have estimated the VMT tax rate to generate the same amount of VMT tax as current fuel tax. Once we have estimated the VMT tax rate corresponding to each type of vehicle model, we have taken average of all the corresponding rates to come up with a fixed rate for all type of vehicle models.

Model	Miles	$\frac{FuelTax}{VMTtax}$ =	Rate(\$/mile)
F150	2764380057	89842351.56	0.0325
RANGER	1591011134	48666222.8	0.030588235
ACCORD EX	1265514908	36559319.16	0.028888889
COROLLA CE/LE/S	797296682	14296354.28	0.017931034
C1500 SILVERADO	1000408958	32513290.68	0.0325
EXPLORER	1217315859	39562765.32	0.0325
ACCORD LX	1095737109	24773186.36	0.022608695
CIVIC LX	861206140	15993828.24	0.018571428
MUSTANG	696963027	16473671.24	0.023636363
CIVIC EX	696963027	12943598.72	0.018571428
F150 SUPERCREW	624833836	24993353.32	0.04
S10	966861787	26461480.24	0.027368421
CAMRY LE/XLE/SE	578742405	14330764.24	0.024761905
RAM 1500 QUAD ST/SLT	463157192	17202981.12	0.037142857
		" Average VMT Tax Rate"	0.027683518

Table 5.11: Fuel Estimation for Each Vehicle Model

5.5.8 Conclusion:

Based on our analysis of DMV data we have estimated an approximate fixed VMT tax rate of 0.028 \$/mile. This tax rate has been calculated based on simple relationship between mileage, fuel consumption and distance Traveled. This VMT tax rate has been calculated to generate the same amount of VMT tax as current fuel tax. As result of this analysis we also have the possibility of having different VMT tax rates for different types of vehicle models depending upon their fuel efficiency

CHAPTER 6

Model for Optimal Control

6.1 Summary

In this chapter, the problem related to revenue generated by VMT system has been studied. Currently, revenue estimation has been done based on the fixed VMT tax rate. But in this chapter, implications of variable tax rate has been studied. The problem of maximization of revenue over a period of time with variable VMT tax rate has been studied using optimal control theory of control system. As part of this theory a cost function and system dynamics are known. Based on this information a function related to control variable is identified such that cost function of revenue is maximized over a given period of time.

6.2 Optimal Control Theory

The basic problem in this is case is to identify the set of PDE for control variables in order to optimize the given cost functional. This cost functional consists of two main components. One is the final cost dependent upon the the end time and other is the dynamic component which changes as the time progressed. This cost functional consists of state variables and control variables. Further optimal control can be

derived using Hamilton-Jacobi-Bellman (HJB) equation. Let the process dynamics is given by:

$$\dot{x}(t) = a(x(t), u(t), t)$$

Cost function based on state and control variable:

$$j(x(t_f), t_f, u(\tau)) = h(x(t_f), t_f) + \int_t^{t_f} g(x(\tau), u(\tau), \tau) d\tau$$

In the above equation. h and g are the functions. t is the initial time and t_f is the final time. Cost h is the cost at the final time t_f while the function g describes the rate of increment of the cost. Hence g has been integrated between t and t_f . For all the $t \leq t_f$, let us find the control variable such that it maximizes the cost functional.

$$j^*(x(t), t) = \max\{h(x(t_f), t_f) + \int_t^{t_f} g(x(\tau), u(\tau), \tau) d\tau\}$$

$$u(\tau) (t < \tau < t_f)$$

Lets take a small step of Δt from t to $t + \Delta t$

$$j^*(x(t), t) = \max\{h(x(t_f), t_f) + \int_t^{t+\Delta t} g(x(\tau), u(\tau), \tau) d\tau + \int_{t+\Delta t}^{t_f} g(x(\tau), u(\tau), \tau) d\tau\}$$

$$u(\tau) (t < \tau < t_f)$$

The above equation can also be written as

$$j^*(x(t), t) = \max\{j^*(x(t + \Delta t), t + \Delta t) + \int_t^{t+\Delta t} g(x(\tau), u(\tau), \tau) d\tau\}$$

$$u(\tau)(t < \tau < t_f)$$

In the above equation $j^*(x(t + \Delta t), t + \Delta t)$ is the maximum cost considering initial state $x(t + \Delta t)$. To analyze it further we assume that j^* twice differentiable, we expand $j^*(x(t + \Delta t), t + \Delta t)$ using Taylor series at point $(x(t), t)$

$$j^*(x(t), t) =$$

$$\max\left\{\int_t^{t+\Delta t} g d\tau\right\} + j^*(x(t), t) + \left[\frac{\partial J^*(x(t), t)}{\partial x}\right] \Delta t + \left[\frac{\partial J^*(x(t), t)}{\partial x}\right]^T (x(t + \Delta t) - x(t))\}$$

$$u(\tau)(t < \tau < t_f)$$

For small Δt it can be represented as

$$j^*(x(t), t) = \max\{g\Delta t + j^*(x(t), t) + [J_t^*]\Delta t + [J_x^*]^T(a(x(t), u(t), t))\Delta t + O(\Delta t)\}$$

