2011

Economic analysis of automated electric highway systems for commercial freight vehicles

Steven Michael Lavrenz
Iowa State University

Economic analysis of automated electric highway systems for commercial freight vehicles

by

Steven Michael Lavrenz

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Civil Engineering (Transportation Engineering)

Program of Study Committee:
Konstantina Gkritza, Major Professor
Shauna Hallmark
Michael Crum
Derrick Rollins

Iowa State University

Ames, Iowa

2011

Dedication

This thesis is dedicated to my loving wife, Natasha, without whose inspiration, support, and endurance of far too many late-night work sessions, this writing would not be possible.

I also dedicate this thesis to my parents, whose own hard-working mentalities in support of five children inspired me from a very early age to pursue my life interests and career goals without fear of failure.

Table of Contents

List of Tables

List of Figures

Acknowledgements

I would like to express my gratitude towards the people who helped me to develop the ideas and research content of this thesis. First of all, I would like to thank my major professor, Dr. Gkritza, whose willingness to embrace innovative research and new transportation technologies had a profound effect on my initial topic selection, and subject matter formulation.

I would also like to thank the other members of my committee, Drs. Hallmark, Crum, and Rollins for their guidance and encouragement. These individuals assisted me in various capacities throughout the course of developing my thesis, and I have appreciated their honesty and willingness to impart sage advice, both in terms of the specific thesis topic, as well as for my future career goals.

Abstract

Commercial highway trucking is a critical component for the reliable and inexpensive transport of freight goods in the United States. In addition to handling over 60% of all goods at some point in the transportation process, the number of truck ton-miles is increasing at a much higher rate than general vehicle miles traveled and lane miles of highway constructed. This growth will set the stage in the coming years for several critical issues that must be overcome by the trucking industry, such as congestion, safety concerns, emissions and fuel use. In order to overcome these challenges, it is evident that a radical approach must be considered to reducing the adverse effects of this mode of transportation, such as the development of an automated electric highway system (AEHS) for these commercial freight vehicles. The AEHS would be comprised of a grade separated system of autonomously controlled freight vehicles, with motive power supplied by inductive or magnetic resonant coupling with an electric source in the roadway.

This thesis establishes a first-of-its-kind comprehensive economic analysis of the AEHS, including a detailing of the costs and benefits associated with a specific corridor of analysis. While various iterations of automated and electrified infrastructures have been analyzed for over 30 years, little has been done to quantify the components necessary to begin the process of economic decision-making with respect to investment and operations. The proposed methodology identifies numerous direct and indirect costs and benefits associated with a hypothetical implementation of this technology on the Interstate 70 corridor in Missouri during the period 2011-2040. This methodology draws on basic principles of quantifying benefits such as travel time savings and user cost savings from reduced crashes and congestion, and utilizes detailed construction cost information developed by the Missouri

DOT for a system of conventional truck-only lanes along the same corridor. Furthermore, the EPA-developed MOVES software was used to estimate the impacts on emissions and energy use along the AEHS corridor as part of the benefit-cost analysis.

The estimation results suggest that application of AEHS on the study corridor would be economically feasible, with a positive net value in terms of present costs and benefits of approximately $2.4 trillion over the 30-year project lifecycle. Additionally, it is estimated that petroleum use would decrease by over 25%, while emissions would decrease by up to 27%, depending on the pollutant being considered. Various sensitivity analyses were also performed, in order to assess the impact of different demand estimates for the system, along with varying estimates of the costs associated with the technology components on the AEHS. While the final economic evaluation outputs were sensitive with respect to these factors, it was found that these sensitivities were relatively inelastic, and that even for the worst-case cost and benefit scenarios, the project was economically favorable to pursue.

This thesis represents one of the first attempts to quantify the direct and indirect costs and benefits of this widely discussed technology, and can serve as a guiding methodology for evaluation of upcoming intelligent transportation system technologies.

Keywords: Automated Highways, Electric Highways, Freight Transportation, Benefit-Cost Analysis

Chapter 1 Introduction

1.1 Motivation

Commercial trucking is a critical mode of transportation for moving freight goods to different areas within the United States (U.S.). Despite its historical success in facilitating the relatively inexpensive distribution of consumer products and raw materials to even the most remote geographic regions, the coming decades will prove to be a critical period of development for this ubiquitous mode of highway travel. Factors such as increasing fuel costs and delay due to traffic congestion will affect the already-slim profit margins of many trucking companies, and ever-stricter regulations on driving time and roadway safety will limit the total number of hours that these companies can operate their vehicles. It is evident that the trucking industry will need to undergo dramatic transformations and improvements in cost effectiveness in order to adapt to these conditions and still remain profitable. Given the reliance of the U.S. economy on inexpensive and efficient transportation, this issue is long overdue for the forum of public discussion.

A potential solution for these challenges exists in developing new ways of thinking about the environment in which these commercial vehicles operate. Such a change in thinking warrants a brief preface; specifically, the passenger car industry has seen a push in recent years, fueled by the rising cost of gasoline, for hybrid-electric vehicles and vehicles which can run off of batteries that are recharged with 120V and 240V household electrical outlets. Additionally, the continued advent and improvement of computing technology has led to the development of Intelligent Transportation Systems (ITS) which can provide infrastructure-based feedback about roadway conditions and navigational aid to vehicle operators. This technology has expanded into the vehicle as well, from electric throttle, steering, and braking systems, to commercial navigation software and entertainment devices.

As a result of these developments, the author proposes a radically new approach to moving commercial vehicles along our nation's interstate corridors—an Automated Electric Highway System (AEHS). This system would consist of a grade-separated network of infrastructure for commercial trucks, in which the motive power for said vehicles would be delivered wirelessly via loops or pads embedded in the roadway. Furthermore, vehicular control would be accomplished by using a combination of distributed computing feedback with Controller Area Network (CAN) technology through a similar system of wireless loops or pads, along with inter-vehicle communications technologies utilizing GPS, Cellular networks, or Bluetooth.

The proposed system would physically separate a large proportion of commercial truck traffic from the general traffic flow, resulting in decreased congestion and pavement wear on both systems. Additionally, the AEHS would significantly reduce mobile emissions at the roadway, instead offloading the motive energy production and resultant environmental impacts to more efficient and possibly non-polluting generation sources, and would realize additional safety benefits from the automated nature of the vehicle control.

To reiterate, the development of any such technology as the AEHS merits a description of the conditions and challenges which led up to its manifestation. In particular, because the AEHS would be developed for commercial vehicles, the following section will discuss several of the broad issues facing the current trucking industry, including those relating to current trends in energy production and pollution.

1.2 Commercial Trucking Current Issues

In 2004, it was estimated that transportation-related goods and services accounted for over 10 percent (~ $1 trillion) of the U.S. Gross Domestic Product (NSSGA, 2008). Some sources place this value even higher, as shown in Figure 1-1:

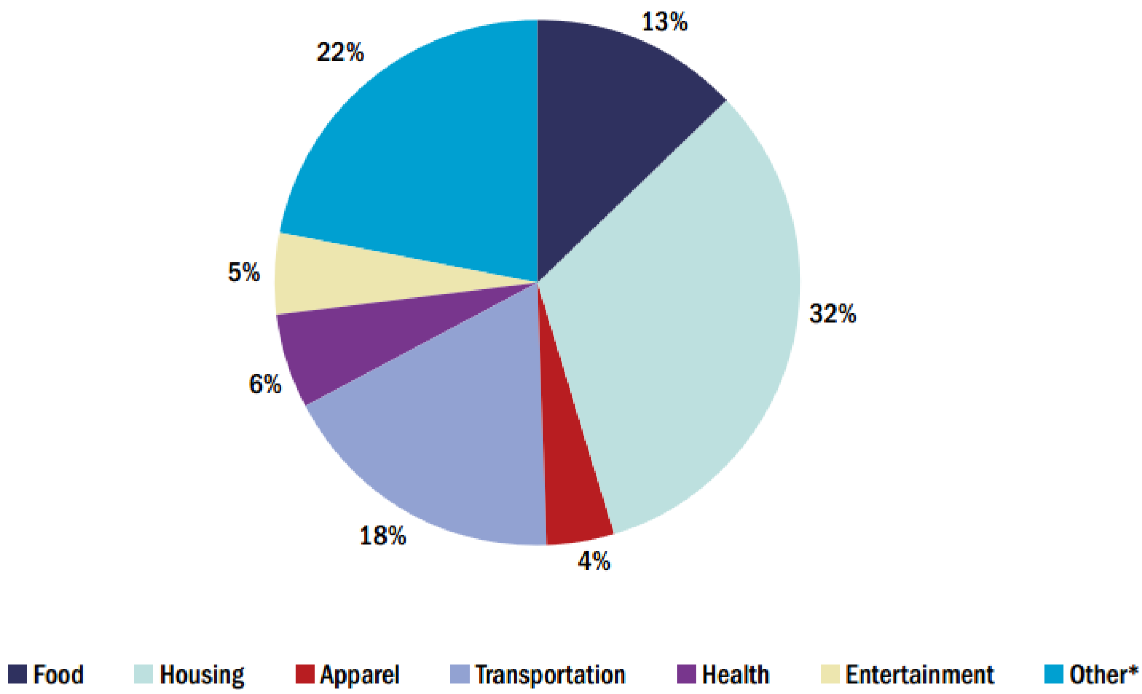

Figure 1-1 Transportation Share of Spending. Source: Bureau of Labor Statistics, 2005

Of this figure, over $200 billion came directly from truck transportation, which was responsible for transporting over 60 percent of all freight moved. In assessing this significant contribution to domestic spending over a period of several years, Figure 1-2 shows that truck transportation ton-miles are growing at a higher rate than total vehicle miles traveled (VMT) or passenger miles traveled (PMT), indicating that as a share of total VMT, truck ton-miles have increased significantly since the early 1990s. Furthermore, commercial trucks possess unique physical and operational characteristics, as compared to passenger vehicles, which cause them to be affected in some ways to a much larger extent by many of the issues facing the general transportation industry. Primarily as a result of trucks performing such a key role in the daily movement of freight goods across the U.S., commercial trucking also faces numerous challenges to its growth heading into the future. These challenges are discussed next.

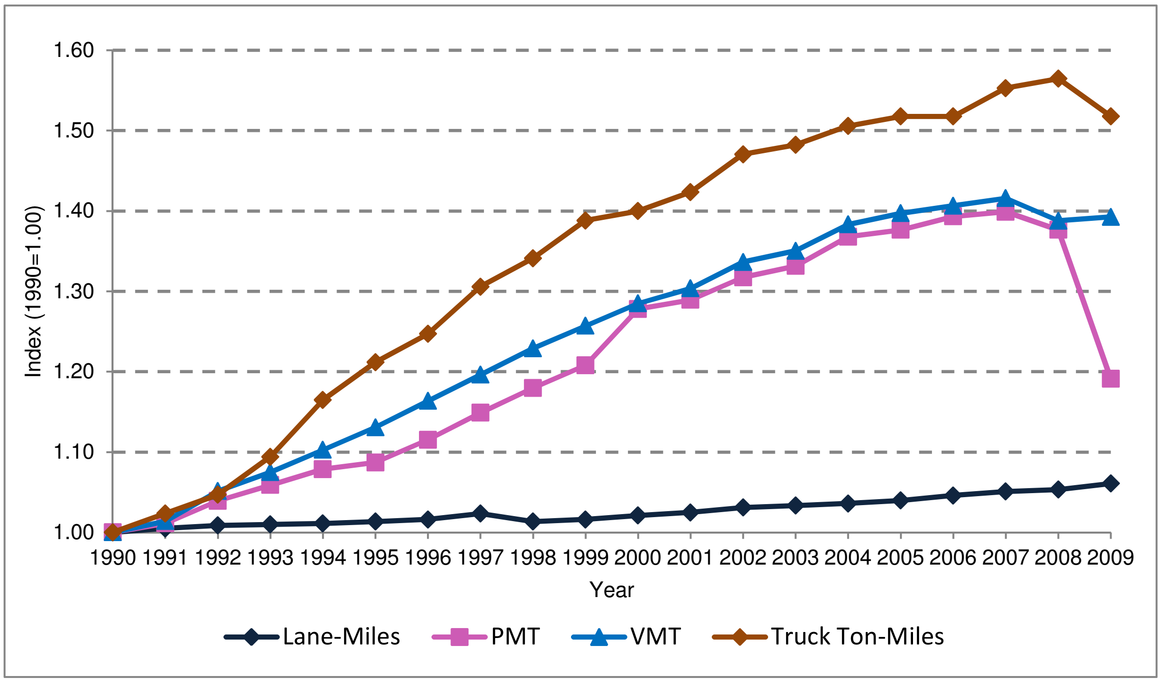

Figure 1-2 Lane Miles, PMT, VMT, and Truck Ton-Miles Growth. Adapted from: 2010 National Transportation Statistics, BTS

1.2.1 Congestion

Perhaps the most serious of all issues faced by the commercial trucking industry is congestion. According to Keith Tuttle, president of Motor Carrier Services, Inc., congestion is choking the nation’s supply and economy, mainly due to the fact that “the great majority of this country’s cities are still served only by trucks” (McNally, 2011). The American Association of State Highway and Transportation Officials (AASHTO) estimates that highway congestion causes 243 million hours of travel delay to freight trucks each year, resulting in $7.8 billion of lost time. Incidents such as inclement weather, accidents, and construction-related lane closures can account for approximately 40% of these delays, while a lack of base roadway capacity is responsible for the remaining 60% (AASHTO, 2007).

Figure 1-3 shows the historical growth in both public road mileage and total VMT, with several noticeable trends. While total road mileage and lane-miles have increased very slightly from 1980 (approximately 6%), total VMT has more than doubled, from 1.5 trillion VMT in 1980 to over 3 trillion VMT in 2008. The inevitable result of this growth relative to roadway capacity is a much higher density of traffic on the roadway, which besides increasing congestion (see Figure 1-4), also has significant implications for roadway safety, air quality, and other factors (Gaj & Sun, 2008).

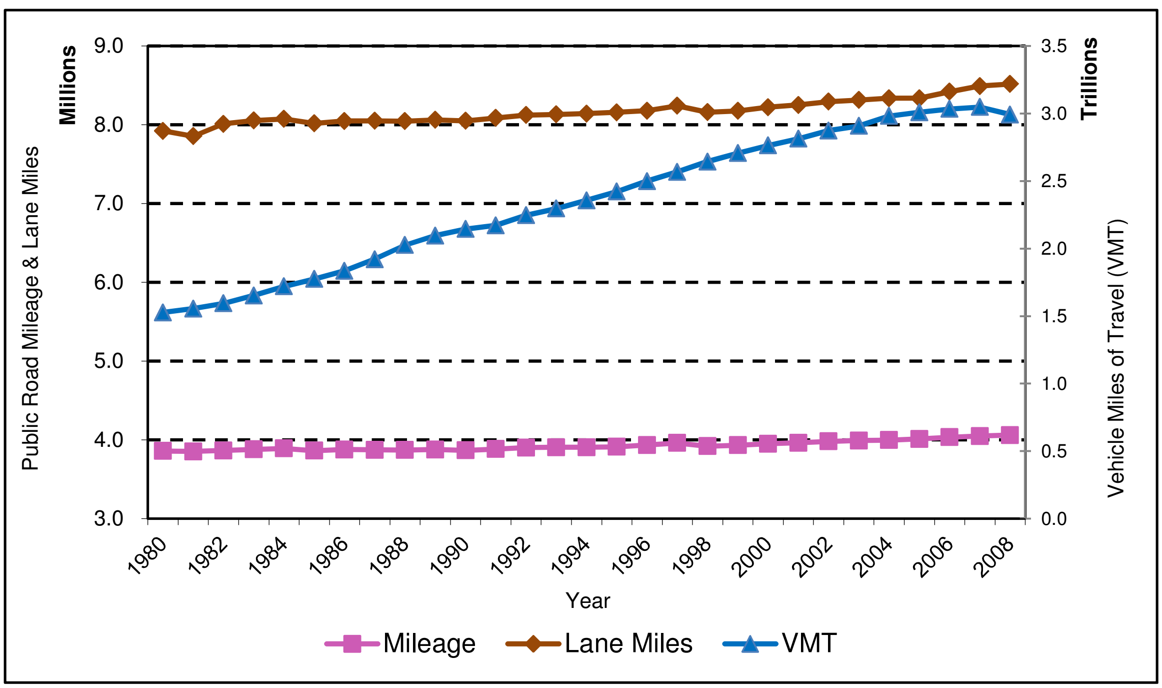

Figure 1-3 Public Road Mileage, Lane Mileage, and Vehicle Mileage, 1980-2008. Source: FHWA, 2008

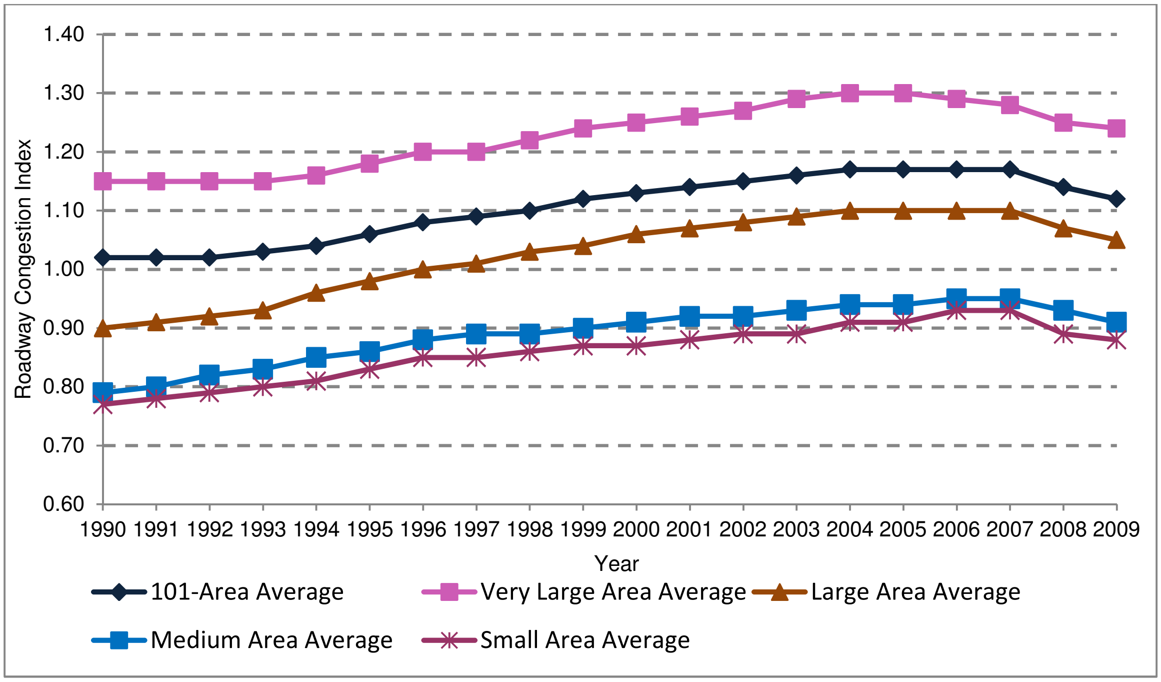

Figure 1-4 Roadway Congestion Index for 101 U.S. Urban Areas. Adapted from: 2010 National Transportation Statistics, BTS

1.2.2 Safety

Figure 1-5 shows the total number of annual crash fatalities in the U.S., along with the percentage of fatal crashes that involve large (and presumably, commercial) trucks. Between 1994 and 2006, these trends both remained relatively steady, with a slight overall increase in the total number of crash fatalities. These statistics do not show whether or not the truck was responsible for the fatal crash; however, with large trucks involved in approximately 8.5% of all crash-related deaths, and an even greater percentage of non-fatal crash injuries and property damage incidents, it is evident that separating these vehicles from the general traffic flow would significantly reduce their involvement in fatal crashes. Furthermore, with the predicted increase in commercial truck traffic as a percentage of total VMT, it is assumed that the percentage of fatal crashes involving large trucks will likely increase in the future (NHTSA, 2009).

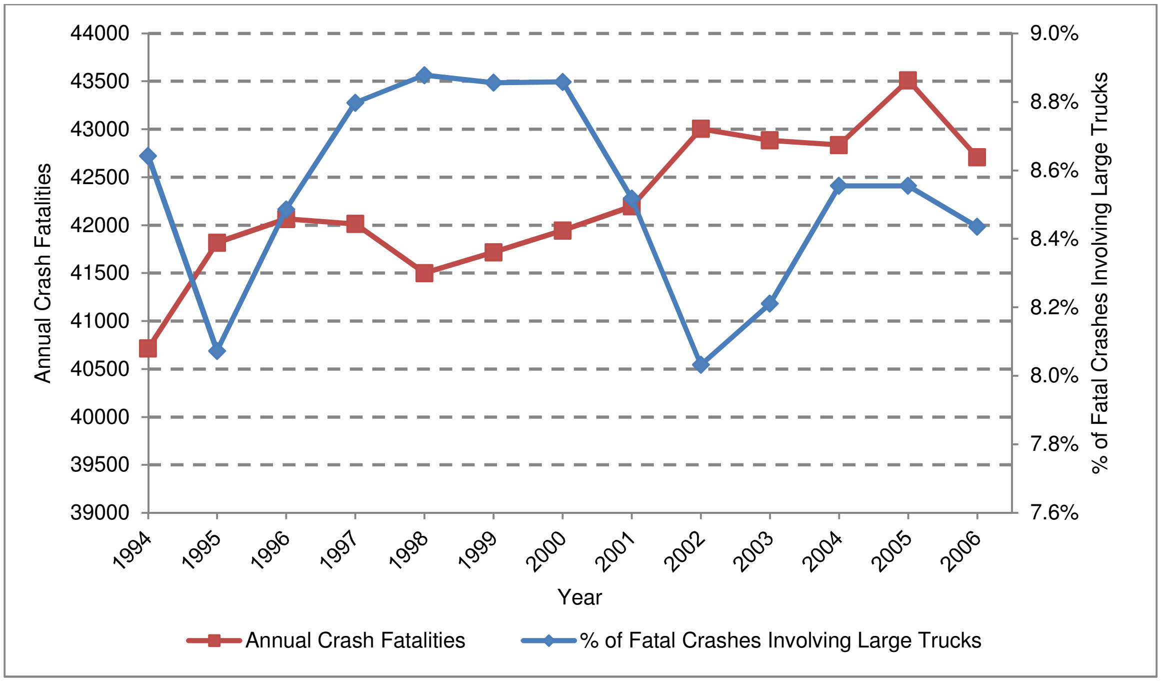

Figure 1-5 - Annual Crash Fatalities & Large Truck Involvement. Source: FARS, 2006

1.2.3 Emissions

A third problematic issue related to commercial trucking is vehicle emissions. Figure 1-6 and Figure 1-7 show the proportion of all Particulate Matter (PM) and Oxides of Nitrogen (NO_x) emissions that derive from heavy duty trucking activities. Note that in both cases, commercial trucks are responsible for just over half of all freight transportation-related emissions. Furthermore, Table 1-1 shows the total amount of greenhouse gasses (primarily, Carbon Dioxide, or CO_2) emitted as a result of heavy-duty trucking activities, along with the proportional contribution to total greenhouse gas (GHG) levels. Of all the modes of freight transportation, heavy-duty trucking accounts for over 75% of all GHG emissions, and constitutes nearly 20% of total transportation-related GHGs, including passenger transportation (FHWA, 2010).

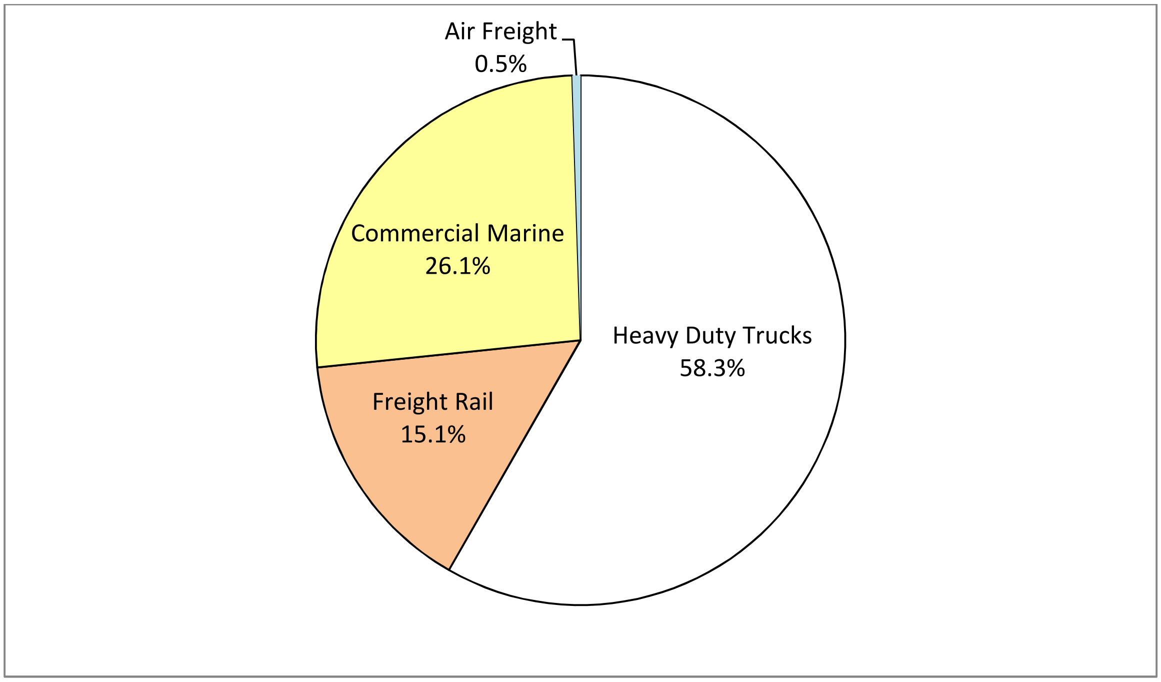

Figure 1-6 PM Emissions by Mode. Source: FHWA, 2010

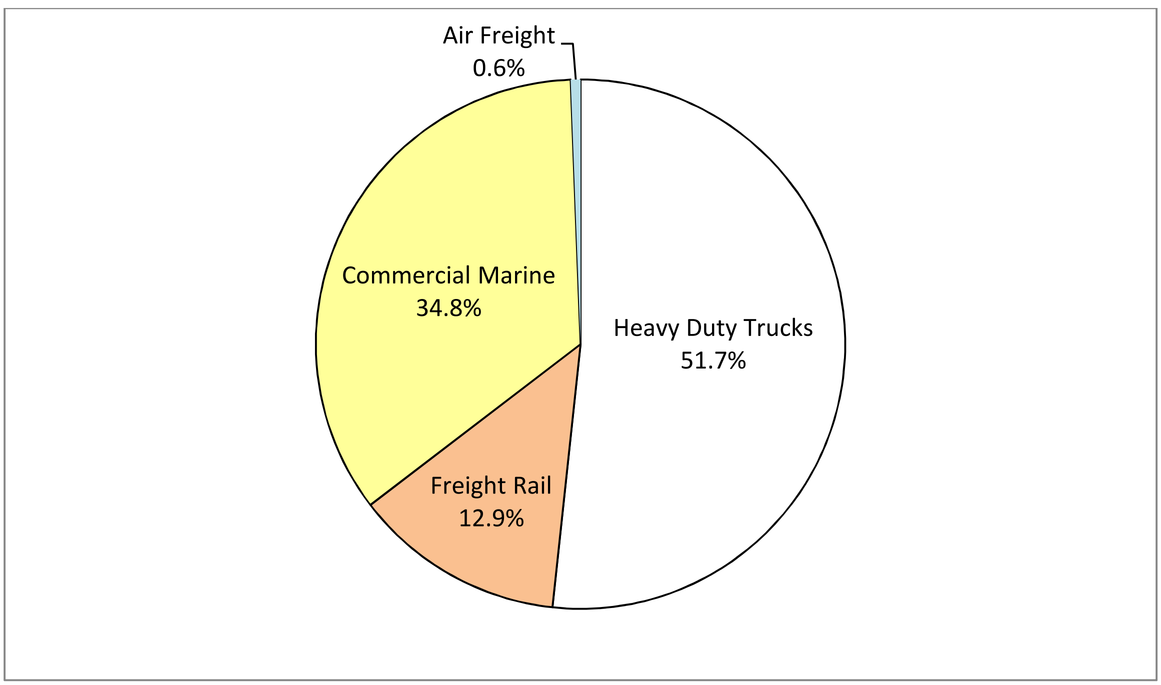

Figure 1-7 NOx Emissions by Mode. Source: FHWA, 2010

Table 1-1 GHG Emissions by Mode. Source: FHWA, 2010

	GHG Emissions (Tg CO2 equivalents)			
	Percent of:			
Mode	Emissions	Percent	All Transportation Sources	All Sources
Heavy-duty Trucks	340.7	77.8%	19.2%	4.9%
Freight Railroads	38.2	8.7%	2.2%	0.6%
Marine Vessels	46.5	10.6%	2.6%	0.7%
Air Freight	12.4	2.8%	0.7%	0.2%
Total	437.8	100%	24.7%	6.3%

Based on this information, it is evident that commercial trucking is a significant antagonist for transportation-related emissions and pollutants, and is the major contributor within the realm of freight transportation. While upcoming federal air quality legislation for freight vehicles aims to improve these figures, significant gains in air quality improvement and GHG emission reductions can nonetheless be realized by focusing on reducing total emissions from the commercial trucking industry.

1.2.4 Fuel Consumption/Energy Usage

Figure 1-8 shows the current and projected worldwide fuel consumption totals by energy type. Liquids, the vast majority of which are petroleum-based distillates (gasoline or diesel fuel) constitute the bulk of this fuel consumption for the foreseeable future. Given the recent worldwide price increases in petroleum-based fossil fuels, and their resultant depressing effect on the global economy, it is not unreasonable to assume that such patterns will only continue to worsen in magnitude and geographic scope. This will cause the price of diesel fuel to rise precipitously, which will have significant debilitating effects on the trucking industry, given that current figures estimate that diesel fuel costs account for over 25% of total commercial trucking operating expenses (The Trucker News Services, 2008).

