A FRAMEWORK AND ANALYTICAL APPROACH TO EVALUATE ALTERNATIVE VEHICLE MILES TRAVELED (VMT) FEE SYSTEMS

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A FRAMEWORK AND ANALYTICAL APPROACH TO EVALUATE
ALTERNATIVE VEHICLE MILES TRAVELED (VMT) FEE SYSTEMS

A Dissertation Presented

By

ELIZABETH EBACHER

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

September 2014

Department of Civil and Environmental Engineering
Transportation Engineering
A FRAMEWORK AND ANALYTICAL APPROACH TO EVALUATE ALTERNATIVE VEHICLE MILES TRAVELED (VMT) FEE SYSTEMS

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DEDICATION

This work is dedicated to Deb Coon, M.M., Sheila Seaman, Ph.D. and Leanne Ksiazek, V.M.D. Deb, Sheila, and Leanne are extraordinary teachers in their respective fields where Deb teaches students at Northampton, MA High School instrumental music, Sheila at the University of Massachusetts in Amherst upper division geoscience courses, and Leanne in her practice of veterinary medicine. They are also superb practitioners and researchers in their respective fields. Their dedication to all aspects of their fields is, simply, inspiring. Coincidentally, they share a love, respect, and commitment to the fauna and flora of this earth.
ACKNOWLEDGEMENTS

I take this opportunity to thank all members, Drs, Collura, Christofa, and Burleson, of this committee for their work, interest, encouragement, and assistance in bringing it to completion. They have been invaluable! I extend a special thank you to the chair, Dr. Collura, for the extra time and effort that he gave. He and I both hope that this adds to the capacity of policymakers to create the best VMT fee systems so that the driving public benefits.
ABSTRACT

A FRAMEWORK AND ANALYTICAL APPROACH TO EVALUATE ALTERNATIVE VEHICLE MILES TRAVELED (VMT) FEE SYSTEMS

SEPTEMBER 2014

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Since the fuel tax is a dwindling source of revenue, states need to find alternative funding sources. A vehicle miles traveled (VMT) fee has received serious consideration from a number of states and the federal government. What is missing from the VMT fee consideration is a framework for developing VMT fee systems and an analytical approach with which to study how well a proposed system conforms to the policies promulgated in the framework. This research strives to fill that void. The framework developed presents five areas of importance in VMT fee systems: 1. Revenue sufficiency; 2. Revenue stability; 3. Environmental Justice; 4. Low implementation cost; and 5. Security and privacy preservation. The analytical approach consists of two methods: 1. Use of NPV in order to evaluate the cost/benefit position of a proposed VMT fee system with respect to monetary and non-monetary but monetizable aspects; and 2. Use of an Index to evaluate all other aspects. To demonstrate the application of the framework and analytical approach, four VMT system designs were formulated,
analyzed, and then compared to each other and to the fuel tax. The four VMT fee system designs are: 1. Alternative A where the total annual VMT is determined at the state inspection and charged for those miles; 2. Alternative B where the out-of-state VMT is deducted from the total annual VMT as determined at the annual state inspection and the fee charged for in-state VMT only; 3. Alternative C where a fee matrix is applied to GPS reported trip data so that fees may vary based on time and locale; and 4. Alternative D where there is a strategic implementation of Alternatives A, B, and C in that order and with two years separating the implementations. If added revenue is the main goal, then Alternative A is the best choice by being the lowest cost. If added revenue and the provision of a better strategy for alleviating such conditions as congestion, noise or air pollution or charging for higher quality roadways, then Alternatives C or D is the best fit. Alternative B performs best as a stepping-stone in Alternative D. All alternatives have better revenue sufficiency and stability than the fuel tax. The fuel tax exceeds all alternatives with respect to security and privacy preservation since no data, personal or otherwise, is recorded. Since security and privacy preservation are considered the weakest aspects of most VMT fee collection systems, added attention must be applied to incorporating design elements that cover aspects where breaches are possible such as in any data transmission, any computational and database processing, and billing/payment functions. The next step beyond this work is to study the construction of the fee matrix and exercise its use either in simulation or with actual data as collected by a state’s department of transportation.
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CHAPTER 1

INTRODUCTION

The fuel tax has been used as a significant revenue source to support Federal and State transportation investments. As the energy sources for powering vehicles expand and vehicles become more efficient, the petroleum based fuel tax provides an increasingly unreliable revenue source and burdens petroleum users disproportionately. Strategies that charge for transportation facility use such as tolls and VMT fees are becoming more important to consider as revenue sources to offset the dwindling revenue of fuel taxes. As energy sources shift, more attention is being paid to the viewpoint that the transportation infrastructure is a resource and its use should be charged accordingly.

A VMT fee system charges a vehicle owner for each mile driven. Even though some states have begun to test the use of VMT fee systems, there is no comprehensive framework to guide transportation policymakers and administrators in formulating alternative VMT fee systems and there is no objective analytical approach to aid in the evaluation of these alternatives. The overarching goal of this research is to develop such a framework and analytical approach. The framework would be designed to help formulate alternative VMT systems based on policy objectives. The analytical approach would be designed to account for anticipated impacts of each alternative including monetary
impacts, non-monetary but monetizable impacts, non-monetary but quantifiable impacts, and non-quantifiable impacts.

The VMT fee reaches into many aspects of the cultural, political, environmental, and physical landscapes. It is indeed a complex stratagem and so requires a well formulated framework and fundamentally sound analytical approach to guide those states interested in instituting a VMT fee.
CHAPTER 2

OBJECTIVES OF THE RESEARCH

The objectives of this research are:

- **Create a comprehensive framework** to assist state transportation policymakers and administrators in the formulation of alternative vehicle miles traveled (VMT) fee systems to support transportation investments.

- **Develop an analytical approach** to assist in the evaluation of the feasibility, appropriateness, benefits, and costs associated with these alternatives. The approach would be designed to account for anticipated impacts of each alternative including monetary impacts, non-monetary but monetizable impacts, non-monetary but quantifiable impacts, and non-quantifiable impacts.

- **Formulate and apply the framework and analytical approach.** Four alternative VMT fee systems will be evaluated via the framework and analytical approach.

- **Assess the strengths and limitations of the framework and analytical approach** and review their usefulness in selecting the best alternative within the broader transportation decision-making process.

- **Prepare the dissertation report** discussing all results as well as current and future research.
CHAPTER 3

BACKGROUND AND RELATED WORK

Even though some implementations of a VMT fee system may be relatively simple, VMT fee systems and their impacts are not. There are many, complex issues to address when defining and evaluating such a system. The adequacy of the revenue generated versus the costs to implement poses questions that policymakers must ascertain since drivers and voters will demand well-founded answers. Likewise, can the burden of an added transportation fee be mitigated for target groups while other groups bear a higher burden due to their transportation choices? Reviewing finance, environmental justice, and systems issues will be necessary in order to formulate a framework for policymakers. Moreover, analytical approaches must be investigated such that the best tools are selected. In short, since a VMT fee collection system is a state’s repository of critical and private data, every aspect of a system must be evaluated with respect to functionality, security, cost, and revenue generation.

3.1 Transportation Financing

3.1.1 VMT Fee History

Road use fees have existed for nearly 3,000 years. The more modern version is the toll road where in some cases such as with the Massachusetts and Pennsylvania Turnpikes the tolls are based on the number of miles traveled. The toll roads are specific routes that have been deemed such but where most other roads are have no fees charged.
The current VMT fee seeks a wider shouldering of the burden for upkeep of the roadway system to include all public roads and is the mechanism that states have begun to investigate as the way to bolster the flagging funding of transportation infrastructure support.

Oregon initiated the evaluation of the VMT fee when the Oregon Department of Transportation (ODOT) realized that the work to raise residents’ awareness of the need to improve air quality and reduce fuel consumption resulted in an enthusiastic embrace of hybrid vehicles. The resulting decline in fuel consumption and thus fuel tax revenue necessitated a search for alternative revenue sources. The road use tax was considered the best alternative. Test cycles produced a workable system and the Oregon legislature, in September, 2013, enacted enabling legislation to institute the road use tax. So, Oregon was the first state to propose what amounts to a VMT fee and the first to mandate its use in the United States (1, 2).

A number of other states have on-going studies including Minnesota, Virginia, Maryland, Nevada, and New Mexico (3). New Jersey has recently abandoned the VMT fee study and has decided to apply a fee to electric vehicles (EV fee) (4).

In 2007, the Minnesota Department of Transportation (MN/DOT) started their review of a VMT fee by conducting a public opinion study. A panel of experts as well as focus groups were used to develop whether such a fee would be accepted by the public, how it would contribute to revenue generation, how it could be implemented, and what risks arose from its use. The consensus was that (5):
1. Drivers saw the VMT fee as fair and reasonable especially considering the condition of the roads;

2. The VMT fee should be used to augment the fuel tax not replace it;

3. The VMT fee should be structured to reflect what a driver does to support the goals of sustainable driving such as driving as little as possible, using a fuel efficient vehicle, minimizing driving in congested areas at peak times; and

4. All care should be taken to minimize fraud, invasion of privacy, and system security breaches.

The Minnesota DOT published an analysis of transportation data from 1992-2010 with respect to VMT trends. VMT has outpaced increases in both employment and population trends (See Figure 1). However, the VMT trend with respect to fuel price plateaued from 2004 to 2010 (See Figure 2). From this trend, the contribution of fuel tax is affected by the cost of fuel so that Minnesota must develop alternative revenue sources in order to support its roadways (6).
In Cascade Policy Institute’s study “Driving the Economy, the trends among gross domestic product (GDP), energy use, and VMT were very similar (7). The study found that VMT was essentially shock proof with respect to fuel prices. Furthermore, VMT increased with increased fuel efficiency making the VMT fee all the more justified since greater use of roadways results but with lower fuel taxes paid.
In 2008, the Virginia Department of Transportation (VDOT) launched its investigation of the VMT fee by publishing an annotated bibliography of reports and studies done by other states. It reviews the work with respect to Alabama, California, Colorado, Indiana, Iowa, Kentucky, Michigan, Minnesota, Oregon, Utah, and Washington states. There is a small section on international materials including Canada, Denmark, and United Kingdom. Also included is a section devoted to U.S. federal reports or federally funded reports. The richest area is that which explores the Oregon contribution to the VMT fee. In general, this bibliography can assist transportation policy makers and practitioners alike in their assessment of whether the VMT fee fits their situation or not (3).

Nevada, in 2010, published the first phase results of its study of the VMT fee.

Phase 1 included six general activities (8):

1. Conduct a literature search;
2. Conduct wide sweeping public outreach and education;
3. Study the impacts of fee payment mechanisms on privacy;
4. Study the impacts of fee payment mechanisms on state policy, legislation, and legal aspects;
5. Develop economic models to evaluate feasibility and environmental justice concerns;
6. Design a pilot program to assist in the feasibility analysis.

One of the significant outcomes of the study was the survey responses for attendees of two public meetings – one in Reno and the other in Las Vegas. Two questions (7 and 9)
are particularly important for those who are developing VMT fee implementation strategies. Question 7 asked the attendees which type of VMT fee structure would they accept. Figure 3 presents the Reno responses while Figure 4 the Las Vegas responses. The percentage distribution between the two meetings is similar and broadly based. In short, VMT fee system designers and policy makers have a range of fee structures from which to pick without alienating their constituents (8).

Figure 3: Reno, Nevada Public Meeting Concerning VMT Fee Usage – Response to Question 7. Image source: Nevada DOT (8).

Question 9 addresses the presence of VMT technology (GPS/cellular) in the vehicles for the pilot program. Figure 5 presents the Reno meeting results while Figure 6 the Las Vegas results. Both Reno and Las Vegas attendees objected to the presence of in-vehicle VMT technology but Las Vegas was emphatically against the presence. The results of the question led the Nevada DOT to re-think the approach for gathering VMT data (8). Perhaps, as time and technology march along, those attitudes will change especially since new vehicles will have this technology integrated into each car’s electronic system.
Figure 4: Las Vegas, Nevada Public Meeting Concerning VMT Fee Usage – Response to Question 7. Image source: Nevada DOT (8).

Figure 5: Reno, Nevada Public Meeting Concerning VMT Technology Presence – Response to Question 9. Image source: Nevada DOT (8).
Another interesting finding is the trend in Nevada with respect to VMT. Unlike Minnesota with its plateauing VMT due to high fuel prices, Nevada has an ever increasing VMT regardless of fuel prices and economic conditions. Also notable is the declining trend of fuel consumption which adds to the evidence of the fuel tax being a decreasing source of revenue. Figure 7 presents the Nevada results.

Both Hanley and Kuhl (9) and Forkenbrock (10) studied the implementation of a VMT fee at the national level. Frokenbrock suggested that the VMT fee would run parallel with the fuel tax for the foreseeable future and be charged to all vehicle types not just passenger vehicles. Hanley and Kuhl found that GPS tracking provided greater accuracy in assigning VMT to a given jurisdiction. Harischandra et al. also studied VMT fee at the national level but from the perspective of a transition from fuel tax to VMT fee (11). They estimate that a $0.0091/mile fee would generate the same revenue as the current $0.184/gallon fuel tax. On an annual basis, 10,000 miles driven would result in a charge of $91.00. Rufulo studied costs of implementing a VMT fee with an eye to a
national implementation (12). He also evaluated Dutch costs for implementing their proposed system.

As more states face the task of finding new revenue sources, their studies of the evolving aspects of the VMT fee will provide better information concerning implementation strategies and design considerations.