$$u(\tau)(t < \tau < t_f)$$

or as $\Delta t \rightarrow 0$

$$0 = [J_t^*] + \max\{g + [J_x^*]^T(a(x(t), u(t), t))\}$$

6.3 Hamilton-Jacobian-Bellman equation

For J^* to be maximum J_t^* must be equal to zero. Lets define Hamiltonian H as

$$H(x(t), u(t), t, J^*) = g + [J_x^*]^T(a(x(t), u(t), t))$$

and

$$H(x(t), u(x(t), u(t), t, J^*), t, J^*) = \max\{H(x(t), u(t), t, J^*)\}$$

As it defines the control based on x,t, J^* , we obtain a Hamilton-Jacobian-Bellman (HJB) equation in order to optimize the cost.

$$0 = J_t^* + H(x(t), u(x(t), u(t), t, J^*), t, J^*)$$

The optimal control variable u(t) in terms of J_x^* is derived from the above equation. Value of u(t) is plugged back in order to achieve PDE in J. Solution to PDE given the behavior of J and u(t) can also be derived buy plugging J_t^* back in u(t). Solution of the above equation can be also guessed using boundary conditions.

6.4 VMT Model for optimal control

VMT is mechanism to collect the road revenue based on the number of miles driven by a vehicle. In this case revenue is collected based on the tax rate $r(t)$ \$per mile and number of miles $v(t)$. At the beginning of any year $t = 0$ revenue collect is also 0. But the number of miles driven increases with time and Value of revenue

also increases. In current system VMT tax rate $r(t)$ has been assumed a fixed value through out the year.

Problem formulation

It has been assumed that the number of miles at any given time, increases at constant rate k due to regular increment in total number cars and assuming similar driving habits through out the year. But, the VMT tax rate also has some impact on the rate of increment of miles driven. If the rate $r(t)$ increases the rate of increment rate of VMT decreases and if $r(t)$ decreases, the increment rate of VMT increases. Considering above factors, the dynamics of the VMT (number of miles) during time t, t_f is given as follows.

$$\dot{v}(t) = kv - cr(t)$$

$\dot{v}(t) \geq 0$; rate of increment of VMT.

$K > 0$; constant increment rate due to increasing number of vehicles mile per unit time.

$r(t) > 0$ VMT tax rate in dollar/mile.

$c > 0$ constant *mile²/dollar²/time* Revenue generated at a given time t can be given as:

$$R(t) = r(t)v(t)$$

But as revenue $R(t) > 0$ at any given time except t .

The cost function J has been chosen such that we maximize the revenue $R(t)$ with the minimum VMT tax rate $r(t)$. Hence J has been chosen as follows:

$$J(t) = \int_t^{t_f} (R(\tau) - \epsilon r^2) d\tau$$

or

$$J(t) = \int_t^{t_f} v(\tau)r(\tau) - \epsilon \int_t^{t_f} r^2 d\tau$$

Now we have to identify control variable VMT tax rate $r(t)$ in order to maximize the cost functional.

Implementation of Optimal Control Theory

Comparing it with above equations.

$$h(x(t_t, t_f)) = 0$$

$$g(x(t), t, u(t)) = v(t)r(t) - \epsilon r^2(t)$$

$$a(x(t), t, u(t)) = kv - cr(t)$$

Putting values of above parameter in Hamilton-Jacobian-Balleman equation:

$$0 = J_t^* + \max\{H(x(t), u(x(t), u(t), t, J^*), t, J^*)\}$$

or

$$0 = J_t^* + \max\{v(t)r(t) - \epsilon r^2(t) + J_v^*(kv - cr(t))\}$$

where H is given by :

$$H(x(t), u(t), t, J^*) = g + [J_v^*]^T(a(x(t), u(t), t))$$

$$H(x(t), u(t), t, J^*) = v(t)r(t) - \epsilon r^2(t) + J_v^*(kv - cr(t))$$

$$\frac{\partial H}{\partial r} = 0$$

Differentiating H with respect to r(t) and we get:

$$\frac{\partial H}{\partial r} = 0 = v(t) - 2\epsilon r(t) - cJ_v^*$$

or

$$r(t) = \frac{(v(t) - cJ_v^*)}{2\epsilon}$$

Lets check $\frac{\partial^2 H}{\partial r^2}$

$$\frac{\partial^2 H}{\partial r^2} = -2\epsilon < 0$$

$\frac{\partial^2 H}{\partial r^2}$ is negative hence it is a maximum

6.5 Hamilton-Jacobian-Bellman equation for VMT model

Plugging value of $r(t)$ back in HJB equation:

$$0 = J_t^* + v(t)\left(\frac{v(t) - cJ_v^*}{2\epsilon}\right) - \left(\frac{v(t) - cJ_v^*}{2\epsilon}\right)^2 + J_v^*(kv - c\left(\frac{v(t) - cJ_v^*}{2\epsilon}\right))$$

or

$$0 = J_t^* + \frac{c^2}{4\epsilon}(J_v^*)^2 + v(t)\left(k - \frac{c}{2\epsilon}\right)J_v^* + \frac{v(t)^2}{4\epsilon}$$

Numerical solution of J will be computed using above PDE. Once function J is identified value of J will be plugged back in $r(t) = (v(t) - cJ_v^*)/2$ in order to get the control variable. The above HJB equation has been solved using numerical techniques in the next chapter. Parameter k will be calculated based on linear curve fitting from the past VMT data.