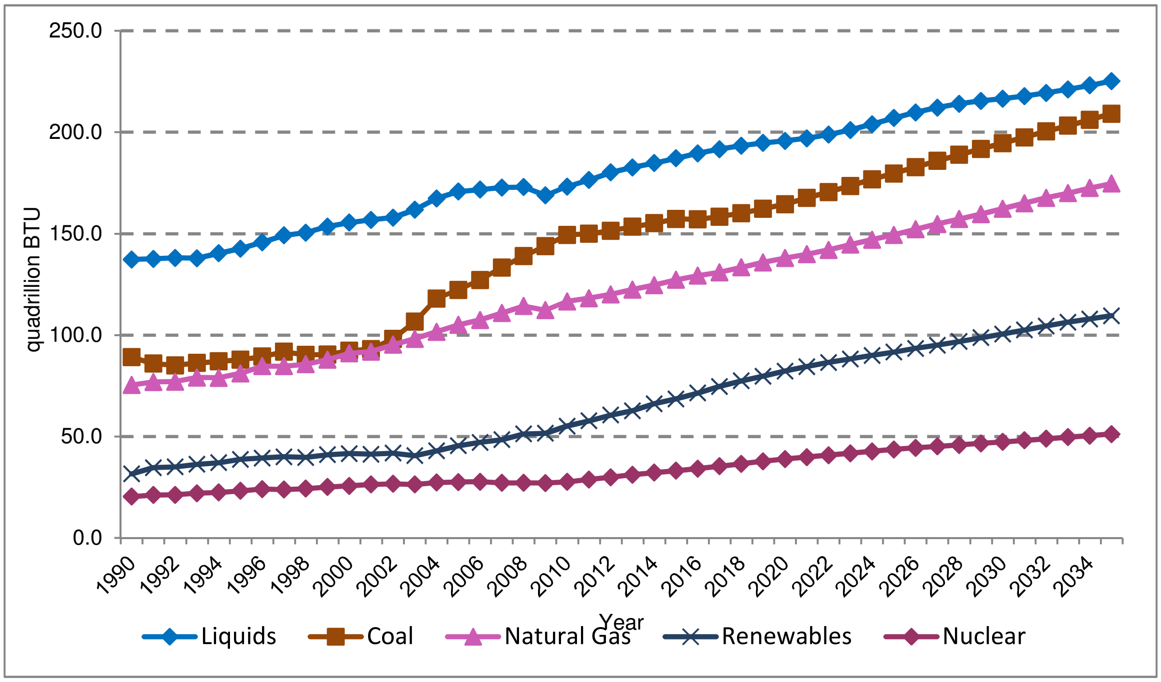

Figure 1-8 Historical and Projected World Fuel Consumption by Energy Type. Source: EIA, 2010

Based on these trends, it is manifest that substantial benefits could be realized by promoting alternative fuel sources within the commercial trucking industry. The ability to use renewable and more efficient energy for freight transportation has the possibility to not only reduce freight carrier fuel costs, but also to improve air quality.

1.3 Thesis Objectives

The overall goal of this thesis, as the title implies, is to develop an economic analysis methodology for AEHS as it relates to the application of commercial vehicle travel. That said, it would be naïve to assume that full automation technology to move electrically powered vehicles is currently anything other than an idealized framework for various systems and concepts which, currently, help to incrementally improve the problems facing commercial truck traffic. As such, the investigation presented herein will be first and foremost an exercise in theoretical analysis; that is, a tool used to generate further discussion on the matter of alternative vehicle propulsion and control technologies, whose potential can hopefully be realized to improve the efficiency and impact of goods movement operations. Thus, the thesis will proceed with the following primary objectives:

- Identify intended benefits of an automated electrified highway system;
- Develop a methodology for examining the costs and benefits of automated electrified highways compared to base case conditions;
- Quantify and monetize the costs and benefits of an automated electrified highway system; and
- Identify organizations and groups who will be affected by an automated electrified highway system, and how those effects will be considered.

1.4 Thesis Organization

This thesis is organized into 6 chapters. Chapter 2, *Literature Review*, includes an overview of previous studies relating to AEHS, including the identification of transportation goals that can be met using AEHS and a comprehensive review of the proposed AEHS technologies. Chapter 3, *Data Description*, will provide details about the specific corridor along which the proposed AEHS will be studied, along with the data used to formulate the analysis. Chapter 4, *Methodology*, will discuss the methodology that will be used for the economic analysis, along with the derivation of the AEHS costs and benefits. Chapter 5, *Results*, will provide the numerical outputs of the information presented in Chapter 4, including the effects of a sensitivity analysis on the final data based on different levels of AEHS demand. Finally, Chapter 6, *Conclusions*, offers concluding remarks on the analysis, including the identification of areas for potential future research relating to the topic of study.

Chapter 2 Literature Review

The aim of this thesis is to explore the challenges and factors which must be considered in developing a fully automated, electrically powered highway infrastructure for commercial freight vehicles. In order to accomplish this, it was necessary to assess the scope of existing research into the fields of both automated and electrified roadways. In doing so, this literature review will explore not only the general concepts and development behind automated and electrified highways, but will also discern the types of technology that must be considered to make such a system viable, and present the most likely candidates for implementation.

2.1 Overview of Automated Highway Systems (AHS)

This section reviews studies primarily focused on automated vehicle control technologies and other ITS, not exclusively of those in which the primary motive power source is electricity.

2.1.1 General Automated Highway Systems Concepts & Developments

A previous cost analysis by Hall (1996) determined that AHS costs should be comprised of electronics costs and roadway construction costs. Based on an analysis of numerous construction scenarios on the landlocked U.S. 101 in downtown Los Angeles, the following conclusions were formed:

- Elevated structures are much less expensive than adding additional lanes at grade, due to the significantly reduced land acquisition cost.
- By far, the cheapest method to implementing AHS is to convert existing conventional lanes for automation.

Additionally, this study compared the cost effectiveness for AHS to the cost effectiveness of adding conventional highway capacity on elevated structures as a means of reducing congestion. The findings suggested that for low adoption rates of vehicles for AHS, the difference in cost effectiveness between AHS and conventional highway expansion is negligible. However, with higher rates of vehicle adoption for AHS, the cost effectiveness is significantly greater than that of conventional highways. While this study provides support for a gradual introduction of AHS, rather than a single implementation of a nationwide system, it fails to consider many of the ancillary benefits of AHS, such as air quality, safety, and time savings improvements.

Hiemstra (2000) discussed the future of intelligent transportation initiatives, and makes a case for separating passenger vehicle and heavy freight vehicle traffic on physically different infrastructure systems. For the passenger vehicle infrastructure, the author proposes the development of an electrified automatic guideway system, as well as several new classes of passenger vehicles that could be used under different scenarios. This quantifies many of the benefits of automated travel in terms of capacity increases, and it provides some guidelines for designing the physical infrastructure, which could be used for either freight or passenger vehicles.

Cheon (2003) segmented AHS technology into two distinct categories: partially automated systems and fully automated systems. The defining fields upon which this categorization is based are four-fold: local position keeping, lane changing, response to obstructions on the roadway, and flow control. For each field, the amount of involvement at the infrastructure level varies from no control whatsoever to the complete handling of all normal and emergency driving tasks. Similarly, at the vehicle level, AHS fleet technology can range from simple environmental sensors on the vehicle which provide warnings and information for the driver to manually process, to complete automated control of the vehicle through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) command algorithms and feedback. Cheon further posits that some of the most basic elements of automated vehicle control, such as active emergency braking and lane change guidance, can be implemented on conventional roadways today, and that adopting these elements may help to parlay public uncertainties with respect to moving to completely automated highways.

Table 2-1, which is based on Federal Highway Administration (FHWA) and United States Department of Transportation (USDOT) data, presents the various concepts for AHS and the corresponding levels of technology needed for each component. This table demonstrates that there are numerous levels of roadway automation that can be achieved, depending on whether the primary control is given to the vehicle, the roadway, or some combination of the two. For the purpose of this thesis, it will be assumed that only infrastructure supported/managed/controlled systems are considered. While these three types of infrastructure-based systems may have different specific technology requirements, many of the benefits are the same.

Recent automated highway research has focused primarily on the development of intelligent vehicle systems, rather than on the automation of the highway infrastructure itself. Programs such as PATH (California DOT) and CHAUFFEUR (European Commission) have focused on developing automated communications systems between heavy-duty trucks, which operate on a set of roadways that are physically separated from the general traffic flow. In many of these systems, drivers are still able to possess manual control of the vehicles, and a group of trucks (known as a platoon) is typically managed by means of a

Table 2-1 Automated Highway Concept Alternatives. Adapted from: Cheon, 2003

System Concept	*Local Position Keeping*	*Lane Changing*	*Obstruction on Roadway*	*Flow Control*
Autonomous: Fully automated vehicles employing sensors and computers operate along with manually driven vehicles without requiring infrastructure assistance and communication.	Vehicle automatically senses vehicle ahead and roadway problems	Looks for and moves into an opening	Vehicle brakes for detected obstacles, changes lanes if possible	
Cooperative: Vehicles equipped with onboard sensors and computers would share information with other vehicles to coordinate maneuvers and enable fully automated travel.	Vehicle Sensors, communications from other vehicle for land changes or platoons	Cooperative negotiation among vehicles	Vehicle senses, communicates warning and coordinates maneuvers	
Infrastructure supported: Fully automated vehicles, operate on dedicated lanes, using global information and two-way communication with smart infrastructure to support vehicle decision-making.	Same as cooperative, but within guidelines from the infrastructure	Same as cooperative	Infrastructure or vehicle senses, communicates to vehicles; vehicles coordinate	Infrastructure monitors traffic, formulates responses, send parameters to local groups of vehicles
Infrastructure managed: The automated roadside system provides inter-vehicle coordination during entry, exit, merging, and emergencies.	Vehicle's sensors, communications from other vehicles and infrastructure as needed	Vehicle requests lane change; infrastructure responds with commands for surrounding vehicles	Infrastructure senses sends commands to vehicles based on infrastructure or vehicle detection, or vehicle actions	Infrastructure monitors individual vehicles, commands vehicles as needed, including entry and exit
Infrastructure controlled: Same as above, but infrastructure takes the entire control in all driving situations.	Infrastructure sense vehicle positions and sends commands to control throttle, braking and steering	Infrastructure determines need for lane change from origin-destination data, controls all necessary vehicles	Infrastructure senses, sends commands to vehicles based on infrastructure or vehicle detection, or vehicle actions	Infrastructure monitors individual vehicles, performs optimizing strategy through control of individual vehicles

lead-follow vehicle system; that is, the first truck serves as the "leader" of the platoon, and its movements are communicated automatically to the following trucks by some means of Dedicated Short Range Communications (DSRC) (such as Cellular network, 802.11n, or Bluetooth). These vehicles have little interaction with the roadway itself, outside of rudimentary lane-keeping and collision warning technologies (Konings et al., 2005).

Lank et al. (2010) explored the implementation of automated truck platoons interspersed with conventional vehicles in a typical high-speed roadway environment. This project, known as KONVOI, implemented platoons which were controlled in a lead-follow fashion, and were guided with a combination of GPS communications, 2.4 GHz broadband, and communication with a central KONVOI server. Overall, the platoons operated for over 3,000 kilometers on German roadways without incident, and were able to adequately handle such events as emergency braking, and non-automated vehicles cutting in between the following vehicles in a platoon. Besides a feasibility analysis of the technology, a survey was given to the operators of the test vehicles (human operators were placed in each of the test trucks at all times, in case of equipment malfunction). The results of several of these survey questions are shown below in Figure 2-1.

Overall, the results of these surveys were positive, and indicated that the operators of the vehicles recognized the inherent benefits involved with automating large truck traffic (Lank, Haberstroh, & Wille, 2010). Such results hold promise for the wider public acceptance of automated freight transportation on a regional or national basis.

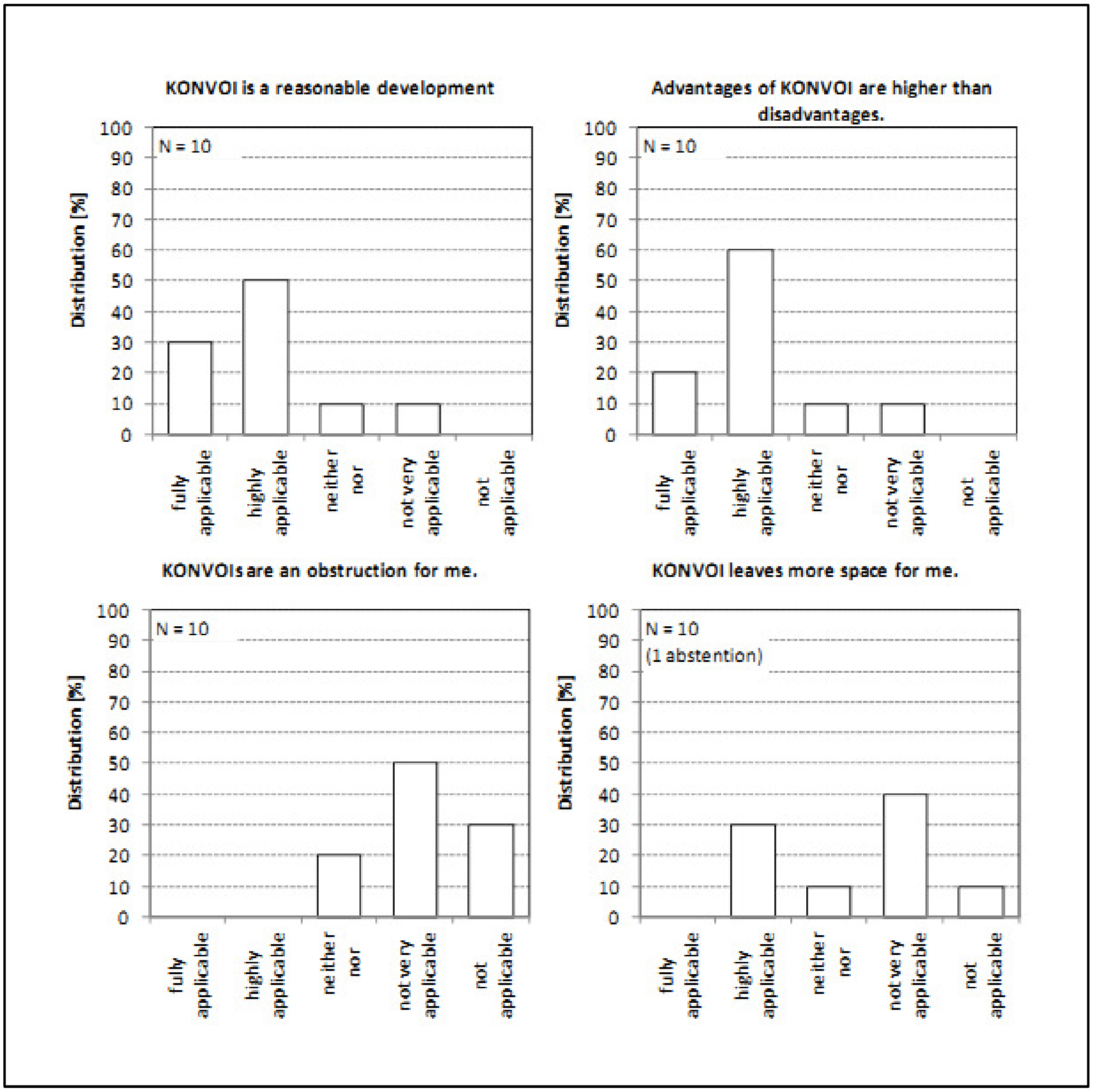

Figure 2-1 - Sample KONVOI Survey Responses. Source: Lank, 2010

2.1.2 Automated Electric Highway Systems and Developments

Automated Electric Highway Systems (AEHS) are one type of AHS, on which vehicles are powered from electricity that flows from the roadway itself. One of the more popular implementations of this electric flow is through inductive power transfer that comes from remote power facilities, although numerous other transmission technologies, such as rolling contact and maglev propulsion have been explored (Ehlig-Economides & Longbottom, 2008).

A study completed by the Texas Transportation Institute and Texas A&M University in 2007 analyzed over 100 different proposed automated vehicle transportation systems, and identified 14 dualmode electrified options that have achieved the highest level of technological development. From this, they reduced to a list of 5 different systems that are likely to be the most practical for commercial implementation. The results of these system reviews may be used to more specifically target systems for a benefit/cost analysis (Ehlig-Economides & Longbottom, 2008).

For an analysis region, this study considered the entire state of Texas (Ehlig-Economides & Longbottom, 2008). Traffic data such as VMT, volume patterns by mode, and occupancy rates were provided by the Texas Transportation Institute. Energy Reliability Council of Texas (ERCOT) data was used to assess current electrical loading patterns in the region. The authors determined that three types of energy are required in the system: energy to overcome drag forces (such as wind resistance and rolling resistance from tires), acceleration energy, and energy for vehicle climate control equipment.

Some seasonal demand variation and power leveling analysis was conducted, and concluded that significant savings in the freight industry could be realized by moving driverless freight during off-peak hours and paying a reduced rate for electricity. Also, the additional electricity usage required from electric vehicles being used on normal surface streets was acknowledged, but never properly addressed. Furthermore, the model has not yet been ported to other states, although rudimentary analysis was conducted on climate control needs in Wisconsin as compared to Texas.

The study concluded that significant additional electrical generation capacity is needed for a fully electric autonomous guideway system to be realized, but that as long as the pace of electric infrastructure growth matches or exceeds the pace of guideway construction, there should be no issues. Furthermore, there needs to be significantly larger amount of electrical grid redundancy measures in place, in order to ensure that the guideway power supply remains uninterrupted in the face of localized component failure (Azcarate Lara, 2010).

Buehrer (1996) proposed a type of dualmode AEHS known as the Electric Energy Line System (EELS). The author is sparse on the technical details of the system, but presents a host of planning tools that should be considered when trying to generate public feedback and acceptance of such a project. Additionally, Buehrer's work focuses mainly on Personal Rapid Transit (PRT), a potential dualmode technology that moves people in on-demand personal transport vehicles. However, many of the planning tools and options that Buehrer identifies may be used in the planning process for automated freight transportation systems as well.

Barber (2005) considered the primary fuel source for the future of transportation, specifically considering nuclear energy with respect to electricity generation. The author argues that electricity will undoubtedly provide the most efficient fuel source for future vehicle fleets, since it is cheaper to use than petroleum on a per-mile basis, and because it can be generated cleanly and safely. Moreover, Barber argues that existing electric distribution networks will serve as a solid launching point for future vehicular powering systems, such that minimal additional investment will be required in order to see electric vehicles achieve near-ubiquitous status in the next 50 years.

Numerous other studies into inductive power supply systems are ongoing or have recently been completed. A 2006 study compared inductive power to traditional cable and current rail/brush systems, and found numerous benefits for inductive systems. While the initial installation cost and complexity of the technology may be much higher than conventional power supply systems, inductive power components are virtually maintenance-free, highly reliable, and use significantly less electricity overall, since significant transfer of electricity only occurs when the presence of an inductively-powered vehicle is detected on the network (Meins, Buhler, Czainski, & Turki, 2006). This contrasts with many conventional electrified rail and guideway systems, where the rail or line which supplies power to the moving fleet is continuously “hot”.

Ongoing research at the University of Auckland in New Zealand has focused extensively on inductive power systems, and their use in transportation and other commercial applications. This research has been used to develop fully-functioning inductive power systems for materials handling and factory automation applications, as well as for limited use on public transportation systems. Besides embedding wireless charging “pads” in the roadway surface, this technology is being explored to develop stationary wireless charging mats, which can be used in the home or in the parking lots of commercial establishments, and which could prove to be beneficial for existing plug-in hybrid-electric vehicles (PHEVs) or plug-in electric vehicles (PEVs) (Boys & Covic, 2010).

2.1.3 The Case for Automated Electrified Highway Systems (AEHS)

A report (RAND Corporation, 2009) on preparing the U.S. freight transportation infrastructure for future economic growth identified four key components of a national infrastructure policy that must be considered in the coming years. While the report does not specifically recommend or detail AHS, these four areas of consideration can be easily adapted to match the goals of AEHS.

Increasing Effective Capacity

> *"Infrastructure enhancements might include specialized truck lanes to ease competition with commuter traffic or investment in a freight information technology–based 'infostructure' to facilitate movement of freight between modes."*

An increase in effective roadway capacity can come just as easily with AEHS as it can with conventional truck-only lanes; indeed, more so, due to the fact that the automated control of vehicles on the AEHS will allow for a much greater density of vehicular traffic. Additionally, the automation of such a roadway would enable for a tighter integration of the proposed "infostructure", by utilizing ITS built in to the AEHS in order to allow shippers and/or carriers to track truck-based freight movements in real time.

Reducing Vulnerability to Disruption

Major sources of disruption include recurring congestion and roadway crashes. By automating the highway system and removing commercial trucks from the general traffic stream, the possibility of such disruption is greatly reduced. On AEHS, traffic will flow smoothly and crash-free at all times, and the separation of passenger cars and commercial trucks will reduce traffic density and vehicle size differentials on both networks. Besides the AEHS, this can reduce congestion, as well as the occurrence and severity of crashes, on the conventional highway lanes.

Achieving Growth and Green Objectives

> *"Projects that increase the system's overall efficiency and eliminate unnecessary trips or steer freight around congested routes reduce total emissions."*

AEHS will increase the overall efficiency of traffic movements by regulating the flow of vehicles on the automated highway, as well as reducing the traffic density and congestion on conventional roadways. Since commercial vehicles using AEHS will be grade-separated from other types of traffic, these freight movements will also be steered around congested routes, which will result in lower emissions and fuel consumption. Additionally, the move to an electric motive power source for a significant number of vehicles on the highway corridor will result in substantial reductions in emissions and total required energy use, as compared to conventional diesel-powered engines.

Ensuring Sustained Funding

> *"Gaining broad support will be easier if improvements have direct local and regional benefits, such as reduced traffic congestion and environmental impacts. Finally, stakeholders should recognize that the private sector is an important source of ideas for increasing productivity of the system, and public-private partnerships should be considered an important part of a solution."*

AEHS is without a doubt one of the most capital-intensive solutions to improving commercial vehicle efficiency. In order to gain widespread support (and funding), the benefits of AEHS must be quantified through traditional economic analysis methods, such as a benefit/cost analysis. Furthermore, the large scale of costs and benefits for this technology suggests that one entity alone should not be responsible for its development, and thus funding and maintenance agreements between the government and various private industry representatives should be established in order to maximize the equity of AEHS.

2.2 Issues with Automated Highway Systems

For the numerous benefits that have been historically associated with the proposed development of AHS (and in particular, AEHS), there are numerous drawbacks and significant costs that must be considered prior to its implementation. In 2002, the FHWA identified the following areas as key issues to consider in the development of automated highway systems (Ferlis, 2007):

- The need for protected, dedicated lanes of travel
- Public acceptance and human factors research
- Sophisticated communications and control systems
- Liability concerns for manufacturers and owners/operators
- Special requirements of truck traffic
- Capital investment requirements and deployment strategy
- Environmental tradeoffs and the consequences for urban sprawl

While some of these issues affect the development of automated highways on a general level, others are specific to either freight or passenger transportation. Regardless, given the novelty of automated highways and the relatively little research that has been completed in the field, both passenger and freight topics with respect to automated highway systems will be addressed herein.

One of the issues that Cheon (2003) identified with AHS is the potential for congestion to occur at the entry and exit points of the automated highway, specifically where the dual-mode vehicles interface with traffic. The author acknowledged the USDOT's awareness of this problem, but did not make any specific recommendations to rectify this issue. It will be assumed in this thesis that appropriate interchanges have been developed to allow for smooth transitions between the automated and conventional road networks. In particular, Chapter 3 will introduce a description of the layout for AEHS, including a series of slip ramps that will allow for the commercial trucks to interface with the general traffic stream.

Another issue that Cheon (2003) stated was the potential impact on land use development from AHS. Similar to the rise in popularity of the automobile in the 1950s, the fear is that more efficient modes of transportation (such as AHS) could lead to a return of less dense development and urban sprawl. While this concern is specifically identified for residential development, commercial and industrial development are also necessary components to consider.

Finally, Cheon (2003) discussed several aspects of deployment strategy for AHS, from financing to public acceptance. In particular, the two cases of deployment that are considered are immediate deployment of fully automated highway segments on a regional level, or an evolutionary deployment of automated vehicle technologies, eventually culminating in a transition to fully automated roadways. While the full deployment option would result in immediate maximized benefits to freight carriers on the system, it may be difficult to justify such a large public expenditure on a system that will initially be used by a very small portion of traffic. Similarly, with the evolutionary deployment strategy, freight carriers could recognize immediate incremental benefits from such technologies as adaptive cruise control and collision warning systems, but they may not be willing to invest in these features as a stop-gap measure to a fully automated system.

In a similar manner, Ehlig-Economides and Longbottom discuss what has been referred to as the "chicken-and-egg" phenomenon; that is, freight carriers may be unwilling to invest in automation technology for their fleets without a robust automated infrastructure already in place. However, public policy and historical trends suggest that it will be difficult, if not impossible, to publicly fund the construction of an automated highway infrastructure without a proven market of vehicles already in place to take advantage of its features. Such a proposal would result in the AEHS being severely underutilized for the first several years of its operation, until freight carriers were able to fully modernize their fleets. While this issue suggests that private funding of the automated highway system may be a more viable solution, there are no clear resolutions at this time about how this problem should be addressed as a matter of public interest (Ehlig-Economides & Longbottom, 2008).

One answer to this problem may be to develop an "AHS Ready Vehicle" (ARV). This vehicle would possess the numerous safety and control features necessary for a vehicle to interface with AHS (electronic steering, braking, throttle control, adaptive cruise control), as well as a programmable controller interface that would allow for a future modular installation of components necessary to allow the vehicle to function on an automated highway. Such a vehicle would provide many of the benefits of automation to its operator, while allowing for a more gradual introduction of AHS and vehicle market penetration (Hall, 1996). As section 2.3.3 will detail, many of the electric systems required for a vehicle to be compatible with the

AEHS are already being developed on a number of passenger and commercial vehicles, in response to stricter requirements for air quality and vehicle safety improvements.

Levinson and Zhou (2005) explore the complicated issue of funding any future automated freight transportation systems. According to the authors, traffic congestion and increasing numbers of small-parcel shipments will necessitate technological innovation in the future to significantly increase the capacity of transportation infrastructure beyond what can be afforded by the simple construction of additional lane-miles. Automated Pipeline Systems (APS), Automated Rail Systems (ARS), and Automated Truck Systems (ATS) are all areas that should be explored, although the high capital cost for each system is likely to result in unique and complex funding arrangements.

ARS will likely receive minimal government funding, since like conventional rail, most of the infrastructure will likely be privately owned. However, the government may contribute in the form of minimal subsidies or the donation of right-of-way (ROW) land, which may provide the railroad companies with additional revenue sources. APS will most likely be funded privately, since it would only be used for freight transportation. ATS presents a more complicated funding scenario, since there are a number of negative externalities that would be reduced, and positive externalities that would be created. These externalities typically arise due to the fact that commercial trucks share the same infrastructure as most passenger vehicles; thus, any decrease in costs, or increase in benefits apart from those which directly impact the profitability of the commercial trucking firm must somehow be distributed over the broader roadway population. Government subsidies would help to offset the initial capital costs required to implement ATS, and would help to bridge the gap between the social demand curve for ATS and the industry demand curve for ATS (the gap which exists due to externalities).

In terms of the specific systems, it is important to realize the fundamental differences between ATS, ARS, and APS, with respect to funding necessity. ARS and APS are likely to be more heavily focused on infrastructure rather than fleet costs, since the fleet faces high levels of physical constraint on the actual network (such as being fixed to the track or the pipeline route). These physical constraints of the ARS and APS systems will limit their flexibility with respect to moving different types of freight, and the focus on infrastructure-bounded capacity will impede their potential for future growth and portability to different geographic scenarios. With ATS, however, vehicles are expected to use both the automated system and traditional non-automated highway lanes, such that the burden lies more with the individual truck owners to pay for the costs to upgrade. These costs will most likely need to be subsidized by the government.

Finally, there are two strategies for deploying AFS: it can either be done on a case-by-case basis in high congestion areas, where one runs the risk of too low of demand because of limited range of the technology, as well as possible incompatibility between various systems. Or, the deployment can be done on a nationwide level, with national standards and guidelines enacted up front, similar in nature to the Interstate Highway System. Initial construction should only take place in high congestion areas, but with a national program being developed, the users of AFS can take comfort knowing that the network and its future implementation will not face major issues of technological incompatibility (Konings, Priemus, & Nijkamp, 2005). This increased confidence by business owners will in many cases serve as the catalyst for a broad level of the AEHS's adoption.

2.3 Technology Description

Although up to this point, a few studies have been cited regarding the nature of the AEHS technology that will facilitate vehicle movement, this section will provide a broad description of the motive power and guidance systems to be used in the proposed AEHS. This description is based on a review of new and previously-mentioned technical sources on the matter, such that key components of the system can be identified in general terms, or as a presentation of the most likely implementation(s) of a particular component. While this thesis does not attempt to provide a detailed technical analysis and support for any particular AEHS technology or standard, it is necessary to establish general parameters about the AEHS in order to define a baseline which may be used as a comparison for future analysis scenarios.

As mentioned before, this thesis will primarily be concerned with infrastructure-supported/managed/controlled highway systems. This is necessary to exclude non-automated vehicles from the proposed infrastructure, which could create additional complications with respect to traffic management and vehicle guidance. The technology necessary for the development and full-scale deployment of an AEHS can be identified as belonging to one of two categories: motive power, and guidance (path-finding). Within each category, the technology can be further decomposed in terms of infrastructure- and fleet-based elements, such as the mechanism by which electricity would be delivered to vehicles using the AEHS (infrastructure), and the hybrid-electric drivetrains for individual vehicles (fleet). Such a distinction made here will prove crucial in the following chapters, especially with respect to the estimation of the costs which will be incurred by users of the system and the general public.

2.3.1 Motive Power Systems

One of the features of the AEHS that distinguishes it from conventional highway systems is the technology and fuel used to move vehicles along the roadway. As its name implies, the vehicles on the AEHS are primarily powered by means of electric propulsion. While on the electrified roadway, this power is supplied continuously via inductive charging, or the wireless transfer of electricity through electromagnetic induction. With inductive charging, the power supplied will be in the form of normal household electricity, or alternating current (AC), which will be converted to direct current (DC) via an in-vehicle rectifier device (Boys & Covic, 2010). This is to maintain compatibility with current automotive power systems, which primarily utilize DC due to the inherent output characteristics of automotive battery technology.

As an alternative method of electric charging, electricity may also be transferred via near-field magnetic resonance. Several companies are actively pursuing magnetic resonance in static applications, including WiTricity, which is working with automakers Toyota and Mitsubishi to deliver a commercial implementation of the product in the next few years. Figure 2-2 shows the physical location of the charging pads in relation to the vehicle and roadway, and field tests would most likely be done in the parking lots of commercial retail centers (Motavalli, 2011).