![Figure 7: Nevada Vehicle Registrations, Fuel Consumption, and VMT as Indices - Image source: Nevada DOT (8).](image)

3.1.2 Comparison of VMT Fee, Fuel Tax, and Other Financing Strategies

3.1.2.1 VMT Fee - Revenue Potential, Fairness Issues, Cost of Implementation

The advantage of a VMT fee is that it is applied to each and every road within a jurisdiction unlike a toll which is attached to a specific roadway. Therefore, the revenue potential is greater than tolls and the fee can be varied for different spatial and temporal
conditions if GPS or cell station tracking is employed (2). The revenue potential of a VMT fee can easily exceed that of the fuel tax since the VMT fee is applied to the miles driven and with a design using geo-tracking can vary the fees based on specified conditions. The fuel tax simply charges for each gallon sold which equates to non-petroleum or minimally petroleum based vehicles such as hybrids and electric cars using the roads at a considerably cheaper rate.

The VMT fee minimizes some of the fairness issues in that all people can pay the same rate for using the roads. Those who can afford hybrid or full electric vehicles get a subsidy under the fuel tax but would pay at least their fair share for road usage under a VMT fee. With a system based on geo-tracking, a fee schedule could be established that provides even greater fairness in that fee schedules could be established based on location of principal garaging of a vehicle or on owner age, or income level, etc. A fairly sophisticated schedule can be developed that increases fairness for all drivers.

For the implementation of a simple system based on transmitting the total miles travelled from one inspection event to the next, the cost is minimal and involves adding no more than five fields to the data set that currently holds the annual inspection data. Minor programming would be required to calculate the fee and either send a bill or notify the inspection station that the owner must pay the calculated fee before a new inspection sticker can be issued. The communications and security measures used for the annual inspection would be sufficient since the mileage now sent would be compared to the mileage of the prior year now held in the database. The costs involve the time spent by a database administrator to add the fields and rebuild the database, programming time for the necessary calculations and billing status, sufficient testing to insure proper system
operation, the establishment of policies and procedures for the inspection station operators and for the staff of a state department of transportation. No additional hardware is necessary. The implementation cost should be well under $250,000.

If a more complex system is selected, then the implementation costs increase substantially. Each vehicle needs a location receiver and storage unit. In addition, much more software development, hardware, communications hardware and software, and testing procedures are required. These needs will drive the system costs up by hundreds of millions of dollars. The location devices will cost about $150 each and for Massachusetts with over five million cars registered, that cost alone exceeds $750M. That cost can be offset some by requiring each vehicle owner to pay a percentage of the device cost. The added hardware, software, and communications requirements could push the total to $1B for the fully installed system. However, as with most electronic instrumentation, the location device cost is expected to fall and could be as low $50/unit by the time a VMT fee system is ready for launch.

3.1.2.2 Fuel Tax - Revenue Potential, Fairness Issues, Cost of Implementation

As has already been mentioned, the revenue generating capacity of a fuel tax has been declining steadily for the past decade and the trend is expected to continue (See Figure 8). The revenue potential, even with an index pegged price/gallon, cannot match the funding requirements for maintenance, repair, and upgrades to the roadway infrastructure. Alternative revenue sources are necessary.

Additionally, fairness issues exist with a fuel tax: 1. Lower income drivers often have older, less fuel efficient vehicles; 2. A fixed unit tax requires a disproportionately higher percent of the income for people of low income; and 3. Hybrid or alternative fuel
vehicles are more expensive than petroleum-only based vehicles such that people with higher incomes can avoid fuel taxes by having alternative energy vehicles. Fuel taxes favor the rich by requiring a smaller percentage of income for a vehicle that is moderately fuel efficient and by having the means to own alternate energy based vehicles.

![Figure 8: Decline in Purchasing Power of Motor Fuel Taxes Due to Inflation.](image)

At present, the Massachusetts Department of Transportation (Mass DOT) estimates that the fuel tax generates $768M ($0.24/gallon X 3.2 billion gallons) annually (14, 15). The Commonwealth has just recently switched from a fixed rate/gallon to an index pegged price/gallon which is expected to raise more revenue than the fixed rate. Despite the evidence of poor condition of the roadway infrastructure brought to the fore by the harsh weather of January, February, March of 2014, there is political movement in
Massachusetts to force the re-instatement of the fixed rate. No matter the evidence of the need for greater revenue, there will, apparently, be a constant movement to minimize any revenue generating strategy. A similar sentiment is being voiced by the Cato Institute and the Civitas Institute on a national level (16, 17). The cost of vehicle repairs, loss of tourism, and the decrease in economic activity due to poorly maintained and inadequate roadways could very well cost the Commonwealth more than the revenue raised via any strategy proposed.

There is no cost for implementation of a state fuel tax since a national fuel tax is already in place as is for most states. This alternative requires no additional cost in order to continue collecting this tax.

3.1.2.3 Other Financing Strategies - Revenue Potential, Fairness Issues, Cost of Implementation

Other financing strategies include tolls, vehicle registration fees, and specially directed fees such as New Jersey’s newly implemented one for electric vehicles. These financing strategies are limited in that toll roads can handle only so much traffic; a state can collect fees only on the vehicles registered; the fees may provide diminishing revenue if they are set too high. VMT fees and fuel taxes apply to a broader base of roadway users and produce revenue more uniformly (2).

Fairness issues may arise depending on the strategy invoked. For example, suppose a state imposed a special fee for all vehicles whose model year predates the year 2000 where the goal is to get as many of the more polluting and less fuel efficient vehicles off the road as possible. While the goal is well-intentioned and certainly one
that would promote a better climate, it burdens many elderly and low income drivers who are more likely to be assessed the fee. They are the least able to afford newer cars.

In the case of additional non-VMT fees, the cost of implementation would be minimal since states charge various fees now and adding one more is an expansion of a well-established system. As for tolls, most states have at least one toll road so the cost of implementation lies more in the hardware and monitoring that would be required.

3.1.3 Frameworks

Any framework used in the analysis of a system for VMT fee collection must include areas where a jurisdiction, state or federal, has significant policy issues to consider. The following represents those areas that are of greatest importance in such a framework.

3.1.3.1 Financial Impacts – Cost/benefit analysis, long term revenue potential, implementation costs, revenue sufficiency and stability

The financial impacts include whether there is revenue sufficiency and stability, whether the cost of implementation greatly exceeds near-term revenue generation, and whether long term revenue generation can remain strong enough to warrant the cost and effort of a system implementation (2, 18).

The essential questions asked and answered are: 1. Does the project advance the goals of the organization; 2. Is the project cost commensurate with the goals and objectives; 3. Can the system be used for a significant amount of time before a major
upgrade or a new system is required? The answers to these questions strike at the heart of the financial soundness of a particular system for a particular installation.

The goals of the organization must be clearly and succinctly defined. More narrowly drawn goals are often required for specific projects. For example, the goal of having better maintained roads is good for the general case. However, for a project such as the imposition of a VMT fee, goals such as giving certain roads or bridges the highest priority in terms of repair or standard maintenance, deploying revenue to different regions equitably require drawing more involved goals designed to address congestion pricing or environmental justice through the use of a more complex VMT fee collection system are necessary in order to assess the worthiness of the project to meet those more specific goals.

Whether the project is simple or complex, the project cost must coincide with the goals. It is of no use to expect the simplest and least costly VMT fee system to achieve complex goals such as congestion pricing or charging high quality resource usage fees if time and location trip tracking are not included in the system design. A system which relies solely on annual mileage as recorded at vehicle inspection is a good example of a basic, inexpensive system that offers little sophistication in its application. Conversely, it is unjustifiable to implement a VMT fee system is that is capable of time and location trip tracking if no use is made of this facility since the inclusion of this capability drives the cost up dramatically. Cost and desired function must always be balanced in defining the best system for the circumstance.
The last cost consideration concerns the longevity of the system itself. If the system is based on elements or features that are rapidly being replaced with new technology, or social or theoretical views, then the system is doomed from the beginning. The system must be sufficiently flexible to allow upgrade as necessary whether it is in hardware and application software, or in security and privacy protection, or in communications protocols. Short life cycles are costly and disruptive as well as unnecessary.

The final financial impact considerations concern whether the VMT fee will provide revenue sufficiency and stability. As to the former, estimates of the annual state mileage, proposed fee per mile, and the budgetary estimates needed for roadway infrastructure will determine whether it is possible to generate enough revenue to cover the needs without alienating voters to the point of ballot box repeal initiatives. A rule of thumb is that for $0.01/mile times 10,000 annual miles a driver will be charged $100 for that annual usage. If a state is poor but has vast size, will the added $100, unfairly burden its citizens? Conversely, if a state has a high average income, will the added $100 be seen as trivial thereby offering that state the opportunity to charge a higher VMT fee per mile. Sufficiency, then, involves both determining what is needed to support the roadway infrastructure and what revenue can be raised. Each state must determine whether the VMT fee meets the sufficiency test by assessing revenue needed versus revenue possible.

Revenue stability addresses whether driving habits will maintain a reasonable, predictable level of mileage. As seen in Figure 2, Minnesota experienced a plateauing of VMT when gas prices rose dramatically. That plateauing would affect the future
estimates of VMT fee revenue and therefore affect the projects the state could or would take up. Economic factors such as fuel price surge, high unemployment, and the like affect the revenue that can be raised both by a fuel tax as well as a VMT fee. As with the fuel tax, the VMT fee can be raised as needed. If a state sets a reasonable base estimate for future VMT, then it would be in a good position to insure that any negative stability factors have minimum impact. The effect of stability factors, then, can be controlled by a state’s behavior. Good and prudent choices maximize stability.

3.1.3.2 Environmental Justice, Equity, and Fairness and Sustainability Impacts – Fuel Usage, Congestion Abatement, Air Quality, Public Transit Expansion

One of the overriding considerations of any financial decision with respect to transportation facilities is whether the cost of use is fairly spread over all who would use it. Can those whose incomes place them in the lower median third of a state’s income range still go where they must without unduly or unfairly burdening them? If the answer to this fundamental issue is no, then the VMT fee structure needs to be changed.

The salient questions for environmental justice, equity, and fairness, in general, to be answered are: 1. Is there financial fairness in this fee; 2. Can the system handle a fairness evaluation that might decrease the burden for low income or other targeted groups; 3. Does the fee or system favor non-targeted groups; 4. Is the VMT fee structured to accomplish goals related to the umbrella of environmental justice; and 5. Can the fee structure itself help in the evaluation of these impacts?
The framework should include a section that measures whether a VMT fee system helps promote sustainability goals. If cleaner air can be achieved through congestion reduction, does the system permit assigning higher fees for specifics time frames and roadways? The framework should permit states to measure the sustainability goals most applicable to situations within the state. The most common goals are: lower greenhouse gas levels, less consumption of petroleum, less noise, less acid rain, etc. (19, 20).

Another area of interest to policy makers is whether a strategy can encourage a mode shift to a more sustainable transportation choice such as a shift from the single occupant car to public transit. Some of the important questions are: 1. Can the system support a fee structure that encourages more sustainable behavior; 2. Can the system provide vehicle data for analysts to study with respect to sustainable goals; 3. Can congestion be lessened in the targeted areas?

3.1.3.3 System Performance Including Reliability, Availability, and Stability

Impacts – System Ease of Use, Uptime Criteria, Revenue Management Requirements and Data for Transportation Infrastructure Analysis such as Statistical Review, GIS Treatment, and Prediction of Maintenance or Upkeep/replacement Needs, New or Redesigned Facility Analysis

For any automated system with a large user base, high quality performance in terms of reliability, availability, and stability is absolutely essential. The best software design but with poor hardware and communications choices is doomed as is the reverse where the best hardware and communications configuration coupled with poorly designed software is equally doomed. All aspects of an automated system must work together harmoniously and efficiently. Nearly continuous up-time is also essential. Above and
beyond the flawless electronic transactions, there must be a competent and responsive technical group to support any system selected.

The system must also be capable of communicating or sharing data with other systems especially those systems that will provide analytical appraisal of the collected data such as GIS and statistical analysis software, or local software developed to estimate roadway maintenance or upgrade requirements. The important questions to be examined are: 1. Is the system designed and configured to run properly in a heavy load environment; 2. Can the system be modified easily to accommodate hardware, software, and communications upgrades; 3. Are the fees properly calculated, billed, and relieved; 4. Is there adequate privacy and security protection?

3.1.4 Analytical Approaches

3.1.4.1 Monetary Impacts

A standard approach to evaluating the worthiness of any project, especially computer based ones, is the application of cost/benefit analysis (20, 21). In the case of a VMT fee, the monetary costs are the costs to design and implement a fee collection system as well as the operational costs incurred annually once the system is in place. These costs have a direct monetary value such as the salaries of added staff, computing hardware, application software, and communications and security software. The monetary benefit is the revenue derived from the VMT fees collected.

To evaluate the balance between costs and benefits, the monies spent or taken in must be brought back to a common point in time since monies may well have been spent early as part of the implementation and revenues may arrive as a periodic stream once the
system is operational. The most common approach to evaluating monies on a time line is the use of net present value (NPV) where, by using of a given interest rate for a specified time period, the value of each money event can be established with respect to the present moment. So, revenue expected 20 years in the future will have a lower value than revenue acquired in the current year even though the absolute dollar amount may be the same. By using NPV analysis, a researcher can sum the NPV costs and revenues and determine whether a project is viable. For the sake of evaluation, costs are cast as negative values while revenues or benefits are positive. Projects with positive summed NPVs are considered viable since revenues exceed costs. The NPV formula for the monetary aspect is:

\[ NPV = \sum_{i=1}^{n} \frac{M_{b,j,n}}{(1 + i)^n} + \sum_{i=1}^{n} \frac{M_{c,j,n}}{(1 + i)^n} \]

Where:

NPV is the net present value of the alternative being studied

\( M_{b,j,n} \) is a monetary benefit/revenue for item j during year n,

\( M_{c,j,n} \) is a monetary cost for item j during year n,

and

\( i \) is the selected discount/interest rate.