In steady state:

$$J_t^* = 0$$

then equation for J_v^* becomes quadratic equation:

$$0 = \frac{c^2}{4\epsilon}(J_v^*)^2 + v\left(k - \frac{c}{2\epsilon}\right)J_v^* + \frac{v^2}{4\epsilon}$$

But for J_v^* to have real roots $b^2 - 4ac > 0$

$$b^2 - 4ac = \left(v\left(k - \frac{c}{2\epsilon}\right)\right)^2 - 4\left(\frac{c^2}{4\epsilon}\right)v^2/4\epsilon$$

or

$$b^2 - 4ac = v^2((k - c/2\epsilon)^2 - (c/2\epsilon)^2)$$

or

$$b^2 - 4ac = v^2((k - c/2\epsilon - c/2\epsilon)(k - c/2\epsilon + c/2\epsilon))$$

or

$$b^2 - 4ac = v^2(k(k - c/\epsilon))$$

For J_v^* to have real roots we choose k, c, ϵ such that

$$b^2 - 4ac \geq 0$$

Hence J_v^* has real roots in steady state and value of J_v^* is given by:

$$J_v^* = \frac{(-b + \sqrt{b^2 - 4ac})}{2a}, \frac{(-b - \sqrt{b^2 - 4ac})}{2a}$$

putting values of a, b, c in the equation.

$$J_v^* = \frac{(-(k - c/2\epsilon)v - v\sqrt{k(k - c/\epsilon)})}{2(c^2/4\epsilon)}, \frac{(-(k - c/2\epsilon)v + v\sqrt{k(k - c/\epsilon)})}{2(c^2/4\epsilon)}$$

or

$$J_v^* = \frac{(2\epsilon v)(-(k - c/2\epsilon) - \sqrt{k(k - c/\epsilon)})}{c^2}, \frac{(2\epsilon v)(-(k - c/2\epsilon) + \sqrt{k(k - c/\epsilon)})}{c^2}$$

As for J_v^* to have real values $k \geq c/\epsilon$ considering

case 1: where $k = c/\epsilon$ plugging value of k in J_v^* and solving for single root as

$b^2 - 4ac = 0$ in this case.

$$J_v^* = \frac{(2\epsilon v)(-(c/\epsilon - c/2\epsilon))}{c^2}$$

$$J_v^* = -v/c$$

Plugging value of J_v^* back in order to identify r for steady state.

$$r(t) = \frac{(v - cJ_v^*)}{2\epsilon}$$

$$r(t) = \frac{(v + cv/c)}{2\epsilon}$$

or

$$r(t) = \frac{v}{\epsilon}$$

case 2: where $k > c/\epsilon$, $k = 4c/3\epsilon$ or $c/\epsilon = 3k/4$. Plugging value of k in J_v^* and

solving for single root as $b^2 - 4ac = k(k - 3k/4 = k^2/4)$ in this case.

$$J_v^* = \frac{(-(k - 3k/8)v + v\sqrt{k^2/4})}{2(c^2/4\epsilon)}, \frac{(-(k - 3k/8)v + v\sqrt{k^2/4})}{2(c^2/4\epsilon)}$$

or

$$J_v^* = \frac{(-v(5k/8) + v(k/2))}{(3ck/8)}, \frac{-(5k/8)v - v(k/2))}{(3ck/8)}$$

or

$$J_v^* = \frac{8v(k/2 - 5k/8)}{(3ck)}, \frac{8v(-5k/8 - k/2)}{3ck}$$

or

$$J_v^* = \frac{8v(-k/8)}{3ck}, \frac{8v(-9k/8)}{3ck}$$

or

$$J_v^* = -v/3c, -3v/c$$

Plugging value of J_v^* back in order to identify r for steady state.

For $J_v^* = -v/3c$

$$r(t) = \frac{(v - cJ_v^*)}{2\epsilon}$$

$$r(t) = \frac{(v + cv/3c)}{2\epsilon}$$

or

$$r(t) = \frac{2v}{3\epsilon}$$

For $J_v^* = -3v/c$

$$r(t) = \frac{(v - cJ_v^*)}{2\epsilon}$$

$$r(t) = \frac{(v + c3v/c)}{2\epsilon}$$

or

$$r(t) = \frac{2v}{\epsilon}$$

6.6 Conclusion

VMT tax rate $r(t)$ has been identified in terms of v for the steady state solution. Plugging back the control variable $r(t)$ into the dynamics of $v(t)$ behaviour of VMT and Revenue will be estimated. Value of other parameters involved in the dynamics have been estimated in the next chapter.