One of the advantages of near-field magnetic resonance as opposed to inductive power transfer is the ability to efficiently operate without perfect horizontal alignment (Giler, 2009). In the case of AEHS, most sources agree that wireless charging will occur via pads

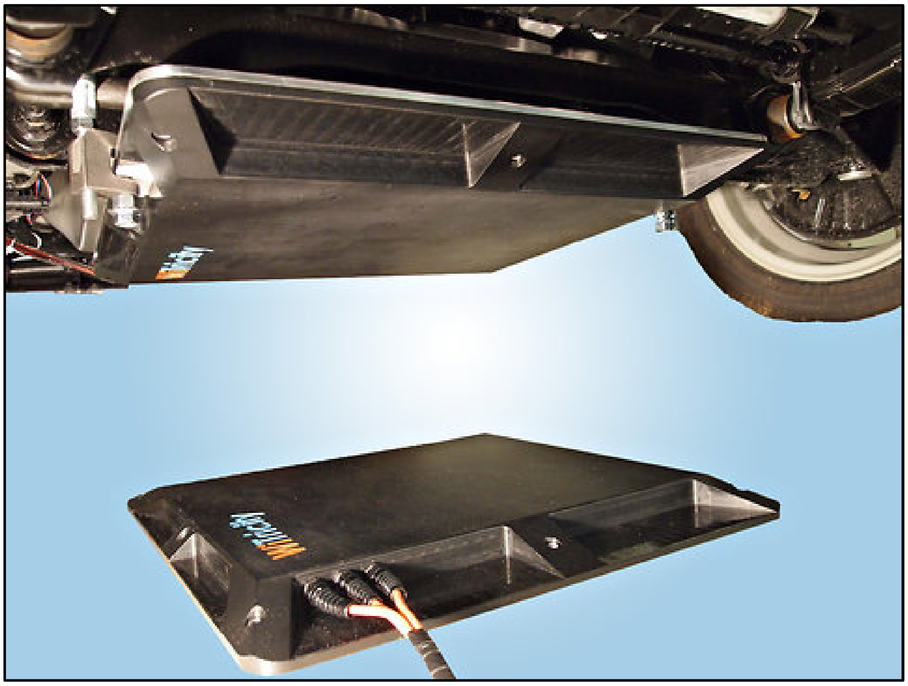

Figure 2-2 Example of the WiTricity Charging System. The bottom unit is embedded in the pavement, and generates a voltage in the unit attached to the vehicle. Source: Motavalli, 2011

embedded in the roadway, with which vehicles must be aligned on the horizontal and vertical planes. Figure 2-3 shows that with inductive power transfer, efficiency drops off quickly as the horizontal offset between the vehicle and the roadway increases; while a constantly changing position of a vehicle with respect to the roadway centerline may not be as large of a concern with fully automated vehicles as it is with manually-operated ones, it nonetheless remains an item of consideration.

2.3.1.1 Vehicle Pickup

The freight vehicles which utilize the AEHS will have electricity delivered wirelessly while the vehicle is in motion at typical highway speeds (Heaslip, Womack, & Muhs, 2011).

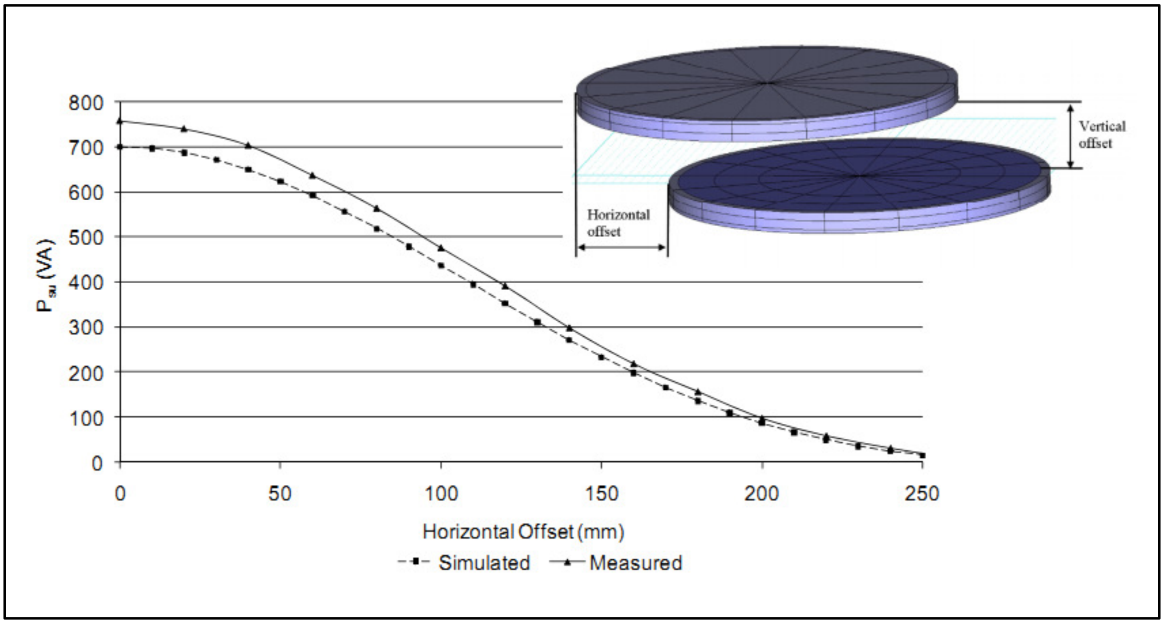

Figure 2-3 - Inductive Power Transfer Efficiency Compared to Horizontal Offset (assuming 210mm vertical air gap). Source: Boys & Covic, 2010

The wireless energy transfer will be accomplished via inductive charging or magnetic resonance, in which an electromagnetic coil mounted in the roadway will generate a current in a secondary electromagnetic coil mounted to the bottom of the vehicle. The current generated in the vehicle pickup pad will serve to maintain voltage in the vehicle's hybrid battery, which will be the primary driver of the vehicle's transmission and electronics. This is similar to how current hybrid-electric and all-electric automotive systems operate.

One of the most important factors in designing the vehicle pickup is the distance between it and the roadway surface. This distance, known as the air gap, is critical for determining the efficiency of the wireless power transfer which takes place between the road and the vehicle. Figure 2-4 shows that the relationship between air gap and charging efficiency is not linear, but rather more closely follows a higher-order polynomial form. Based on this, it is recommended that the air gap be a nominal 8 inches, or 200 millimeters.

As inductive charging technology is further developed, and efficiency increases, this gap can be increased until it is more in line with conventional truck clearances.

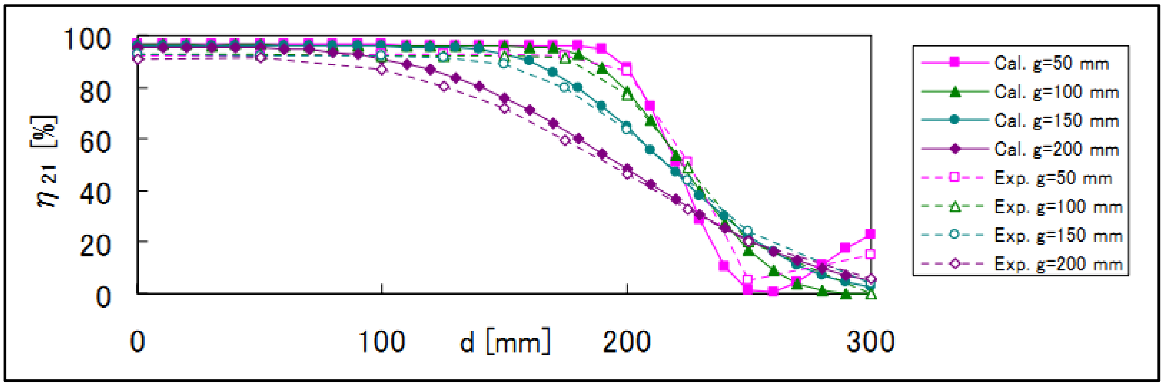

Figure 2-4 - Experimental results of vertical air gap vs. transfer efficiency. Source: Imura et al. 2009

Once the vehicle receives the current generated in the secondary vehicle-mounted coil, it will be in the form of alternating current. This presents a problem, as all modern automotive systems utilize direct current in order to operate. Due to this, a rectifier unit will need to be present on the vehicle being charged. This unit will take the AC signal and convert it to DC for use in the vehicle. Because this process generates a considerable amount of heat, the rectifier unit will be cooled via a dedicated cooling system, much in the same way that current hybrid-electric batteries and power distribution systems are cooled (Frank, 2007).

2.3.1.2 Track Conductor

The second part of the motive power technology for the AEHS is the roadway infrastructure itself. Embedded in the roadway will be a series of electromagnetic coils which will receive electricity from an off-site source. When trucks on the AEHS pass over these coils, a current will be generated in the vehicle pickup via electromagnetic induction or magnetic resonance, allowing for a transfer of energy to occur from the roadway to the vehicle.

The primary coil pads embedded in the roadway will be of a circular design and construction; this shape will allow the electromagnetic waves to propagate in the most efficient manner, and will maximize the availability of these waves to be absorbed by the secondary vehicle coil (Boys & Covic, 2010). The coil pads themselves will be constructed of a composite of materials: the coil will be made with Litz wire, which will reduce skin and proximity effects that cause undesirable increases in resistance in the system (Sullivan, 1999), and will rest on top of an arrangement of ferrite bars surrounded by an aluminum ring in order to generate the necessary electromagnetic force.

One German company, Ingenieurgesellschaft Auto und Verkehr (IAV) is currently working on their own electromagnetic induction system to charge electric vehicles at highway speeds. This system has so far been able to achieve over 90% air gap efficiency, and the power transfer mechanism is only activated when an electric vehicle is detected in the induction field, which would prevent accidental electrical shock to bystanders and other roadway users. Additionally, radio chip technology can be implemented with these electric vehicles such that the freight carrier or other roadway user would be billed for their actual power usage on a recurring basis (Technovelgy LLC, 2009).

Figure 2-5 shows the general layout for an electric coupling system between the AEHS vehicle and roadway. While this figure is from a study undertaken more than 30 years ago (Bolger, Kirsten, & Ng, Inductive Power Coupling for an Electric Highway System, 1978), the concept of wireless power coupling is largely the same. The authors propose a system of inductive power transfer, estimated at over 90% transfer efficiency on roadways with high congestion. One of the biggest challenges to implementing the electric highway system, according to the authors, would be to ensure that power leakage, including standby power losses, such as when electricity is used at the roadway conductor when a vehicle is not passing over the charging pad, is kept to a minimum.

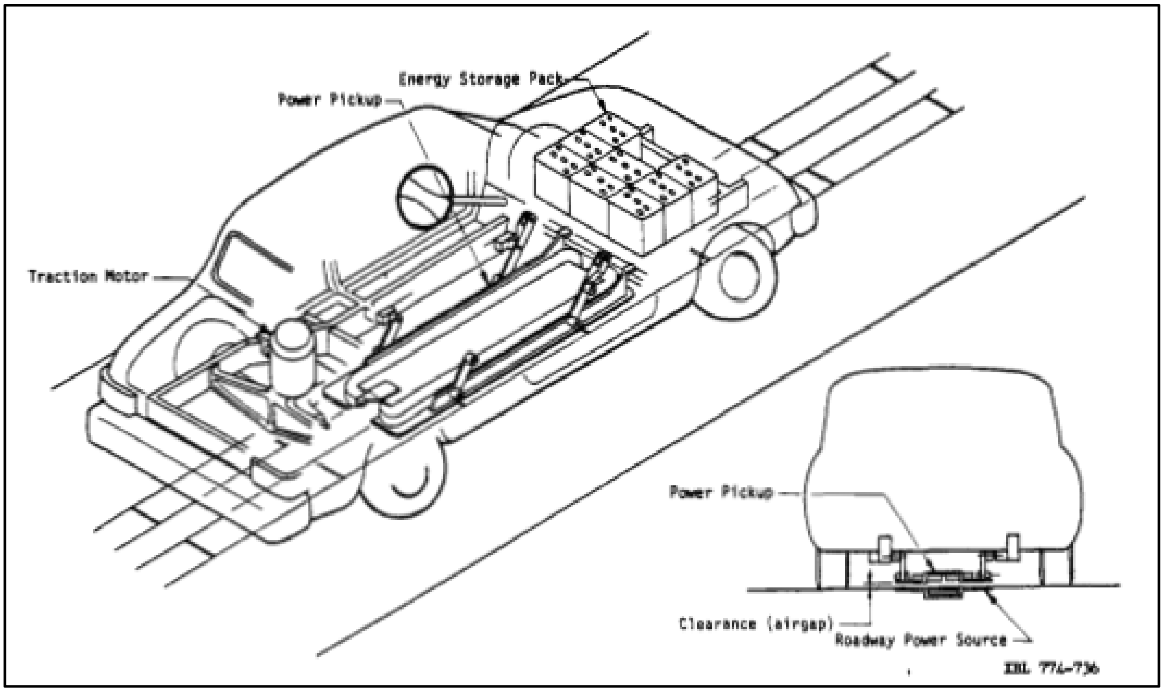

Figure 2-5 Overview of Vehicle and Roadway Power Coupling System. Source: Bolger et. al., 1978

Figure 2-6 provides a proposal for the general layout of electric infrastructure associated with the AEHS. Note how the track conductors would be arranged in a series of "loops", each of which connects back to a power conditioning station. The authors propose the use of such power conditioning stations for making changes to the electricity that will be supplied to the system which would not be practical to implement on the broader grid. An example of this is modifying the electricity frequency to a phase-shifted 180Hz, which is comprised of three overlapping 60Hz frequencies (Bolger & Kirsten, 1977).

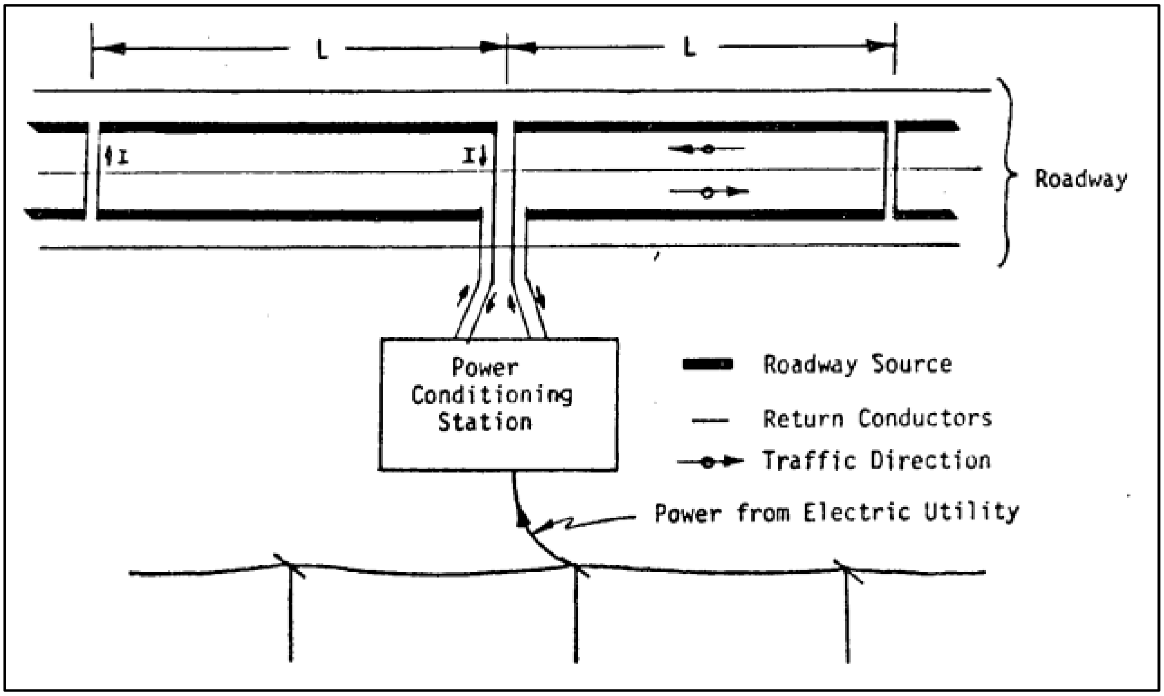

Figure 2-6 Proposed Layout of AEHS Power System. Source: Bolger et. al., 1977

2.3.1.3 Power Supply

It is estimated that the electricity used to power the system and supply energy to vehicles on the AEHS would continue to be generated by remote sources, such as coal-fired power plants or wind farms. The amount of electricity required for the AEHS necessitates an efficient process of energy supply, which lends itself to utilize the economies of scale developed by large-scale electricity generation facilities. Based on an energy usage rate of 1.5 kWh per vehicle per mile (Mescherin, Zhuravlev, Barsuk, & Izotov, 2008), and with an estimated maximum capacity of 32,000 vehicles per mile per hour for a 4-lane AEHS segment (Carbaugh, Godbole, & Sengupta, 1998), it is estimated that 48 MWh per mile would be required to supply energy to the vehicles on the AEHS, assuming the system is at its saturation capacity. Furthermore, the maximum estimated electric demand for the AEHS will have a large buffer built in, at least initially, in order to account for unforeseen operating situations which may draw higher levels of power from the grid.

With regards to generation options for electrified roadways, the options are too numerous to list here. One of the more interesting concepts is being explored by a company called Solar Roadways: their goal is to replace current asphalt- and concrete-based roads with roadways that are comprised of solar panels. The general concept is that these solar panels would be able to sustain the weight of cars and trucks travelling at up to 80mph, and that the electricity generated from one mile of solar roadway would be enough to power approximately 430 homes (Schonfeld, 2010). While the company is not currently focused on inductive power development alongside this technology, this type of roadway may very well serve as a basis for generating the large amounts of electricity required to realize a nationwide electrified highway network.

2.3.2 Guidance Systems

Ioannou and Bose (2005) postulated that in order to provide fully automated guidance for heavy freight vehicles, both longitudinal and lateral control must be considered; that is, the truck must be able to accelerate, decelerate, or stop in response to vehicles and other external stimuli within its own lane, and also in adjacent lanes. The components of the guidance system for the AEHS, therefore, must include both longitudinal and lateral control mechanisms, as well as a way for vehicles to communicate these movements to surrounding vehicles in the network. The following sections will provide a description of the control systems necessary for the AEHS, as well as the short- and long-range inter-vehicle communications that will be needed to fully automate the system.

2.3.2.1 Longitudinal Control

Longitudinal control of a freight vehicle is concerned with control within its own lane; thus, it primarily considers the effect of throttle and braking systems, for acceleration and deceleration, respectively. The matter of longitudinal control of a freight vehicle can be further broken down into two areas: the algorithm used to direct the longitudinal control, and the external vehicle sensors which provide input data to the control algorithm. With respect to the control algorithm, it would be erroneous to assume that the same programming can be used for heavy commercial vehicles as for passenger cars and light duty trucks: numerous studies have shown that the operating dynamics of these two types of vehicles are entirely different (Fancher & Mathew, 1987) (National Transportation Research Center, 2011). This includes the fact that heavy freight vehicles have much more profound issues and effects with higher-order lateral and longitudinal interactions, such as wind shear and the unstable loading of cargo. In order to account for these and other differences from passenger vehicles, Kanellakopoulos and Tomizuka (1997) proposed a 6^{th}-order algorithm to control the longitudinal guidance systems for commercial truck traffic. Despite the seemingly complex nature of this model, it can be reduced to a first-order algorithm by eliminating dynamic effects of wheel angular velocity, fuel systems, intake manifold pressure, engine speed, and the rotor speed of turbocharged diesel engines.

The second part of longitudinal control is the sensors used to provide environmental feedback to the vehicle. Such sensors will most likely be radar based, following the form of current luxury automakers that use them for adaptive cruise control systems (Moon, Moon, & Yi, 2009). Figure 2-7 shows the general layout for such an adaptive cruise control system, including the location of the radar module at the front of the vehicle. Note that the vehicle utilizes the Controller Area Network (CAN) protocol to relay information from the radar module; this technology will be described in Section 2.3.3.

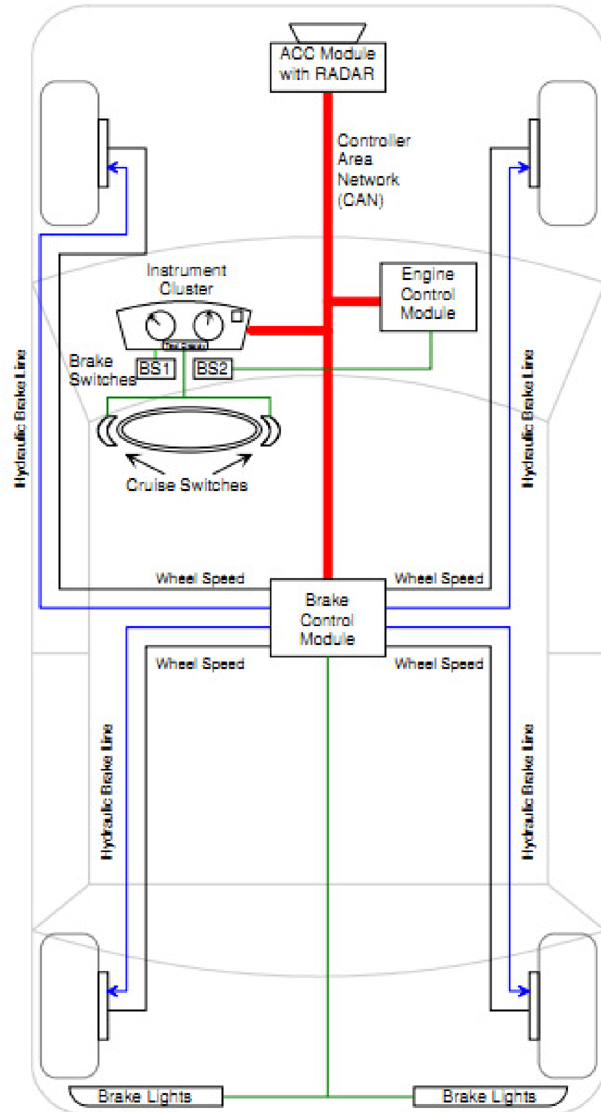

Figure 2-7 - Layout of Modern Adaptive Cruise Control. Source: U.S. Software System Safety Working Group, 2007

Laser systems may also be used, although these devices have been shown to perform poor under adverse weather conditions, or when attempting to track dirty vehicles. Additionally, while a single mounted radar sensor provides the least interference with respect to false detection of objects in the truck's path, it leaves vulnerable the outside areas immediately in front of the vehicle. While this does not present a problem with regards to vehicle interactions (vehicles will communicate their relative positions to one another via a separate system, as described later), additional video-based or multiple radar systems may be considered to look for roadway obstructions or small animals.

Figure 2-8 provides an overview of the various functions served by a radar-based adaptive cruise control system. Note that these functions can be grouped into four broad categories: constant speed control, deceleration, constant headway maintenance, and acceleration. Because it is assumed that the vehicles on the AEHS will all be traveling at the same speed, the constant speed and headway control systems are expected to be of vital importance for the majority of the time spent on the AEHS. The deceleration and acceleration features are expected to be primarily of use in the event of non-vehicle obstacles which may enter the roadway. Examples of these obstacles include wild animals, or vehicles from the general purpose lanes which may be involved in lane departure crashes.

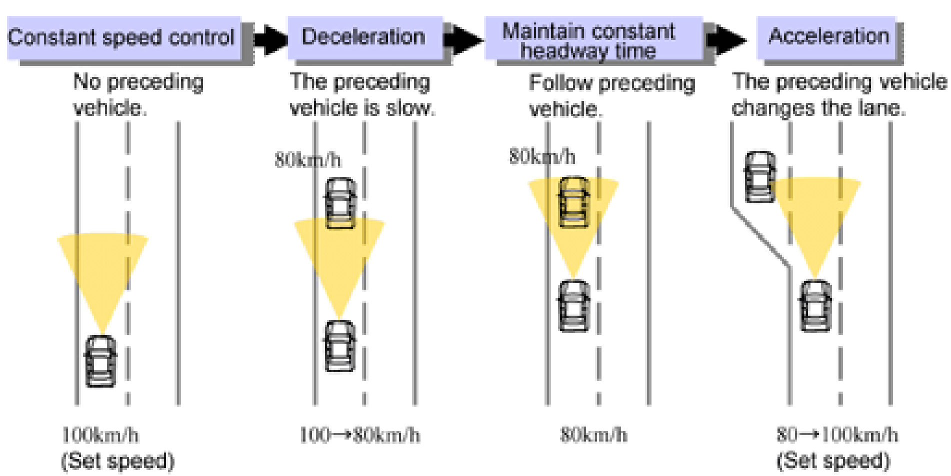

Figure 2-8 Overview of Radar-Based Adaptive Cruise Control Systems. Source: Denso, 2011

Also in Figure 2-8, note that the vehicle makes use of a single-sensor radar system. This illustrates the gaps in coverage that occur at the front corners of the vehicle, making a dual-sensor system a more likely solution to ensure complete coverage of the longitudinal field.

2.3.2.2 Lateral Control

The lateral control of a vehicle refers to its ability to maintain position within its own lane on the highway; that is, the vehicle must be able to sense not only its location within a designated or marked pathway, but also the locations of other vehicles in adjacent pathways. With lateral control, the steering system is the primary vehicle component used to maintain or alter the truck's position. The braking system can also be used to provide small to medium lateral corrections, by selectively apply braking force to different wheels.

Numerous strategies have been sought to maintain lateral control of heavy duty trucks. Currently, technologies such as windshield mounted video sensors, bumper-mounted lasers, and infrared sensors are used with conventional automobiles and trucks for lane departure warning systems. The Iteris Lane Departure Warning System (LDWS), for example, uses a video camera mounted to the windshield of commercial trucks to identify pavement markings and calculate the vehicle's position relative to adjacent lane. Figure 2-9 shows an example of the optical recognition controls used in this system; if these controls sense that the vehicle is in danger of entering another lane, the LDWS uses the vehicle's dynamic control system to selectively apply braking power and keep the truck along its intended path (Iteris, 2008). Note however, that since this technology only utilizes the brakes for lane-keeping, it is not a fully-automated lateral control system.

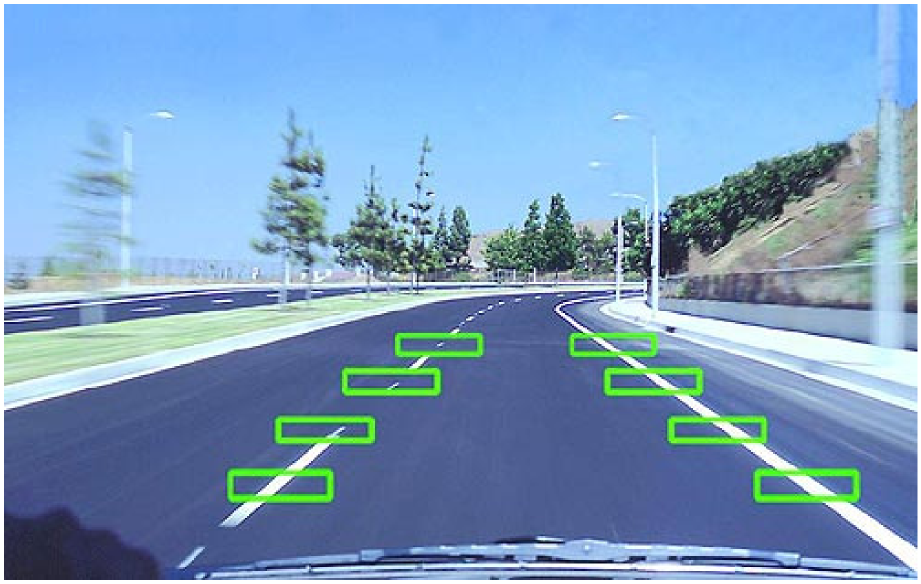

Figure 2-9 Iteris Lane Departure Warning System. Source: Iteris, 2008

Future developments in lateral control systems include fully active steering correction technologies which utilize a vehicle's steering system to maintain lane position. Many of these systems are currently exploring the use of fuzzy logic controller systems as a means of providing a greater level of refinement in the predictive capacity of the technology (Behroozi & Arabi, 2010). Unlike longitudinal control systems, which define a minimum forward-looking threshold for object detection, typically the distance it would take a vehicle with near-instantaneous reaction to come to a complete stop, lateral control systems must be much more sophisticated. With a standard 12-foot lane and a typical width in excess of 10 or 11 feet for combination semi-trucks, there is very little space for reaction and correction of vehicles in the face of adverse external stimuli. As such, these control systems must to a much larger extent involve predictive or preemptive control methods, balanced against road surface variations which occur in the natural environment due to factors such as poor pavement marking application and adverse weather conditions.

As with longitudinal control, additional considerations and algorithmic adjustments will need to be made to the lateral control software in order to account for the additional vehicle dynamics that effect heavy commercial trucks over passenger and other light-duty vehicles.

2.3.2.3 Inter-vehicle Communications

Besides being able to maintain their own positions along a pathway, trucks which use the AEHS will need to know the positions of other vehicles relative to their own. While this could potentially entail a completely different [from the lateral and longitudinal control sensors] set of sensors on each vehicle dedicated to detecting and monitoring the presence of nearby vehicles, a more efficient and elegant solution is to utilize the vehicle's lateral and longitudinal control sensors, in conjunction with a GPS signal, in order to report location and performance metrics. This is accomplished via inter-vehicle communications, which enable vehicles to wirelessly transmit data between one another in real time.

Inter-vehicle communications can be thought of as taking place at two different levels: on the first level, trucks which are in the immediate vicinity of one another can communicate information to each other about such factors as relative locations, tire pressures, and planned exit information. This near-range wireless communication can be achieved via a number of technologies, such as Bluetooth, CDMA cellular technology, or 802.11 wireless transmissions (Heddebaut, Rioult, Klingler, Menhaj, & Gransart, 2008) (Luo & Hubaux, 2004). Line-of-sight communications technologies such as infrared might even be considered, although these come with significant drawbacks and the threat of disruption from conditions which might systematically obscure or distort the light waves, such as high levels of atmospheric water vapor (Anderson & Hadden, 2011). The purpose of these close-range communications is primarily positional; based on the location relative to other vehicles on the AEHS, and by utilizing a common GPS signal that is standard on many newer vehicles, trucks are not only able to maintain their position across lanes, but they are also able to recognize and adapt to vehicles in the same lane in order to avoid collisions. In this respect, near-range wireless communications between vehicles will serve to complement the lateral and longitudinal vehicle sensors that directly monitor the physical roadway environment.

The second level of inter-vehicle communications involves conferring information about the traffic stream to vehicles not in the immediate area, in order to accomplish a systemic effect of flow control. With near-field communications, it is assumed that the operating environment is homogeneous for all trucks in the vicinity, and that no interaction with the central infrastructure is required in order to facilitate inter-vehicle communications. With long-range communications, however, comes the need to feed large amounts of information about vehicle operating conditions, crashes, and roadway obstacles over a long distance to potentially thousands of other vehicles. While such a system may theoretically be achieved via vehicle to vehicle communications in a chained setup, a more efficient solution would be to utilize the AEHS infrastructure as a centralized server for information. By having trucks on the highway wirelessly transmit operating and environmental information to infrastructure-based receivers, relevant notifications about crashes or approaching inclement weather, for instance, can be fed to specific groups of vehicles on the network (Belanovic, et al., 2010). Furthermore, the networking infrastructure required to connect the infrastructure-based receivers can utilize the same conduits and right-of-way as the primary coils used to charge vehicles on the highway. By using the same DSRC technology to communicate vehicle information wirelessly to sensors in the roadway, vehicles can maintain connection with the rest of the network so long as they are traveling on the AEHS.