Derived from (2, 21).
3.1.4.2 Non-Monetary, Monetizable Impacts

The non-monetary but monetizable impacts are instances where a particular cost or benefit does not have a direct monetary value but that value can be estimated using agreed upon standards for the value of a good, service, or situation. Similar to the direct monetary impacts discussed above, once the non-monetary but monetizable impacts have been converted into a monetary equivalent, they can subjected to the benefit/cost analysis with NPV analysis as with the monetary impacts discussed above. The difficult aspect of this type of impact is the conversion to a monetary equivalent. Reliance on studies considering that particular case should assist in a realistic monetary conversion. For example, if a state wishes to mitigate congestion in a certain zone in order to reduce childhood asthma that is attributable to a higher level of pollutants, the monetary value associated with that reduction could be expressed in the cost of health care at the present level versus the cost with pollutant reduction. While the cost of the social, psychological, cultural aspects of childhood asthma, cannot be estimated with reasonable accuracy, the cost of health care can. This estimate is worth using in the project evaluation since it is a determinable estimate.

As with the monetary case, NPV is used to assess these impacts. The formula follows:

\[
NPV = \sum_{i=1}^{n} \frac{N_{b,i,n}}{(1+i)^n} + \sum_{i=1}^{n} \frac{N_{c,i,n}}{(1+i)^n}
\]

Where:

NPV is the net present value of the alternative being studied
\( N_{b,j,n} \) is a non-monetary, monetizable benefit/revenue for item \( j \) during year \( n \),

\( N_{c,j,n} \) is a non-monetary, monetizable cost for item \( j \) during year \( n \),

and

\( i \) is the selected discount/interest rate.

Derived from (2, 21).

3.1.4.3 Non-Monetary, Non-Monetizable Impacts

This set of impacts is the most difficult of all to build an adequate monetary value approach. What monetary value can be estimated for the personal effect of noise or air pollution or for the personal burden of transportation policies such as fees assessed for resource use.

Weatherford maintains that the VMT fee is less regressive than the fuel tax and benefits low income, rural, and elderly drivers more than the use of the fuel tax (22). He developed a regression equation to predict VMT in order to support his hypothesis. The regression equation does not offer a direct translation to a monetary value for the benefit defined nor is it a practical methodology to employ for there are a myriad of environmental justice issues with more emerging regularly. Therein lies the difficulty of any reported approach: the derivation of a monetary value or impact is indirect and tenuous. In response to this result, Weatherford concludes that concerns about insuring equity should have lower priority in evaluating the VMT fee as a revenue source.
This author’s conclusion is quite the reverse. Simply because something is very
difficult to define and apply does not mean that one should reduce its importance or
ignore it. It should behoove researchers to seek a solution for this approach because the
non-monetary, non-monetizable impacts affect life on earth as much if not more than any
other set of impacts. Many of the aspects of environmental justice are a significant part
of the non-monetary, non-monetizable impacts. To ignore these is to ignore the
importance of life - all flora and fauna – and the complex, dynamic balance.

3.2 Environmental Justice

Environmental justice goals, for example, include the reduction of greenhouse
gases, noise pollution, night light pollution, dissemination of contaminants, poorly
renewed fuel sources; and the protection of plant and wildlife habitats and water supplies.
Furthermore, it includes minimization of disruption of bedrock structures. The disruption
of deep geologic structures as seen with fracking has led to increased earthquake activity
and contaminated water supplies. Minimization of fossil fuel dependence will positively
affect all environmental justice goals.

Also included in environmental justice goals are those that specifically involve
social justice. Social justice involves protection of the most vulnerable individuals in the
society. Minimizing undue or increased financial requirements on those with low
incomes or reduced means or possibilities of being employed in positions that provide
sustainable wages is a major goal of social justice with respect to transportation.
Frequently, low income people must live closer to their place of employment which often
occurs in urban settings. In this respect they may need better public transportation
options as well as some relief from either fuel tax or VMT fee assessment. Furthermore, they may experience greater exposure to air, water, and noise pollution. So in this sense, those who have a greater need for social justice also may have a greater need for environmental justice in its broadest definition. Their options are fewer and their needs greater.

3.2.1 Transportation Issues

With the earth’s population in the billions, there is a great need to move goods and people and do it efficiently so that the results are timely and minimize negative impacts on the earth’s climate (23, 24). To this end, a number of studies have been conducted with respect to the minimization of congestion and the improvement of urban vehicle use. Han found that policies that were well coordinated gave rise to better results when addressing issues of urban transportation and environmental impact (25).

In general, the current hot issues with respect to environmental justice emphasize the response to the urban landscape and transportation (20, 25, 26, 27, 28, 29, 30, 31). Ironically, the environmental justice movement arose in a rural area of North Carolina in 1978, when over 30,000 gallons of PCB laced toxic waste was transported to and then dumped along 210 miles of North Carolina roads. In 1982, North Carolina decided that a consolidation of this waste was needed and a site was selected in a county that was predominantly poor and African American (32). Out of this particular injustice arose the ever expanding environmental justice consciousness and concern. While it is easy to envision urban issues with respect to environmental justice and vehicular traffic, wherever vehicular travel is possible so too are the environmental issues that arise from that travel.
3.2.2 Strategies for Assessing and Insuring

One of the most illuminating and powerful techniques available for assessing issues concerning environmental justice involve the use of Geographic Information Systems (GIS) (33, 34, 35, 36, 37). With the application data available from the U.S. Census Bureau coupled with data for licensed drivers and registered vehicles available within a state’s DOT, a state can assess environmental justice issues before a policy is set and can estimate the future impact as if the policy were in place (38).

With a well-constructed data structure within a VMT fee collection system utilizing GPS trip technology, on-going impact analysis is possible via GIS and recommended since environmental justice issues are not static. Even without the GPS trip technology, basic analysis of environmental justice parameters is still possible but not as refined.

As to insuring that environmental justice goals are being met, Han’s research concerning the increase in VMT in Singapore indicates that cohesive policies are a must (25, 39). Well-coordinated policies are easier for the motoring public to understand and abide by. If the policies are well done, then it is clear that no one constituency is being served to the detriment of others, in other words, there is an inherent fairness that all recognize.

Weir et al. approach the environmental justice issues by focusing on the injustices incurred by earlier transportation planning in San Francisco (31). In an attempt to inventory the injustices in a particular section of the city, they enlisted the assistance of the community members. Their research became community action and a baseline for
evaluating any transportation policy or planning proposals. This is a model for assessment becoming insurance of environmental justice.

Raje takes up the issue of social inclusion or exclusion as a result of transportation policy decisions (23). Social issues are just as important as those concerning climate. This research provides a list of critical elements of social inclusion such as values recognition, proximity, and material well-being. The study indicates that residents of Bristol, U.K. are willing to accept a VMT type fee as long as they see the fees collected for their city returned to that area for reinvestment into transportation improvements and that those improvements promote social inclusion. Lucas furthers Raje’s work and presents a diagram (see Figure 9) that ties the issues of transportation and social disadvantage to social exclusion (40).
Schweitzer and Valenzuela present their work in constructing a framework for determining whether the costs and benefits of transportation expenditures give rise to claims of environmental injustice in poor and minority communities (41). They found that there were regional differences in that some wealthier areas had greater ozone pollution than poorer ones and the reverse for other areas. The lesson is that policy decisions and their consequences are very dependent on the local situation.

Schuitema et al. employed regression analysis to determine whether six selected policies in the Netherlands were fair and acceptable (42). While the approach was reasonable for the limited area and scope, this approach would be too cumbersome for
states to employ in the establishment and evaluation of their policy sets. States often deal with far more than six policies for any major transportation endeavor.

Kastrouni developed a US national model involving the use of analysis of variance and asymptotic t tests to assess the equity of the fuel tax and VMT fee (43). When applied to a more local construct, that of the state of Iowa, the national model did not reflect the local conditions as well as hoped. This lends support that each state must develop its own tools for assessing and insuring environmental justice based on the area conditions. Iowa has a larger land mass and is a predominantly agrarian state; Massachusetts is nearly opposite Iowa. Finding low energy efficient vehicles that may be hauling farm products many miles would be expected in Iowa where that would not be the case in Massachusetts. An assessment and insurance approach must be flexible enough to reflect the local conditions.

Greene maintains that energy efficiency, one of the prized goals of environmental justice, cannot be attained with a VMT fee in substitution for a fuel tax (44). He suggests that an indexed energy fee be used instead. He concedes that the indexed energy fee will do nothing to relieve congestion so something that incorporates more than one strategy may well provide better overall results. Moreover, energy efficiency is only one of many goals that concerns environmental justice.

As with most of the studies in this area, there is a circular dynamic such that methods used for assessing the state of environmental justice can then be used to help insure the same. In many cases, the most powerful technological tool is GIS not a large, cumbersome collection of regression equations.
3.3 VMT Fee System Technology

The technology discussion and recommendations arise from the author’s more than forty years of professional experience in complex system design, development, implementation, and operation.

3.3.1 System Design, Implementation, and Testing

3.3.1.1 System Design

3.3.1.1.1 Hardware – Processors, Servers, Peripherals

The hardware requirements are highly dependent on the number of transactions expected to be processed and the complexity of the transaction processing. The simpler the system the less robust will be the hardware needed. California and New York will need far more hardware to support a VMT fee collection system than New Mexico or Rhode Island since the later states have a much lower population density that the former states.

The hardware requirements will also depend on the complexity of the system design chosen. For a relatively simple system based on an yearly VMT capture at an annual inspection, the processors and communications servers will be less numerous and less powerful than a system based on GPS technology where the trip information for a particular vehicle could be downloaded numerous times during a given year.

Peripherals such as printers will also be more numerous for states with greater numbers of drivers especially if there is a printed billing option offered.
3.3.1.1.2 Application Software – Programming, System Integration

The selection of a programming language very much depends on what a state or state department of transportation has set as its choice. Python, currently a popular language, would serve well since it can interact with web protocols and other specialized software (45). SQL based languages would do well also. Again, the simpler the system design, the less robust the programming language needs to be. However, the language needs to be capable of integrating with other software that a department of transportation is using and it needs to be able to interact with whatever the database selection is. These requirements are relatively easy to satisfy.

3.3.1.1.3 Communications – Methods, Security, and Protection

The important aspects of communication are the high availability and capacity such that there is a better than 99% up-time as well as high levels of security such as the use of encryption, firewalls, and secure socket layer (SSL) technology. Attention to communications protocols and security from the very onset of a system design is essential in order to protect the VMT data.

3.3.1.1.4 Data Storage – Database Management, Security, and Protection

The data storage requirements are critical to the success of any system. Slow access, cumbersome programming access methods, arcane requirements, meager capabilities, and insufficient security spell disaster for any real-time system. A robust relational database such as Oracle is a must. While Oracle requires sophisticated technological management and programming, it offers all the necessary features and performs well in either complex or simple systems. The security features offered in a
database management system (DBMS) must be complementary to the other security aspects of a system such as with communications and software.

In addition to the data structure selected, archival aspects of the system design are important. For highly sensitive and vulnerable systems, decisions as to off-site storage and redundant-parallel systems should be considered. At the very least, back-up copies of the database should be created at least once per day. If the DBMS offers an audit feature as does Oracle, then activating that feature for certain parts of the data structure is well worth the additional storage requirements. Storage is inexpensive, lost or compromised data are not.

3.3.1.1.5 GPS Receivers and Vehicle Tracking Devices

At present there are two basic methods for acquiring trip time-location data: 1. A GPS receiver that plugs into the OBD-II (On Board Diagnostic) port; and 2. A smart cell phone application, for example FreeSim_Mobile (46) that collects the desired data.

The OBD-II GPS receiver combination can provide both time and location information that is necessary for the most sophisticated implementation of a VMT fee collection system. A complex fee schedule can be developed to take full advantage of the detailed information provided with this hardware selection. The drawback is that older cars may have only the initial OBD or have no OBD at all which would require the state to have alternative options available for those vehicles. However, in the near future, this technology will be part of any new vehicle and will be provided by the automakers as standard equipment.
The smart cell phone alternative can be used in cases where there is no OBD-II.
This is a less desirable solution in that the state will have to stipulate an acceptable
application and then build a system interface in order for the data to be transferred to the
DOT data center. Additional security and privacy concerns arise with cell phone use and
these must be addressed in the privacy and security aspects of the system design.

3.3.1.2 Implementation

System implementation involves all activities necessary to take the design through
to a system actively being used by the organization requesting it. The first aspect of the
implementation is to develop a time line for the development of all system components.
Use of standard project management techniques including Gantt charts and project
management software is essential for large, complex implementations.

The first task is to select the programming language to be used or to select a
vendor to out-source the programming development. Whether developed in-house or by
a software house, all computer code should be written in reusable modules wherever
possible. For example, if it necessary to calculated the difference between two dates, one
callable module should be developed and all other modules should call that one module.
This provides continuity, uniformity, minimal error, and minimal maintenance issues. If
something is incorrect in the date difference calculation, the error is corrected in one
place and the support staff does not have to worry about whether there are other places
that should also be corrected. As each module is completed, it should be tested and
documented. This will minimize the ever present problem of poor documentation and
costly errors either in design or programming.
When all the necessary modules have been completed, documentation as to the system function, operation support, and finally testing criteria must be developed. This is the time to recheck whether the policy objects have been set in place and can be measured when the system is fully operational. Once the final assembly is complete, then the final testing phase may begin. As with any testing activity, critical analysis of the results is extremely important since the system will represent the organization to the public which in this case are the voting, driving citizens. Donath et al. of the Intelligent Transportation Systems Institute at the University of Minnesota has developed an implementation guide for VMT fees that is replete with examples of the more esoteric aspects of the system design (47). While Donath’s guide is not a complete manual for system implementation, it is useful for understanding the complexity of implementation. Depending on the system a state wishes to implement, the guide could be overly technical or not sufficiently complete.

3.3.1.3 Testing

Testing often suffers from its position as the last set of activities. The, development of most computer based systems of some complexity takes a tremendous amount of time and effort to reach the point where it can be used by the organization desiring it. To combat the end of implementation fall off, it is best to engage in unit testing which amounts to testing every process or routine as it is completed. The results of a unit test can point up design inconsistencies and programming errors very early thus saving time, money, and needless end-point redesign. When all the units have been sufficiently tested and fixed, then the system is ready for an end-to-end test where the
most prominent and important features are tested in a manner that represents the daily operation of the system as if it were fully implemented.