CHAPTER 7

RESULTS AND CONCLUSION

7.1 Summary

In this chapter, various parameters of optimal control model derived in previous chapter has been estimated. Based on steady state solution of HJB equation, VMT tax rate (Cents per mile) has been estimated. Monthly VMT tax rate has been estimated for past years based on VMT data available for United states and Nevada. Based on estimated VMT tax rate, revenue generating using estimated VMT tax rate and actual VMT has been estimated. Estimated VMT revenue has been compared with Estimated revenue required for improvement in infrastructure.

7.2 Estimation of Parameter K_0

Approximate value of parameter k has been estimated assuming exponential growth of VMT with time. Monthly data for VMT since 1970 till 2011 is available on website of FHWA (Federal Highway Administration). Parameter K has been estimated considering logarithmic growth of data. Yearly VMT data for Nevada, available in reports published by NDOT (Nevada, Department of Transportation) is also used to estimate K using same methodology. Figure 7.1 below describes the VMT data since

Annual VMT data for Nevada

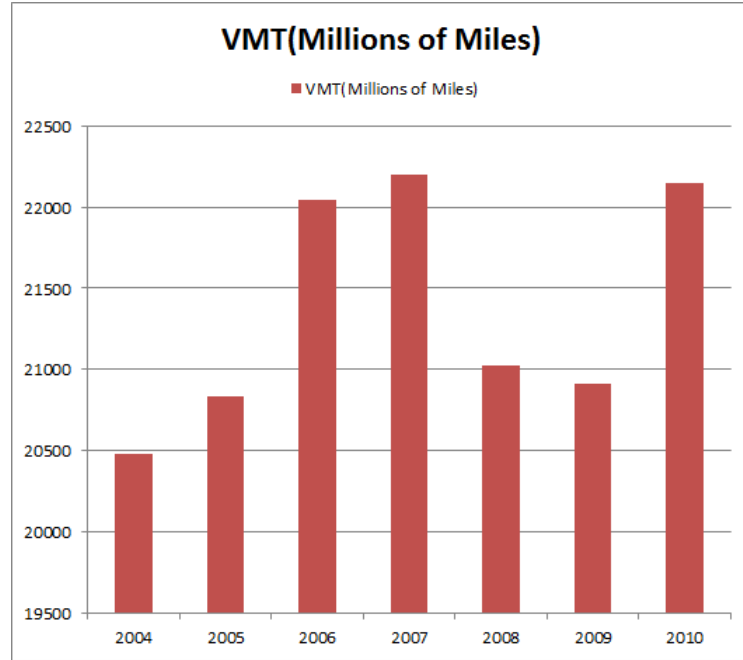


Figure 7.1: Annual VMT data (2004-2010) VMT Report, NDOT.

2004 published in reports of Nevada Department of Transportation (NDOT). Value of yearly increment rate K has been estimated approximately $K_0 = 0.013069$. Below figure 7.2 represents the monthly VMT data since 1970 to 2011, published in website of FHWA (Federal Highway Administration). It represent Vehicle miles traveled in millions of miles per month. Based on monthly VMT data since 1970 to 2011 of FHWA, estimated value of monthly increment rate K_0 is 0.0022693. Below figure 7.3 compares the the $\log(ActualVMT)$ data with $\log(EstimatedVMT)$ data using the estimated month increment rate k .

Least Square estimation:

K_0 has been estimated to 0.00221 using least square estimation technique. Below

Monthly VMT data

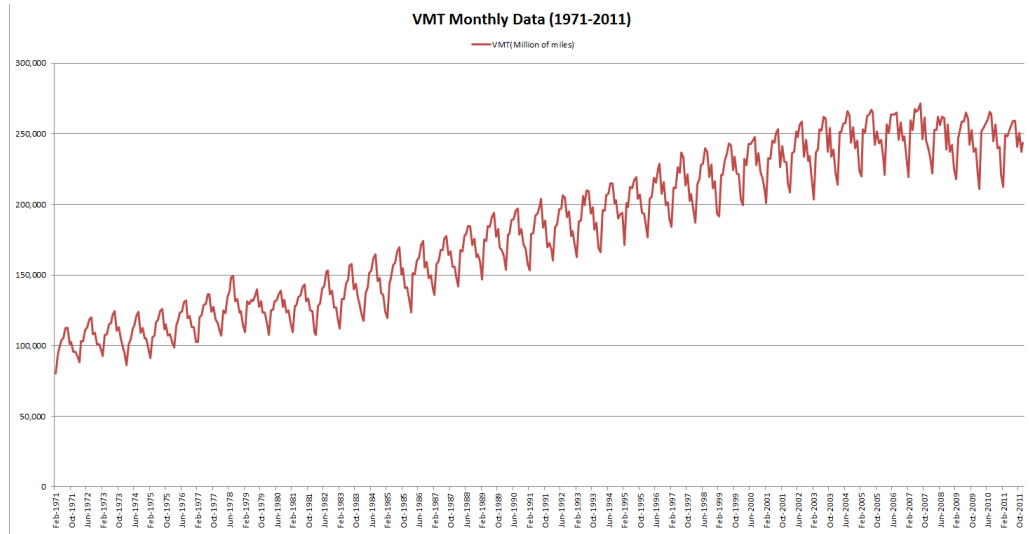


Figure 7.2: VMT data(1970-2011),Historical Monthly VMT Report,FHWA

Log(Actual VMT) Vs Log(Estimated VMT)