2.3.3 Intra-vehicle Communication Technology

Another component of the AEHS technology portfolio is that of the internal system used to control individual automobiles. While software algorithms and fail-safe mechanisms will need to be developed for vehicles on the network, the technology used to relay communications across internal vehicle systems is expected to largely remain the same. Every vehicle manufactured for the U.S. market since 2008 utilizes a newer communications protocol known as CAN (controller-area network). This protocol, based on the 1986 federally-mandated Onboard Diagnostics Protocol II standard, allows vehicle systems to communicate with one another without the need for a central junction point (such as the Engine Control Unit, or ECU) (U.S. EPA, 2005). These systems, which encompass everything from throttle and steering control to headlights and power convenience accessories, are typically divided up into a series of modules subdivided into nodes, with each node corresponding to an individual sensor or electronic component. Furthermore, in order to communicate with the rest of the vehicle network, each node requires a host processor and CAN controller in order to decipher electronic inputs into the system and rank them according to priority of information (CAN in Automation (CiA), 2011). Based on the priority of the input data to be relayed, it will move along one of several BUS lines of varying transmission speed; the number of lines and speeds varies by vehicle manufacturer (General Motors, for instance, utilizes a 33.3 Kbps and 500 Kbps dual-speed transmission system, while Mercedes Benz can include five or more BUS lines of varying speeds in its passenger and commercial vehicles). Inputs such as throttle position, steering angle, and brake pedal input are all deemed as critical input components, since the monitoring of these components is necessary to maintain control of the vehicle (Brown, 2010).

2.4 Summary

Despite the highly conceptual nature of AEHS, it appears that a fairly large amount of research and thinking has been performed in this field. Proposed technologies are diverse in their cost, impacts, and versatility, but most assume complete or near-complete automated guidance of the vehicles operating on the network in order to maximize benefits such as improved crash safety and congestion reduction. Additionally, it appears that most previous studies recommend some type of electrically-generated motive power source for the vehicles, thereby further increasing system benefits by reducing fuel costs, as well as local and greenhouse gas (GHG) emissions.

With respect to the specifics on AEHS technology, it is evident that numerous systems must interact with one another, from motive power to guidance systems. It appears that most of the technology which could be used to develop the AEHS is already in either limited public or experimental use. Further development and transitional use of these technologies on conventional roadways will reduce some of the major hurdles faced by a full-scale AEHS implementation, including a public acceptance of active vehicle control systems.

Although numerous difficulties still remain for the adoption of AHS (and more specifically, AEHS), there seems to be a consensus in prior work that the long-term benefits and cost reductions of such a system would greatly outweigh the initial capital requirements, and that further study should be performed to gain a better understanding of how to valuate these effects.

Chapter 3 Data Description

This chapter describes the primary data sources that were utilized in developing the methodology for the economic analysis of the AEHS. The primary source of data for this project is the Freight Analysis Framework (FAF), and an overview of the data hierarchy, including its modeling of aggregate freight flow data, is discussed. Additionally, data sets used in quantifying the costs and benefits of the AEHS project, such as the inputs used in the MOVES emissions model, are explored. Finally, a justification of the corridor that was selected for the case study analysis, Interstate 70 in Missouri, along with a description of its unique features in terms of traffic flow and geometric characteristics, is included.

3.1 Corridor Selection

In order to evaluate the impacts on energy use and emissions of the AEHS, a corridor was selected to serve as a case study for the technology. Interstate 70 in Missouri, from Kansas City to St. Louis (see Figure 3-1), has been identified as an ideal location for the analysis, due to several factors. First, this corridor serves as one of the busiest east-west interstate highway connections in the country, and has been identified as a critical link for freight transportation between the Midwest and the Western U. S. (Battelle, Mallett, Jones, Sedor, & Short, 2006). Furthermore, its significance as a transportation corridor lends itself to a high base volume of commercial truck traffic, reaching upwards of 30% of the total AADT on some segments (FHWA, 2011).

Finally, I-70 is currently being explored by the Missouri Department of Transportation (MODOT) as a potential site for the implementation of dedicated truck-only

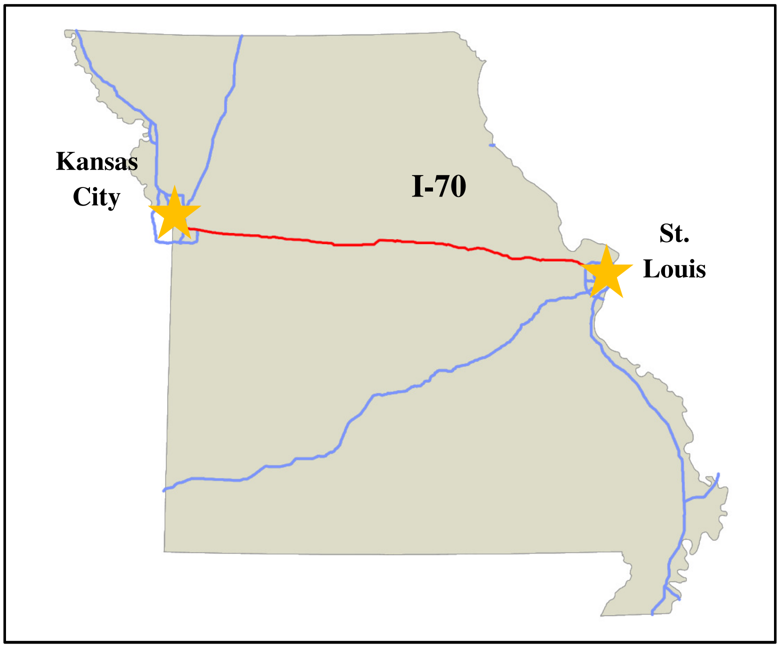

Figure 3-1 - Proposed Study Corridor for Interstate 70 AEHS. Adapted from www.*i70.mobi*

lanes. These lanes, while still physically separated from the general traffic roadways, are designed for conventional diesel-fueled truck use, in that they do not include the advanced technology components relating to AEHS listed in Chapter 2. These lanes will serve as the primary means of conveyance for long-haul, combination-unit trucks along the I-70 corridor, and will be joined to the outside general purpose lanes, as well as the surrounding road network, by a series of slip ramps and dedicated-purpose interchanges (MODOT, 2009).

Figure 3-2 shows a proposed layout of the dedicated truck-only lanes, in which the truck lanes reside in the center of the corridor's right of way, with medians on other side to separate vehicles in the general traffic lanes. It is expected that the AEHS would have a similar cross-section, with the additional infrastructure components needed for the power and guidance systems to be either located in the inside highway medians or on the outside edge of the roadway. These additional components are shown the proposed AEHS cross section in

Figure 3-3. The fact that I-70 was selected for dedicated truck lanes because of its growing importance in freight transportation, and because of the high predicted future volumes of heavy commercial vehicles (FHWA, 2011), serves as independent verification for the suitability of the I-70 corridor for use in assessing the environmental benefits of the AEHS.

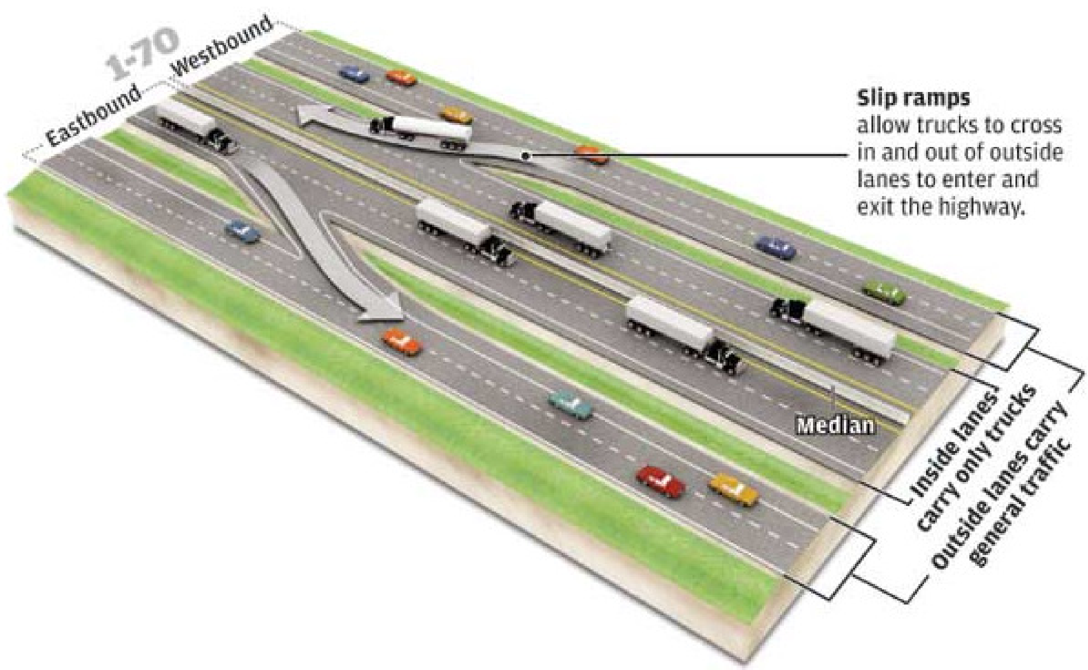

Figure 3-2 - Proposed Layout for I-70 Truck-Only Lanes. Source: Missouri DOT

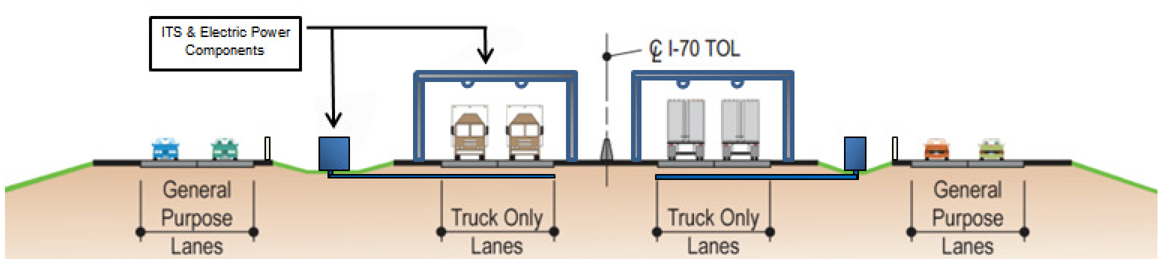

Figure 3-3 Proposed Cross-Section for AEHS. Adapted from MODOT, 2009

3.2 Corridor Information

Once the study corridor was selected, it was necessary to gather data relating to the base operational characteristics of the highway. Information on the existing and predicted traffic data comes primarily from FAF version 3. The FAF is a collection of national freight flows that draws largely from information in the Commodity Flow Survey (CFS), a nationwide sampling of goods movements conducted with carriers and shippers every five years. Version 3 of the FAF relies primarily on data from the 2007 CFS, along with numerous other smaller sources for supplementary information. This data lists freight movements across the country by mode, commodity type, origin, and destination, and allows freight planners to obtain a comprehensive view of the flows of goods for individual states and regions (FHWA, 2011). Because of the freight-oriented nature of the proposed AEHS, it was thought that dedicated freight sources for traffic data may be more suitable in the analysis.

One of the useful components of the FAF database, in addition to numerous spreadsheets describing freight flows across highway segments in the U.S., is that it includes a series of detailed highway network files and associated metadata for use in GIS software, which cover nearly all interstate, U.S., and state highway routes. Furthermore, commodity flow data is disaggregated along specific highway corridors, each identified with a unique numeric key. A few of the important fields from this dataset are described here briefly:

ID – This is a unique identifier for individual highway segments, and corresponds to an analogous ID found in the FAF network database. Further use of this field will be described below.

AADT07 – This is a measure of average annual daily traffic along a highway corridor for the year 2007, and is derived from the 2008 Highway Performance Monitoring System (HPMS) database.

AADTT07 – This is a measure of average annual daily truck traffic along a highway corridor for the year 2007, and is derived from algorithms which utilize a combination of 2008 HPMS data, state truck percentages, and roadway functional class.

FAF07 – This is a measure of trucks recorded in the *AADTT07* field which can be considered as long-distance trucks. This is based on estimated FAF tonnage flows and a standard freight capacity for individual vehicles.

NONFAF07 – This is a measure of trucks recorded in the *AADTT07* field which are not considered as long-distance trucks, according to the FAF. As such, they will be considered solely as short-distance trucks for the purpose of this analysis.

SPEED07 – This is the estimated peak period link speed in 2007 for individual highway segments, measured using a combination of 2008 HPMS data and standard Highway Capacity Manual (HCM 2000) geometric relationships. Because local speed data was not available for all hours of the day, this speed data will be used to form a daily distribution of vehicle speeds on the corridor, as explained below.

For all of the fields above defined for 2007, the same fields exist for the year 2040. These future traffic estimates are again derived from historical VMT trends, FAF data and proprietary algorithms, and will be used in the modeling described in Chapter 4 to establish growth factors for the traffic along the I-70 corridor.

The FAF network files are editable using Geographic Information System (GIS) software such as the popular ArcGIS; as such, this software program was used in order to visually identify the FAF network links that would be used in the final analysis. The study corridor extends from mile marker 15 in western Missouri (east of the I-470 interchange in Kansas City) to mile marker 214 (Lake St. Louis Blvd exit in St. Louis) in the eastern edge of the state, for a total distance of 203 miles. This is the same corridor utilized in the conventional truck-only lanes study, and will be crucial in establishing a comparative analysis for the various costs and benefits of the AEHS. Based on the selected study corridor, and a visual review of the FAF network shapefiles, a total of 82 highway links were identified to be included in the analysis. Once these links were identified, the link IDs were recorded, so that the roadway information in ArcGIS could be combined with the separate FAF database tables that contain information about the traffic characteristics for each section of highway. This combination was completed by performing a series of table joins in ArcGIS, where the database traffic information was joined to the network shapefiles by means of the aforementioned ID field.

Table 3-1 provides a summary of key traffic parameters identified in the FAF data set, including the mean and standard deviation of AADT, AADTT, peak period link speed, and peak period delay per vehicle, for the years 2007 and 2040. Note the distinctions between AADT (all vehicles), AADTT (all commercial trucks), FAF Daily Traffic (combination unit long-haul trucks only), and Non-FAF Daily Traffic (single unit short-haul trucks only). Based on these summary statistics, it appears that, given the current physical dimensions of the I-70 corridor, traffic conditions will deteriorate significantly by the year 2040. There are significant increases in all types of traffic counts, as well as the average volume to capacity (V/C) ratio, which nearly doubles, along with a decrease by one half of the average peak period link speed. Because road segments classified as "urban interstate" by the FAF comprise 50% of the links along the corridor, but only 15% of the mileage, it is likely that they will experience even worse effects from traffic congestion, while the effects on road segments classified as "rural interstate" are likely to be somewhat lower. These statistics alone provide a motivation for the study of solutions to reduce or eliminate the problem of future traffic congestion on the I-70 corridor.

Table 3-1 - I-70 Summary Characteristics. Source: FAF v3

Variable	*Mean*	*Std Dev.*	*Obs.*	*Maximum*	*Minimum*
Segment Length	2.47	4.19	82	19.93	0.02
2007 AADT	53838	28766	82	113286	19799
2007 AADTT	12323	4407	82	21576	5939
2007 FAF Daily Traffic	9825	566	82	11905	8897
2007 Non-FAF Daily Traffic	3265	3741	82	11934	0
2007 V/C Ratio	0.69	0.18	82	0.97	0.34
2007 Peak Period Speed (mph)	62.4	8.8	82	73.1	53.6
2007 Peak Period Delay (hours)	0.00	0.00	82	0.03	0.00
2040 AADT	79920	42702	82	168168	29390
2040 AADTT	24417	4637	82	35971	18558
2040 FAF Daily Traffic	18660	1002	82	21646	16426
2040 Non-FAF Daily Traffic	5756	4438	82	16752	519
2040 V/C Ratio	1.07	0.22	82	1.46	0.64
2040 Peak Period Speed (mph)	30.6	28.9	82	73.0	0.1
2040 Peak Period Delay (hours)	0.14	0.15	82	0.46	0.00

Urban/rural	
% by number of links	50/50
% by length	15/85

3.3 Data Sources for Emissions and Energy Use Modeling

MOVES, whose use will be described further in Chapter 4, is a speed-based emissions modeling software developed by the U.S. Environmental Protection Agency (U.S. EPA) in order to replace their aging MOBILE6 model. It is widely used by municipal and federal organizations for modeling emissions from a national scale down to the individual project level. MOVES is able to model several dozen combinations of pollutants and vehicle/fuel types, and uses a great amount of local information, such as temperature data, speed distributions, and total vehicle-miles traveled (VMT), in order to refine the modeling process (U.S. EPA, 2011). An additional benefit of MOVES is that it includes a large number of built-in tables with regionally-defined default values for these data sources, such that a reasonably accurate analysis is still possible with only limited data available for the corridor.

Some of the data that was used in MOVES based on I-70-specific operating characteristics are presented next. Where such local data were unavailable, the default values in MOVES for the state of Missouri (such as for vehicle age distribution) were utilized.

3.3.1 Average Speed Distribution

In order to complete an analysis of emissions along a highway, MOVES requires input about the speed profile of traffic on the roadway; in essence, the distribution of actual vehicle speeds on the highway. Unfortunately, detailed traffic count information and speed profiles for individual roadway segments were not available for this analysis. Instead, a speed distribution was created based on the peak period speeds reported in the FAF data. Figure 3-4 shows the distribution of peak period link speeds. Because these speeds represent individual highway links along the analysis region, and because MOVES can only apply a single speed distribution to the data being analyzed, this distribution was then assumed to be representative for the entire I-70 corridor.

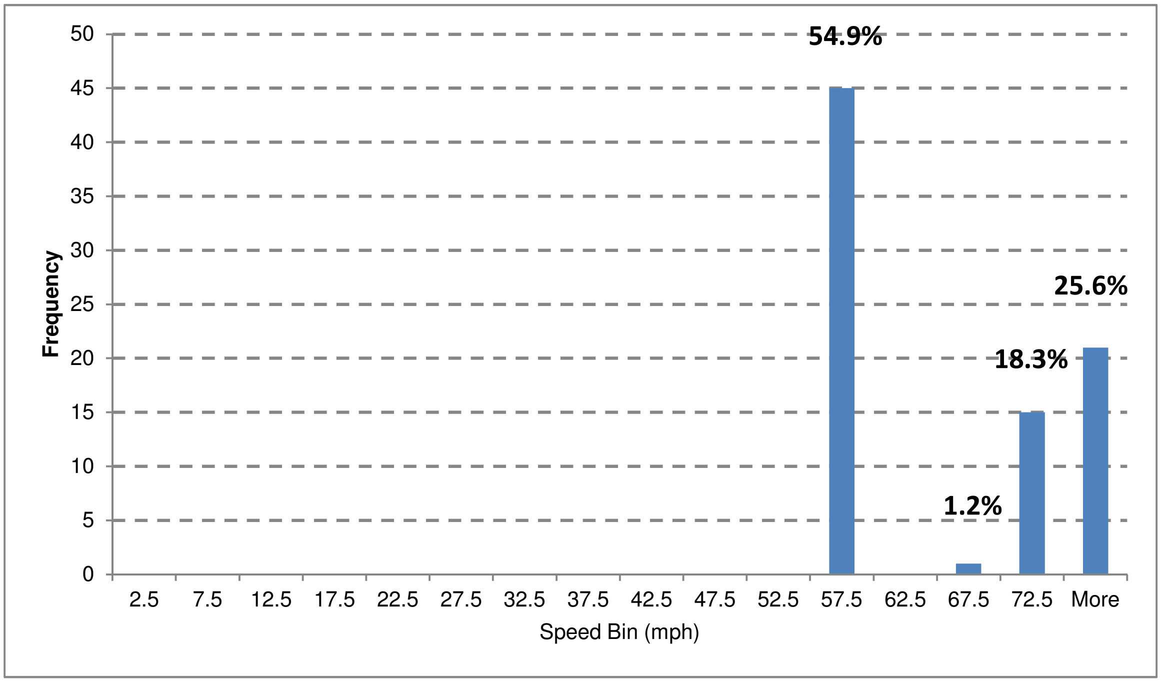

Figure 3-4 - Peak-Hour Speeds for Links on the I-70 Corridor. Percent of total links is given above each frequency column.

3.3.2 Total VMT and Vehicle Populations

MOVES requires three primary components in order to generate a profile of the traffic stream being analyzed: vehicle age distribution, source type population, and source type VMT. For this analysis, only 3 vehicle (source) types are considered: passenger cars, short-haul single unit trucks, and long-haul combination unit trucks.

In addition to the vehicle age distributions utilized in the analysis, it was necessary to estimate the VMT and total population of each vehicle type on the highway corridor. Note that MOVES only uses the source type population in calculating start-up and diurnal emissions, which are not of concern on a highway corridor with non-stop traffic. As such, generating an accurate estimate of VMT by vehicle type was of primary interest.

In order to accomplish this, the Annual Average Daily Traffic (AADT) and Annual Average Daily Truck Traffic (AADTT) values were input to a spreadsheet developed by the EPA, entitled *"AADVMT Calculator"*. This spreadsheet contained link-level AADT values for each vehicle type, and generated an annual estimate of VMT, along with a list of weekend and peak-hour weighting factors that are used internally for the calculations (U.S. EPA, 2011). Outputs of this step included estimates for the total annual VMT by vehicle type along with estimates of the fraction of VMT generated by hour and day type. Next, the annual VMT by vehicle type was divided by an estimate of the annual VMT per vehicle per type, in order to determine the vehicle populations along the I-70 corridor. The following values of annual VMT per vehicle per type, as determined by the FHWA, were used in this estimation:

- Passenger Cars: 14,600 miles per year
- Single Unit Short Haul Trucks: 11,000 mile per year
- Combination Unit Long Haul Trucks: 80,000 miles per year

3.3.3 Vehicle Age Distribution

As described in the previous section, one of the required inputs for MOVES is an estimate of the distribution of vehicles by age and by vehicle type for any given year in the analysis. The vehicle age distribution used in the analysis was based on that included within the MOVES database, and is itself derived data from the Vehicle Inventory Use Survey (VIUS). VIUS is a now-discontinued publication from the U.S. Census Bureau, and gathered data on vehicle registrations in Missouri, amongst other sources, in order to estimate the age distributions by vehicle type within the state, as well as to measure changes related to economic development and productivity (U.S. Census Bureau, 2004).

One potential fallacy with this technique may occur with the distribution of the commercial truck age distribution. Should companies which adopt the AEHS technology choose to purchase new vehicles in the transition process, rather than retrofit existing ones, it will skew the distribution away from older vehicles. However, because no forecast data is available for this, it was not taken into consideration in the data development.

3.3.4 Distribution of VMT by Road Type

MOVES also requires input as to the percentage of total VMT by vehicle type on each class of roadway. For this analysis, only restricted access roadways were considered, since the modeling is limited to the primary I-70 right of way (ROW). More specifically, roadways can be classified in MOVES as “Urban Restricted Access” or “Rural Restricted Access”. The FAF database includes a classification for each roadway segment as “Urban” or “Rural”, based on the geometric design of the roadway, and the surrounding land use. Based on this field, and by computing the VMTs for each vehicle type and highway link (for example, *Long-Haul Truck VMT = Truck Count*Link length*), a distribution of the urban versus rural restricted access VMT by vehicle type was generated.

3.3.5 Meteorological Data

Weather conditions can have a large influence when modeling emissions on a transportation corridor. For example, carbon monoxide emissions are typically higher in areas with colder climates, because vehicles consume more fuel when starting in colder weather, and because many emissions control systems do not operate as efficiently when they are cold (U.S. EPA, 2003). The meteorological data used as input in MOVES was compiled using information from the National Oceanic and Atmospheric Administration's National Weather Service. It includes hourly averages of temperature and humidity based on a monitoring station in Columbia, Missouri, for a 12-month time period. Also included is an estimate of barometric pressure along the corridor (National Weather Service, 2011), for which MOVES can only accept a single value.

3.3.6 Fuel Formulation Information

In order to estimate the energy use and emissions for a highway corridor, MOVES must first have information relating to the types and adoption rates by vehicles type of the various fuels used for motive power. For the analysis, the default MOVES information for fuel types and adoption rates in the state of Missouri was used. These fuel formulations include ethanol-free gasoline and E10 (10% ethanol content) gasoline for passenger vehicles, the same gasoline formulations, along with diesel and biodiesel fuel for single unit short-haul trucks, and diesel and biodiesel-only for combination unit, long-haul commercial trucks. The level of adoption for the base year of the various fuel types, along with the levels of adoption for subsequent years is included in the MOVES default database.

Chapter 4 Methodology

This chapter describes the methodology used in developing the economic analysis for the AEHS. Besides identifying and quantifying the specific factors used to establish the benefits and costs of the system, a key contribution of this chapter is a detailed explanation of the overarching methodology that can be used in establishing not only the necessary components of the analysis, but also the background information needed to define and monetize these components from an appropriate perspective. This methodology will be applied to the I-70 corridor in Missouri as a case study of AEHS, and will include two different types of benefit cost analysis: net present value, and benefit/cost ratio.

4.1 Establishing Background Components

In order to establish the necessary components for an economic analysis for the AEHS, one must first define the general goals of the AEHS, the perspective from which the analysis is being undertaken, and finally, the intended costs and benefits. This multistep process prior to the economic analysis being performed is important in order to minimize the collection of unnecessary information with respect to the project parameters, and will help to ensure that the interpretation of the analysis results are appropriate for the audience of concern.

4.1.1 Goals of the AEHS

While there are seemingly a wide array of competing goals and motives in establishing a viable commercial implementation of AEHS, the overarching desire is to improve the efficiency of highway travel over the current conditions, in this case along the I-70 corridor in Missouri. This primary goal of improving efficiency with the AEHS is achieved two-fold: first, by reducing congestion along the I-70 highway corridor. This congestion reduction will occur not only because of the increase in total number of lanes available to vehicular traffic on I-70, but also because commercial trucks, whose larger size as compared to passenger vehicles is often a source of additional safety hazards and slowdowns in the traffic stream, will be operating on an infrastructure that is physically separate from the general vehicle population. By creating a more uniform distribution of vehicles on both the conventional general-purpose lanes, and the automated electric truck lanes, sources of congestion such as differentials in vehicle acceleration, crashes involving large commercial trucks and passenger cars, and others, will be greatly reduced or even eliminated.

Second, efficiency is improved by utilizing technology that expands the capacity and reduces the energy use of the highway corridor in such a way that cannot be achieved with conventional highway construction and design methods; this is the essence of the automated control and electrification systems present in the AEHS. This goal is accomplished by utilizing advanced control and electric motive power systems in order to establish the separate guideway for combination unit, long-haul commercial trucks. As these vehicles are typically the largest and least fuel efficient vehicles found in an ordinary mix of traffic, their placement on an autonomous highway infrastructure is expected to produce improvements in efficiency of the highway corridor greater than the proportionate VMT of the long-haul trucks. Additionally, the automation and electrification of these vehicles is expected to produce numerous ancillary benefits.

While these goals of reduced congestion and energy use are worthy in their own right, the same motives can be found for nearly any major transportation infrastructure project, AEHS or not. As such, once the general goals of the project are laid out, it is necessary to establish the perspective from which the analysis will be carried out, which, in doing so, will then allow the researcher to explicitly define the specific benefits and costs to be considered in the project.

4.1.2 Perspective of the Analysis

In the case of the AEHS economic analysis, the benefits and costs will be assessed from the perspective of the public agency, the Missouri State Department of Transportation (DOT). Accordingly, the project benefits and costs can be assessed for the entire length of the I-70 corridor in the state of Missouri, as opposed to the DOT in an individual county, which would not have a vested interest in the broader impacts of the AEHS technology beyond their own jurisdiction. Furthermore, establishing the party of interest as a government transportation agency will allow for the consideration of benefits and costs which affect the general public welfare and may not be wholly accrued or incurred by a single private firm. These benefits, such as improved air quality from reduced emissions, and costs, such as the adverse environmental impacts from road construction, are typically defined as externalities, in that they only affect the costs and benefits of individual firms within a project in terms of the availability of permits, taxes, and subsidies which offset their effects.

4.1.3 Identifying Costs and Benefits

Once the goals of the AEHS have been laid out, and the perspective of an economic analysis has been established, the specific costs and benefits to be considered in the analysis can be defined in terms of their overall qualities and scope of detail. Specifically, from the viewpoint of a government organization, only those costs and benefits which are directly incurred or accrued by the agency, or else those which affect all users of the AEHS, can be considered. Furthermore, the preliminary nature of the economic analysis suggests that only those costs and benefits viewed as the most significant should be considered. Based on the results of the preliminary analysis, additional benefits and costs at a greater level of detail can be defined.

The following benefits are viewed as the most significant of the AEHS, and will consequently be quantified and monetized in the preliminary economic analysis:

- Travel Time Savings
- Vehicle Operating Cost Savings
- Crash Savings
- Emissions Reductions

The corresponding list of significant costs to be quantified and monetized is given as:

- Initial Construction Costs
- Operating and Maintenance (O&M) Costs
- End-of-Life Capital Recovery

Note that for the benefits and costs listed above, the quantities of each should be monetized in the economic analysis according to a marginal perspective. That is, the purpose of the AEHS economic analysis is to compare the costs and benefits of the system relative to the base case, or "do-nothing" alternative, in which no significant infrastructure improvements are made to the I-70 corridor, and traffic is allowed to reach its previously-predicted values. For example, when computing the total vehicle operating costs for the economic analysis, only those which are different between the AEHS scenario and the base case scenario should be monetized as a cost or benefit. The methods of measuring the total changes of these items in computing the costs and benefits for the economic analysis will be described in the sections below.

4.2 Components of the Benefit-Cost Analysis

4.2.1 Overview

In order to judge the suitability of the AEHS technology in real-world conditions, it is necessary to develop a set of criteria which can be used to objectively evaluate the advantages and disadvantages of the system. More specifically, it is desired to quantify the positive and negative effects of AEHS in such a way as to allow comparison, not only of dissimilar elements within the AEHS framework, but also as compared to other systems, projects, and technologies, which may purport to obtain similar or greater benefits for similar or lower costs.

The preferred method in which to carry out this evaluation is through a benefit-cost analysis (BCA). This type of economic analysis is considered to be the process by which the total benefits and costs for a project are computed for allowing a solely monetary evaluation of a proposal with respect to:

- Comparative attractiveness to other projects competing for the same dollars, time, or physical space;
- Feasibility (on its own, is the project even reasonable to pursue?)

In performing a BCA, all current and future costs and benefits related to the project are taken into account and converted into monetary terms. The monetization of these items provides a uniform medium by which dissimilar elements of a project can be compared (FHWA, 2011).