Whether the testing is at the unit level or the end-to-end stage, test data that fully exercises the critical aspects must be developed. Not every aspect of a system can be fully tested since the testing would never end but it is important to test critical aspects so that the state knows that the system has both accuracy and integrity.

3.3.2 Protection of Security, Privacy, and Communications

In order to convince the motoring and voting public that the VMT fee and the system necessary to collect it is acceptable, a sense that personal privacy, data security, and communications security will be rigorously enforced is essential. Breaches can occur at the point of initial data collection, at data transmission, during active data storage, and during fee analysis and processing.

According to Shostack (48), there are six basic threat models that must be addressed:

- Spoofing – an intruder pretends to be some other user or customer, a file, network address, or a program held in memory which can be countered by use of passwords, tokens, full file path names, and SSL;
- Tampering – data is changed at any point in the system’s operation where counter measures include the use of access control lists (ACL), digital signature, and SSL;
- Repudiation – denial that a threat occurred perhaps by altering operation logs where counter measures include heavy use of protected logs and ACLs;
- Information Disclosure – unacceptable or improper database access which results in the publication of private information such as social security numbers or trip details where counter measures are the use of file encryption, ACLs, and SSL;
- Denial of Service – flooding a system with a vast number of requests for access where counter measures are the use of network ACLs, login encryption, and elastic resources; and
- Elevation of Privilege - the user accesses areas that are reserved for IT staff or specific users where counter measures include the use of language and database role validation and operating system memory protection techniques.

System designs should incorporate elements that prevent these threat models from occurring since one embarrassing breach could ruin the public’s view that the system is secure and that their data remains private. Tampering and information disclosure are the most severe threats for a VMT fee system since they strike at the very center of system’s purpose. Tampering with data can change the true fees owed by changing the trip data. Information disclosure can expose people to public scrutiny or financial peril. Prevention techniques should focus both on the attacker and aspects of the system that are likely to be targets.

The distinction must be made between security and privacy. Security is the protection of all aspects of a system. Privacy is the assurance that personal data will remain confidential. Breaches of security can endanger private information such as in the case with Target stores when credit card information was compromised.
To protect data during collection and transmissions, a number of strategies may be employed such as encryption, firewalls, and SSL technologies. These strategies have rapid lifecycles and are somewhat dependent on both the hardware, software, and communications protocols selected. It is important that staff charged with these protections maintain a current knowledge of the field and be ready to introduce new approaches when and as necessary.

Active or current data storage protection can rely on protection installed in system logon and security features available within a DBMS. For example, Oracle DBMS offers security features at the data set/record level as well as at the variable/field level. Access to social security number is often set at a very strict variable level access. Furthermore, Oracle offers a “role” definition access facility in which database administrators might have a different set of access rules than programmers or analysts. In addition to those capabilities, Oracle also offers an audit function that records who is accessing variables for which this feature is activated. For example, educational institutions often activate the audit function for the field that holds a student’s course grade. If there is a question of which person altered grades for a student, the logon, time, and date are available. This feature can be very helpful in studying patterns of access or breach follow-up.

Archived data should also be protected rigorously. If the storage is off-site the location and access should be on a very strict need to know basis. If it is within the facility, either physical separation or difficult to penetrate firewalls should be employed.

Program access to data during processing should be tested for improper storage or use and reviewed periodically for such activity. Employing privacy features available in
some languages such as Python (49) are worth exploring and, if used, setting a policy for usage.

Staff access whether DOT general administrators or IT staff should be restricted on a need to know basis (50). Moreover, if data is to be shared with others whether within the state’s employ or outside, the data must be sanitized such that no one trip or record can be linked to a specific vehicle. For data that is to be shared, a program should be written to sanitize the data and store it in a separate database so that outside access is physically separated from the active, sensitive data. The U.S. Census Bureau employs a strategy that if fewer that ten records exist for a given data request, no data will be delivered. This adds another level of protection that should be considered quite seriously when a VMT fee collection system is implemented.

Skelly has studied the relationship of privacy preservation and data utility and has found that there is an inverse relationship between the two (51). Data utility can be characterized as the amount and type of data stored, in this case, trip data as collected via transportation system smart cards. The nature of the inverse relation is that the more information an organization collects and stores decreases the likelihood that privacy can be preserved effectively. Therefore, data structures should be pared down to the minimum so as bolster privacy preservation as much as possible. Furthermore, if a large data repository is necessary for the effective functioning of a given system, then careful attention should be paid to designing, developing, implementing, and maintaining privacy with the same commitment as calculating a flawless VMT fee bill.
If the DOT has a sound record of data, privacy, communications, and general security protection, then adhering to established policies and procedures is warranted otherwise, this is the time to change and improve these functions.
4.1 Research Objectives

The objectives of this research are:

- **Create a comprehensive framework** to assist state transportation policymakers and administrators in the formulation of alternative vehicle miles traveled (VMT) fee systems to support transportation investments and goals.

- **Develop an analytical approach** to assist in the evaluation of the feasibility, appropriateness, benefits, and costs associated with these alternatives. The approach should be designed to account for anticipated impacts of each alternative including monetary impacts, non-monetary but monetizable impacts, non-monetary but quantifiable impacts, and non-quantifiable impacts.

- **Formulate four system designs and apply the framework and analytical approach** to the VMT fee collection systems (Alternatives A, B, C, and D) which will range from simple to complex.

- **Assess the strengths and limitations of the framework and analytical approach** and review the usefulness in selecting the best alternative within the broader transportation decision-making process.
• **Prepare the dissertation report** discussing all results as well as current and future research.

### 4.2 Research Approach

Given the complexity of VMT fee and any system designed to support its implementation, the best strategy is to set forth a framework that presents the major elements that must be considered in such a way that each state or the federal government can adjust the content and import of these elements as well as add elements that are pertinent to the individual case. The two most important areas to consider are the financial aspects and the environmental justice issues.

The analytical approach must accommodate analysis of both the financial and environmental justice considerations. In the case of the financial aspects, these can be grouped together and can use the same analytical method that is oriented towards monetary assessment. Environmental justice aspects do not lend themselves so easily to a monetary analysis and so a different method must be developed to serve non-monetary, non-monetizable aspects.

Once the framework and analytical approach have been developed, system design can begin. Since state DOTs have varying needs and electronic sophistication, four alternative VMT fee collection system that range from simple to complex will be designed. When the system designs for Alternatives A, B, C, and D have been completed, the analytical approach will be applied to each alternative. The results of the analytical approach application should demonstrate under what conditions an alternative might be reasonably employed. The alternatives should be formulated in such a fashion that a state
can move from one alternative to another as the experience with the VMT fee develops. A concluding review that evaluates how well the alternative conformed to the framework will accompany the analytical approach review.

When the four alternatives have been developed and analyzed, a summary review of the framework and the analytical approach will be done so as to demonstrate the applicability across a range of alternative systems.

4.3 Research Scope of Work

In order to accomplish the stipulated objectives, the following tasks need to be completed:

4.3.1 Task 1: Develop a framework

As has been stated previously, the framework is important in casting the complexity of the VMT fee and supporting systems in a more manageable form for policymakers. The framework identifies key areas in which policymakers must select design elements that advance those areas.

The framework must:

- Articulate the policy objectives concerning revenue sufficiency and stability, environmental justice, implementation and operation costs, and sustainability.
- Develop measurable criteria for each policy objective established.
- Identify revenue sources to achieve the objectives.
- Identify the short and long-term implications of each financing approach.
• Identify potential impacts for each financing approach.

4.3.2 Task 2: Develop an analytical approach

In an attempt to assist in the management of the complexity of the VMT fee and to effectively assess a system design, the analytical approach has two methods: 1. Method 1 is the use of NPV to assess monetary and non-monetary but monetizable items; and 2. Method 2 is the use of an Index to address all other items. These methods are described below.

4.3.2.1 Method 1 - NPV

The research will use NPV to assess monetary and non-monetary but monetizable impacts. The monetary benefit for a VMT fee is the annual aggregate VMT fee revenue collected whereas the monetary costs are the capital to implement the collection system, financing charges, and operating costs necessary to sustain the system. Non-monetary but monetizable benefits include congestion reduction, time-savings, public transit ridership increases whereas the cost impacts maybe the increase in costs necessary to support the increased demand for public transit services by indigent or dependent riders.

4.3.2.2 Method 2 – Index

Another method to assess non-monetary, non-monetizable impacts must be developed. These impacts have no dollar value but may be either numeric or non-numeric. Numeric impacts are air quality measures, for example, while non-numeric impacts are fairness ratings and contributions to sustainability. The proposed method
would use an index that would range from 0-100 and would be based on scores that would be added or subtracted from a standard starting score of 100 based on policy decisions such as place of residence or type of vehicle. The resulting index value for each vehicle would be multiplied by fee based strictly on mile traveled. The index should include evaluation of four factors: 1. Fairness; 2. Energy efficiency; 3. Air quality; and 4. Traffic congestion reduction.

4.3.3 Task 3: Formulate alternative VMT fee collection system designs.

4.3.3.1 Alternative A

Develop a system design for VMT fee collection Alternative A as part of a state’s annual vehicle inspection with regard to total miles traveled in a year.

4.3.3.2 Alternative B

Develop a system design for VMT fee collection Alternative B as part of a state’s annual vehicle inspection with regard to in-state miles travelled only.

4.3.3.3 Alternative C

Develop a system design for VMT fee collection Alternative C using a fee schedule that allows fees to vary based on time and space criteria.

4.3.3.4 Alternative D

Develop a system design for VMT fee collection Alternative D that implements Alternatives A, B, and C sequentially over a course of five years.
4.3.4 Task 4: Apply the framework and the analytical approach to each alternative

For each alternative, evaluate the impacts using the framework and the analytical approach as developed in tasks 1 and 2.

4.3.5 Task 5: Prepare the Final Report

The final report should coincide with the research objectives.
CHAPTER 5

RESEARCH RESULTS

5.1 Introduction

As states move forward in search of new revenue sources to replace the dwindling
collection of a state’s fuel tax and the waning the contribution from federal sources,
alternatives need to be identified and evaluated for their sufficiency to meet the revenue
needs, long-term stability in generating revenue, and the ability to support environmental
justice goals including issues of fairness and sustainability while protecting security and
privacy. The framework provides the mechanism for which the policy makers can set out
important issues and the expected outcomes in order for a particular revenue generation
choice to be acceptable. The analytical approach provides the tool for evaluating the
choices generated from the framework.

The framework and analytical approach provide the theoretical and practical
fabric upon which proposed systems can be laid out and evaluated. In this instance, the
framework and analytical approach will be used to evaluate four proposed VMT fee
systems. These systems are primarily fee collection systems but will have the capability
of providing data for study with respect to travel trends, satisfaction of environmental
justice concerns, and revenue projections.
5.2 Task 1: Develop a framework

The goals of the framework are to:

- Insure revenue sufficiency and stability over time and be relatively immune to changes in energy sources for propulsion, in price changes in fuel sources, and in changes in global economic conditions.
- Support public policy with respect to environmental justice.
- Insure system security and personal privacy.
- Provide the best system at the least cost.

Haque et al. present a graphical approach to their study of transportation policies in Singapore (38). Figure 10 is their approach and provides guidance in formulating coherent, workable transportation policies as well as a framework for transportation projects.

![Diagram](Image Source: Haque (8)).

Figure 10: Major Policy Directions of Singapore’s Evolving Transportation Policies.
In the case of this research, the issues of zero casualties and safe behaviors are embedded in providing sufficient revenue to maintain or improve the roadway infrastructure. Figure 11 presents a capsulized form of the policy issues and solutions for policymakers to consider that this research has produced. Included in the revenue sources are the VMT possibilities as well as the fuel tax since this already exists and can be used for comparison purposes – a benchmark for basic performance.

![Conceptual Framework for Selecting Transportation Revenue Sources](image)

**Figure 11: Conceptual Framework for Selecting Transportation Revenue Sources.**

With respect to revenue sufficiency, both VMT options can easily out-perform the fuel tax in the near future. The fuel tax, however, does not earn any marks for revenue stability since higher petroleum costs have and will continue to send drivers to alternate energy sources thus lowering the fuel tax collected.
With respect to environmental justice issues, the VMT fee, in any presentation, has greater potential than the fuel tax for relieving climatic issues such as air, water, and noise pollution while providing some economic relief for targeted groups such as poor and elderly drivers.

Among the VMT fee choices and the fuel tax, only the fuel tax can guarantee the preservation of security and privacy since the tax is collected at the pump and only a non-cash payment method provides any knowledge of the driver and the vehicle being serviced. Therefore, if a VMT fee system is selected, then special care must be included in the design to protect against any system breach or misuse of system data especially confidential data.

As to implementation cost, the fuel tax is the lowest at zero since it already exits, at least for Massachusetts. For states without a fuel tax that wish to implement it, there are ample examples of tax collection systems and devices available so the price of launching such a system would be minimal especially since each filling station collects federal fuel tax. With the VMT fee collection system alternatives, the simplest and least costly implementation is the one that piggybacks on the annual state vehicle inspection system and requires a limited upgrade of that system. Other VMT fee systems are far more expensive since they rely on a much more sophisticated system requiring much greater and more complex hardware, software, communications, and security components.

With this framework, policymakers must craft system requirements in terms of minimum revenue needed, maximum stability desired, specific environmental justice issues addressed, and maximum cost acceptable within a payback period.
5.3 Task 2: Develop an Analytical Approach

The analytical approach proposed and used is comprised of two methods: 1. Use of NPV for monetary or monetizable items; and 2. Use of an Index for all other items. NPV will handle the bulk of the items presented since the implementation of any new system requires notable financial commitment in the capital outlay and on-going operational needs.