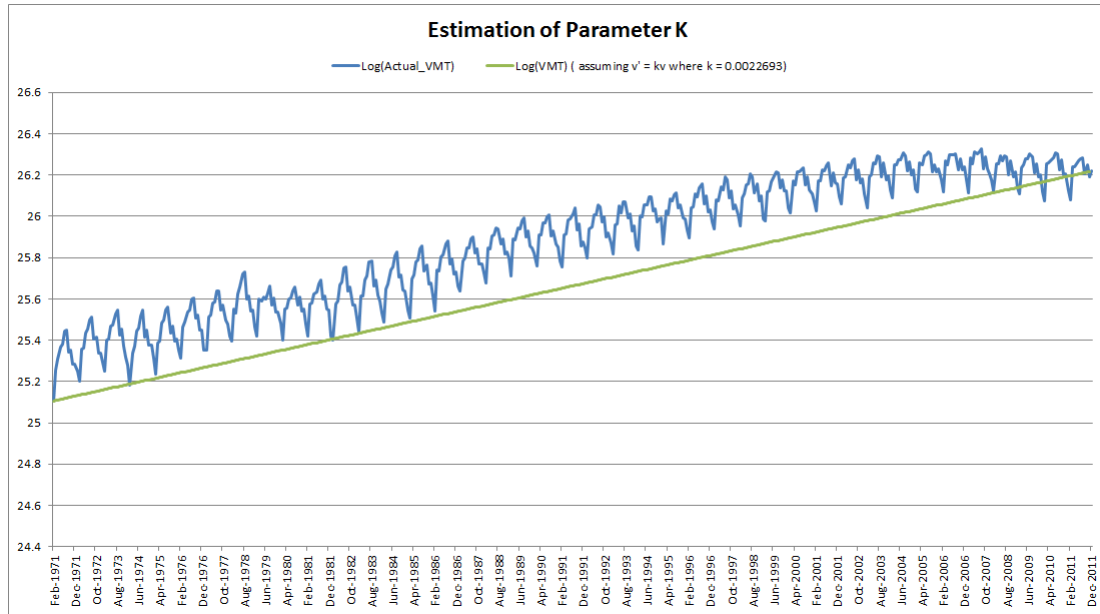


Figure 7.3: Log(Actual VMT) Vs Log(Estimated VMT), using $k = 0.0022693$.

Least Square Estimation of linear Log(Actual_VMT)

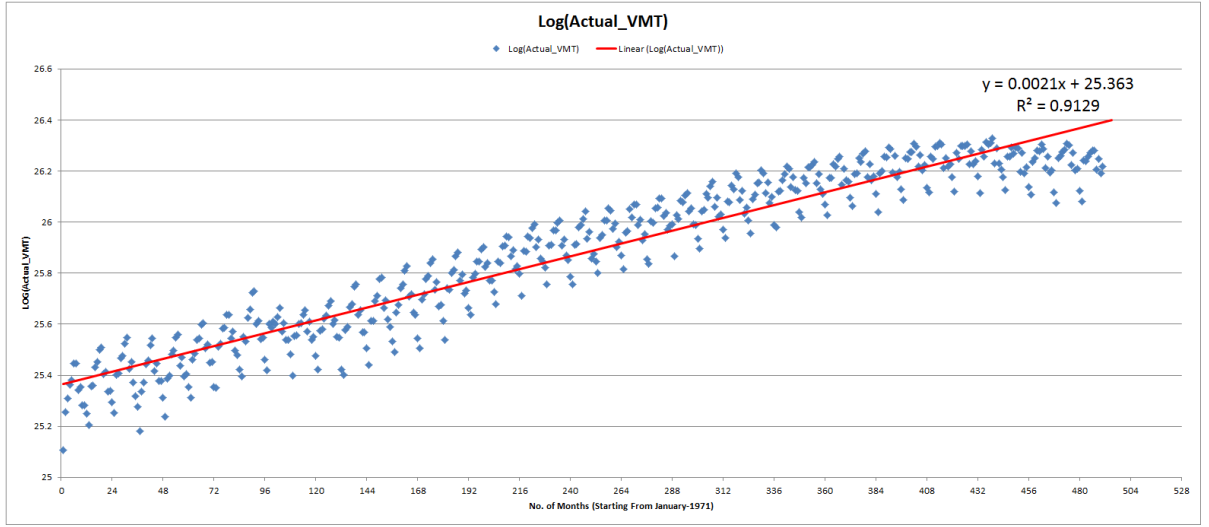


Figure 7.4: Log(Actual VMT) Vs Log(Estimated VMT) using least square estimation, using $k = 0.00221$.

figure 7.4 shows the linear curve fitting of $\log(\text{ActualVMT})$ using least square estimation. It also represent the linear equation of $\log(\text{ActualVMT})$ versus number of months starting from January 1971.