4.2.2 Establishing the Base Case

The first step in performing a BCA is to establish the base case conditions from which any proposed alternatives can be differentiated and analyzed. This is crucial, since the BCA will focus on monetizing only those effects which differ significantly between the base case and alternative cases. Additionally, the base case should be modeled for the analysis period with as much information as possible about changing conditions (such as traffic levels) that are expected to occur, regardless of the final decision regarding construction of an alternative system. Typically, the base case is defined as a continuation of the existing physical infrastructure, accounting for differences in traffic levels. As stated in the previous section, such a case is referred to as the "do nothing" alternative.

In this analysis, the base case (denoted as the "Without AEHS" scenario) is considered to be the I-70 corridor between Kansas City and St. Louis (the exact points were defined in Chapter 3) in its current condition: a predominantly rural, 4-lane interstate with all vehicle types operating within the same space on conventional paved lanes. However, as explained in Chapter 3, significant changes are expected to occur along this corridor by the year 2040, in terms of total predicted traffic levels, speeds, and congestion. These naturally-occurring changes, which are based on an I-70 corridor that is not significantly improved from its 2007 configuration, will be modeled in the analysis for both the base case and alternative case conditions.

4.2.3 Establishing the Alternative Case

Besides the base case, the alternative case must be defined for any BCA to be carried out; as previously stated, the goal of the BCA is to monetize and assess the differences in benefits and costs between competing systems. While the proposed AEHS has been described extensively in Chapter 2 and Chapter 3, it is important to reiterate that the alternative case (denoted as the "With AEHS" scenario) will consist of the same geographic scope as the base case, again the I-70 corridor from Kansas City to St. Louis. In cases where the proposed alternatives consist of different physical lengths or geographic areas, care must be taken to ensure that an equivalent level of costs and benefits are considered.

4.2.4 Time Period for Analysis

In order to establish an adequate measure of the costs and benefits that would occur on the system which are not directly attributable to the initial capital outlay, it is necessary to establish a sufficient time period for the analysis.

Specifically for the AEHS, the problem of establishing a time period for analysis is two-fold: for one, the radical nature of the AEHS will almost certainly mean an incremental adoption rate by system users, which will most likely not realize significant benefits compared to the general purpose lanes until several years have passed from the project completion. At the same time, the intensity of the physical infrastructure required for automated control and electricity generation carries some risk of technical obsolescence after a period of time. The economic analysis must balance the benefits of higher adoption rates later on in the project with those factors which weigh against the project as time progresses, such as the aforementioned technical obsolescence.

For these reasons, a time period of 30 years has been selected for the analysis period. While major highway infrastructure components, such as bridges, can often have a useable life of 50 years or more, it was felt that 30 years was an appropriate compromise between the competing factors for such a new system. Furthermore, as described in Chapter 3, this time period will occur from the years 2011-2040, such that the built-in datasets from the MOVES software program can be used in aiding the estimation and analysis of emissions reduction benefits.

4.2.5 Discount Rate for Analysis

Because the costs and benefits for the project occur at different stages of the project lifecycle, and because the BCA must have these costs and benefits expressed in terms of present-day value, it is necessary to transform their monetary value at the time the benefit or cost is accrued or incurred into present day dollars. This is accomplished by a discount rate, wherein the present value of a benefit accrued or a cost incurred at some point in the future is given (in general) by:

$$PV = \frac{FV}{(1+i)^t} \tag{4.1}$$

Where *PV* denotes the present value of the cost or benefit, *FV* denotes the monetary value of the cost or benefit at the time it is incurred or accrued, respectively, *i* denotes the discount rate which will be used to convert the future value to present day dollars, and *t* denotes the time period, typically in years, between the present day and the time of the cost or benefit occurrence.

The most important factor to consider in establishing the discount rate for an economic analysis is the perspective from which the analysis is being performed. For a private firm, the discount rate would reflect the opportunity cost of the firm to invest the money elsewhere. In other words, what percentage could be earned on the original funds if they were not used for the AEHS? For a government organization, the discount would reflect the value of the money that could be spent on another infrastructure project. Note when discounting the future value of money, the effects of inflation are not considered, since it is desired to express all costs and benefits in terms of constant dollars. Also note that the discount rate does not consider a risk aversion component; this typically consists of an increasing percentage over time to reflect the greater levels of uncertainty in the future value of money. From a government perspective, because the funds would be used for a different public infrastructure project if not for the AEHS, this risk component is not considered.

For this analysis, the discount rate will be equivalent to the real discount rate, as determined by the US Office of Management and Budget (OMB). This discount rate removes the effects of inflation, and is used for discounting constant dollar flows. According to the OMB, for a 30-year project lifecycle, the discount rate should be 2.3% (USOMB, 2010).

4.2.6 Type of BCA

Once the monetization of the project costs and benefits is complete, the methodology used to perform the BCA must be chosen. Depending on the goals and limitations of the agency performing the BCA, there are several different methodologies that can be used, the most common of which are (TRB Transportation Economics Committee, 2010):

- Benefit/Cost Ratio
- Net Present Value
- Cost Effectiveness
- Internal Rate of Return
- Payback Period

Each type of BCA has distinct advantages and disadvantages, depending on whether the goal is to maximize benefits for a given cost (cost effectiveness), to determine the number of years it would take for the project benefits to recoup the costs (payback period), or some other objective. In this analysis, the goal is simply to assess the difference between discounted costs and benefits for the project ("With AEHS" scenario), as compared to the base case conditions ("Without AEHS" scenario); as such, the Benefit/Cost Ratio and Net Present Value will be the primary methodologies used.

4.2.6.1 Net Present Value

Net present value (NPV) is a means of evaluating the economic viability of a project by which current and future benefits (in terms of positive cash flows) are compared against current and future costs (in terms of negative cash flows). This comparison is conducted in the current time period, such that future benefits and costs are discounted in order to determine their present value. The NPV procedure of analyzing lifecycle costs and benefits in the present time period is justified in that the capital outlay, which comprises the majority of costs for most projects, primarily occurs in the first year of operation, and so the total benefits for the project should be similarly defined in this current time period.

The formulation of a Net-Present Value analysis can be defined according to the following equations:

$$NPV = PWB - PWC \quad \textbf{(4.2)}$$

where $$PWB = \sum_{i=0}^{n} \frac{B_i}{(1+d)^i}$$

and $$PWC = \sum_{i=0}^{n} \frac{C_i}{(1+d)^i}$$

PWB stands for "Present Worth of Benefits (B)", and PWC stands for "Present Worth of Costs (C)". According to economic theory, an NPV of a project which is economically feasible will be greater than 0; that is, the present worth of lifecycle benefits for the project will exceed the present worth of lifecycle costs. Likewise, a project whose NPV is less than zero will not be economically feasible, and should not be undertaken without significant justification not accounted for in the economic analysis, while a project whose NPV is exactly zero should have an indifferent effect on the prospective funding agency.

4.2.6.2 Benefit/Cost Ratio

The benefit/cost ratio (BCR) is a relatively simple form of economic analysis in which the total benefits of the project are divided by the total costs. The total costs and benefits are first monetized, and then discounted to present day values. The BCR is useful for examining the relationship between the magnitudes of lifecycle benefits and costs; a BCR of greater than 1 indicates positive net benefits, and is representative of a project that is economically feasible for investment. The higher the BCR, the higher the total benefits are relative to the costs. The formulation for the BCR is given as:

$$BCR = \frac{PWB}{PWC} \qquad \textbf{(4.3)}$$

where $PWB = \sum_{i=0}^{n} \frac{B_i}{(1+d)^i}$

and $PWC = \sum_{i=0}^{n} \frac{C_i}{(1+d)^i}$

with the same definitions holding as for NPV. One of the possible shortcomings with BCR is that it is insensitive to the raw magnitude of benefits and costs; for this reason, smaller projects may return extremely high BCRs than larger ones with greater net benefits, due to very low constructions costs for the small project. Although this is not a major concern in this analysis, since only one alternative, and of the same geographic scope, is being considered, in general, it is good practice to use the BCR in conjunction with another form of economic analysis, such as NPV (Sinha & Labi, 2007), (TRB Transportation Economics Committee, 2010).

4.3 Quantify and Monetize Benefits and Costs

Once the components costs and benefits are identified in the analysis, and the type of BCA is selected, the costs and benefits for the project must be estimated and monetized. This section, in addition to describing the methodology used in order to accomplish this, begins with a brief introduction to the analysis in terms of microeconomic theory, and describes how benefits might be estimated according to marginal-cost pricing.

4.3.1 Monetizing Costs and Benefits According to Microeconomic Theory

One way in which the cost savings benefits to users of the AEHS (herein referred to as "total direct user benefits") can be estimated is through marginal-cost pricing, in accordance with simple microeconomic theory. According to this theory, the cost savings benefits to roadway users can be estimated by considering the reductions in the marginal cost of shipping that would occur to carriers, and presumably be passed on to shippers.

Figure **4-1** provides a graphic portrayal of the concepts needed in order to assess total direct user benefits. The graph represents the market for shipping freight along the highway corridor; in this case, the corridor is I-70 in Missouri. The demand curve *D* represents the total demand for truck trips by shippers at all price levels of shipping; it can be derived by using locally-available information about the highway corridor, along with estimates of price elasticity of demand for shippers in order to determine the shape of the demand curve. Likewise, the supply curve *S* represents the total supply of truck trips by carriers at all price levels of shipping; it is estimated by using historical data on shipping volumes on the corridor, along with estimates of price elasticity of demand for carriers.

Initially, the implementation of the AEHS is expected to reduce the costs of truck trips for carriers at all price levels, which would result in a rightward shift to supply curve *S'*. The magnitude of this shift is calculated using the estimated marginal operating costs for carriers on the AEHS; this can be derived by computing total costs, including capital and operating costs, for various levels of usage, such that a marginal cost can be determined from this information.

Based on this shift in the supply curve from *S* to *S'* the price and quantity of truck trips on the highway corridor moves from *P* and *Q*, respectively, to *P'* and *Q'*, while the market equilibrium point shifts from *A* to *B*. Along with this shift in equilibrium comes a shift in total consumer surplus; this net change is the area bounded by *PABP'*. As this additional consumer surplus can be monetized by calculating the area of *PABP'*, it is representative of the total direct user benefits that would result from implementation of the AEHS.

Over time, it is expected that additional changes would have even greater effects on the total benefits of the AEHS, not all of which are positive. For example, the degree to which the supply curve will shift is uncertain, as it is based on rough estimates of the marginal costs to carriers on the AEHS. Thus, a second shift in the supply curve, represented by *S''*, may be introduced in order to represent a bounded range of estimates for the true market supply curve shift. Based on the new supply curves *S'* and *S''*, a corresponding range for total user benefits on the AEHS would be produced. Additionally, it is expected that capacity increases, travel time reductions, and cost savings afforded by the AEHS would result in a certain level of induced demand on the highway corridor for all price levels of shipping. This shift in the demand curve is represented by the new demand curve *D'*. With additional usage of the highway corridor at all price levels, the total direct user benefits of the AEHS would be expected to decrease, as shipping prices would incrementally increase. The amount of this increase depends on the shift in the demand curve, which in turn would depend on various exogenous factors for shippers, including the availability of competitive shipping modes and routes.

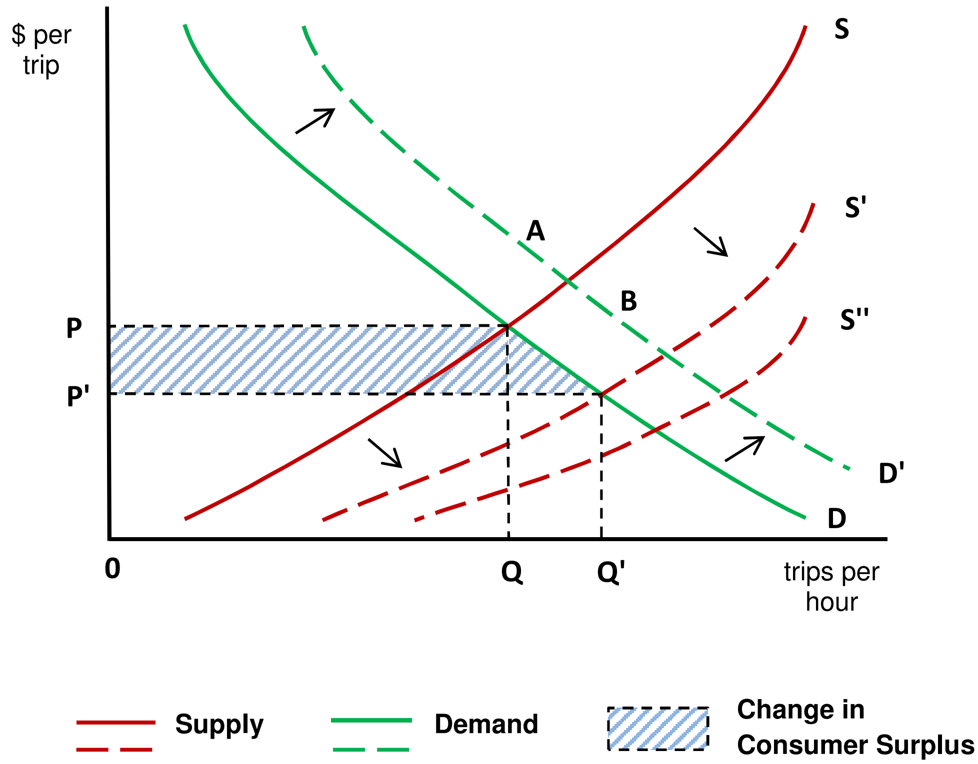

Figure 4-1 - Consumer Surplus Generated by AEHS

While microeconomic theory may be useful for deriving a total of direct user benefits from the AEHS, it will not be used in this analysis for numerous reasons. The primary reason is the lack of the necessary information for establishing the original supply and demand curves, especially with respect to historical shifts in the curves relative to one another. Instead, a piecewise monetization of costs and benefits will be utilized, wherein each major cost and benefit category identified in Section 4.1.3 is described separately. These costs and benefits are then monetized using the selected discount rate, and the totals are applied to the aforementioned economic analysis methods.

4.3.2 AEHS Demand

As discussed in the previous section, one of the most common factors that encourage the adoption of an alternative route or mode of transportation is the corresponding reduction in costs for the users who choose to take advantage of the new system. However, this alludes to the assumption that users are choosing a transportation alternative that is either a derivative of their original mode, or has at least seen successful commercial operation, at least in some other geographic area. Therein represents the key challenge with estimating demand of the AEHS, as all of the necessary technology components have yet to be assembled in a single commercially viable package.

In order to derive an estimate of the demand rate for AEHS, expressed herein as a percentage of the long-haul truck VMT on the I-70 corridor, the author reviewed previous literature in order to determine commonly used methodologies for estimating VMT growth and demand rates in conventional highway projects.

In many cases, travel demand models are suitable for determining the origin and destination pairs for trips within the analysis area, which can then be used to identify the number of trips where AEHS would be a suitable alternative, based primarily on distance and the congestion of surrounding systems (the general purpose I-70 lanes, in this case). However, for this study, only aggregated link-level traffic count information was available; as this dataset does not include the origins or destinations of the trips made on the highway, it was impossible to identify likely users of AEHS based on minimum travel distance or other disaggregate methods. When only more aggregate trip data are available for conventional highway projects, the elasticity of demand with respect to factors such as price or travel time savings is typically estimated to predict future demand rates and totals for a system, given that baseline demand information is available. When that information is not obtainable, elasticities of demand for similar services on other corridors can be used, but it is recommended that those areas have very similar characteristics to the roadway under study (Sinha & Labi, 2007). Given the dissimilar characteristics of the AEHS, compared to general purpose highways, it was concluded that such measures of elasticity would not return accurate estimates of demand, and may in fact imply a causal relationship between demand factors for general purpose highways and AEHS, where none existed. Finally, the perceived radical nature of the AEHS suggested that an approach to demand estimation based specifically on the technological factors of the system may be more appropriate for this application.

Based on this review, the authors decided to consider studies which estimated the adoption rates of similar, albeit more incremental in scope, automated control systems for heavy-duty commercial trucks. In particular, Cantor et al. (2006) surveyed several hundred long-haul truck carriers from across the country in order to assess and compile the adoption rates of various safety-related technologies for heavy commercial vehicles, including lane keeping, obstacle detection, and adaptive cruise control systems (all previously described independently in Chapter 2). A partial summary of these results can be found in Table 4-1, and consists of the percentage of responding firms that had adopted each of the control technologies. For each level of adoption (i.e., minimal, partial, moderate, above average, or substantial), percentages across all three control technologies were averaged to estimate a single set of adoption rates. These averages were then reverse-transposed as the incremental rates of demand (as a percentage of total long-haul truck VMT on the I-70 corridor) for the AEHS, as shown in Figure 4-2.

Table 4-1 - Adoption Rates of Vehicle Control Technologies. Adapted from Cantor et. al. (2006)

Technology	*Level of Adoption (% of Respondents)*				
	Minimal	*Partial*	*Moderate*	*Above Average*	*Substantial*
Adaptive Cruise Control	36.84%	13.16%	10.53%	13.15%	2.64%
Obstacle Detection System	36.84%	26.32%	13.16%	5.26%	7.89%
Lane Keeping System	50%	20%	26.32%	10%	0.00%
Average	**41.23%**	**19.83%**	**16.67%**	**9.47%**	**3.51%**

The 30-year analysis period was divided into five 6-year periods. Beginning with a demand rate of 0% in year 1, the 3.51% rate for "substantial adoption" was used to denote the demand rate at the end of the first 6-year period. This rate represents the small portion of truck drivers who are already attuned to the latest vehicle control technology, and thus, may be more likely to adopt the AEHS technology first. For the second 6-year time period, the 9.47% "Above Average" adoption group was added to the existing 3.51% to obtain a total demand rate in year 12 of 12.98%. This represents the group of current truck drivers who are next most likely to adopt the AEHS technology. This process continues until the largest group, the "Minimal" current technology adopters, eventually utilizes the AEHS, for a cumulative demand rate of just over 90% of all truck VMT on I-70. Note that at its estimated maximum, almost 10% of long-haul trucks on the I-70 corridor do not use AEHS; this is to account for a small percentage of trucks which might never use the system because of factors such as low perceived travel time benefits, personal preferences, or other factors. For those years which do not fall at the end of one of the five 6-year periods mentioned above, simple linear interpolation between the period beginning demand rates and ending demand rates was performed. Thus, each year in the 30-year analysis period will have a slightly different demand rate, as shown in Figure 4-2.

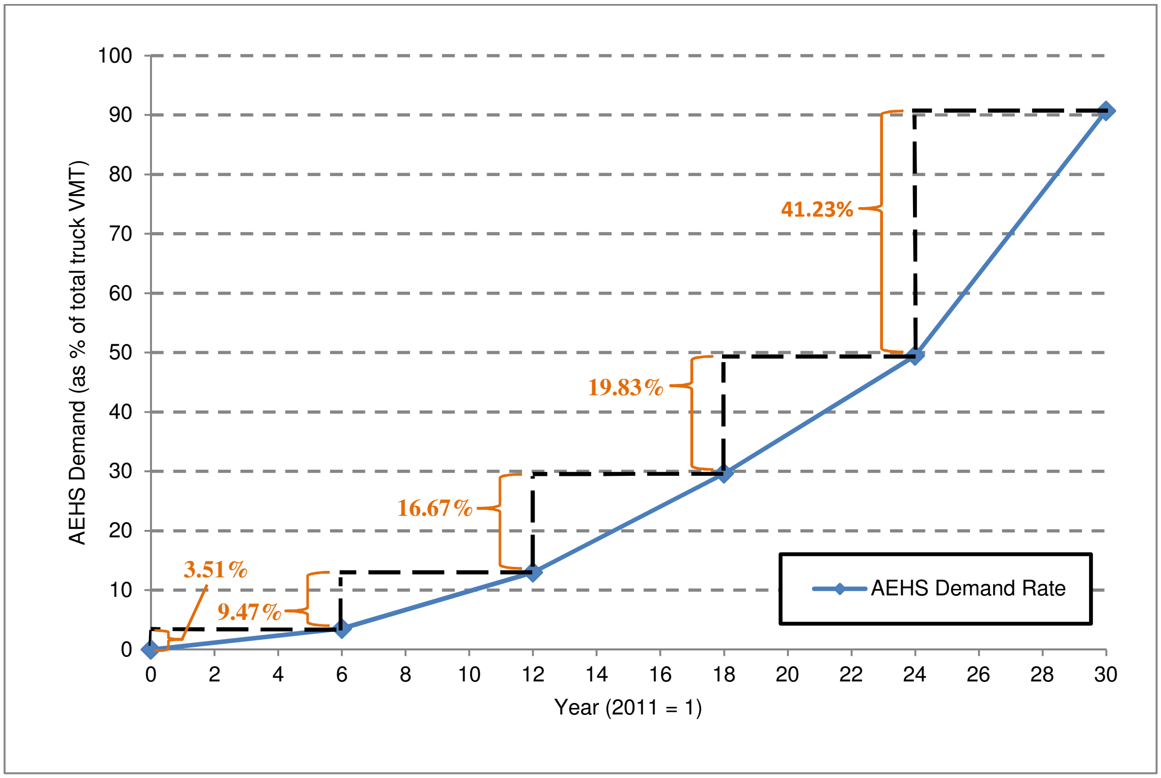

Figure 4-2 - AEHS Demand Rate as a Percentage of Total Long-Haul Truck VMT. The Labeled Percentages Represent Different Groups from Table 4-1.

4.3.3 AADT Growth Factor

As discussed in Chapter 3, the FAF data includes estimates of traffic by vehicle type for the years 2007 and 2040. In order to generate an estimate of the AADT along the I-70 corridor for the base case conditions for all years, a simple linear growth factor was applied. Note that, based on the FAF methodology of estimating traffic growth, a different annual growth factor was generated for each of the 82 highway links that comprise the I-70 analysis corridor.

4.3.4 Costs

4.3.4.1 Right of Way Costs

Right of Way (ROW) costs typically involve the acquisition of land for construction of a proposed infrastructure project. In the case of highway construction, these costs are typically incurred if the proposed project does not follow the exact physical footprint of the existing roadway. In the case of the AEHS project on I-70, the original layout of the highway in most places consists of two or three lanes in each direction, with a wide grass median in between opposing lanes. The proposed AEHS will construct two adjacent but opposing 2-lane sections in the middle of the highway for the automated electric vehicles, with the general purpose lanes on the outside edges of the highway, separated via additional medians. Because of these additional lanes, it is estimated that a significant amount of additional ROW will be needed in completing the AEHS.

The costs and quantities for ROW acquisition were derived from the original construction cost estimates for conventional truck-only lanes (shown in Appendix 1). These estimates, compiled by the Missouri DOT, include a number of factors, such as agricultural and residential land acquisition, hazardous waste disposal, outdoor advertising removal, and the modification of existing interchanges. These costs, calculated in 2008 dollars, were updated for the 2011 time period by utilizing the Civil Works Construction Cost Index System (CWCCIS). This system, developed by the U.S. Army Corps of Engineers (USACE), is used to adjust the construction cost information for different years and geographic areas on projects ranging from highway construction to lock and dam rehabilitation, and is based on a broad semi-annual national survey by the USACE of various construction projects and their final and projected costs (USACE, 2011).

Using a base year of 1967 and a CWCCIS score of 100, the land acquisition scores for 2008 and 2011 are 727.11 and 747.60, respectively. Thus, the 2011 ROW acquisition cost can be computed as:

$$(2011\ ROW\ Costs) = (2008\ ROW\ Costs) * \frac{747.60}{727.11} \quad \textbf{(4.4)}$$

$$= 1.028 * (2008\ ROW\ Costs)$$

4.3.4.2 Construction Costs

In similar fashion to the ROW costs for the AEHS, construction costs were derived primarily based on construction cost estimates for roadways of similar roadway geometry to the proposed truck-only lanes system. These construction costs primarily apply to roadways and bridges, and are again updated to 2011 dollar amounts using the CWCCIS. For 2008 and 2011, respectively, the construction cost coefficients are 727.11 and 747.60. Note that these are the same coefficients as those for land acquisition costs, most likely due to the fact that they are based on the same highway construction projects.

Another factor not accounted for in the estimate of construction costs for truck-only lanes is the cost of the additional infrastructure needed to supply motive power and communications to the AEHS. Only a few previous studies have made any attempt at quantifying these costs, and those which largely focused on the cost components of physical infrastructure itself, without accounting for the additional labor or technical expertise required for installation (Bolger & Kirsten, 1977), (Hall, 1996). Because the exact technical specifications of this system have not been determined, and because the additional infrastructure needed for the AEHS will be extensive and wholly integrated with the processes of paving, grading, and site preparation, a simple 50% AEHS contingency cost was added to the 2011 estimates of cost for the conventional highway construction. Thus, the final AEHS construction cost can be taken as:

$$(2011\ AEHS\ Construction\ Costs) = 1.5 * (Revised\ Truck\ Only\ Lane\ Construction\ Costs) \quad \textbf{(4.5)}$$

While this methodology is not particularly elegant or representative in any way of the specific corridor conditions, it will serve as a starting point for future revisions of the cost estimate. Additionally, the effects of varying the ITS contingency from anywhere between 25% and 100% of conventional highway construction costs will be examined via a sensitivity analysis presented in Chapter 5.

4.3.4.3 Operations & Maintenance Costs

The operations and maintenance (O&M) costs of conventional truck-only lanes are estimated to be $13 million per year, according to the Missouri DOT. These costs, in 2008 dollars, must be updated to 2011 prices to be used for the AEHS cost estimate. This can be accomplished via the CWCCIS by using the "Permanent Operating Equipment" cost category for a comparison between the 2008 and 2011 O&M costs. The cost factors for 2008 and 2011, respectively, are 731.03 and 766.37.

An additional component to the O&M costs must be included to account for those additional costs which arise as a result of the maintenance, repair, and replacement of ITS and electric transmission equipment along the AEHS. In similar fashion to estimating the AEHS construction costs, a 50% AEHS contingency cost will be added to the base O&M costs to account for this additional work. Also, varying the amount of this contingency along with that for construction costs will be explored in Chapter 5.

4.3.4.4 Capital Recovery

Capital recovery is concerned with the expected residual value of the AEHS and its infrastructure at the end of the 30-year lifecycle. Although not necessarily a cost, it is closely related in that is directly dependent on the initial construction costs and quality of the various infrastructure components. For the purposes of a BCA, the capital recovery "cost" is treated as a lump-sum positive cash flow in the final year of the project lifecycle, and is discounted to a present value accordingly.

This residual value of the AEHS is expected to vary between the various components of the system, and is based on similar residual value assumptions for the I-70 truck-only lanes project (with the exception of the ITS and Electric Transmission Components contingency cost). These expected residual values are given as (MODOT, 2009):

- Roadway: 0% of original value
- Bridges: 75% of original value
- Land: 100% of original value
- ITS and Electric Transmission Components: 50% of original value

These residual values are discounted to their present values by using a time period of 30 years (since they occur at the end of the analysis period), and the previously described discount rate.

4.3.5 Benefits

4.3.5.1 Travel Time Savings

Travel time cost refers to the time that users spend in their vehicles on the highway. For commercial vehicles, this cost is typically incurred directly by the business, since the drivers of commercial vehicles are sometimes paid an hourly rate; however, more often drivers are paid a certain amount per mile of travel. If a particular length of the trip is congested or otherwise takes longer to drive, that additional time cost becomes the driver's opportunity cost to drive another route with the same distance, but faster speeds. For personal vehicles, the travel time cost represents the occupants' opportunity cost to engage in other activities besides traveling to their intended destination. By reducing congestion and crashes on the I-70 corridor, the AEHS is projected to significantly reduce travel times of vehicles on the automated electric lanes, as well as the general purpose lanes. Besides decreasing the opportunity and business costs to users of the highway, this reduction in travel time can also result in lower vehicle operating costs, as described in Section 4.3.5.2. In order to estimate the travel time savings that would occur as a result of the AEHS, it was first necessary to determine the total delay that would occur for the "Without AEHS" scenario.

As discussed in chapter 3, the FAF data used in the economic analysis includes peak period link delay for the years 2007 and 2040. This value, estimated in terms of hours per vehicle using standard HCM 2000 methodological procedures, represents that total amount of time for daily peak hours that vehicles waste in traffic due to factors such as lane closures and congestion. In order to determine a total amount of travel time delay for each year of the analysis period, it was assumed that the delay for each individual highway segment would grow in a linear fashion from the base year of 2007 to the final year of the analysis, 2040; furthermore, several other key assumptions were made. First, it was assumed that the only travel time delay that would occur on any highway link would occur during the peak hour, and that delay would only occur on weekdays. Thus, for a typical week, the total amount of travel delay would equal:

$$Weekly\ Delay = Daily\ Peak\ Period\ Delay * 5\ Weekdays \qquad \textbf{(4.6)}$$

Second, it was assumed that the daily peak hour delay would not vary based on time of the year. As such, an estimate of the yearly travel delay for each highway segment can be calculated by multiplying the weekly delay by 52 weeks per year. This assumption may be moot, as it was thought that perhaps the delay values calculated in the FAF data were already adjusted for seasonal variance. However, attempts to contact the FHWA Freight Management & Operations office for more information about this factor were unsuccessful.

Once a total peak hour travel delay was calculated for each year, it was allocated to passenger cars and commercial trucks based on the proportionate AADT and AADTT of the specific highway segment; that is, if passenger cars comprised 70% of the AADT on a specific highway link, it was assumed that they would incur 70% of the total link delay. Next, the delay was reduced for each vehicle type in proportion to the demand rate for the AEHS in the given year. For example, in the year 2040, when the AEHS demand rate is at 90%, approximately 90% of the total peak hour delay is eliminated.

Finally, once the total amount of delay reduction for each year was computed, it was necessary to assign a monetary value to this reduction. In order to accomplish this, the US DOT planning document, titled "Valuation of Travel Time in Economic Analysis" was consulted to provide values of time for passenger vehicles and commercial trucks. It was determined that the value of time for all passenger cars, including both business and leisure trip purposes, was $18.58 per hour, while the value of time for commercial trucks was $24.46. These values are for the year 2011; for subsequent years, they are assumed to increase by 1.6% annually for expected income growth, according to a directive from the Congressional Budget Office for using these values in economic analyses (U.S. DOT, 2011).

4.3.5.2 Vehicle Operating Cost Savings

Total vehicle operating cost (VOC) savings were also considered as one of the benefits of the AEHS. For the economic analysis, it was determined that savings in fuel costs would comprise the majority of operating costs savings; additional costs such as insurance and labor are not expected to change significantly between the two scenarios. This cost savings is two-fold, in that fuel costs of trucks which utilize the AEHS will decrease when switching to an electric motive power source, and vehicles on the general purpose lanes will save fuel due to the aforementioned decrease in total delay. In order to estimate the reduction in total fuel costs due to delay, following methodology from AASHTO (2003) is considered:

$$change\ in\ fuel\ VOC = g(D_0 - D_1)p \tag{4.7}$$

Where g represents the fuel consumption in gallons per minute of delay, D_0-D_1 equals the total change in delay (described in Section 4.3.5.1), and p equals the price of fuel. The AASHTO values used for fuel consumption in gallons per minute of delay are denoted in Table 4-2. Retail diesel and gasoline fuel prices were estimated based on data from the Energy Information Administration (EIA, 2011).