5.3.1 Method 1 - NPV

The use of NPV is well accepted and recognized as an analytical tool for adjusting monetary and monetizable revenues and costs to a given point in time and with a common discount rate. The way in which NPV is used in this research coincides with the accepted use in any cost/benefit analysis. This is a standard application of NPV. The NPV formula used is:

\[
NPV = \sum_{i=1}^{n} \frac{M_{b,j,n}}{(1+i)^n} + \sum_{i=1}^{n} \frac{M_{c,j,n}}{(1+i)^n} + \sum_{i=1}^{n} \frac{N_{b,j,n}}{(1+i)^n} + \sum_{i=1}^{n} \frac{N_{c,j,n}}{(1+i)^n}.
\]

Where:

- NPV is a net present value for an alternative,
- \(M_{b,j,n}\) is a monetary benefit for variable j during the year n,
- \(M_{c,j,n}\) is a monetary cost for variable j during the year n,
- \(N_{b,j,n}\) is a non-monetary monetizable benefit for variable j during the year n,
$N_{c,j,n}$ is a non-monetary monetizable cost for variable $j$ during the year $n$,

and

$i$ is a selected discount rate.

Source: Plotnikov (2)

In accord with accepted practice, revenue items have a positive value and costs a negative one. All items subjected to the NPV method are additive such that projects with a positive total NPV are deemed better since the total revenues are greater than the total costs. By using NPV, systems and projects can be compared so as to assist in selecting the one that fits the framework best. When engaging in comparisons of complex systems such as with VMT fee collection, the highest NPV may not be indicative of the best system choice since only monetary based items are included. However, the most poorly NPV performing systems are frequently deemed inadequate since it would be difficult to generate sufficient revenue to offset costs. Poorly performing systems may be adopted simply because they help lead to better solutions over time.

While NPV can be an extremely powerful tool for judging a system’s usefulness, one must always cast an eye back to the framework and ask how does the system being reviewed fit into the larger vision and the policies attendant with that system.

5.3.2 Method 2 – Index

The VMT fee Index is a tool to incorporate environmental justice into the VMT fee structure. The VMT fee Index attempts to establish value levels consistent with a state’s interest and policy requirements concerning environmental goals. The final
definition of the Index would be applied to the vehicle mileage to determine the fee due. The Index reflects both a state’s policies and an individual’s particular situation. The index value applied to a vehicle’s mileage would range from 0 to 100 and at the time of fee determination that value would be divided by 100 such that any index of less than 100 would reduce the fee owed.

Environmental justice goals, for example, include reduction of greenhouse gases, noise pollution, night-light pollution, dissemination of contaminants, poorly renewed fuel sources; and the protection of plant and wildlife habitats and water supplies as well as protection of the most vulnerable individuals in the society. Furthermore, it includes minimization of disruption of bedrock structures. The disruption of deep geologic structures as seen with fracking has led to increased earthquake activity and contaminated water supplies. Minimization of fossil fuel dependence will positively affect all environmental justice goals.

Moreover, minimizing undue or increased financial requirements for those with low incomes or reduced means or possibilities of being employed in positions that provide sustainable wages is a major goal of the social aspects of environmental justice with respect to transportation. Frequently, low income people must live closer to their place of employment which often occurs in urban settings. In this respect, they may need better public transportation options as well as some relief from either fuel tax or VMT fee assessment. Furthermore, they may experience greater exposure to air, water, and noise pollution. So, in this sense, those who have a greater need for social justice also may have a greater need for environmental and climatic justice. Their options are fewer and their needs greater.
The following is an example of the construction of a sample Index:

Let $X_1 = \text{Total Annual Mileage}$

<table>
<thead>
<tr>
<th>Total Annual Mileage (miles)</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 10,000</td>
<td>100</td>
</tr>
<tr>
<td>8,000-10,000</td>
<td>80</td>
</tr>
<tr>
<td>6,000-7,999</td>
<td>60</td>
</tr>
<tr>
<td>4,000-5,999</td>
<td>40</td>
</tr>
<tr>
<td>2,000-3,999</td>
<td>20</td>
</tr>
<tr>
<td>&lt;2,000</td>
<td>0</td>
</tr>
</tbody>
</table>

Let $X_2 = \text{Vehicle Efficiency (based on model type)}$

<table>
<thead>
<tr>
<th>Vehicle Efficiency (mpg, city)</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;15</td>
<td>100</td>
</tr>
<tr>
<td>15-19</td>
<td>80</td>
</tr>
<tr>
<td>20-24</td>
<td>60</td>
</tr>
<tr>
<td>25-29</td>
<td>40</td>
</tr>
<tr>
<td>30-34</td>
<td>20</td>
</tr>
<tr>
<td>&gt;35</td>
<td>0</td>
</tr>
</tbody>
</table>

Let $X_3 = \text{Vehicle Weight (based on model type)}$

<table>
<thead>
<tr>
<th>Vehicle Weight (Lb)</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 6,000</td>
<td>100</td>
</tr>
<tr>
<td>5,000-5,999</td>
<td>80</td>
</tr>
<tr>
<td>4,000-4,999</td>
<td>70</td>
</tr>
<tr>
<td>3,000-3,999</td>
<td>60</td>
</tr>
<tr>
<td>2,000-2,999</td>
<td>20</td>
</tr>
<tr>
<td>&lt;2,000</td>
<td>0</td>
</tr>
</tbody>
</table>
Let \( X_4 \) = Location of Residence

<table>
<thead>
<tr>
<th>Zone</th>
<th>( X )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Urban/suburban income &gt; $200,000</td>
<td>100</td>
</tr>
<tr>
<td>2 - Urban/suburban income $75,000-199,999</td>
<td>80</td>
</tr>
<tr>
<td>3 - Urban/suburban income $40,000-74,999</td>
<td>40</td>
</tr>
<tr>
<td>4 - Urban/suburban &lt; $40,000</td>
<td>0</td>
</tr>
<tr>
<td>5 - Rural income &gt; $200,000</td>
<td>90</td>
</tr>
<tr>
<td>6 - Rural income $75,000-199,999</td>
<td>70</td>
</tr>
<tr>
<td>7 - Rural income $40,000-74,999</td>
<td>30</td>
</tr>
<tr>
<td>8 - Rural income &lt; $40,000</td>
<td>0</td>
</tr>
</tbody>
</table>

VMT Fee Index Equation

\[
I = X_1 + X_2 + X_3 + X_4 \quad \text{Ceiling} = 100; \ \text{Floor} = 0; \ I \text{ to be adjusted as necessary;}
\]

Variable weighting ok.

\[
I_{\text{applied}} = I / (100 * N) \quad \text{Where N is the total number of variable Xs included in the Index}
\]

VMT Fee Assessed

\[
F = \text{Fee per mile}
\]

\[
M = \text{Miles traveled}
\]

\[
\text{VMT Fee} = F \times M \times I_{\text{applied}}
\]

The value points specified in the above tables will be those that match a state’s policies and goals and may be quite different from state to state. Furthermore, variables may be added or removed depending on what data a state maintains concerning its registered vehicles and drivers as well as the demographic and environmental data available. The above tables are illustrations of the Index concept. The Index is the non-
monetary, non-monetizable component in the VMT fee system and it can be coupled with the NPV analysis to generate an effective analysis of any VMT system design.

A what-if analysis using the Index is possible and certainly encouraged. With the use of data concerning average mileage per vehicle/owner and generalized data concerning zone demographics and environmental parameters, VMT fee revenue estimates can be generated for each fee/mile level. These estimates can be used to evaluate expected revenue. Furthermore, these estimates can be compared with the use of NPV analysis in the determination of which VMT system strategy to implement. Variables can be added or removed from the index equation, categories within variables can be added or removed with the corresponding values adjusted, and different fee/mile rates can be applied to each index equation. A comprehensive analysis comparing any number of strategies and systems can be achieved. Annual appraisals maybe instituted such that current conditions can be included in transportation decisions.

Once an index equation is determined, the actual VMT fee can be calculated for each vehicle mileage case as seen above. Furthermore, the index is not stagnant. The equation can be adjusted as necessary to reflect changes in policies and environmental, economic, and monetary needs.

5.4 Task 3: Develop Alternative VMT Fee Collection System Designs

The proposed system designs are based on a stepwise increase in complexity and performance. Alternative A is the simplest and C is the most complex with D being a stepwise phase-in starting with Alternative A followed by Alternative B and then by C.
There have been no costs associated with the database management system. It is assumed that whatever the state is using currently will suffice and provide a smoother integration of the VMT fee system with existing systems that the state might already have. However, if a DBMS purchase is necessary, then one that has the sophistication, and features of Oracle is recommended.

Another cost decision that weighs on the cost and design aspects is the selection of GPS or cell technology for Alternatives B, C, and D. The designs have standardized on GPS technology for the following reasons:

- At the onset of a new system and the introductory experience with this technology, GPS standardization will minimize system design, development, implementation, and security issues since only one, uniform technology will be used.
- With cellular technology, multiple operating systems at various levels of update provide vastly increased difficulties to say nothing of varying degrees of stability, reliability, accuracy, and sophistication issues.
- The state will not own the cell phones used.
- The state will own the GPS units so that the state can include language regarding unit tampering within its VMT fee enabling legislation.
- The capital and operating costs used were derived from discussions with members of the University of Massachusetts in Amherst Office of Information Technology and from 2014 typical costs for Massachusetts (52). They should not be used without researching current costs. The important aspect of the costs is that the list represents components that are typical for system costing. One should check with
the local jurisdiction as to additional items such overhead that a particular state may use.

5.4.1 Alternative A: VMT Fee Added to State Inspection

The first VMT fee system is incorporated into the annual state vehicle inspection. Nothing at the inspection station changes. In Massachusetts, the current odometer reading is uploaded with the other inspection data. What does change occurs when the uploaded inspection data is received and saved, a program retrieves the last inspection information for that vehicle identification number (VIN) and calculates the appropriate fee based on the mileage difference times the current fee/mile times the Index. The program could then generate a bill for that amount and issue it. Other billing motifs are certainly possible and dependent on a state’s desired strategy. Figure 12 presents the decision tree that policymakers can apply as the first step in formulating a system design. Figure 13 presents a brief and basic flowchart for software processing for this alternative. This is added processing that should be incorporated into the current inspection software. Alternative A requires no new technology with respect to security, privacy, or communications. Figure 14 presents the system characteristics and estimated costs encumbered for implementing Alternative A. The cost profile for Alternative A is presented in two tables: 1. Table 1 presents the summary of the capital costs for one and five years; and 2. Table 2 presents the operating costs for year one and thereafter.
Figure 12: Decision Tree for Alternative A.
Figure 13: Basic Software Processing Flowchart for Alternative A.
Hardware: $15k
   No additional processors needed
   100T additional storage per 5 million vehicles

Software: $50k
   Add 2-4 fields to existing record – Index, Fee Due,
   Apply Total Mileage (Y/N), Fee Paid (Y/N)
   Load Index for all vehicles with value = 1
   Adjust Index based on individual definition
   Search for prior year mileage
   Calculate fee from current – prior mileage
   Multiply fee by Index for actual fee due
   Bill? – Determine when payment will be made

Database System: $0k
   Use what is currently available

Communications: $0k
   Use what is currently available

Security/Privacy: $0k
   Use what is currently available

Index Definition: $50k
   Develop policies and equation for determining
   value for each vehicle.

Capital Investment: $115k
Testing and Implementation Costs: $100k
Total Costs: $215k

Figure 14: System Costs and Characteristics for Alternative A.
While Alternative A is the most basic of all the alternatives proposed, it can provide better implementation of environmental justice policies than the fuel tax since the Index is applied in this alternative in the same fashion as the more complex system alternatives.

5.4.2 Alternative B: VMT Fee from Alternative A Minus Out-of-state Miles

Alternative B seems, via its description, to be a simple step up from Alternative A but that is quite misleading. In order to determine when a vehicle is outside the state’s
boundary, the vehicle’s position must be compared to the state’s geographic polygon. Whenever the vehicle is outside that polygon, that mileage is recorded in a separate storage area from the odometer reading. The determination requires the use of either GPS or cellular position processing. For this research, GPS has been used as the standardized technology for position determination. For vehicles with OBD II, a geo-tracking device can be plugged into the OBD II port. For those with older vehicles that do not have the OBD II device or for individuals who want maximum privacy, they can opt to pay the fee on the differential mileage from one inspection to the next as in Alternative A. In fact, Alternative A programming should be incorporated into Alternative B. However, to implement Alternative B, much more programming including application, communications, and security software is required. Security measures must include data acquisition from the satellite source, data storage, and data upload to the fee collection system. With Alternative B, personal, confidential data is also at risk and therefore measures to insure privacy must be incorporated in the design in all areas of the system whether in the application programming, data structure, or access, etc. Figure 15 presents the decision tree for Alternative B. The basic flowchart for Alternative B is presented in Figure 16. Figure 17 presents the estimated costs and characteristics for Alternative B. The cost profile is presented in two tables: 1. Table 3 presents the capital costs for years one and five; and 2. Table 4 presents the operating costs for year one and thereafter. As with Alternative A, the Index is applied to the VMT fee for the final billing per each vehicle.
Figure 15: Decision Tree for Alternative B.
Figure 16: Basic Software Processing Flowchart for Alternative B.
Hardware: $60k + ($675M-$825M)
- 3 additional processors
- 300T additional storage per 5 million vehicles
- 4.5-5.5M GPS receivers ($150/receiver)

Software: $200k
- Add 2-5 fields to existing record – Index, Fee Due,
  - Apply Total Mileage (Y/N), Fee Paid (Y/N),
  - In-state miles
- Load Index for all vehicles with value = 1
- Adjust Index based on individual definition
- Search for prior year mileage
- Determine In-state mileage from cell phone or GPS data
- Calculate fee from current – prior mileage or In-state mileage
- Multiply fee by Index for actual fee due
- Bill? – Determine when payment will be made

Database System: $0k
- Use what is currently available

Communications: $0k
- Use what is currently available

Security/Privacy: $1M
- Use what is currently available
- Add as necessary for GPS/Cell transmissions

Index Definition: $50k
- Develop policies and equation for determining
  value for each vehicle.