7.3 Estimation of Parameter ϵ and c

During VMT phase 2 field test in 2011, value of VMT tax rate (r) has been estimated 2 cents per miles. Using the estimated value of r and monthly VMT data Value of ϵ has been estimated. The estimated approximate value of ϵ is $\epsilon = 1.175 \times 10^{11}$ based on the steady state control variable r . Value of c has been estimated approximately 2.66×10^8 Value of k and c can be chosen considering $K_0 = (k - c/\epsilon) = 0.0022693$ as K_0 has been already estimated from the actual monthly VMT data.

Plugging back the steady state value of r , $r = V/\epsilon$, in the dynamics of v :

$$v' = kv - cr$$

From previous chapter, Value of r in steady state:

$$r = v/\epsilon$$

or

$$v' = (k - c/\epsilon)v$$

or

$$\int \frac{dv}{v} = (k - c/\epsilon) \int dt$$

or v can be given as

$$v = v_0 e^{(k - c/\epsilon)t}$$

7.4 Estimation of VMT tax rate r

In previous chapter function of r has been estimated in terms of v by plugging value of J_v in steady state. Putting value of J_v , r has been estimated as v/ϵ . Further function r has been approximated to a piecewise constant function whose value remains constant every month. Now, monthly value of r has been estimated for the past data. The monthly estimate of r is based upon the ϵ , which has already been estimated in the previous section and actual monthly data of VMT. Below figure 7.5

Estimated monthly Value of r (cents/mile)

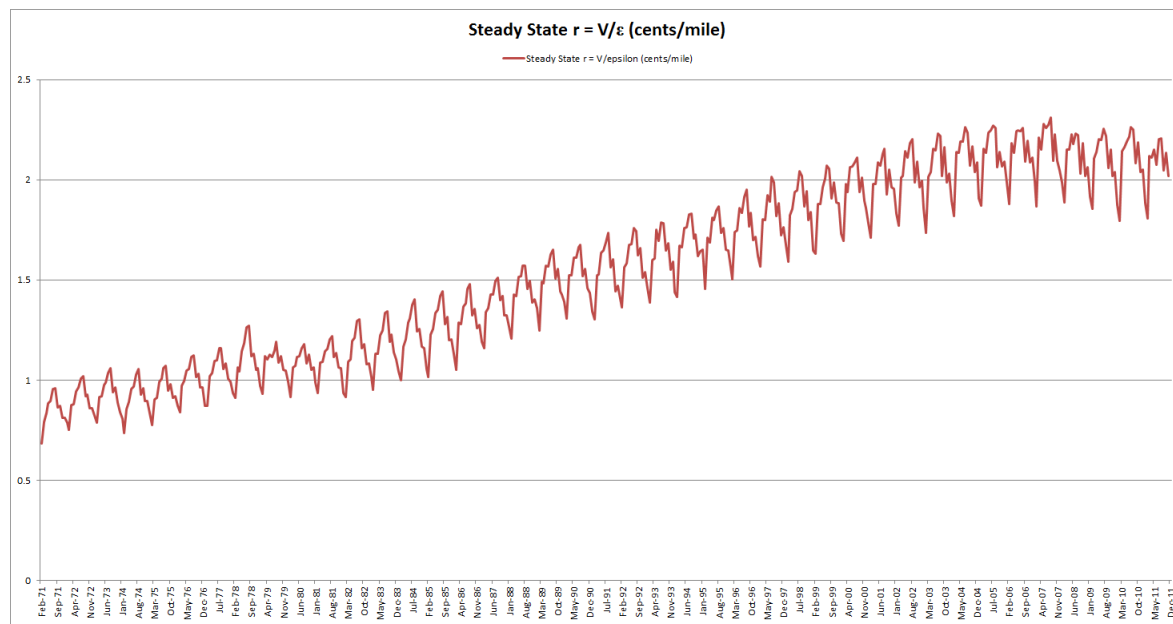


Figure 7.5: Estimated monthly Value of $r(1970-2011)$, $\epsilon = 1.175 \times 10^{11}$.

represent the estimated value of r for the past years.

Figure 7.6 below shows the estimated value of r based on VMT data of Nevada of past years. Value of r remains close to 2 cents per mile.