Table 4-2 - Fuel Consumption in Gallons per Minute of Delay by Fuel Type. Source: AASHTO (2003)

Highway Link Speed (mph)	*Large Automobile*	*Single-Unit Truck*	*Multi-Unit Truck*
50	0.048	0.235	0.453
55	0.054	0.266	0.495

60	0.060	0.297	0.537
65	0.066	0.328	0.578
70	0.073	0.360	0.620
75	0.080	0.392	0.661

The other principle component of VOC savings comes from trucks changing from diesel fuel to electricity for motive power. An estimate for truck fuel costs of 21.41 cents per mile was determined from Barnes and Langworthy (2003). By comparison, studies estimate that a commercial truck operating under electric motive power would consume approximately 1.5 kilowatt-hours of electricity per mile. At a price of ten cents per kilowatt-hour, this is cost per mile of 15 cents, and is significantly less than the operating cost for diesel fuel. The cost savings based on this information was determined by summing the diesel fuel and electricity operating costs across all commercial truck VMT that is predicted to use the general purpose lanes and the AEHS for all years.

4.3.5.3 Crash Savings

Another direct user benefit of the AEHS is the expected reduction in crashes that will occur along the I-70 corridor. In general, one way in which the crash reduction along a corridor can be determined is by looking at the crash history of the corridor in order to determine a crash rate for different vehicle types. Then, based on predetermined crash modification factors (CMFs), which consider the local conditions surrounding a safety improvement, along with the expected crash reduction of the safety improvement based on a survey of similar projects, the total estimated reduction in crashes can be determined.

With the AEHS project along the I-70 corridor, crash modification factors could not be determined, since no similar project exists to serve as a source for estimating the CMF. As such, it was assumed that the decrease in total truck traffic crash exposure would serve as a direct surrogate measure of the total expected reduction in crashes as a result of the AEHS implementation. To accomplish this, crash rates, and proportion of crashes by severity (fatal, injury, and property-damage only), were utilized with the previously calculated estimates of total truck VMT from FAF data in order to determine the expected total number of truck crashes for each year of the analysis period. These crash rates and proportions were originally developed by the Missouri DOT based on historical crash information along the I-70 corridor. Once the expected number of crashes involving trucks was calculated, these crashes were removed from the system at the same rate as that for demand of the AEHS; for example, if the demand rate for the AEHS is 90% of all trucks, the total number of crashes on the corridor is expected to decrease by 90% of total truck crashes calculated for that year.

Once the total number of crash reductions was determined, in terms of magnitude and severity type, the savings was converted to a monetary form. To do this, per-crash injury values were determined with guidance from the AASHTO Standing Committee on Highway Traffic Safety's recently published report on fatal and non-fatal injury crash costs (AASHTO, 2011). Table 4-3 shows the values that were used for each type of crash severity:

Table 4-3 Comprehensive Unit Crash Costs by Severity. Source: AASHTO, 2009

Crash Severity	*Comprehensive Cost*
K (Fatal)	$6,460,726
A (Injury)	$285,309
O (Property Damage Only)	$7,962

4.3.5.4 Emissions Reductions

In order to estimate the emissions and energy use savings that would occur as a result of the AEHS implementation on the I-70 corridor, two scenarios were run using the MOVES software, each consisting of a 30-year analysis period, from 2011 to 2040. These scenarios are termed "Without AEHS" for the base case situation, and "With AEHS" for the situation in which the AEHS is constructed. The 30-year analysis period was selected because of the availability of the FAF database and MOVES data sources. Other assumptions inherent to this analysis are described below.

4.3.5.4.1 Pollutant Selection

A standard list of criteria pollutants, as defined by the EPA, was evaluated. This list includes carbon monoxide, nitrogen dioxide, sulfur dioxide, particulate matter at the 10- and 2.5-micron levels, and ozone (U.S. EPA, 2002). However, because ozone could not be directly estimated within MOVES, its constituent pollutants, namely oxides of nitrogen and volatile organic compounds, were considered instead.

Changes in fuel use were estimated by considering those fuel types derived from fossil fuel sources – namely, gasoline and diesel. MOVES is unable to account explicitly for either individual fuel type, but rather estimates differences in "fossil fuel use" between the "Without AEHS" and "With AEHS" scenarios. It is expected that, compared to the base case, gasoline use would increase as a result of growth of passenger car VMT on the general purpose highway lanes, while diesel fuel use would decrease, due to a growing amount of VMT from long-haul commercial trucks on the AEHS. Whether these a priori expectations would hold true will be discussed in the results section.

4.3.5.4.2 Setting up the Data in MOVES

Once all of the relevant data sets have been identified and prepared, they can be entered into the MOVES software program for emissions modeling. For those unfamiliar with the MOVES modeling process, the U.S. EPA offers a large number of technical resources and training information at their website. Because the I-70 corridor spans multiple counties, and because modeling at the year level was desired, the decision was made to use a custom county domain within MOVES. Based on this, the County Data Manager was used to import all of the necessary data into the model; once this was completed, the "Generate XML Importer" tool was used to create an XML file of all of the necessary database inputs. This file is useful for quickly generating input databases for additional years, where the same files are used for each year, but incremental changes within the files themselves are required.

Once the input database and model parameters were completed for the base year (2011), and all of the input and output databases were created for subsequent analysis years, the Multiple RunSpec creator tool was used in order to generate a command file for the 30-year analysis period. This command file serves as a guide for reading the correct inputs and outputs for each analysis year, and from this file, a list of run specifications (the actual files that MOVES uses to describe each analysis year) was generated. Additionally, a BAT file was generated by the Multiple RunSpec creator, which allows the software program to automatically run each specification file in succession when clicked; based on an analysis period of 30 years, and with limited available computing resources, each scenario took approximately 2 hours to run. This "batch mode" within MOVES is visualized in Figure 4-3.

In order to generate the input database needed for each year of the analysis, additional steps (which are not adequately described in the MOVES User Manual) are required. These

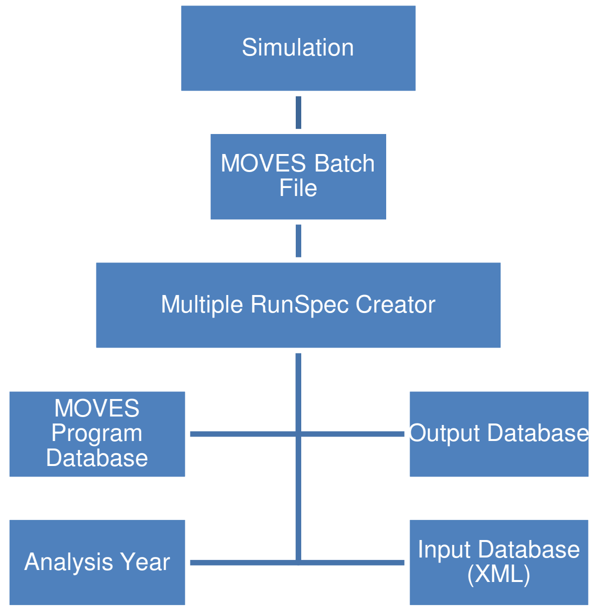

Figure 4-3 MOVES Multiple RunSpec Simulation Hierarchy

steps are displayed in Figure 4-4, and can be referenced from a 2010 Webinar sponsored by the EPA Office of Transportation and Air Quality titled "MOVES Batch Mode: Setting up and running groups of related MOVES run specifications". The most important component of the multiple input database generation is the syntax for the Java command that is used in the command prompt to transform the XML files into usable databases. This command,

Java –Xmx512M gov.epa.otaq.moves.master.commandline.MOVESCommandLine –I MYFILE.xml

where *MYFILE* is the name of the Data Manager XML file for the selected year, is listed incorrectly in the user's manual. Additionally, several extraneous error messages are displayed at this stage of the database generation process. According to the MOVES Supplementary Technical Guidance, these messages can be ignored.

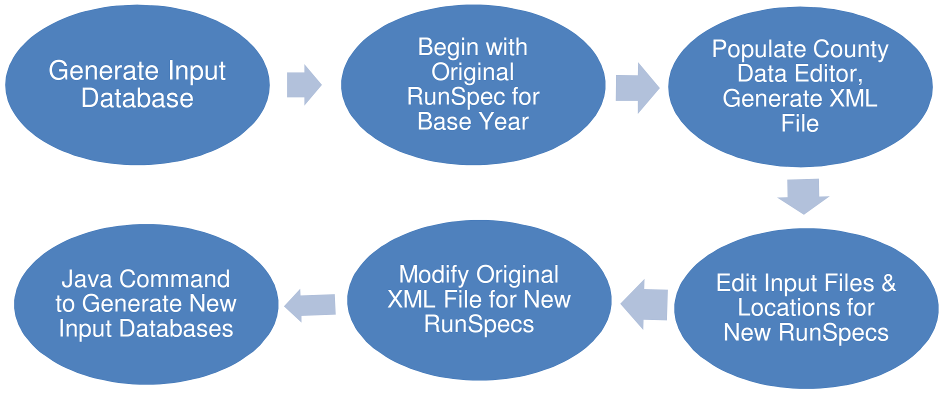

Figure 4-4 Generating Multiple Input Databases in MOVES

4.3.5.4.3 Monetizing Emissions

Once the modeling process is complete in MOVES, the output emissions inventories must be monetized for use in the BCA. The technical guidance that accompanies the FHWA's Highway Economic Requirements System – State Version (HERS-ST) includes values for the various pollutant types (FHWA, 2011). These values are listed in Table 4-4.

Table 4-4 Air Pollutant Damage Costs and Adjustment Factors Used in HERS (2000 $)

Pollutant	*Damage Cost ($/ton)*	*Adjustment Factor*	
		Urban	*Rural*
Carbon Monoxide	$100	1.0	0.5
Volatile Organic Compounds	$2,750	1.5	1.0
Nitrogen Oxides	$3,625	1.5	1.0
Sulfur Dioxides	$8,400	1.5	1.0
Fine Particulate Matter (PM2.5)	$4,825	1.0	0.5

Because the cost values are in 2000 dollars, they were first converted to 2011 dollars by using the Consumer Price Index (Williamson, 2008). Also note that each pollutant type includes an urban and rural adjustment factor. The HERS-ST model recommends these adjustment factors to account for different population densities in these areas; because the pollutants considered in this analysis are local pollutants, there will be a more significant cost per ton in urban areas than rural areas, due to the greater number of people living in proximity to the highway in the former area. These factors were combined into a single weighted factor by using the relative proportions of urban and rural link length from the FAF data.

Chapter 5 Results & Discussion

This chapter will present the results of the economic analysis for the AEHS along the I-70 corridor, including a breakdown of the total costs and benefits associated with the project, with a discussion of the figures for the Benefit/Cost Ratio and Net Present Value. It will also include the details of several sensitivity analyses which were conducted, and provides a detailed description of the various pollutant trends which were modeled.

5.1 Total Costs

Table 5-1 shows the total present value of costs derived for the AEHS. The largest total cost, by far, is the initial capital investment needed to construct the physical infrastructure of the AEHS. This is to be expected, since the construction phase of any roadway project typically consumes the greatest amount of materials, labor-hours, and design work. The novelty of AEHS and unfamiliarity with construction and design techniques needed to ensure the functionality of unique system components, this effect is expected to be even more profound than with ordinary highway construction. Also note that the salvage costs in this case are negative; this is indicative of the expectation of additional revenue potential from the components of the AEHS at the end of the 30-year analysis period. This potential can either be in the form of revenues from recycling scrap materials, such as worn-out ITS components, or in the continued productivity of the infrastructure components for their intended purpose. The latter is the case especially with the bridges along the corridor, whose design life is assumed to be far in excess of the 30-year analysis period.

Note that within the sub-categories which comprise the total initial capital costs, the cost of the ITS components to be implemented along the AEHS is second in value only to the construction of the roadway itself. Because the cost of the ITS components associated with the AEHS is projected to be so large (assumed $1.7 billion initially, or approximately 50% of base construction and O&M costs), and because so little data exists in order to properly determine a valuation for these items, it was desired to see what effect varying the cost of the ITS infrastructure would have on the final results of the BCA. This impact will be addressed via a sensitivity analysis, discussed in Section 5.3.2.

Table 5-1 Present Value of Cost Differences Between "Without AEHS" and "With AEHS" Scenarios

Cost Item	*Present Value ($ million)*
Capital Costs	
ROW Costs	1034.52
Construction Costs	2111.27
Bridge Costs	554.21
ITS Costs	1850.00
Total Capital Costs	5550.01
Total O&M Costs	435.23
Salvage Costs	(1,228.30)
Total Costs	4756.94

By adding the present values of the costs associated with the initial AEHS construction, as well as the operations and maintenance, one arrives at a total present value for the AEHS of approximately $5.99 billion. Since the values here are in relation to total costs, this represents a deficit of $5.99 billion for the project. With the addition of the positive value of the infrastructure components at the end of the analysis period in the form of salvage, the total present value of costs is revised downwards to $4.75 billion.

5.2 Total Benefits

Table 5-2 shows the total present value of benefits derived for the AEHS, as detailed in Chapter 4. The largest total benefit, by far, is from the reduction in user operating costs associated with a decrease in total fuel costs once the AEHS is in place. This is somewhat expected, due to the fact that user operating costs are being curtailed on two levels; for one, users of the AEHS are realizing significant saving in fuel costs by utilizing electric motive power, which on a per-mile basis is substantially less expensive than diesel fuel. Also, users which continue to operate on the conventional lanes are realizing fuel savings from the decrease in delay, due to the removal of commercial truck traffic to the AEHS.

Note that compared to the rest of the benefits categories, the total effect of emissions reductions on the AEHS is significantly smaller; there are several reasons for this. First, as discussed in Chapter 4, emissions reductions are typically considered as a public benefit, or externality. Because their cost (or savings, in the case of evaluating the reductions in emissions) is not typically accounted for by any single firm, it is inherently difficult to determine the true cost to the general population. While the values used for monetizing the emissions reductions in this analysis are based on years of research from the FHWA and other public and private entities, the process of assessing and valuating the full extent of effects from pollutants is still ongoing; as such, it is likely that these pollutant costs will continue to be revised upwards in the future, which will result in even greater benefits for the AEHS. Second, although a significant amount of commercial truck VMT will move to the AEHS, there still remains a large amount of growth that will occur on the conventional lanes, in the form of passenger vehicles and short-haul commercial trucks. The increased pollution from this additional traffic will offset some of the gains made by the AEHS, and will be detailed in Section 5.4. By adding the present values of the incremental benefits associated with the AEHS, one arrives at a total present value for benefits of approximately $7.17 billion.

Table 5-2 Present Value of Benefit Differences Between "Without AEHS" and "With AEHS" Scenarios

Benefit	*Present Value ($ Million)*
Travel Time Savings	1,816.8
Crash Reductions	833.4
Operating Cost Savings	4,367.5
Emissions Reductions	154.7
Total Benefits	7,172.4

5.3 Benefit-Cost Analysis

Table 5-3 shows a summary of the present values of the total incremental costs and benefits associated with the AEHS, along with the results of computing the BCR and NPV from these values. The details of these calculations can be found in Section 4.2.6.

Table 5-3 Benefit/Cost Ratio and Net Present Value for AEHS

Present Value of Benefits	$7,172,400,000
Present Value of Costs	$4,756,900,000
Benefit/Cost Ratio	1.51
Net Present Value	$2,415,500,000

5.3.1 Net Present Value and Benefit/Cost Ratio

By dividing the total present value of benefits by the total present value of costs for the AEHS, one arrives at a BCR of 1.51. This indicates that the total benefits are approximately 1.5 times as much as the total costs, and since the value is higher than 1, suggests that the AEHS project is economically feasible to pursue.

Similarly, by subtracting the total present value of costs from the total present value of benefits for the AEHS, one arrives at a NPV of approximately $2.4 billion. This indicates the dollar amount by which total benefits exceed total costs, and again suggests that the project is economically feasible to pursue.

5.3.2 Sensitivity Analysis

The novelty of the AEHS implies a great deal of uncertainty with respect to the final estimates of total costs and benefits. This uncertainty manifests itself in all levels of the estimation of costs and benefits, but is evident in some areas more so than others. In particular, the demand rate for the AEHS and the cost of the ITS components of the AEHS were identified as the two biggest sources of uncertainty in the economic analysis, based on the limited historical data and methodology available on which to base these calculations. Various sensitivity analyses regarding the economic feasibility of the AEHS with respect to fluctuations in these areas were conducted, and the results reported below.

5.3.2.1 ITS Cost Variability

The estimated cost for the ITS components of the AEHS, both in initial capital outlay, as well as in operations and maintenance, was perceived as one of the most significant factors that would affect the estimates of economic feasibility for the AEHS. A sensitivity analysis was performed in order to quantify the variability of the BCR and NPV with respect to these cost estimates. In the initial economic analysis for the AEHS, it was assumed that ITS capital costs would be computed by multiplying the total value of the construction cost for the conventional highway components by 50%, and that ITS O&M costs would be equal to 50%

of the O&M costs for conventional components of the AEHS. The sensitivity analysis considered scenarios in which this 50% contingency was changed to 25%, 75%, and 100%, which would effectively change the total ITS costs by -50%, 50%, and 100%, respectively, from the original estimates.

The results in Table 5-4 present the percentage differences in the components of the economic analysis for the original AEHS scenario and the modified scenarios. These results show that over the 30-year analysis period, a 50% reduction in ITS costs for the AEHS from the original estimate would result in a 19% increase in the final project BCR and a 32% increase in the final project NPV. A 50% increase in ITS costs for the AEHS would result in a 13% decrease in the final project BCR and a 30% decrease in the final project NPV. A 100% increase in ITS costs for the AEHS would result in a 23% decrease in the final project BCR and a 61% decrease in the final project NPV. Note that changing ITS costs do not affect the user benefits in any way; thus for all scenarios, the total present value of benefits for the AEHS is expected to remain the same. Additionally, for all scenarios, even the one in which ITS costs are double the original estimate, the project still remains modestly economically feasible, based on positive values for the NPV and BCR estimates greater than 1.

It appears that for all of the scenarios considered in this sensitivity analysis, the various components of the total project costs are approximately equally affected. It also appears that in all cases the percentage change in the economic analysis measures (BCR and NPV) is less than that of the percent change in ITS costs; thus, while the NPV and BCR of the AEHS are sensitive to changes in the cost of the ITS components, they are inelastic with respect to these changes.

Table 5-4 ITS Cost Variation – Sensitivity Analysis Results

		Present Value ($ million) & Change from Base AEHS Scenario					
		Reduce ITS 50%		Increase ITS 50%		Increase ITS 100%	
Benefits	Travel Time Savings	1,816.8	0%	1,816.8	0%	1,816.8	0%
	Crash Reductions	833.4	0%	833.4	0%	833.4	0%
	Operating Cost Savings	4,367.5	0%	4,367.5	0%	4,367.5	0%
	Emissions Reductions	154.7	0%	154.7	0%	154.7	0%
	Total Benefits	7,172.4	0%	7,172.4	0%	7,172.4	0%
Costs	Capital Costs	4,625.0	-16.7%	6,475.0	16.7%	7,400.0	33.3%
	O&M Costs	343.2	-21.1%	480.4	10.4%	549.0	26.1%
	Salvage Costs	(989.1)	19.5%	(1,467)	-19.4%	(1,706.7)	-38.9%
	Total Costs	3,979.0	-16.4%	5,488.0	15.4%	6,242.4	23.8%
Benefit/Cost Ratio		1.80	19.2%	1.31	-13.2%	1.15	-23.4%
Net Present Value		3,193.4	32.2%	1,684.5	-30.3%	930.0	-61.5%

5.3.2.2 AEHS Demand Rate Uncertainty

The estimated demand rate for the AEHS was perceived as another significant factor that would affect the estimates for the system's economic feasibility. A sensitivity analysis was performed in order to quantify the variability of the BCR and NPV with respect to this demand estimate. Specifically, the total truck VMT that was estimated to use the AEHS during the entire analysis period was reduced by 10%, assuming those vehicles would instead remain on the general purpose highway lanes.

The results in Table 5-5 show that over the 30-year analysis period, a 10% reduction in AEHS VMT would result in a 5% decrease in the final project BCR, compared to the original AEHS scenario, and a 14% decrease in the final project NPV. Note that changing

AEHS demand rates do not affect the project costs in any way; thus for all scenarios, the total value of costs for the AEHS is expected to remain the same. Additionally, for the revised AEHS demand rate, despite the decrease in the BCR and NPV, the project still remains economically feasible.

It appears that for a 10% reduction in the AEHS demand rate, the various components of the total project benefits are approximately equally affected, with the exception of crash savings. Because total crash reductions are computed solely on the basis of Missouri DOT crash rates derived from commercial truck VMT, by reducing the VMT on the AEHS by 10% for all years, it is logical that the estimate of crash reductions would also decrease by 10%. It also appears that in the case of a 10% reduction in AEHS demand, the percentage change in the economic analysis measures (BCR and NPV) is less than that of the percentage change in the demand rate; thus, while the NPV and BCR of the AEHS are sensitive to changes in the estimates of AEHS demand, they are inelastic with respect to these changes.

Table 5-5 AEHS Demand Rate Variation – Sensitivity Analysis Results

	Present Value ($ million) & Change from Base AEHS Scenario		
Benefits	*Travel Time Savings*	1,736.5	-4.4%
	Crash Reductions	750.1	-10.0%
	Operating Cost Savings	4,174.8	-4.4%
	Emissions Reductions	145.6	-5.9%
	Total Benefits	6,806.9	-5.1%
Costs	*Capital Costs*	5,550.0	0%
	O&M Costs	435.2	0%
	Salvage Costs	(1,228.3)	0%
	Total Costs	4,756.9	0%

Benefit/Cost Ratio	1.43	-5.3%
Net Present Value	2,057.2	-14.8%

Figure 5-1 and Figure 5-2 provide a more graphical means of visualizing the changes in the BCR and NPV of the AEHS project with respect to a 10% reduction in AEHS demand from the original scenario. In Figure 5-1, the total costs of the project are plotted on the horizontal axis, while the total benefits of the project are plotted along the vertical axis. For each project scenario, a point is placed at the intersection of the total costs and benefits; from this point, a line is drawn back to the origin, and from basic algebraic theory, an equation for this line can be computed. Because of the way in which benefits and costs are presented in the figure, the slope of the line for each project scenario is equal to that scenario's BCR. Thus, in the case of the AEHS project, the slope of the line in Figure 5-1 indicates the total BCR of each AEHS project scenario; "With AEHS" represents the original AEHS project scenario, while "With AEHS – 10% Demand Reduction" represents the alternative project scenario in which AEHS demand is forecasted to be 10% lower than initial estimates. The "Threshold Line" represents the scenario for which the line slope indicates a BCR of 1. At this point, the total benefits and costs are equal, and the project is neither economically favorable nor unfavorable. Since both project scenario lines have a slope greater than the threshold line, both alternatives have a BCR greater than 1, and are thus economically favorably to pursue.

In a somewhat analogous manner, in Figure 5-2, the total costs and benefits are plotted on the horizontal and vertical axes, respectively. Again, for each project scenario, a point is marked at the intersection of the total costs and benefits. From this point, a line with a positive (from left to right) slope of 1 is extended back to the vertical axis. The point at which this line crosses the vertical axis, often denoted as the y-intercept, represent the NPV for that project scenario. The "With AEHS" line represents the original AEHS project scenario, while "With AEHS – 10% Demand Reduction" represents the alternative project scenario in which AEHS demand is forecasted to be 10% lower than initial estimates. The "Threshold Line" represents the scenario for which the y-intercept of 0 indicates a NPV of 0 as well; at this point, the total benefits and costs are equal, and the project is neither economically favorable nor unfavorable. In the case of the AEHS project, the y-intercepts of the lines in Figure 5-2 indicate that the total NPV of each AEHS alternative is greater than 0. Since both lines have a y-intercept greater than the threshold line, both alternatives are economically favorable to pursue.

While the interpretation of Figures 5-1 and 5-2 may present some initial confusion to the reader, the graphical method of presenting BCR and NPV is recognized in many public and private agencies as a standard practice for reporting the results of an economic analysis, and can provide an even greater level of utility when a large number of project scenarios are being considered (CalTrans, 2007), (Konings, Priemus, & Nijkamp, 2005); in such cases, the use of tabular methods would most likely convolute the results.

5.4 MOVES Analysis

For the results of the analysis performed in MOVES, the output is shown in the context of the general purpose highway lanes on the I-70 corridor. This was done in order to give a more accurate portrayal of the "before and after" conditions along the corridor as a result of the AEHS.

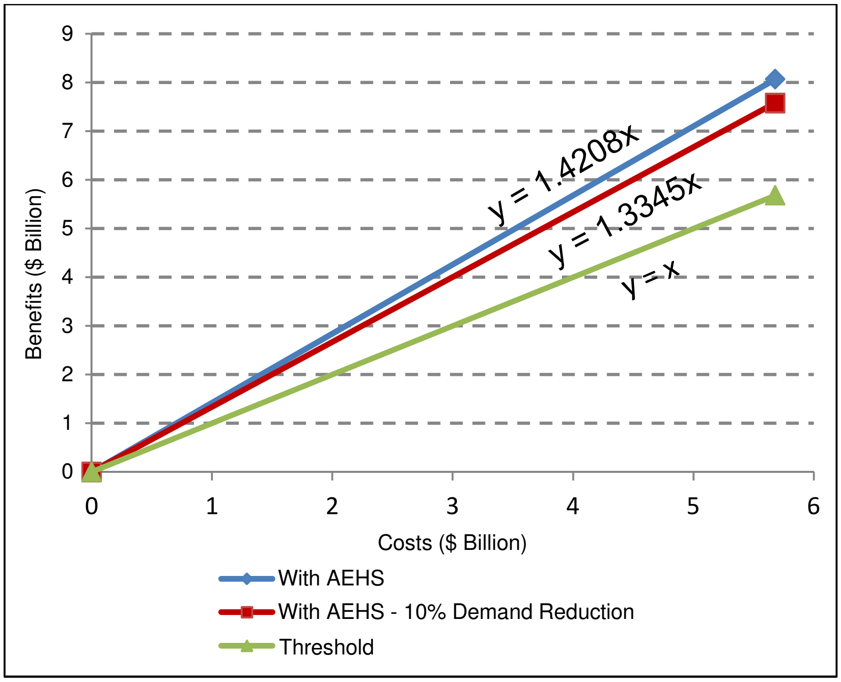

Figure 5-1 Comparison of Benefit/Cost Ratios (BCR) between Original AEHS Scenario & AEHS with Reduced Demand. The Slope of Each Line Indicates Its BCR.

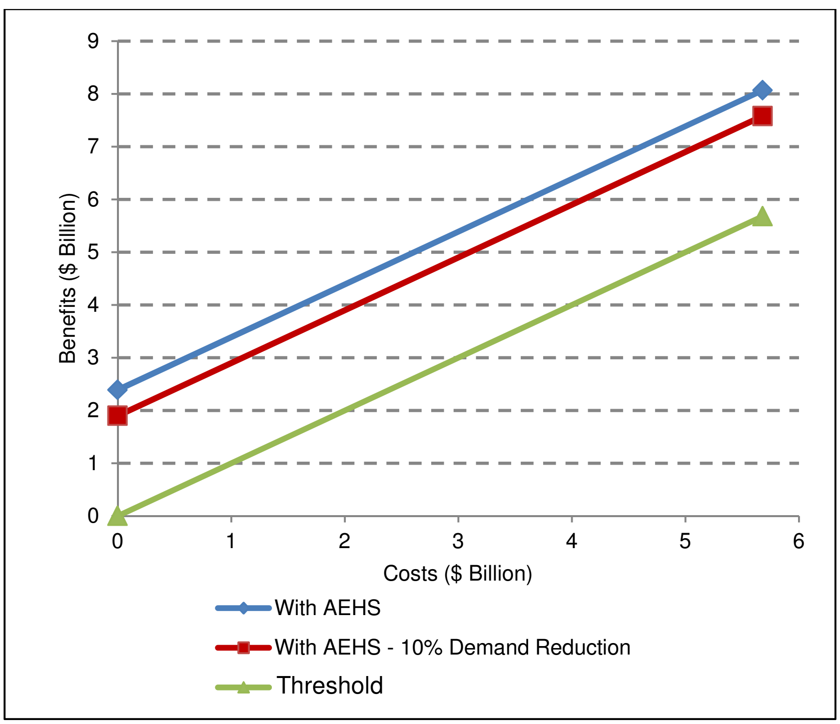

Figure 5-2 Comparison of Net Present Value (NPV) between Original AEHS Scenario & AEHS with Reduced Demand. The Y-Intercept of Each Line Indicates Its NPV.

5.4.1 Estimates of Changes in VMT, Energy Use, and Individual Pollutants

Figure 5-3 shows the expected change in VMT in response to the implementation of the AEHS, while Figure 5-4 shows the associated decrease in fossil fuel consumption on the I-70 corridor. In contrast with a steady increase in VMT in the "Without AEHS" scenario, the implementation of the AEHS would result in a zero growth of VMT for the first 20 years of the system implementation, followed by a noticeable downward trend. This can be partially explained in that towards the beginning of the "With AEHS" scenario, VMT growth from passenger vehicles and short-haul trucks is offset by a loss in VMT from long-haul trucks moving to the AEHS. Later on, as the adoption rate of AEHS increases, the long-haul truck VMT decreases on the general purpose lanes even more rapidly, that results in a net loss of VMT on these lanes.

Also note that the predicted decrease in fuel use is larger than the decrease in VMT; this is due to the fact that, under the "With AEHS" scenario, combination-unit long-haul truck VMT reduced significantly on the general purpose lanes. Because these vehicles consume a larger amount of fuel due to their size and weight than their relative contribution to total VMT, the reduction in energy use is likewise of a greater proportion than that of VMT. Furthermore, based on this reduction in VMT and fuel use over the lifetime of the AEHS, it is expected that total emissions and energy use would also decrease on some order of magnitude. The amounts and patterns of these factors are discussed next.

Figure 5-5 through Figure 5-11 show the predicted changes in emissions in the "With AEHS" scenario. Specifically, the figures show large decreases in pollutant levels for oxides of nitrogen (including nitrogen dioxides), particulate matter, and sulfur dioxide, and smaller decreases for carbon monoxide and volatile organic compounds.