Capital Investment: $1.31M + ($675M-$825M) \rightarrow \text{Max} \$850M
Testing and Implementation Costs: $500k
Total Costs: $850M

Figure 17: System Costs and Characteristics for Alternative B.
5.4.3 Alternative C: GPS Trip Recording with Spatial and Temporal Pricing

Alternative C is the most complex design in that it utilizes the full capabilities of GPS tracking. With this alternative, a matrix of locations and times can be coupled with a fee schedule. Thus, a driver utilizing a congested route during standard commuting hours would be charged more than if the driver used that same route at off hours.

Moreover, rural and less traveled roads may have the lowest rates and may not need a fee change based on time. Establishing the fee schedule matrix will be one of the more challenging aspects of this alternative. Alternative C uses the same equipment and general logic found in Alternative B but applies more sophistication in the trip analysis.
The cost profiles of Alternatives B and C are similar in that the costs are much higher than A due to the necessary inclusion of geo-tracking with the GPS device. As with Alternatives A and B, Alternative C uses the Index to achieve the desired environmental justice goals. Alternative C’s cost structure includes double the funding of Alternative B for security and privacy protection since: 1. Breach of the system that could generate substantial revenue and hold extremely confidential information like complete trip traverses could be destructive in untold ways and degrees; and 2. Misuse of personal data may well doom an otherwise well-designed and constructed system that could benefit all.

Figure 18 presents the decision tree for policy makers while Figure 19 presents the basic system logic. Figure 20 presents the general system costs and the system characteristics. The cost profile for Alternative C is presented in two tables: 1. Table 5 presents the summary of the capital costs for one and five years; and 2. Table 6 presents the operating costs for year one and thereafter.

![Decision Tree for Alternative C](image-url)
Figure 19: Basic Software Processing Flowchart for Alternative C.
Hardware: $400k + ($675M-$825M)
10 additional processors
800T additional storage per 5 million vehicles
4.5-5.5M GPS receivers ($150/receiver)

Software: $100M
Add 2-5 fields to existing record – Index, Fee Due,
Apply Total Mileage (Y/N), Fee Paid (Y/N),
In-state miles, Trip and Fee databases
Load Index for all vehicles with value = 1
Adjust Index based on individual definition
Determine fee per trip and sum all trips for current year using
   cell phone or GPS data
Calculate fee from current – prior mileage or trip fees
Multiply fee by Index for actual fee due
Bill? – Determine when payment will be made

Database System: $150k
Use what is currently available

Communications: $1M
Communicate from pump or cell app

Security/Privacy: $2M
Use what is currently available
Add as necessary for GPS/Cell transmission

Index Definition: $50k
Develop policies and equation for determining value for each
   vehicle.

Capital Investment: $4.5M + ($675M-$825M) => Max $1B
Testing and Implementation Costs: $5M
Total Costs: $1B

Figure 20: System Costs and Characteristics for Alternative C.
5.4.4 Alternative D: Strategic Implementation of Alternatives A, B, and C

Alternative D is the implementation of Alternative A first; then after two years Alternative B is instituted; and finally after two additional years Alternative C is brought online. This phased implementation allows drivers, policymakers, and the state technology staff the opportunity to adjust to the VMT fee and make any changes as necessary for each phase-in.

The major cost change is at the implementation of Alternative C where the costs are substantially lower than C alone since the acquisition of the GPS tracking devices happens in the Alternative B phase and does not need to be replicated for C. For capital

Table 5: Capital Costs Summary for Alternative C.

<table>
<thead>
<tr>
<th>Capital Costs</th>
<th>After Year 1</th>
<th>After Year 5</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware</td>
<td>$825,500,000</td>
<td>$500,000</td>
<td>Replace servers at 5 years</td>
</tr>
<tr>
<td>Application Software</td>
<td>$100,000,000</td>
<td>$0</td>
<td>and GPS/Cell equipment on</td>
</tr>
<tr>
<td>Database System</td>
<td>$0</td>
<td>$0</td>
<td>a rolling basis</td>
</tr>
<tr>
<td>Communications</td>
<td>$1,000,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Security/Privacy Software</td>
<td>$2,000,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Index Definition + Software</td>
<td>$50,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Training + Implementation</td>
<td>$500,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$929,050,000</td>
<td>$500,000</td>
<td></td>
</tr>
</tbody>
</table>

Table 6: Operating Costs Summary for Alternative C.

<table>
<thead>
<tr>
<th>Operating Costs</th>
<th>% of Total</th>
<th>After Year 1</th>
<th>After Year 1</th>
<th>After Year 1</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salary</td>
<td>75.0</td>
<td>$500,000</td>
<td>$525,000</td>
<td>Add 5 people to IT staff</td>
<td></td>
</tr>
<tr>
<td>Software</td>
<td>7.0</td>
<td>$0</td>
<td>$49,000</td>
<td>Increase salary by 5%/year</td>
<td></td>
</tr>
<tr>
<td>Hardware</td>
<td>7.0</td>
<td>$0</td>
<td>$49,000</td>
<td>Benefits included at 25%</td>
<td></td>
</tr>
<tr>
<td>Network</td>
<td>5.0</td>
<td>$0</td>
<td>$35,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communications</td>
<td>3.0</td>
<td>$0</td>
<td>$21,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilities</td>
<td>1.0</td>
<td>$10,000</td>
<td>$7,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training</td>
<td>1.0</td>
<td>$25,000</td>
<td>$7,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel</td>
<td>0.5</td>
<td>$10,000</td>
<td>$3,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplies</td>
<td>0.5</td>
<td>$2,000</td>
<td>$3,500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>$547,000</td>
<td>$700,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
costs for alternatives A and B phase-ins, please refer to Tables 1 and 3 respectively. The operating costs for phase-ins of alternatives A and B are also identical to each alternative as a stand-alone and those tables are 2 and 4 respectively. With the phase-in of Alternative C, the operating costs remain the same as for C as a stand-alone but the capital costs decrease by the cost of the GPS tracking units since they have already been purchased for the Alternative B implementation. The hardware costs would decrease by approximately $750,000,000 which is presented in Table 7. Considerably more will be spent on application software, communications, security, and privacy in order to implement a system that fulfills all the needs of a well-formed system including the always present requirements of reliability and accuracy.

Table 7: Capital Costs Summary for the Alternative C Phase of Alternative D.

<table>
<thead>
<tr>
<th>Capital Costs</th>
<th>Year 1</th>
<th>Year 5</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware</td>
<td>$75,500,000</td>
<td>$500,000</td>
<td>Replace servers at 5 years</td>
</tr>
<tr>
<td>Application Software</td>
<td>$100,000,000</td>
<td>$0</td>
<td>and GPS/Cell equipment on</td>
</tr>
<tr>
<td>Database System</td>
<td>$0</td>
<td>$0</td>
<td>a rolling basis</td>
</tr>
<tr>
<td>Communications</td>
<td>$1,000,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Security/Privacy Software</td>
<td>$2,000,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Index Definition + Software</td>
<td>$50,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Training + Implementation</td>
<td>$500,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$179,050,000</td>
<td>$500,000</td>
<td></td>
</tr>
</tbody>
</table>

5.5 Task 4: Apply the Framework and Analytical Approach

5.5.1 Introduction

Due to the complexity of VMT fee and any system designed to support it, the main aspects of the framework that address financial items and environmental justice issues will be the focal points in reviewing each alternative. This is also true in the application
of the analytical approach. Certain assumptions and facts are used where appropriate in this section. Unless otherwise stated, these relate to Massachusetts travel. They are:

- Massachusetts fuel tax annual revenue is to be $0.24 /gallon X 3,200,000,000 gallons = $768,000,000 (14).
- Massachusetts drivers travel 54,800,000,000 miles annually (15).
- Out-of-state travel is 10% of the total mileage. Therefore, for revenue estimates, 90% of total travel was used for Alternatives B and C and in D where applicable (15).
- In 2010, there were 4,316,291 vehicles traveling in metropolitan Boston. For Alternatives C and D, assume 80% are traveling during commuting timeframes and that the average travel is 10 miles. Therefore, there are 4,316,291 X 0.8 X 10 = 34,530,328 vehicle miles that can be charged a higher fee/mile. For purposes of analysis, the fee will be calculated using $.04 and $.08/mile added on to the general mileage fee.
- The I93/I95 (Rte. 128) interchange handles 375,000 vehicles per work week day. Therefore there are 375,000 X 250 work days/year = 9,375,000 vehicles/year that could be charged a higher fee. The add-on fee will be assessed at $0.06 and $0.10/mile for 2 miles surrounding the interchange. That increases vehicle miles by 9,375,000 X 2 = 18,750,000 miles/year.
- Revenue for Alternative C assumes the use of Alternative B’s in-state mileage.
- The Index, $I_{Applied}$, is assumed to be 0.75 for an average application in all analyses. Each state in their respective analyses may assume a different overall
Applied. With the use of 0.75, there will be a 25% reduction in the fees collected.

- Alternative D uses the appropriate cost and revenue estimates with respect to which Alternative timeframe is ongoing
- The cost of GPS receivers was set at $150/unit which is the current average cost. The cost is expected to drop as time passes.
- Five million GPS units will be needed for the initiation of Alternatives B and C independently and Alternative B initiation within Alternative D.

5.5.2 Alternative A

Alternative A utilizes annual mileage as derived from the current state inspection odometer reading minus the previous annual odometer reading for the same owner. Applying the assumptions and facts stated above, Table 8 presents the revenue estimates for Alternative A. The Index is not applied in Table 8 but will be reflected in the NPV analysis. VMT fees/mile vary from $0.005 to 0.03/mile. With a VMT fee of $.01/mile, a vehicle driven 10,000 miles incurs a $100 charge. At a fee of $.015/mile, the VMT fee overtakes the fuel tax and exceeds it by $50 million dollars. With an estimated cost of $215,000 capital outlay and $147,000 operating expenses for a total of $362,000 for the first year, that $50 million in revenue greatly exceeds the costs. Much additional infrastructure support occurs immediately. Moreover, if the fuel tax is maintained, the total revenue gained is doubled. With such revenue intake, the state can consider not financing this project but paying the costs out of proceeds gained through that first year.
Table 8: Revenue Estimates for Alternative A.

<table>
<thead>
<tr>
<th>Revenue Source</th>
<th>VMT Fee per mile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$0.005</td>
</tr>
<tr>
<td>Fuel Tax</td>
<td>$768,000,000</td>
</tr>
<tr>
<td>VMT Fee</td>
<td>$274,000,000</td>
</tr>
<tr>
<td>Total</td>
<td>$1,042,000,000</td>
</tr>
</tbody>
</table>

With respect to the framework, Alternative A does well with revenue sufficiency in that a modest fee/mile generates near or above revenue when compared to the fuel tax. This alternative performs with at least the same stability as the fuel tax. In fact, given the experience of other states, VMT is relatively immune to instability. Moreover, Alternative A has the lowest cost of implementation. In terms of environmental justice, Alternative A will deliver well so long as the Index is well constructed. What Alternative A cannot do is attempt to alleviate congestion on specific roadways since no roadway specific data are collected. As to security and privacy, Alternative A relies on what the state has in place with respect to the state inspection process. If the security and privacy measures have been adequate, then no additional work need be done. If not, now would be the time to update.

In the application of the analytical approach, Table 9 presents the basic NPV analysis for a VMT fee of $.01/mile with the proposed 0.75% Index applied. Appendix A contains applications of the analytical approach for other fee/mile cases. With the use of $.01/mile this alternative has a positive $592,580,363 project NPV for a five year period with no Index applied and a positive $444,295,787 when the Index of 0.75 is applied.
Alternative A is considered a viable project whether the Index is applied or not so it should be considered as a possible choice for implementing the VMT fee.

### Table 9: NPV and Index Application at $0.01/mile for Alternative A

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without use of Index, VMT $.01/m</th>
<th>Revenue with use of Index = 0.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>$215,000</td>
<td>$147,000</td>
<td>$0</td>
<td>$411,000,000</td>
</tr>
<tr>
<td>Year 5</td>
<td>$15,000</td>
<td>$170,171</td>
<td>$548,000,000</td>
<td>$411,000,000</td>
</tr>
<tr>
<td>Item NPV (i=0.05)</td>
<td>$226,753</td>
<td>$331,188</td>
<td>$593,138,304</td>
<td>$444,853,728</td>
</tr>
<tr>
<td>Total NPV (i=0.05)</td>
<td></td>
<td></td>
<td>$592,580,363</td>
<td>$444,295,787</td>
</tr>
</tbody>
</table>

#### 5.5.3 Alternative B

Alternative B focuses on taking the total mileage traveled in a year (from one inspection to the next) subtracting out-of-state mileage, and charging only for in-state travel. Charging for in-state travel only is viewed as appropriate from an equity perspective since the VMT fee represents a tax on the use of a state’s roadways. This is particularly important for drivers who live in towns bordering another state and may commute to work in that adjoining state.

While Alternative B may seem to be a logical extensive of Alternative A, technologically it is not. Alternative B introduces GPS tracking and the necessity of determining whether travel outside the state polygon occurs and how much of that travel is outside. Once that total out-of-state travel has been determined and removed from the total mileage, the fee determination is as simple as that of Alternative A.

With respect to the framework, Alternative B can provide revenue stability as all VMT fee alternatives do but it generates lower revenue sufficiency since the mileage
charged is reduced by 10%. Furthermore, Alternative B is not a low cost implementation. This alternative, however, does offer the same level of environmental justice attention that Alternative A does. Alternative B introduces greater requirements for providing security protection due to GPS tracking and the consequent upload of these data. Furthermore, since there is increased personal data in the form of trip information, more privacy measures are needed to protect it.