7.5 Estimation of Revenue

In this section, Revenue has been estimated based upon the estimated value of R and actual VMT data. The revenue has been estimated for both Nevada and total Federal Revenue. The estimated total VMT revenue has been also compared with the previous estimates of required revenue for improvement of infrastructure for similar years. Below figure 7.7 shows the revenue estimated for Nevada based on actual

Estimated Value of r (cents/mile) for Nevada

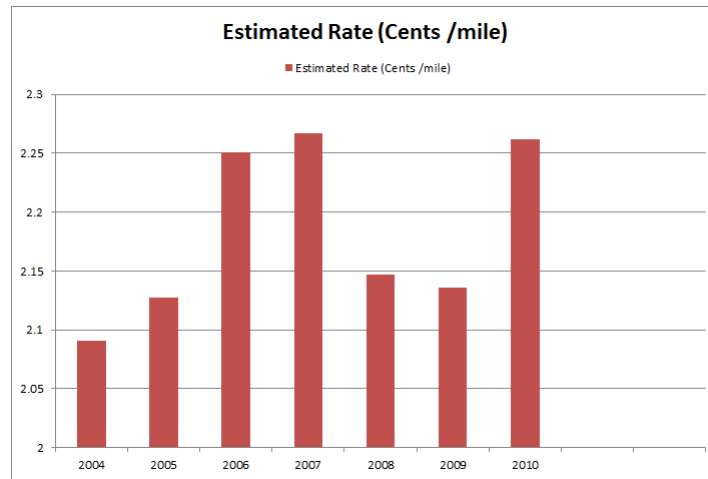


Figure 7.6: Estimated Value of r for Nevada(2004-2010), $\epsilon = 1.175 \times 10^{11}$.

yearly VMT data reported by NDOT and estimated r (cents per mile) in previous section. Below figure 7.8 shows the federal revenue estimate based on actual yearly VMT monthly data reported by FHWA and estimated r (cents per mile) in previous section.

Below figure 7.9 shows the comparison between above Estimated VMT revenue Vs Estimate of required revenue to improve infrastructure reported in Dissertation "Policies For Highway Financing: Gasoline Taxes And Other Alternatives", (Vinod Vasudevan, 2008 UNLV)

7.6 Conclusion

Based on the above analysis, VMT has been proved an potential alternative to the current road revenue system based on fuel tax. The proposed solution is technically feasible and addresses the major concern of "privacy" for the end users. Qualitative

Estimated VMT Revenue(Billion Dollars) for Nevada

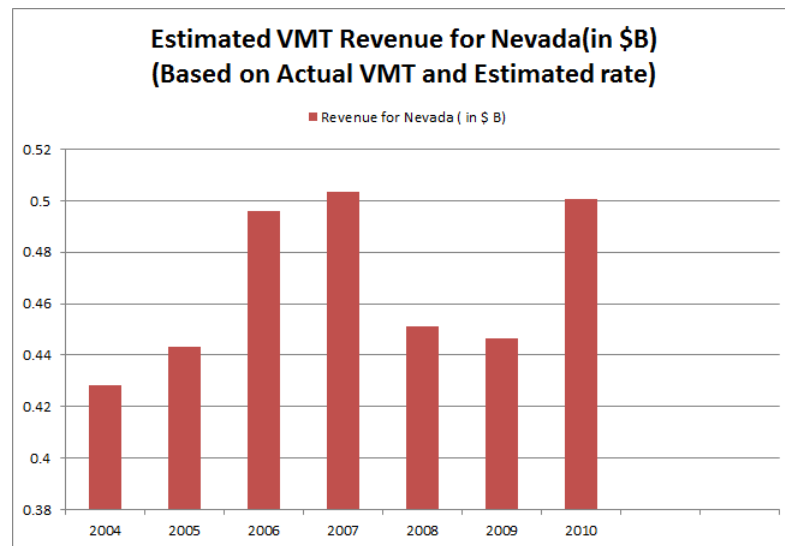


Figure 7.7: Estimated Revenue(Billion Dollars) for Nevada based on Actual VMT and estimated r.

Estimated Federal VMT Revenue(Billion Dollars)