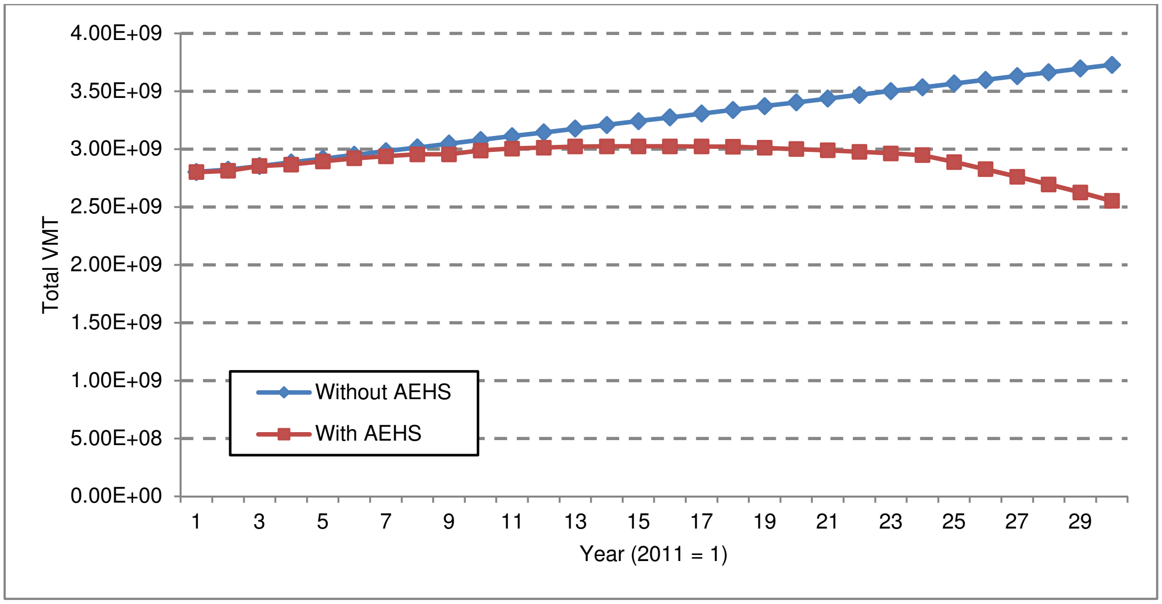

Figure 5-3 Comparison of VMT on Conventional Highway Lanes: With & Without AEHS

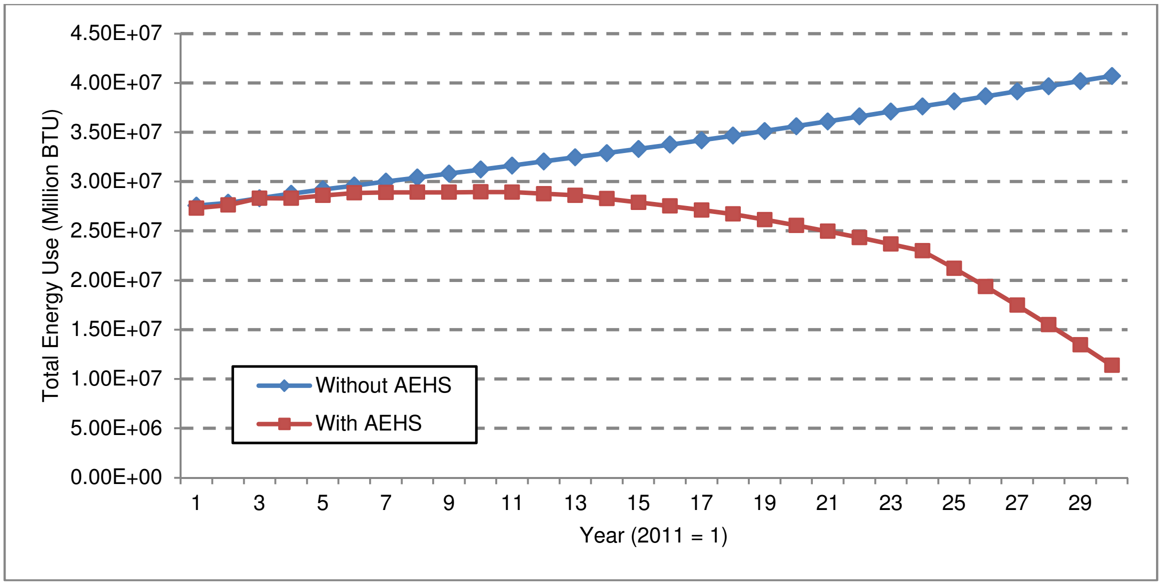

Figure 5-4 - Comparison of Petroleum Fuel Usage: With & Without AEHS

It is noteworthy to comment first on the trends of the emissions patterns for the "Without AEHS" scenario. In nearly all cases, the pollutant curves appear to follow a parabolic trend, and ultimately end at a lower point than the beginning year of the analysis. Even without AEHS, the total amount of each emissions type is expected to decrease by a

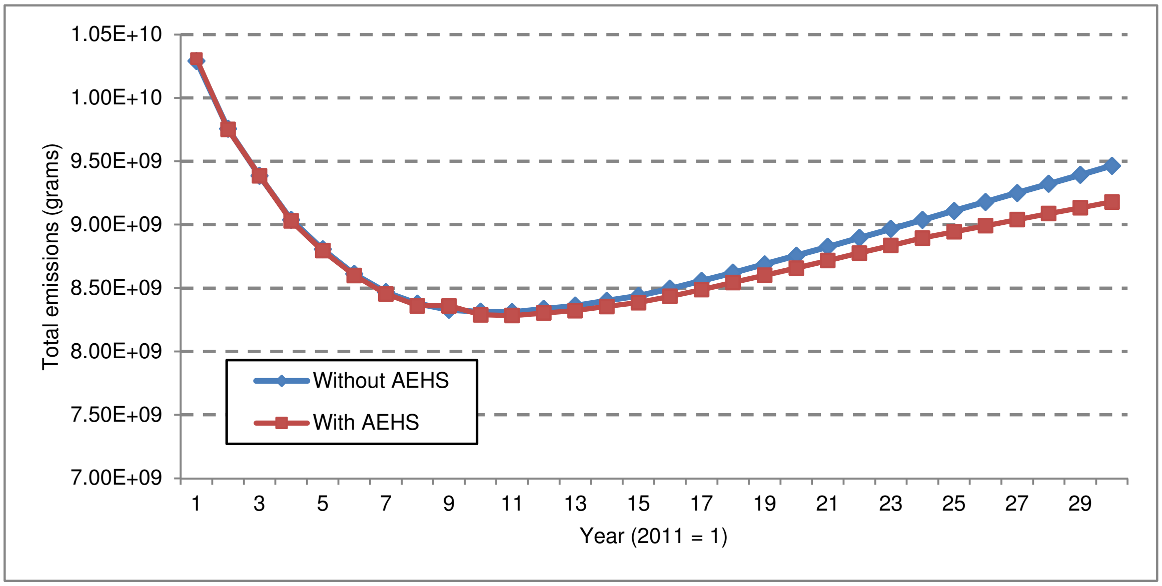

Figure 5-5 - Comparison of Carbon Monoxide Emissions: With & Without AEHS

significant amount in the coming decades, as a result of continued improvements in fuel economy and engine operation. That said, sulfur dioxide emissions (Figure 5-11) seem to follow a different trend, a markedly steady increase, which suggests that additional major improvements in diesel engine efficiency, the primary contributor to sulfur dioxide, are not expected. However, this may also indicate that MOVES does not adequately account for recent mandates regarding ultra-low sulfur diesel fuel, or some other environmental factors which in reality may serve to reduce sulfur dioxide emissions below what MOVES has predicted. Interestingly, for the remaining pollutants, the trends of the emissions are such that they eventually begin to increase again, albeit at a smaller rate than the initial decrease. This

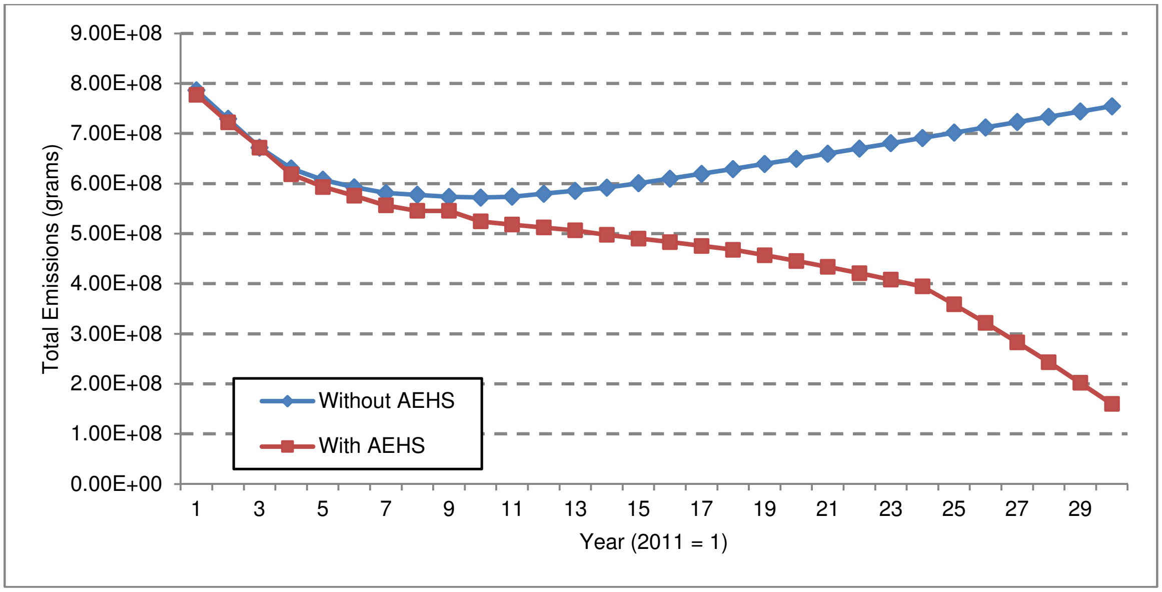

Figure 5-6 - Comparison of Nitrogen Dioxide Emissions: With & Without AEHS

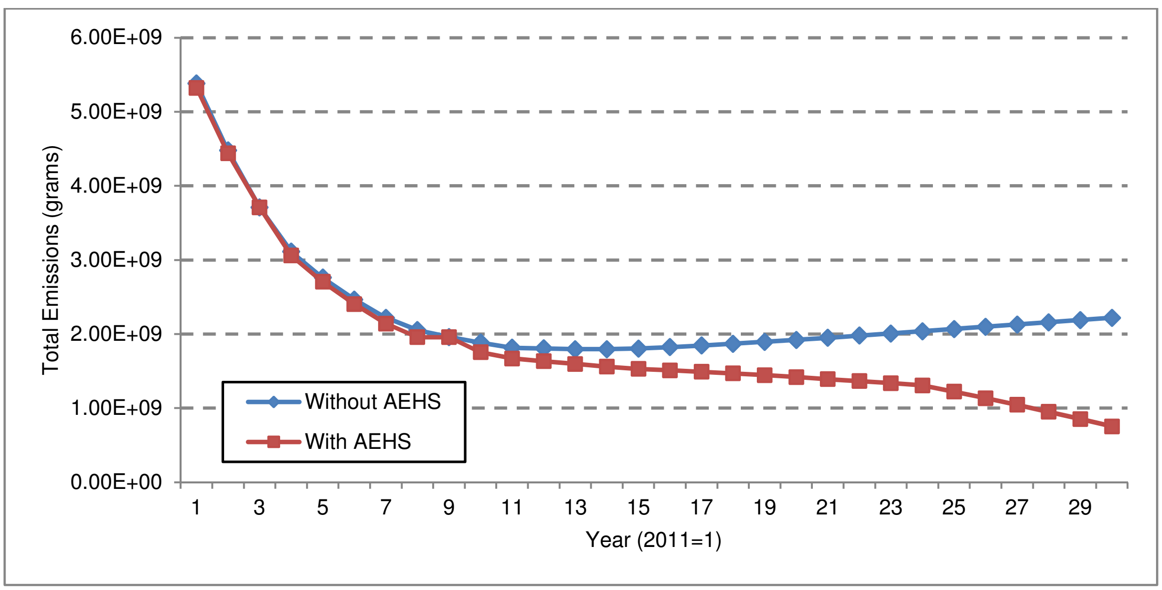

Figure 5-7 - Comparison of Oxides of Nitrogen Emissions: With & Without AEHS

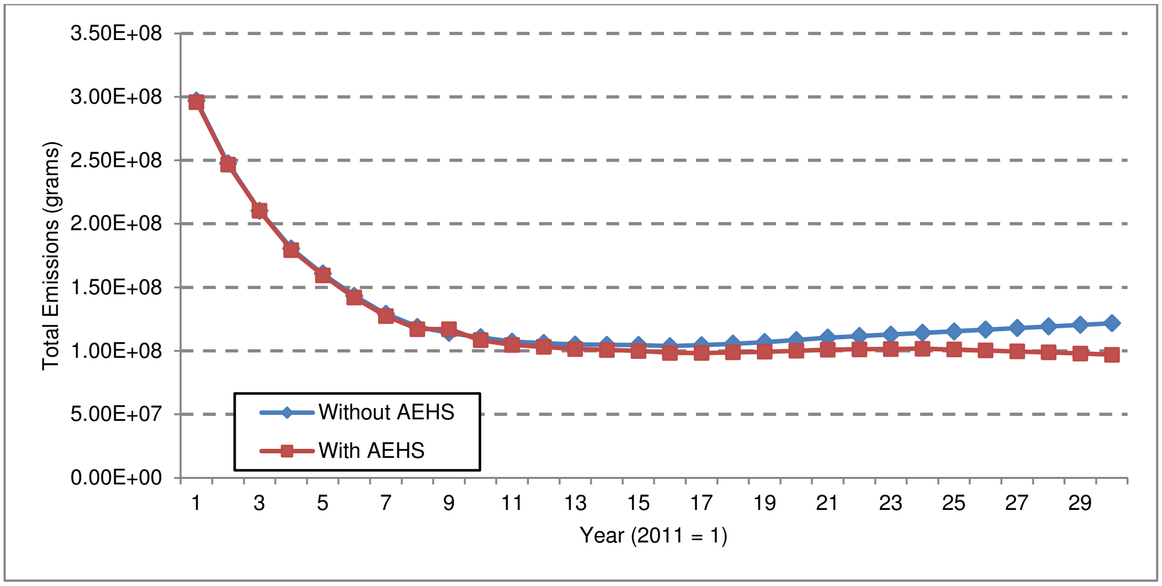

Figure 5-8 - Comparison of Volatile Organic Compounds Emissions: With & Without AEHS

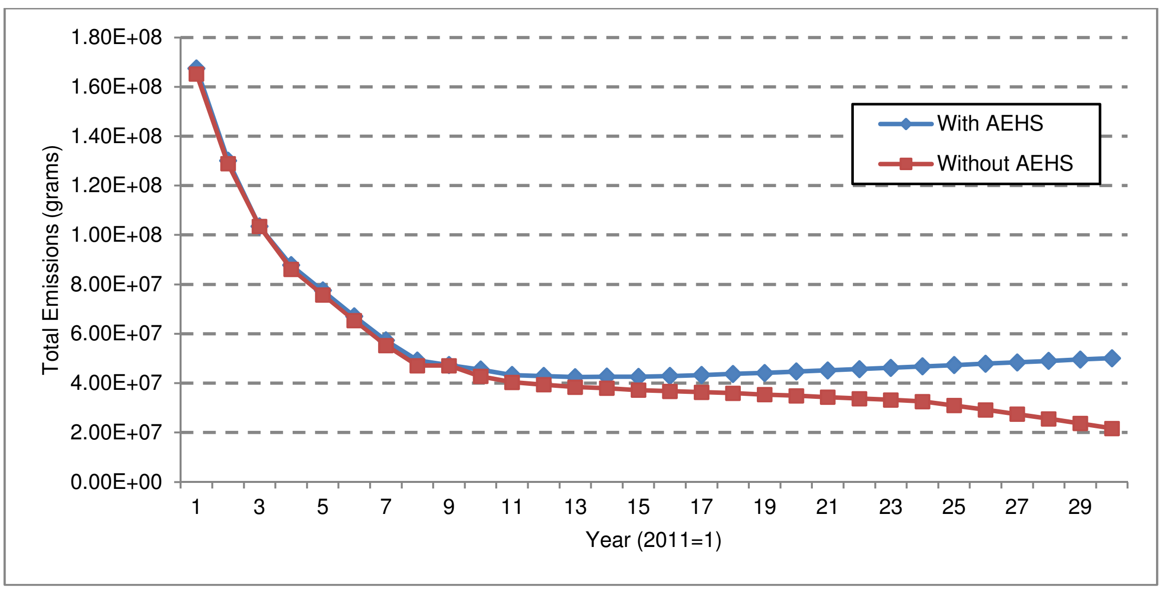

Figure 5-9 - Comparison of PM10 Emissions: With & Without AEHS

pattern can most likely be explained by the fact that while individual vehicles become less polluting over time, the magnitude of the increase in total vehicle population and VMT is such that there is still a total increase in levels of pollutants from 2011 levels.

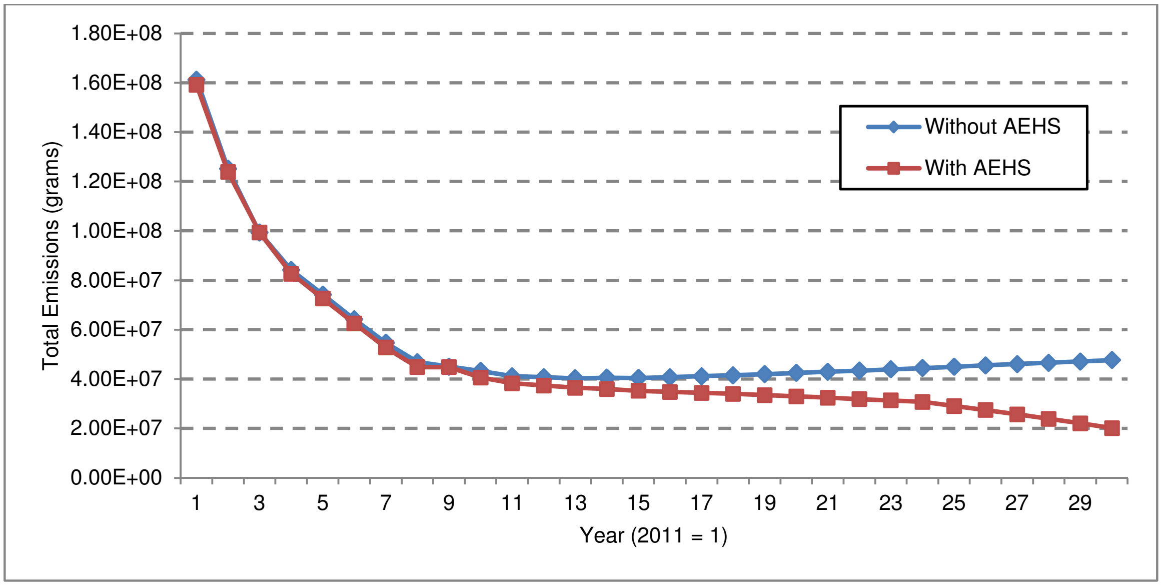

Figure 5-10 - Comparison of PM2.5 Emissions: With & Without AEHS

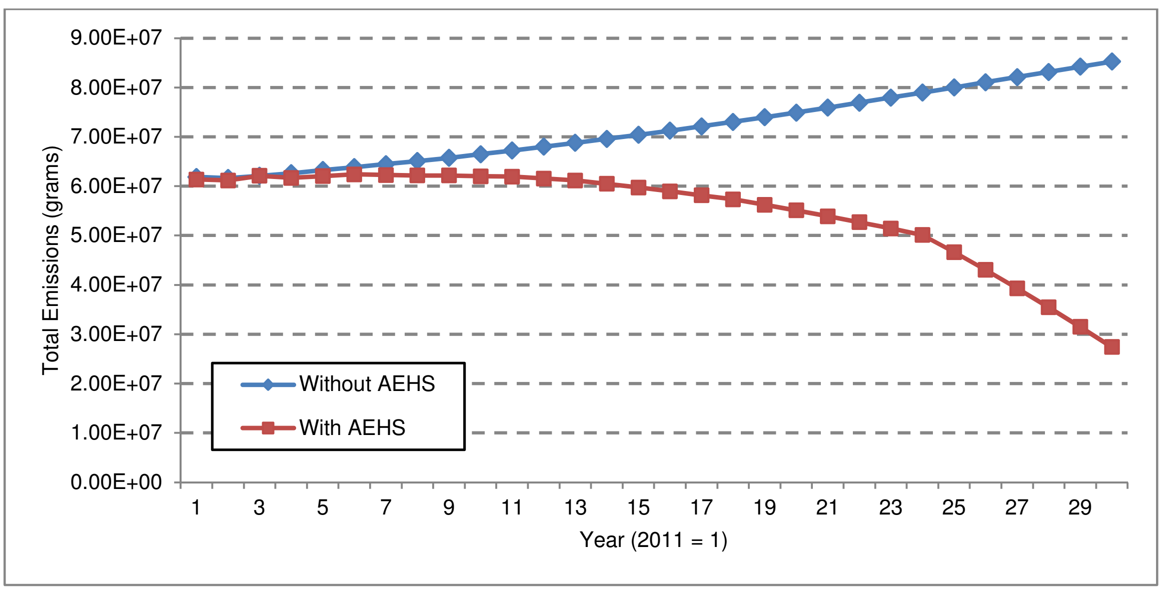

Figure 5-11 - Comparison of Sulfur Dioxide Emissions: With & Without AEHS

Turning to the "With AEHS" emissions results, it appears that carbon monoxide and volatile organic compounds are very close to their base case levels. This may be attributed to the fact that gasoline engines are the primary sources of these pollutants (U.S. EPA, 2002). As commercial long-haul trucks customarily make use of diesel technology, the effect on overall CO and VOC reductions is negligible. Table 5-6 presents a summary of the comparisons of VMT, energy use, and emissions between the "Without AEHS" scenario, and the "With AEHS" scenario, summed over the 30-year analysis period. It can be concluded that the use of AEHS technology will result in significant savings with respect to diesel fuel use and emissions, and especially in those pollutants whose primary contributors are commercial long-haul trucks (such as NO2, NOx, and SO2).

Table 5-6 - Summary of VMT, Fuel Use and Emissions: With & Without AEHS.

Measure		*Without AEHS*	*With AEHS*	*% Difference*
Vehicle Miles Traveled (billions)		97.7	87.4	10.62%
Petroleum Use (trillion BTU)		1,010	755	25.54%
Total Emissions (billion grams)	*CO*	266	263	0.93%
	NO_2	19.5	14.2	27.00%
	NO_x	69.2	56.1	18.91%
	VOC	3.93	3.71	5.64%
	PM_{10}	1.74	1.48	14.87%
	$PM_{2.5}$	1.66	1.41	15.11%
	SO_2	2.15	1.64	23.73%

5.4.2 Sensitivity Analysis

The estimated demand rate for the system was perceived as the most significant factor that would affect the estimates for the emissions and energy use savings of the AEHS. A sensitivity analysis was performed in order to quantify the variability of the outputs of the MOVES model with respect to this estimate. Specifically, the total truck VMT that was estimated to use the AEHS during the entire analysis period was reduced by 10%, assuming those vehicles would instead use the general purpose highway lanes.

The results in Table 5-7 show that over the 30-year analysis period, a 10% reduction in AEHS VMT would result in a 1.19% lower VMT compared to the original "With AEHS" scenario estimates. Additionally, energy use will increase by 5.29%, and the levels of emissions will increase anywhere from 0.07% to 3.56%, depending on the pollutant. Predictably, the pollutants affiliated with gasoline engines, such as Carbon Monoxide, will see smaller effects from the decrease in AEHS VMT than pollutants like Sulfur Dioxide. Overall, the results suggest that total emissions and energy use savings with the AEHS are relatively inelastic to varying estimates of demand for the system, at least for minor deviations from the original estimates.

Table 5-7 –Sensitivity Analysis Results of Reducing AEHS demand by 10%

Measure		*With AEHS – Original Demand*	*With AEHS – 10% Lower Demand*	*% Difference*
Vehicle Miles Traveled (billions)		87.4	88.4	1.19%
Petroleum Use (trillion BTU)		755	794	5.29%
Total Emissions (billion grams)	*CO*	263	263	0.07%
	NO_2	14.2	14.7	3.56%
	NO_x	56.1	57.3	2.07%
	VOC	3.71	3.72	0.45%
	PM_{10}	1.48	1.50	1.51%
	$PM_{2.5}$	1.41	1.43	1.54%
	SO_2	1.64	1.69	3.06%

Chapter 6 Conclusions

6.1 Summary of Study

This thesis studied the concept of Automated Electric Highway Systems (AEHS) within the context of serving as a conduit for heavy commercial freight transportation. A broad review of the current proposals for technological detail, and a subsequent recommendation of the most likely candidates for implementation, was undertaken. Based on this review, it was thought that a combination of distributed vehicle sensor technology, mated to an underlying infrastructure-based ITS framework, and supplemented by an inductive electric motive power system, would represent a probable design of the AEHS, such that current freight vehicles can be retrofitted with the technology. It was determined that the goal of the AEHS, at least in the near and intermediate terms, is to provide a dual-mode system of sorts, in that vehicles which utilize the AEHS would do so with a hybrid-electric powertrain system, with the ability to revert to either diesel or battery power upon exiting the AEHS.

A benefit-cost analysis (BCA), formulated using benefit/cost ratios and net present value, of the AEHS was performed for a sample corridor for the analysis period 2011-2040. The corridor chosen was Interstate 70 in Missouri, and was selected because of its current and projected high volumes of commercial truck traffic (as estimated by FAF), and based on the fact that preliminary analyses of this corridor have already been conducted for assessing the suitability of truck-only lanes. These lanes, while conventional in terms of technological character, would nonetheless provide a grade separated system for commercial vehicles, and would realize a number of the costs and benefits of the AEHS. In order to conduct the BCA, a large number of data (related to freight, traffic operations, and meteorological conditions) was collected and spatially visualized.

6.2 Key Findings

6.2.1 Benefit Cost Analysis

For the BCA, and based on a review of AEHS technology and similarly-structured analyses, the following were identified as significant contributors to the total benefits and costs of the AEHS:

- Benefits: Travel Time Savings, User Operating Cost Savings, Crash Savings, Emissions Reductions
- Costs: Initial Capital Costs, Operations & Maintenance Costs, Capital Recovery

Various sources and methodologies were consulted in the process of quantifying these costs and benefits, including previous information that was developed for the conventional truck-only lanes analysis. Once these costs and benefits were quantified, they were monetized and discounted using standard factors for the discount rate and time period of analysis. The results are summarized of the BCA are summarized here:

- The present value of the total benefit of travel time reductions over the project lifecycle is $1,816,797,573. This benefit is realized by assuming a decrease in the FAF-calculated delay along each highway segment, in proportion to the demand rate of the AEHS. By removing trucks from the general purpose lanes, congestion and travel time impacts will be significantly reduced.

- The present value of the total benefit of crash reductions over the project lifecycle is $833,431,177. By reducing the total number of interactions between commercial trucks and passenger vehicles on the I-70 corridor, the crash exposure is subsequently reduced, which results in a decrease in crashes at all injury levels, as well as property damage-only crashes.

- The present value of the total benefit of operating cost reductions over the project lifecycle is $4,367,504,075. This benefit is largely realized through savings in fuel costs, as electricity is more efficient (and therefore) cheaper on a per-mile basis than diesel fuel.

- The present value of the total benefit of emissions reductions over the project lifecycle is $154,676,877. This benefit is largely realized by reducing the number of heavily-polluting and fuel-inefficient commercial trucks on the general purpose lanes, and guiding them towards more efficient and pollution-free (at the roadway) motive power sources.

- The present value of the total costs over the project lifecycle is $4,756,938,463. This cost includes the effects of the initial construction of the project, as well as the operations and maintenance costs, and is reduced by the total amount of capital recovery that occurs at the end of the analysis period.

- Based on the reported costs and benefits, a benefit-cost ratio (BCR) of 1.51 was developed, along with a net present value (NPV) of $2,415,471,238.

Additionally, the sensitivity analysis performed by reducing AEHS demand estimates by 10% shows a reduction in the BCR and NPV to 1.43 and $2,049,986,282, respectively.

The results of the economic analysis suggest that the AEHS will be economically feasible, and it is recommended that further refined analysis be pursued. Some caveats of the additional analysis, along with identifying components to include in further analyses, are described in Section 6.4.

6.2.2 Emissions Reduction and Energy Use

In calculating the total benefits to the AEHS from reductions in emissions with the AEHS, a detailed analysis of pollutants was undertaken. This analysis concluded that the use of AEHS for long-haul commercial freight vehicles has the potential to provide significant benefits in terms of emissions and energy use reductions. An analysis using the MOVES software program from the U.S. EPA showed a 10% decrease in total VMT on conventional highway lanes through the year 2040, with significant reductions in petroleum-based energy use (over 25%) and mobile-source emissions (up to 27%, depending on the pollutant being considered). As expected, those pollutants which do not rely heavily on diesel trucks for their generation, such as carbon monoxide, exhibited much smaller decreases for the AEHS scenario as compared to base case conditions. The sensitivity analysis, in part facilitated by MOVES, further showed that minor variations in the demand estimate for AEHS did not significantly change the estimates of emissions and energy use savings, with a 10% reduction in AEHS VMT having an effect of 5% or less on the criteria of concern.

6.3 Study Limitations

In the process of developing a set of manageable results for an economic analysis of the AEHS, a number of assumptions and simplifications were made, many in part due to the nature of the proposed technology; AEHS is not currently in commercial use, thus, the estimation of costs and benefits from its use are necessarily constrained by the same assumptions. Perhaps the most critical assumption made in this model was the level of demand of the AEHS. This demand was based not on the price or time elasticity of demand for commercial trucking, but rather on a review of previous literature which had established rates of adoption for various automated vehicle control technologies. As the sensitivity analysis showed, the demand rate for AEHS was relatively robust with respect to controlling variations in estimates of the costs and benefits, although this should not replace a detailed analysis using proven transportation modeling tools, should such a system reach a point of commercial viability. The following represents a few additional qualifying remarks and assumptions which should be considered when interpreting the analysis results.

- *Data Limitations*: The unprecedented nature of the AEHS inherently lends itself to unique challenges with respect to data availability, or lack thereof. In order to account for the traffic conditions present in the "Without AEHS" and "With AEHS" scenarios, the FAF was used as the primary data source for AADT, link speeds, and delay. This data source is fairly aggregate in nature, and while parameter estimates were included for the years 2007 and 2040, in most cases a series of linear growth factors had to be developed to account for changes in corridor characteristics across all years of the analysis.

- *Future VMT Growth:* Another factor that is not considered in the current analysis is additional demand that occurs on the conventional roadway once AEHS is implemented. Conceivably, the removal of up to 90% of long-haul trucks from the general purpose highway lanes would result in a large amount of additional available capacity, and would generally have the effect of smoother traffic flow, higher speeds, and fewer delays. As such, additional demand may be induced by factors such as additional development along the highway due to improved accessibility, and the shift of current latent demand into actual vehicle trips. In addition, it is possible for demand to shift from alternate east-west routes adjacent to the I-70 corridor in response to more favorable operating conditions. This additional demand will serve to lower the original estimate of reductions in emissions and energy use along the corridor, although without a working model of the system from which to draw observable data, the magnitude of this effect is difficult to estimate.