In terms of the application of the analytical approach, revenue estimates for Alternative B are presented in Table 10 and the NPV and Index analysis for $0.01/mile in Table 11. This alternative generates less revenue than A since a 10% reduction in total miles has occurred and needs a fee of $.02/mile to surpass the revenue generated by the fuel tax. Since NPV combines both revenue and cost items, the true picture of Alternative B is seen in Tables 11 and 12. In Table 11 with a fee of $0.01/mile, the NPV is negative which indicates an unacceptable project. However, when the fee is raised to $0.02/mile (see Table 12), the project NPV is positive and can thus be viewed as viable. With the use of the Index, B does not become a viable project until the fee reaches $0.03/mile (see Appendix A). Whether the driving public and the policymakers view a $0.02/mile fee as acceptable must be determined by the state itself. The negative NPV at $0.01/mile is due to the large increase in capital costs associated with the state’s standardization and purchase of GPS tracking devices. Despite Alternative B’s lower NPVs, implementing B may be a wise strategic move in that the state has an opportunity to decide and then prepare for a more robust application of geo-tracking as is evident in Alternative C.
### Table 10: Revenue Estimates for Alternative B.

<table>
<thead>
<tr>
<th>Revenue Source</th>
<th>VMT fee per mile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Annually</td>
</tr>
<tr>
<td>Fuel Tax</td>
<td>$768,000,000</td>
</tr>
<tr>
<td>VMT Fee</td>
<td>$246,600,000</td>
</tr>
<tr>
<td>Total</td>
<td>$1,014,600,000</td>
</tr>
</tbody>
</table>

### Table 11: NPV and Index Application at $0.01/mile for Alternative B.

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without use of Index, VMT $.01/m</th>
<th>Revenue with use of Index, VMT $.01/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>$827,250,000</td>
<td>$447,000</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Year 5</td>
<td>$500,000</td>
<td>$680,684</td>
<td>$493,200,000</td>
<td>$369,900,000</td>
</tr>
<tr>
<td>Item NPV (i=0.05)</td>
<td>$827,641,763</td>
<td>$1,183,751</td>
<td>$533,824,473</td>
<td>$400,368,355</td>
</tr>
<tr>
<td>Total NPV (i=0.05)</td>
<td>-295,001,041</td>
<td>-428,457,159</td>
<td>$238,823,433</td>
<td>-$28,088,804</td>
</tr>
</tbody>
</table>

### Table 12: NPV and Index Application at $0.02/mile for Alternative B.

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without use of Index, VMT $.02/m</th>
<th>Revenue with use of Index, VMT $.02/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>$827,250,000</td>
<td>$447,000</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Year 5</td>
<td>$500,000</td>
<td>$680,684</td>
<td>$986,400,000</td>
<td>$739,800,000</td>
</tr>
<tr>
<td>Item NPV (i=0.05)</td>
<td>$827,641,763</td>
<td>$1,183,751</td>
<td>$1,067,648,947</td>
<td>$800,736,710</td>
</tr>
<tr>
<td>Total NPV (i=0.05)</td>
<td>$238,823,433</td>
<td>$28,088,804</td>
<td>-28,088,804</td>
<td>$800,736,710</td>
</tr>
</tbody>
</table>

5.5.4 Alternative C

With Alternative C, full use of the GPS tracking and the consequent fee matrix with respect to time and locale is possible. In fact, the use of the matrix offers the
possibility of a very sophisticated fee system capable of generating much more revenue than expected and certainly much more than used in this analysis.

With the framework, this alternative attains the best possible revenue sufficiency and stability goals since fees can be set higher for better roads or more desirable routes. Environmental justice goals are better served than with Alternatives A and B since such goals as congestion relief, noise reduction, etc., can be addressed via the use of the fee matrix. With Alternatives A and B, the satisfaction of environmental justice goals relied solely on the application of the Index. With C, the application of the Index remains and the power of the fee matrix is employed to achieve more. Due to the even greater trip data acquired, privacy protection must be stressed in both the design and implementation phases. Any system breach of Alternative C would be extremely detrimental. To minimize the possibility of a security and/or privacy breach, the cost structure includes a generous allocation to support the robust development and implementation of protective measures. The disadvantage of Alternative C is that its capital and operating costs are the highest. It is not a low cost implementation by anyone’s definition.

As mentioned above, the analytical approach includes only two fee matrix elements: 1. Travelling during the commuting timeframe in metropolitan Boston; and 2. Traveling within a two mile radius of the I93/I95 (Rte. 128) interchange. These two elements were used because there was ample information about the traffic load to make it possible to generate a plausible application. Other possible elements might be travel from Lexington, MA to Cambridge, MA on Rte. 2 during commuting hours or a similar use with the Southeast Expressway.
The revenue estimates for Alternative C are presented in Table 13. In reviewing Alternative C, it is important to remember that C like B contains only the miles traveled in Massachusetts. The estimated revenue for C surpasses the fuel tax at a fee level of $0.02/mile as was the case with Alternative B. Also like Alternative B, the NPV for C without the Index applied at $0.01/mile is negative, as seen in Table 14, but becomes positive at a fee of $0.02/mile (see Table 15). When the Index is applied, the NPV is becomes positive at a fee of $0.03/mile (see Appendix A). The increase in capital costs in the form of more software and security development, acquisition of GPS tracking devices, and the development of a fee matrix as well as greater operating costs all contribute to lower NPVs. However, if the fee matrix is sufficiently developed beyond the two elements used here, far greater revenues will be generated. The greater revenue potential and the likelihood of better performance with respect to environmental justice goals are quite possible.

Table 13: Revenue Estimates for Alternative C.

<table>
<thead>
<tr>
<th>Revenue Source</th>
<th>VMT fee per mile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$0.005</td>
</tr>
<tr>
<td>Anually</td>
<td></td>
</tr>
<tr>
<td>Fuel Tax</td>
<td>$768,000,000</td>
</tr>
<tr>
<td>VMT Fee at $.04 and $.06</td>
<td>$249,106,213</td>
</tr>
<tr>
<td>VMT Fee at $.08 and $.10</td>
<td>$251,237,426</td>
</tr>
<tr>
<td>Total at $.04 and $.06</td>
<td>$1,017,106,213</td>
</tr>
<tr>
<td>Total at $.08 and $.10</td>
<td>$1,019,237,426</td>
</tr>
</tbody>
</table>
Table 14: NPV and Index Application at $0.01/mile for Alternative C Using Additional Fees of $0.08 and $.0.10.

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without</th>
<th>Revenue with use of Index, VMT $0.01/m of Index = 0.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>$929,050,000</td>
<td>$700,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Year 5</td>
<td>$500,000</td>
<td>$850,854</td>
<td>$497,837,426</td>
<td>$373,378,070</td>
</tr>
<tr>
<td>Using $.08 and $.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item NPV (i=0.05)</td>
<td>$929,441,763</td>
<td>$1,620,938</td>
<td>$538,843,880</td>
<td>$404,132,910</td>
</tr>
<tr>
<td>Total NPV (i=0.05)</td>
<td></td>
<td></td>
<td>$-392,218,821</td>
<td>$-526,929,791</td>
</tr>
</tbody>
</table>

Table 15: NPV and Index Application at $0.02/mile for Alternative C Using Additional Fees of $0.08 and $.0.10.

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without</th>
<th>Revenue with use of Index, VMT $.02/m of Index = 0.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>$929,050,000</td>
<td>$700,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Year 5</td>
<td>$500,000</td>
<td>$850,854</td>
<td>$991,037,426</td>
<td>$743,278,070</td>
</tr>
<tr>
<td>Using $.08 and $.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item NPV (i=0.05)</td>
<td>$929,441,763</td>
<td>$1,620,938</td>
<td>$1,072,668,354</td>
<td>$804,501,265</td>
</tr>
<tr>
<td>Total NPV (i=0.05)</td>
<td></td>
<td></td>
<td>$141,605,653</td>
<td>$-126,561,436</td>
</tr>
</tbody>
</table>

5.5.5 Alternative D

Alternative D consists of the strategic implementation of Alternative A for the first two years then the implementation of Alternative B for the next two years, and finally the implementation of Alternative C in the fifth year. The strength of Alternative D lies in the phased implementation that allows a state to adjust the goals, work, and policies with time while knowing that each stage is leading to the next. When Alternative C is finally implemented, the state should have sufficient time to create a fee matrix that truly represents the goals and revenue needs and to incorporate sophisticated, robust security and privacy measures to protect it. By starting with Alternative A, much needed additional revenue is available immediately at a very low cost. The two-year intervals
between each new implementation are to some extent arbitrary. However, a shorter timeframe is not recommended since that would not provide sufficient time to prepare for the next step.

Alternative D adheres to the framework in the same fashion as its constituent alternatives do. However, since there is a formal strategy for moving from alternative to alternative, better planning and adherence to stipulated goals are expected.

The financial performance of Alternative D is summarized in Tables 16 (Index = 1.00) and 17 (Index = 0.75). Both tables present the performance of a $0.01/mile fee. With Alternative D, the biggest cost occurrence happens at the onset of year 3 when Alternative B is implemented. That period presents a negative NPV but recovers to a positive NPV for Alternative C. With Alternative D, it is possible to keep the fee lower than with Alternatives B and C as stand-alone options. As with Alternatives A, B, and, C, the Index is applied throughout the phases. Moreover, Alternative D enjoys the same expanded attention to environmental justice that Alternative C introduced with the inclusion of the fee matrix.

**Table 16: Revenue, Costs, and NPV for Alternative D with Fee at $0.01/mile and Index = 1.00.**

<table>
<thead>
<tr>
<th>Alternative Parameters</th>
<th>Implement Alternative A</th>
<th>Implement Alternative B</th>
<th>Implement Alternative C</th>
<th>Index = 1.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Costs</td>
<td>$215,000</td>
<td>$287,000</td>
<td>$1,007,000</td>
<td>$1,247,000</td>
</tr>
<tr>
<td>Operating Costs</td>
<td>$353,988,782</td>
<td>$353,988,782</td>
<td>$353,988,782</td>
<td></td>
</tr>
<tr>
<td>VMT Fee Add-on $0.08 and $0.10</td>
<td>$139,519,028</td>
<td>$139,519,028</td>
<td>$139,519,028</td>
<td>$139,519,028</td>
</tr>
<tr>
<td>Item NPV (i=0.05)</td>
<td>$101,627,327</td>
<td>$56,558,709</td>
<td>$308,700,163</td>
<td>$353,898,782</td>
</tr>
<tr>
<td>Total NPV (i=0.05)</td>
<td>$139,519,028</td>
<td>$139,519,028</td>
<td>$353,898,782</td>
<td></td>
</tr>
</tbody>
</table>
Table 17: Revenue, Costs, and NPV for Alternative D with Fee at $0.01/mile and Index = 0.75.

![Table 17](image)

5.6 Comparison of Alternatives

All alternatives were designed with the framework in mind. Some are more successful at adhering to the desired policy elements than others. Table 18 presents a comparison of the four alternative designs and the fuel tax. It is important to include the fuel tax so as to compare where the state might be going with respect to where it is currently. If additional revenue and low implementation cost are the goals, then Alternative A is the option to choose. If greater gains in environmental justice and revenue potential, then Alternative C or D is the best choice. Alternative B is the weakest of the four alternatives in that the costs rise dramatically for a small gain in equity. However, Alternative B is quite useful as a step in the implementation of Alternative D in that practice with a basic fee matrix and GPS tracking is available. The inclusion of Alternative B as a step before Alternative C makes the implementation of C smoother and less error prone. So, B as a part of D is well worth it.
Using Skelly’s general theme that there is an inverse relationship between privacy preservation and data utility (50), Figure 21 presents the four alternatives with respect to this relationship. Alternative A stores very little additional data and virtual no personal data while Alternatives C and D store considerable quantities of detailed trip data that drivers will no doubt consider private.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Revenue Sufficiency</th>
<th>Revenue Stability</th>
<th>Low Cost Implementation</th>
<th>Environmental Justice</th>
<th>Security and Privacy Preservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Middle</td>
<td>Stable</td>
<td>Best</td>
<td>Middle</td>
<td>Middle</td>
</tr>
<tr>
<td>B</td>
<td>Worst</td>
<td>Stable</td>
<td>Middle</td>
<td>Middle</td>
<td>Worse</td>
</tr>
<tr>
<td>C</td>
<td>Best</td>
<td>Stable</td>
<td>Worst</td>
<td>Best</td>
<td>Worst</td>
</tr>
<tr>
<td>D</td>
<td>Best</td>
<td>Stable</td>
<td>Worst</td>
<td>Best</td>
<td>Worst</td>
</tr>
<tr>
<td><strong>Fuel Tax</strong></td>
<td><strong>Worst</strong></td>
<td><strong>Unstable</strong></td>
<td><strong>Best</strong></td>
<td><strong>Worst</strong></td>
<td><strong>Best</strong></td>
</tr>
</tbody>
</table>

**Figure 21: Alternatives A, B, C, and D with Respect to the Privacy Preservation-Data Utility Relationship.**
With the collected fuel tax at $768,000,000, all alternatives generate that and more at the $0.03/mile VMT fee whether the index is employed or not. Table 19 presents the revenue comparison of the four alternatives. Alternative A surpasses the fuel tax at the $0.02/mile whether the Index is employed or not. All other alternatives are close to the collected fuel tax with the Index employed and over the fuel tax if the Index is not employed at a VMT fee of $0.02/mile. These system designs can perform well even with the choice of a modest VMT fee.