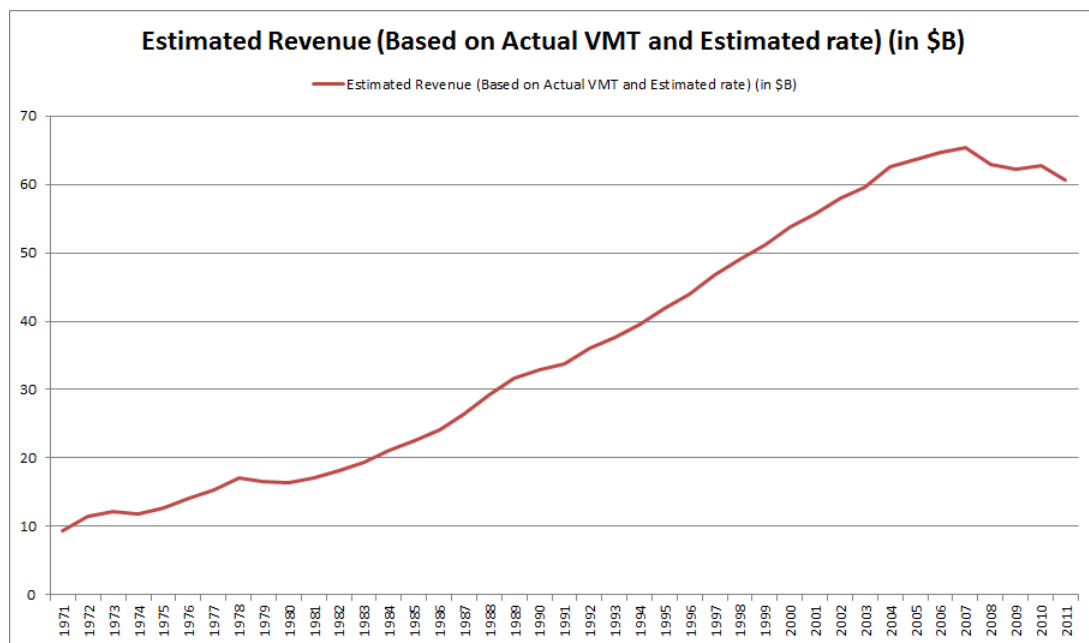


Figure 7.8: Estimated Federal Revenue(Billion Dollars) based on Actual VMT and estimated r

Estimated Revenue to Improve Vs Estimated VMT revenue

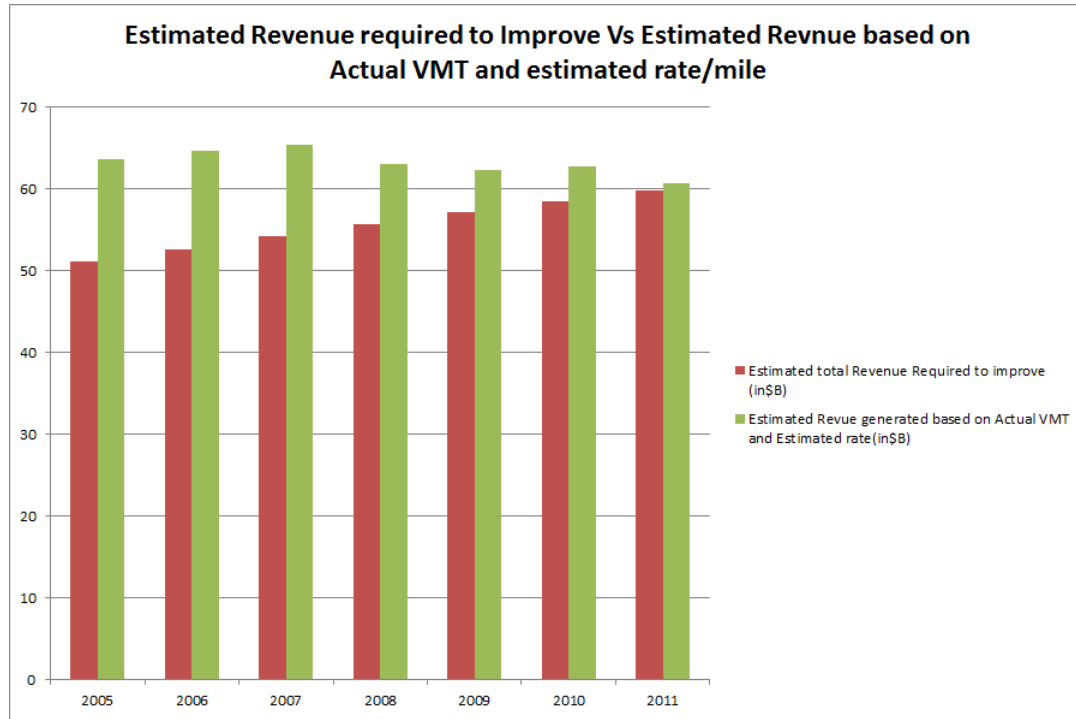


Figure 7.9: Estimated Revenue to Improve Vs Estimated VMT revenue(2006-2011)

analysis validates the conclusion of "Privacy" concern going down among users. An Integrated system of various hardware and software component can be designed to achieve robust infrastructure for VMT. Based on the revenue estimates, VMT shows the potential to address the gap between required and currently generated gas tax revenue.

7.7 Future Work

As part of future work, optimal control model can be improved to stochastic optimal control to incorporate affect of noises like inflation, change in gas price and other parameters. Hardware solution can be improved to achieve more robust functionality

while software interface needs to be improved in order to provide user friendly environment to the end user. "Privacy" concern needs to be studied rigorously using qualitative analysis of data from much larger sample size. A more efficient and secure system to provide access to the recorded data needs to be developed. Considering VMT to replace existing fuel tax based road revenue system more rigorous economical analysis needs to be done.

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VITA

Graduate College
University of Nevada, Las Vegas

Pratik Verma

Home Address:

1861 Arbol Verde way Las Vegas, Nevada 89119

Degrees:

Bachelor of Technology, in Electrical Engineering, 2008

Indian Institute of Technology, Banaras Hindu University, India

Thesis Title: An End To End V.M.T Framework With Controlled V.M.T Tax Rate
Using Optimal Feedback Control Technique

Thesis Examination Committee:

Committee Chair: Dr. Pushkin Kachroo

Committee Member: Dr. Yingtao Jiang

Committee Member: Dr. Emma E. Regentova

Graduate Faculty Representative: Dr. Robyn L. Raschke