**Table 19: Net Revenue after Year 5 (Revenue Collected – Operating Costs) Where Alternative C has $0.8,$0.10 Additional Charge.**

<table>
<thead>
<tr>
<th>VMT Fee (dollar/mile)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.75</td>
<td>$410,895,000</td>
<td>$547,860,000</td>
<td>$369,480,000</td>
<td>$492,640,000</td>
</tr>
<tr>
<td>1.00</td>
<td>$821,895,000</td>
<td>$1,095,860,000</td>
<td>$739,380,000</td>
<td>$985,840,000</td>
</tr>
<tr>
<td>0.75</td>
<td>$1,232,895,000</td>
<td>$1,643,860,000</td>
<td>$1,109,280,000</td>
<td>$1,479,040,000</td>
</tr>
<tr>
<td>1.00</td>
<td>$1,479,495,000</td>
<td>$1,972,660,000</td>
<td>$1,479,180,000</td>
<td>$1,976,737,426</td>
</tr>
<tr>
<td>0.75</td>
<td>$2,054,895,000</td>
<td>$2,739,860,000</td>
<td>$1,849,080,000</td>
<td>$2,465,440,000</td>
</tr>
<tr>
<td>1.00</td>
<td>$2,054,895,000</td>
<td>$2,739,860,000</td>
<td>$1,849,080,000</td>
<td>$2,465,440,000</td>
</tr>
</tbody>
</table>
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The need for states to find revenue sources that will bolster or supplant the fuel tax is real and urgent. To that end, the VMT fee has generated considerable interest since it represents a “pay for use” strategy with regards to transportation infrastructure support. Drivers using the roadways the most should support that resource the most. What has been lacking is a framework for policies that are most important in the evaluation of the VMT fee and any system to support it. In conjunction with the framework, the analytical approach is included for that evaluation. In this research, five areas standout as policy areas important for the VMT fee: 1. Revenue sufficiency; 2. Revenue stability; 3. Low cost implementation; 4. Environmental justice; and 5. Security and privacy preservation.

The analytical approach has centered on two methods for evaluation: 1. Use of NPV for monetary and non-monetary but monetizable impacts; and 2. Use of an Index for all other impacts. NPV, by its nature, is attuned to placing all costs and benefits at a particular point in time so that they are additive. In doing so, NPV provides a good tool for comparing all VMT fee collection systems in order to select the one best suited for the situation. The Index serves several purposes in that it casts each vehicle/owner in terms of environmental justice so that equity maybe served in ways that are simply impossible with a fuel tax. Moreover, the aggregated Index can be used to estimate the effect on VMT fee revenue with respect to an annual value thus giving the state a sense of how much revenue will actually be received. Any organization that lives by a budget fully
appreciates well-formulated revenue estimates. The analytical approach draws in and evaluates the economic factor that is an important part of any sustainability discussion.

In order to test the soundness of both the framework and the analytical approach, four VMT fee collection systems (Alternatives A, B, C, and D) were designed and then subjected to evaluation via the framework and analytical approach. The alternatives were developed from least complex (A) to most complex (C and D). Since the Index was applied to all four alternatives, there was some environmental justice applied throughout. Alternative A took the odometer reading data supplied by the state inspection, determined the elapsed miles from the previous inspection, and applied the fee to that elapsed mileage. If revenue at the least cost is the primary objective, Alternative A will suffice. Alternative B introduced the use of GPS but in a limited application in that only in-state travel was subjected to the VMT fee assessment. The implementation costs for Alternative B are significantly higher than A and the revenue is reduced from A. Alternative C takes full advantage of the GPS tracking in that a fee matrix that is based on time and locale can be applied to individual trip data such that higher fees for commuting during congested times and in congested areas can be charged. Moreover, roadways that are deemed a higher quality resource may have higher fees in all cases. Like Alternative B, C has a high implementation costs but unlike B can deliver much higher revenue depending on how the fee matrix is defined and implemented. Alternative D is the strategic implementation of Alternatives A, B, and C. Two years separates the implementations of each alternative and begins with A is followed by B and finally C. Alternative D allows all concerned to adjust to the VMT fee and the systems necessary to support it. Moreover, it allows modification of the policies, standards, and technology as
needed. In the beginning, Alternative D gives a much needed boost in revenue at a low cost and in the end provides a sophisticated system that can provide greater revenue and better environmental justice results.

Alternative A presents the greatest security and privacy preservation since it gathers no additional data than the annual state inspection and performs minimal computational and storage activities. Alternative B introduces GPS processing and the determination of in-state versus out-of-state travel. Due to more data transmission and greater personal data transmission and storage, Alternative B requires more application of protective techniques than Alternative A. Alternatives C and D incur the greatest challenge to security and privacy preservation since these alternatives have the greatest amount of data, especially personal data, transmitted, processed and stored. Alternatives C and D must include the most rigorous application of protective techniques in order to satisfy the policymakers and the public.

The natural follow-on to this research is an examination of the fee matrix and how well a richly defined matrix can produce much needed revenue and how such a matrix affects driving behavior. More research into the financial effect of the fee can illuminate what fee range can produce revenue at a desirable level without hurting or angering the voting public. This fee range research can also be applied to the fee matrix.

This research supports the application of a VMT fee and demonstrates that very modest fee charges can produce revenue comparable to the fuel tax. This work also offers a framework and analytical approach that can be used effectively by policymakers.
in determining whether to use a VMT fee and if used, what system design works best for the conditions of that state.
## APPENDIX: NPV TABLES

### Alternative A

#### Case 1: VMT Fee = $.01/mile

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without use of Index, VMT $.01/m</th>
<th>Revenue with use of Index = 0.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>$215,000</td>
<td>$147,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Year 5</td>
<td>$15,000</td>
<td>$170,171</td>
<td>$548,000,000</td>
<td>$411,000,000</td>
</tr>
</tbody>
</table>

| Item NPV (i=0.05)         | $226,753 | $331,188 | $593,138,304 | $444,853,728 |
| Total NPV (i=0.05)        |         |         | $592,580,363 | $444,295,787 |

#### Case 2: VMT Fee = $.02/mile

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without use of Index, VMT $.02/m</th>
<th>Revenue with use of Index = 0.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>$215,000</td>
<td>$147,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Year 5</td>
<td>$15,000</td>
<td>$170,171</td>
<td>$1,096,000,000</td>
<td>$822,000,000</td>
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</tbody>
</table>

| Item NPV (i=0.05)         | $226,753 | $331,188 | $1,186,276,608 | $889,707,456 |
| Total NPV (i=0.05)        |         |         | $1,185,718,667 | $889,149,515 |

#### Case 3: VMT Fee = $.03/mile

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without use of Index, VMT $.03/m</th>
<th>Revenue with use of Index = 0.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>$215,000</td>
<td>$147,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Year 5</td>
<td>$15,000</td>
<td>$170,171</td>
<td>$1,644,000,000</td>
<td>$1,233,000,000</td>
</tr>
</tbody>
</table>

| Item NPV (i=0.05)         | $226,753 | $331,188 | $1,779,414,912 | $1,334,561,184 |
| Total NPV (i=0.05)        |         |         | $1,778,856,971 | $1,334,003,243 |
Alternative B

Case 1: VMT Fee = $0.01/mile

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without use of Index</th>
<th>Revenue with use of Index = 0.75</th>
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<tbody>
<tr>
<td>Current</td>
<td>$827,250,000</td>
<td>$447,000</td>
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<td></td>
</tr>
<tr>
<td>Year 5</td>
<td>$500,000</td>
<td>$680,684</td>
<td>$493,200,000</td>
<td>$369,900,000</td>
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<tr>
<td>Item NPV (i=0.05)</td>
<td>$827,641,763</td>
<td>$1,183,751</td>
<td>$533,824,473</td>
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<tr>
<td>Total NPV (i=0.05)</td>
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<td>$-295,001,041</td>
<td>$428,457,159</td>
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Case 2: VMT Fee = $0.02/mile

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without use of Index</th>
<th>Revenue with use of Index = 0.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>$827,250,000</td>
<td>$447,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Year 5</td>
<td>$500,000</td>
<td>$680,684</td>
<td>$986,400,000</td>
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<td>Item NPV (i=0.05)</td>
<td>$827,641,763</td>
<td>$1,183,751</td>
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<td>$238,823,433</td>
<td>$-28,088,804</td>
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</table>

Case 3: VMT Fee = $0.03/mile

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without use of Index</th>
<th>Revenue with use of Index = 0.75</th>
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</thead>
<tbody>
<tr>
<td>Current</td>
<td>$827,250,000</td>
<td>$447,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Year 5</td>
<td>$500,000</td>
<td>$680,684</td>
<td>$1,479,600,000</td>
<td>$1,109,700,000</td>
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<tr>
<td>Item NPV (i=0.05)</td>
<td>$827,641,763</td>
<td>$1,183,751</td>
<td>$1,601,473,420</td>
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</tr>
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<td>Total NPV (i=0.05)</td>
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<td>$772,647,906</td>
<td>$372,279,551</td>
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</table>
### Alternative C

#### Case 1: VMT Fee = $.01/mile

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without use of Index, VMT $.01/m</th>
<th>Revenue with use of Index = 0.75</th>
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</thead>
<tbody>
<tr>
<td>Current</td>
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<td>$700,000</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Year 5</td>
<td>$500,000</td>
<td>$850,854</td>
<td>$495,706,213</td>
<td>$371,779,660</td>
</tr>
<tr>
<td>Using $.04 and $.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item NPV (i=0.05)</td>
<td>$929,441,763</td>
<td>$1,620,938</td>
<td>$536,537,121</td>
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<td>Total NPV (i=0.05)</td>
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<td></td>
<td>$-394,525,580</td>
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</table>

#### Case 2: VMT Fee = $.02/mile

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without use of Index, VMT $.02/m</th>
<th>Revenue with use of Index = 0.75</th>
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</thead>
<tbody>
<tr>
<td>Current</td>
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<td>$0</td>
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<td>Year 5</td>
<td>$500,000</td>
<td>$850,854</td>
<td>$988,906,213</td>
<td>$741,679,660</td>
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<tr>
<td>Using $.04 and $.06</td>
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<td></td>
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<tr>
<td>Item NPV (i=0.05)</td>
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<td>$1,620,938</td>
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<td>$802,771,196</td>
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<td>Total NPV (i=0.05)</td>
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<td>$139,298,893</td>
<td>$128,291,505</td>
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</table>
Case 3: VMT Fee = $.03/mile

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without use of Index, VMT $.03/m</th>
<th>Revenue with use of index = 0.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>$929,050,000</td>
<td>$700,000</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Year 5</td>
<td>$500,000</td>
<td>$850,854</td>
<td>$1,482,106,213</td>
<td>$1,111,579,660</td>
</tr>
<tr>
<td>Using $.04 and $.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item NPV (i=0.05)</td>
<td>$929,441,763</td>
<td>$1,620,938</td>
<td>$1,604,186,068</td>
<td>$1,203,139,551</td>
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<tr>
<td>Total NPV (i=0.05)</td>
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<td></td>
<td>$673,123,367</td>
<td>$272,076,850</td>
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</table>

Case 4: VMT Fee = $.04/mile

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without use of Index, VMT $.04/m</th>
<th>Revenue with use of index = 0.75</th>
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</thead>
<tbody>
<tr>
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<td>$700,000</td>
<td>$0</td>
<td>$0</td>
</tr>
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<td>Year 5</td>
<td>$500,000</td>
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<td>$1,484,237,426</td>
<td>$1,113,178,070</td>
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<td>Using $.08 and $.10</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Item NPV (i=0.05)</td>
<td>$929,441,763</td>
<td>$1,620,938</td>
<td>$1,606,492,827</td>
<td>$1,204,869,621</td>
</tr>
<tr>
<td>Total NPV (i=0.05)</td>
<td></td>
<td></td>
<td>$675,430,126</td>
<td>$273,806,919</td>
</tr>
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</table>
### Case 5: VMT Fee = $.05/mile

<table>
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<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without use of Index, VMT $.05/m of Index = 0.75</th>
<th>Revenue with use of Index, VMT $.05/m of Index = 0.75</th>
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</thead>
<tbody>
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<td>$929,050,000</td>
<td>$700,000</td>
<td>$0</td>
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</tr>
<tr>
<td>Year 5</td>
<td>$500,000</td>
<td>$850,854</td>
<td>$2,468,506,213</td>
<td>$1,851,379,660</td>
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<td>Using $.04 and $.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item NPV (i=0.05)</td>
<td>$929,441,763</td>
<td>$1,620,938</td>
<td>$2,671,835,015</td>
<td>$2,003,876,261</td>
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<tr>
<td>Total NPV (i=0.05)</td>
<td></td>
<td></td>
<td>$1,740,772,314</td>
<td>$1,072,813,560</td>
</tr>
</tbody>
</table>

### Case 6: VMT Fee = $.06/mile

<table>
<thead>
<tr>
<th>Year of Impact</th>
<th>Capital Costs</th>
<th>Operating Costs</th>
<th>Revenue without use of Index, VMT $.06/m of Index = 0.75</th>
<th>Revenue with use of Index, VMT $.06/m of Index = 0.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>$929,050,000</td>
<td>$700,000</td>
<td>$0</td>
<td></td>
</tr>
<tr>
<td>Year 5</td>
<td>$500,000</td>
<td>$850,854</td>
<td>$2,470,637,426</td>
<td>$1,852,978,070</td>
</tr>
<tr>
<td>Using $.08 and $.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item NPV (i=0.05)</td>
<td>$929,441,763</td>
<td>$1,620,938</td>
<td>$2,674,141,774</td>
<td>$2,005,606,331</td>
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<tr>
<td>Total NPV (i=0.05)</td>
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<td></td>
<td>$1,743,079,073</td>
<td>$1,074,543,630</td>
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46. Menard, Timothy, and Miller, Jeffrey.  Comparing the GPS capabilities of the iPhone 4 and iPhone 3G for vehicle tracking using FeeSim_Mobile.  _IEEE Intelligent Vehicle Symposium (IV)_, Baden-Baden, Germany, 278-283, June 5-9, 2011.


52. Heidi Dollard, Deputy CIO/Director of Administration Applications, et al., Office of Information Technology, University of Massachusetts, Amherst, Massachusetts, Private conversations.