- *Emissions*: For this study, pollutants and reductions in emissions were only considered on the general purpose highway lanes; pollutants on the AEHS were assumed to be zero. Besides the environmental contamination normally associated with new road construction, there are mobile source factors that must be considered. The primary contributor to mobile source pollutants from the AEHS will be particulate matter from vehicular tire wear. While particulate matter from braking may also be considered, the nature of the AEHS is such that braking is expected to be kept to a minimum, due to predictive systems that will allow vehicles to coast to a necessary reduce speed, in combination with the engine braking that will occur from the use of hybrid powertrains.

6.4 Recommendations for Future Research

In addition to the limitations of the thesis herein described, there are several recommendations for pursuing future research within this subject area, which may help to better elucidate the full scope of costs and benefits relating to the AEHS.

Part of the appeal of technologies such as AEHS is the ability for these systems to perform the same functions as conventional roadways while significantly reducing, or potentially eliminating, fossil fuel usage and associated pollutants. In the case of AEHS, this potential for zero-emissions operation in fact exists; while vehicles which use the AEHS derive their motive power from electricity, the source of this electricity for the roadway is not explicitly defined. Based on the estimated electricity demands for the system over the project lifecycle, an analysis should be carried out to determine the extent to which this electricity can be supplied by renewable energy sources. In the case of Missouri, approximately 85% of current electricity demand is supplied by coal and other fossil-fuel sources (EIA, 2011); this represents a vast potential to reduce the emissions, and increase the efficiency of one of the state's leading contributors to pollution and energy use. Conversely, the smart grids which will be utilized to supply electricity to the hybrid-electric vehicles on the AEHS, and the real-time nature of this interaction could serve as a way to provide electricity back to the grid in times of peak demand, thus tempering one of the primary criticisms of volatility for renewable sources such as wind and solar power.

As discussed extensively in Chapter 4, the estimates for the AEHS demand rate were derived from a survey of the varying levels of current automated control technologies by trucking companies. While this provides enough detail for a sufficient initial estimate of AEHS demand, a more thorough economic analysis may be completed which contains AEHS demand estimates based on econometric factors. Specifically, more study should be conducted to see if existing trucking demand elasticities can somehow be altered to account for the unique characteristics of the AEHS, or else a new survey should be conducted in which truck companies are asked specifically about their estimates for whether or not they would embrace the AEHS concept.

Additionally, while a number of uncertainties in this thesis were investigated through sensitivity analyses, there remain a number of additional factors which might be given further consideration. For example, differences in total operating cost savings as a result of fluctuating electricity prices may have a significant effect on the viability of the corridor; this effect may be considered in two respects. First, increasing global energy demand is likely to continue driving an increase in electricity prices in the U.S., as the demand for non-renewable fossil fuels rises. While this increase may be tempered to some extent as increasing amounts of renewable energy are generated in the coming decades, many of these alternative energy sources are only profitable at higher electricity prices. On the other hand, it is entirely feasible that the operator(s) of the AEHS would be able to contract with a utility company to supply electricity usage at a fixed long-term or commercial rate. As these rates are often substantially lower than the average price of electricity for residential use, it is possible that the AEHS may generate even greater fuel cost savings than predicted here.

Finally, the broader implications of this analysis should not be underestimated. The analysis contained herein is one of the first to utilize an emissions modeling package widely used by industry professionals, along with various accepted methodologies for estimating crashes, user costs, and travel time savings, and adapt them for the unique characteristics of this de novo infrastructure. By clearly stating the assumptions and methodologies used in the economic analysis, it is hoped that future research will focus on refining the estimation technique, as opposed to developing entirely new methodologies. Indeed, by quantifying the economic analysis of AEHS in terms of estimable parameters and aggregate data sets, there is potential for a similar methodology to be applied to any number of alternative transportation technologies and infrastructure systems. Therein lays a great potential for this proposed analytical methodology; that it may be adapted to a generic tools of sorts, for application by any number of public and private agencies for a wide variety of infrastructure. Currently, a number of such generic planning tools exist, such as HER-ST from the FHWA, Cal-B/C from the California Department of Transportation (Caltrans), and StratBENCOST from the National Cooperative Highway Research Program (NCHRP). While these software tools are purport to accurately measure various costs and benefits associated with transportation infrastructure projects, they do so in the context of conventional highway technology and construction methods. In most of these programs, there is little flexibility to account for such radical components as systemic automation technology or wireless power transfer components. By presenting these novel technologies within an analytical framework that is compatible with these programs, it is hoped that a new type of software could eventually be developed to allow this type of economic decomposition to be performed regardless of the specific scenarios being considered.

Appendix 1 I-70 Truck-Only Lanes Construction Costs

Note: MoDOT has left the ultimate mileage and location of the I-70 Truck-Only Lanes Project flexible to allow for project delivery innovations within the design-build phase. MoDOT is committed to delivering the project within a set budget of $240 million, as proposed within the TIGER Grant Application.			Adjusted Quantities		Practical Design	
			Length	29.867	Length	29.867
					U.I.P. I-70 Lanes and Shldrs	
Item	**Unit**	**$/unit or % Const. (2008)**	**Segment Quantity**	**Segment Cost**	**Segment Quantity**	**Segment Cost**
Pavement & Base						
Mainline I-70						
- Mainline - 11" on 4" Perm on 4" Agg Base	Sq. Yd.	$ 46.50	981,231	$ 45,627,219	490,615	$ 22,813,609
- Mainline - 8" on 4" Agg	Sq. Yd.	$ 29.50	455,571	$ 13,439,354	595,747	$ 17,574,539
- A2 Shoulder	Sq. Yd.	$ 15.00	806,011	$ 12,090,162	455,571	$ 6,833,570
- Median Barrier	Lin. Ft.	$ 35.00	157,698	$ 5,519,422	157,698	$ 5,519,422
Cross Roads						
- Medium Duty - No. Interchange* 7,111 sq yd	Sq. Yd.	$ 29.50	35,555	$ 1,048,873	94,219	$ 2,779,461
- Medium Duty - No. Crossover * 3,111 sq yd	Sq. Yd.	$ 29.50	12,444	$ 367,098	12,444	$ 367,098
Outer Roadway						
- Light Duty - Rural	Sq. Yd.	$ 29.50	357,869	$ 10,557,136	343,605	$ 10,136,348
General						
- Existing I-70 Pavement Removal	Sq. Yd.	$ 3.50	665,835	$ 2,330,422	0	$ -
- Existing Outer Road Pavement Removal	Sq. Yd.	$ 2.25	318,444	$ 716,499	318,444	$ 716,499
TOTAL PAVEMENT & BASE				**$ 91,696,183**		**$ 66,740,545**
Interchanges						
General Purpose						
- Ramps (Grading)	Each	$ 1,250,000	0	$ -	0	$ -
- Ramp Pavement	Sq. Yd.	$ 29.50	96,515	$ 2,847,193	96,515	$ 2,847,193
- Illumination, Signing and Signalization	Lump Sum	2471198	1	$ 2,471,198	1	$ 2,471,198
Truck Only (US-65)						
- Ramps (Grading)	Lin. Ft.	$ 500	5,575	$ 2,787,500	5,575	$ 2,787,500
- Ramp Pavement	Sq. Yd.	$ 35.50	18,550	$ 658,525	18,550	$ 658,525
- Additional Truck Interchange Bridges	Sq. Ft.	$ 112.50	0	$ -	0	$ -
- Additional Retaining Walls	Sq. Ft.	$ 45.00	113,713	$ 5,117,085	113,713	$ 5,117,085
Slip Ramps						
- Slip Ramps Rural (Includes 4 Ramps)	Each	$ 875,000	3	$ 2,625,000	3	$ 2,625,000
TOTAL INTERCHANGES				**$ 16,506,501**		**$ 16,506,501**
Bridges						
Mainline						
- I-70 over Road or Drainage	Sq. Ft.	$ 120	208,821	$ 25,058,520	190,477	$ 22,857,240
- Bridge Removal	Sq. Ft.	$ 20	11,893	$ 237,860	11,893	$ 237,860
Cross Roads						
- Over I-70 - 4-Span Open End	Sq. Ft.	$ 100	102,604	$ 10,260,400	56,880	$ 5,688,000
- Bridge Removal	Sq. Ft.	$ 20	43,354	$ 867,080	43,354	$ 867,080
- Bridge Rehab	Sq. Ft.	$ 20	0	$ -	0	$ -
Retaining Walls						
- MSE Walls	Sq. Ft.	$ 45	49,184	$ 2,213,280	49,184	$ 2,213,280
TOTAL BRIDGES				**$ 38,637,140**		**$ 31,863,460**
Grading & Drainage						
- Clearing and Grubbing	Acre	$ 2,000	1,266	$ 2,532,000	1,266	$ 2,532,000
- Unclassified Excavation	Cu. Yd.	$ 3.75	7,527,945	$ 28,229,794	7,527,945	$ 28,229,794
- Compaction	Cu. Yd.	$ 0.50	8,733,839	$ 4,366,920	8,733,839	$ 4,366,920
- Borrow	Cu. Yd.	$ 6.50	1,519,505	$ 9,876,783	1,519,505	$ 9,876,783
- Outer roadways -- Grading	Mile	$ 300,000	30.50	$ 9,150,000	23.03	$ 6,909,000
- Incidental Drainage - Freeway	Mile	$ 250,000	24.55	$ 6,137,500	29.867	$ 7,466,750
- Incidental Drainage - Local Road	Mile	$ 100,000	30.50	$ 3,050,000	23.03	$ 2,303,000
- Erosion Control	Mile	$ 200,000	24.55	$ 4,910,000	29.867	$ 5,973,400
- Drainage Structures	Sq. Ft./lin. ft.	$ 9.00	337,400	$ 3,036,600	428,800	$ 3,859,200
- Fence	Lin. Ft.	$ 7.50	130,286	$ 977,145	130,286	$ 977,145
TOTAL GRADING & DRAINAGE				**$ 72,266,741**		**$ 72,493,991**

Note: MoDOT has left the ultimate mileage and location of the I-70 Truck-Only Lanes Project flexible to allow for project delivery innovations within the design-build phase. MoDOT is committed to delivering the project within a set budget of $240 million, as proposed within the TIGER Grant Application.			Adjusted Quantities		Practical Design	
			Length	29.867	Length	29.867
					U.I.P. I-70 Lanes and Shldrs	
Item	**Unit**	**$/unit or % Const. (2008)**	**Segment Quantity**	**Segment Cost**	**Segment Quantity**	**Segment Cost**
Right of Way Acquisition						
- Land - Agricultural (Vacant)	Acre	$ 2,500	647	$ 1,617,418	647	$ 1,617,418
- Land - Rural Residential Acreage	Acre	$ 5,000	39	$ 195,492	39	$ 195,492
- Improvements - Rural Residential	Lump Sum	$ 100,000	28	$ 2,754,098	28	$ 2,754,098
- Land & Improvement - Urban/Sub Residential	Lump Sum	$ 150,000	3	$ 516,393	3	$ 516,393
- Land - Rural Industrial Acreage (vacant)	Acre	$ 10,000	18	$ 179,016	18	$ 179,016
- Comm. Bus. (not at Interchange) Rural/Sub	Lump Sum	Varies	3	$ 497,696	3	$ 497,696
- Land - Rural Interchange (undeveloped)	Acre	$ 20,000	8	$ 167,213	8	$ 167,213
- Land - Developed Interchange	Sq. Ft.	$ 8	1,236,104	$ 9,888,830	1,236,104	$ 9,888,830
- Improvements - Developed Interchange	Lump Sum	$ 100,000	19	$ 1,935,484	19	$ 1,935,484
- Hazardous Materials Removal	Per Site	$ 100,000	11	$ 1,105,991	11	$ 1,105,991
- Outdoor Advertising Removal	Each	$ 50,000	31	$ 1,549,180	31	$ 1,549,180
- Acquisition and Relocation (Includes Condemnation Costs)	% ROW	25%	$29,116,490	$ 7,279,122	$29,116,490	$ 7,279,122
- Relocation Contingency	% Improv	25%	$14,608,841	$ 3,652,210	$14,608,841	$ 3,652,210
TOTAL RIGHT OF WAY				**$ 31,338,145**		**$ 31,338,145**
Utility Relocations						
- Along Existing Alignment	Mile	$ 354,900	29.867	$ 10,599,798	29.867	$ 8,479,839
- ITS	Lump Sum	1		$ 250,000		$ 250,000
- Major Utility	L.S. Each	1		$ -		$ -
TOTAL UTILITY RELOCATIONS				**$ 10,849,798**		**$ 8,729,839**
Miscellaneous Costs						
- Mobilization	% Const.	2%	$ 261,294,507	$ 5,225,890	$ 227,672,479	$ 4,553,450
- Traffic Control	% Const.	2%	$ 261,294,507	$ 5,225,890	$ 227,672,479	$ 4,553,450
- Maintenance of Traffic During Construction	% Const.	4%	$ 261,294,507	$ 10,451,780	$ 227,672,479	$ -
- Construction Management	% Const.	6%	$ 261,294,507	$ 15,677,670	$ 227,672,479	$ 13,660,349
- Miscellaneous Construction	% Const.	2.5%	$ 261,294,507	$ 6,532,363	$ 227,672,479	$ 5,691,812
- Engineering Design	% Const.	6%	$ 261,294,507	$ 15,677,670	$ 227,672,479	$ 13,660,349
- Program Management and Administration	% Const.	2%	$ 261,294,507	$ 5,225,890	$ 227,672,479	$ 4,553,450
- Contingency	% Const.	5.5%	$ 261,294,507	$ 7,185,599	$ 227,672,479	$ 6,260,993
			$ 261,294,507	$ 7,185,599	$ 227,672,479	$ 6,260,993
- Corridor Enhancements	% Const.	4%	$ 261,294,507	$ 10,451,780	$ -	$ -
TOTAL MISCELLANEOUS COSTS				**$ 88,840,132**		**$ 59,194,845**
Range of Potential Design-Build Options:						
TOTAL (2008 Dollars)				**$ 350,134,640**	Build 29.867 miles	**$ 286,867,324**
Subtract 3.05 miles (Rte M to Rte 135)			$ 26,701,934		Build 26.817 miles	**$ 260,165,390**
Subtract 4.55 miles (Lamine River to Rte 135)			$ 47,264,208		Build 25.317 miles	**$ 239,603,116**
Subtract 7.80 miles (Rte K to Rte 135)			$ 75,413,124		Build 22.067 miles	**$ 211,454,201**

Appendix 2A Summary of Benefits & Costs – "With AEHS" Scenario

	BENEFITS								COSTS			
Year	Pollutants		Travel Time Savings		Crashes		Operating Cost Savings		Capital Costs		O & M Costs	
	Value	Present Value	Value	Present Value	Value	Present Value	Value	Present Value	Value	Present Value	Value	Present Value
2011	$1,397,089	$ 1,397,089	$ 5,666,668	$ 5,666,668	$ 589,598	$ 589,598	$1,945,934	$ 1,945,934	$ 5,550,008,663	$ 5,550,008,663	$ 20,643,198	
2012	$879,054	$ 859,290	$ 7,486,391	$ 7,318,075	$ 1,207,906	$ 1,180,749	$4,096,960	$ 4,004,848		$ -	$ 20,731,035	$ 20,264,941
2013	$0	$ -	$ 9,482,589	$ 9,060,990	$ 1,854,924	$ 1,772,454	$6,461,525	$ 6,174,244		$ -	$ 20,731,035	$ 19,809,327
2014	$1,139,278	$ 1,064,150	$ 11,663,838	$ 10,894,682	$ 2,530,652	$ 2,363,771	$9,046,558	$ 8,449,995		$ -	$ 20,731,035	$ 19,363,956
2015	$1,246,571	$ 1,138,189	$ 14,038,735	$ 12,818,153	$ 3,235,089	$ 2,953,818	$11,859,365	$ 10,828,265		$ -	$ 20,731,035	$ 18,928,598
2016	$1,300,597	$ 1,160,820	$ 16,616,180	$ 14,830,405	$ 3,968,236	$ 3,541,761	$14,907,254	$ 13,305,141		$ -	$ 20,731,035	$ 18,503,028
2017	$1,630,258	$ 1,422,337	$ 19,790,149	$ 17,266,140	$ 5,877,481	$ 5,127,875	$22,611,749	$ 19,727,877		$ -	$ 20,731,035	$ 18,087,027
2018	$1,884,158	$ 1,606,896	$ 23,283,853	$ 19,857,539	$ 7,864,186	$ 6,706,939	$30,965,111	$ 26,408,468		$ -	$ 20,731,035	$ 17,680,378
2019	$122,072	$ 101,768	$ 27,113,777	$ 22,603,982	$ 9,928,350	$ 8,276,982	$39,987,057	$ 33,336,068		$ -	$ 20,731,035	$ 17,282,872
2020	$2,554,130	$ 2,081,433	$ 31,297,020	$ 25,504,821	$ 12,069,972	$ 9,836,160	$49,697,301	$ 40,499,727		$ -	$ 20,731,035	$ 16,894,303
2021	$2,823,816	$ 2,249,469	$ 35,851,313	$ 28,559,377	$ 14,289,054	$ 11,382,748	$60,115,558	$ 47,888,424		$ -	$ 20,731,035	$ 16,514,470
2022	$3,350,373	$ 2,608,923	$ 40,795,043	$ 31,766,943	$ 16,585,594	$ 12,915,139	$71,261,545	$ 55,491,091		$ -	$ 20,731,035	$ 16,143,177
2023	$3,876,930	$ 2,951,076	$ 47,010,760	$ 35,784,065	$ 20,522,377	$ 15,621,403	$90,009,192	$ 68,513,990		$ -	$ 20,731,035	$ 15,780,232
2024	$4,586,904	$ 3,413,001	$ 53,808,379	$ 40,037,474	$ 24,595,510	$ 18,300,906	$110,066,175	$ 81,897,498		$ -	$ 20,731,035	$ 15,425,447
2025	$5,296,201	$ 3,852,171	$ 61,218,012	$ 44,526,683	$ 28,804,993	$ 20,951,200	$131,467,199	$ 95,622,158		$ -	$ 20,731,035	$ 15,078,638
2026	$6,069,808	$ 4,315,593	$ 69,270,907	$ 49,251,149	$ 33,150,827	$ 23,570,015	$154,246,968	$ 109,668,558		$ -	$ 20,731,035	$ 14,739,627
2027	$6,862,296	$ 4,769,352	$ 77,999,478	$ 54,210,269	$ 37,633,012	$ 26,155,248	$178,440,186	$ 124,017,373		$ -	$ 20,731,035	$ 14,408,237
2028	$7,679,514	$ 5,217,326	$ 87,437,346	$ 59,403,385	$ 42,251,548	$ 28,704,954	$204,081,557	$ 138,649,398		$ -	$ 20,731,035	$ 14,084,298
2029	$8,659,891	$ 5,751,101	$ 98,222,702	$ 65,230,464	$ 47,769,863	$ 31,724,340	$234,960,785	$ 156,039,294		$ -	$ 20,731,035	$ 13,767,642
2030	$9,685,772	$ 6,287,778	$ 109,874,070	$ 71,327,692	$ 53,450,376	$ 34,698,741	$267,621,843	$ 173,733,879		$ -	$ 20,731,035	$ 13,458,106
2031	$10,726,291	$ 6,806,705	$ 122,433,979	$ 77,694,323	$ 59,293,086	$ 37,626,288	$302,106,014	$ 191,710,852		$ -	$ 20,731,035	$ 13,155,529
2032	$11,804,060	$ 7,322,226	$ 135,946,517	$ 84,329,549	$ 65,297,994	$ 40,505,270	$338,454,580	$ 209,948,167		$ -	$ 20,731,035	$ 12,859,754
2033	$12,913,153	$ 7,830,119	$ 150,457,385	$ 91,232,498	$ 71,465,099	$ 43,334,128	$376,708,824	$ 228,424,062		$ -	$ 20,731,035	$ 12,570,630
2034	$14,053,708	$ 8,330,122	$ 166,013,944	$ 98,402,242	$ 77,794,403	$ 46,111,450	$416,910,026	$ 247,117,080		$ -	$ 20,731,035	$ 12,288,006
2035	$16,250,738	$ 9,415,814	$ 188,671,097	$ 109,317,619	$ 89,981,076	$ 52,135,792	$490,120,683	$ 283,980,043		$ -	$ 20,731,035	$ 12,011,736
2036	$18,511,345	$ 10,484,486	$ 213,202,215	$ 120,753,818	$ 102,504,987	$ 58,056,942	$567,328,742	$ 321,324,577		$ -	$ 20,731,035	$ 11,741,677
2037	$20,833,581	$ 11,534,465	$ 239,700,846	$ 132,709,829	$ 115,366,135	$ 63,872,199	$648,620,037	$ 359,107,011		$ -	$ 20,731,035	$ 11,477,690
2038	$23,216,182	$ 12,564,601	$ 268,264,005	$ 145,184,514	$ 128,564,520	$ 69,579,134	$734,080,399	$ 397,284,405		$ -	$ 20,731,035	$ 11,219,639
2039	$25,660,335	$ 13,575,148	$ 298,992,285	$ 158,176,601	$ 142,100,141	$ 75,175,576	$823,795,659	$ 435,814,580		$ -	$ 20,731,035	$ 10,967,389
2040	$28,165,454	$ 14,565,432	$ 334,683,499	$ 173,077,623	$ 155,972,999	$ 80,659,597	$921,593,229	$ 476,591,067	$ (2,375,182,024)	$ (1,228,297,365)	$ 20,731,035	$ 10,720,810
SUM	$253,179,559	$ 154,676,877	$ 2,966,292,983	$ 1,816,797,573	$ 1,376,519,989	$ 833,431,177	$ 7,313,568,016	$ 4,367,504,075	$ 3,174,826,639	$ 4,321,711,298	$ 621,843,213	$ 435,227,165

Total Benefits	$ 7,172,409,701		BCR	1.507778534
Total Costs	$ 4,756,938,463		NPV	$ 2,415,471,238

Appendix 2B Summary of Benefits & Costs – Reduce AEHS Demand By 10%

	BENEFITS								COSTS			
Year	Pollutants		Travel Time Savings		Crashes		Operating Cost Savings		Capital Costs		O & M Costs	
	Value	Present Value	Value	Present Value	Value	Present Value	Value	Present Value	Value	Present Value	Value	Present Value
2011	$1,366,203	$ 1,366,203	$ 5,658,830	$ 5,658,830	$ 530,639	$ 530,639	$1,923,974	$ 1,923,974	$ 5,550,008,663	$ 5,550,008,663	$ 20,643,198	
2012	$828,353	$ 809,729	$ 7,466,429	$ 7,298,562	$ 1,087,116	$ 1,062,674	$4,040,937	$ 3,950,085		$ -	$ 20,731,035	$ 20,264,941
2013	$551,689	$ 527,160	$ 9,445,728	$ 9,025,768	$ 1,669,432	$ 1,595,208	$6,358,491	$ 6,075,790		$ -	$ 20,731,035	$ 19,809,327
2014	$1,072,146	$ 1,001,445	$ 11,605,020	$ 10,839,743	$ 2,277,586	$ 2,127,394	$8,882,872	$ 8,297,103		$ -	$ 20,731,035	$ 19,363,956
2015	$1,172,157	$ 1,070,245	$ 13,952,553	$ 12,739,464	$ 2,911,580	$ 2,658,436	$11,620,656	$ 10,610,311		$ -	$ 20,731,035	$ 18,928,598
2016	$1,220,787	$ 1,089,587	$ 16,496,857	$ 14,723,906	$ 3,571,412	$ 3,187,585	$14,578,420	$ 13,011,648		$ -	$ 20,731,035	$ 18,503,028
2017	$1,526,162	$ 1,331,517	$ 19,593,050	$ 17,094,179	$ 5,289,733	$ 4,615,088	$22,071,489	$ 19,256,521		$ -	$ 20,731,035	$ 18,087,027
2018	$1,757,785	$ 1,499,120	$ 22,992,575	$ 19,609,124	$ 7,077,767	$ 6,036,245	$30,171,218	$ 25,731,400		$ -	$ 20,731,035	$ 17,680,378
2019	$1,414,599	$ 1,179,310	$ 26,710,839	$ 22,268,064	$ 8,935,515	$ 7,449,284	$38,895,352	$ 32,425,945		$ -	$ 20,731,035	$ 17,282,872
2020	$2,380,198	$ 1,939,691	$ 30,763,816	$ 25,070,298	$ 10,862,975	$ 8,852,544	$48,261,635	$ 39,329,763		$ -	$ 20,731,035	$ 16,894,303
2021	$2,628,863	$ 2,094,169	$ 35,168,068	$ 28,015,099	$ 12,860,148	$ 10,244,474	$58,287,809	$ 46,432,428		$ -	$ 20,731,035	$ 16,514,470
2022	$3,117,617	$ 2,427,677	$ 39,940,762	$ 31,101,718	$ 14,927,035	$ 11,623,625	$68,991,619	$ 53,723,509		$ -	$ 20,731,035	$ 16,143,177
2023	$3,606,371	$ 2,745,129	$ 45,876,831	$ 34,920,930	$ 18,470,139	$ 14,059,263	$87,017,184	$ 66,236,507		$ -	$ 20,731,035	$ 15,780,232
2024	$4,267,101	$ 3,175,044	$ 52,355,854	$ 38,956,686	$ 22,135,959	$ 16,470,815	$106,261,074	$ 79,066,218		$ -	$ 20,731,035	$ 15,425,447
2025	$4,925,458	$ 3,582,513	$ 59,405,607	$ 43,208,438	$ 25,924,494	$ 18,856,080	$126,754,524	$ 92,194,412		$ -	$ 20,731,035	$ 15,078,638
2026	$5,644,197	$ 4,012,986	$ 67,054,906	$ 47,675,587	$ 29,835,745	$ 21,213,014	$148,528,768	$ 105,602,956		$ -	$ 20,731,035	$ 14,739,627
2027	$6,380,656	$ 4,434,608	$ 75,333,636	$ 52,357,487	$ 33,869,711	$ 23,539,723	$171,615,039	$ 119,273,841		$ -	$ 20,731,035	$ 14,408,237
2028	$7,140,448	$ 4,851,094	$ 84,272,788	$ 57,253,440	$ 38,026,393	$ 25,834,458	$196,044,571	$ 133,189,211		$ -	$ 20,731,035	$ 14,084,298
2029	$8,051,453	$ 5,347,033	$ 94,447,488	$ 62,723,315	$ 42,992,877	$ 28,551,906	$225,451,628	$ 149,724,189		$ -	$ 20,731,035	$ 13,767,642
2030	$9,005,335	$ 5,846,054	$ 105,425,181	$ 68,439,577	$ 48,105,338	$ 31,228,867	$256,509,823	$ 166,520,214		$ -	$ 20,731,035	$ 13,458,106
2031	$9,972,234	$ 6,328,194	$ 117,244,939	$ 74,401,455	$ 53,363,777	$ 33,863,660	$289,256,311	$ 183,556,669		$ -	$ 20,731,035	$ 13,155,529
2032	$10,974,134	$ 6,807,411	$ 129,947,258	$ 80,608,124	$ 58,768,195	$ 36,454,743	$323,728,246	$ 200,813,213		$ -	$ 20,731,035	$ 12,859,754
2033	$12,004,992	$ 7,279,440	$ 143,574,109	$ 87,058,702	$ 64,318,590	$ 39,000,715	$359,962,781	$ 218,269,803		$ -	$ 20,731,035	$ 12,570,630
2034	$13,065,426	$ 7,744,332	$ 158,168,980	$ 93,752,259	$ 70,014,962	$ 41,500,305	$397,997,070	$ 235,906,713		$ -	$ 20,731,035	$ 12,288,006
2035	$15,107,845	$ 8,753,613	$ 179,182,171	$ 103,819,656	$ 80,982,969	$ 46,922,213	$467,454,895	$ 270,847,295		$ -	$ 20,731,035	$ 12,011,736
2036	$17,209,503	$ 9,747,147	$ 201,910,626	$ 114,358,469	$ 92,254,489	$ 52,251,247	$540,609,125	$ 306,191,076		$ -	$ 20,731,035	$ 11,741,677
2037	$19,368,416	$ 10,723,279	$ 226,439,475	$ 125,367,701	$ 103,829,521	$ 57,484,979	$617,537,009	$ 341,897,963		$ -	$ 20,731,035	$ 11,477,690
2038	$21,583,478	$ 11,680,981	$ 252,856,992	$ 136,846,236	$ 115,708,068	$ 62,621,221	$698,315,796	$ 377,928,597		$ -	$ 20,731,035	$ 11,219,639
2039	$23,855,742	$ 12,620,460	$ 281,254,697	$ 148,792,842	$ 127,890,127	$ 67,658,018	$783,022,733	$ 414,244,382		$ -	$ 20,731,035	$ 10,967,389
2040	$26,184,686	$ 13,541,102	$ 314,256,595	$ 162,514,091	$ 140,375,699	$ 72,593,637	$875,102,491	$ 452,548,930	$ (2,375,182,024)	$ (1,228,297,365)	$ 20,731,035	$ 10,720,810
SUM	$237,384,036	$ 145,556,272	$ 2,828,802,659	$ 1,736,499,750	$ 1,238,867,990	$ 750,088,059	$ 6,985,253,540	$ 4,174,780,664	$ 3,174,826,639	$ 4,321,711,298	$ 621,843,213	$ 435,227,165
	Total Benefits	$ 6,806,924,745		BCR	1.430946563							
	Total Costs	$ 4,756,938,463		NPV	$ 2,049,986,282							

Appendix 2C Summary of Benefits & Costs – Reduce ITS Costs By 50%

Year	BENEFITS								COSTS			
	Pollutants		Travel Time Savings		Crashes		Operating Cost Savings		Capital Costs		O & M Costs	
	Value	Present Value	Value	Present Value	Value	Present Value	Value	Present Value	Value	Present Value	Value	Present Value
2011	$1,397,089	$ 1,397,089	$ 5,666,668	$ 5,666,668	$ 589,598	$ 589,598	$1,945,934	$ 1,945,934	$ 4,625,007,219	$ 4,625,007,219	$ 17,202,665	
2012	$879,054	$ 859,290	$ 7,486,391	$ 7,318,075	$ 1,207,906	$ 1,180,749	$4,096,960	$ 4,004,848		$ -	$ 17,202,665	$ 16,815,899
2013	$0	$ -	$ 9,482,589	$ 9,060,990	$ 1,854,924	$ 1,772,454	$6,461,525	$ 6,174,244		$ -	$ 17,202,665	$ 16,437,829
2014	$1,139,278	$ 1,064,150	$ 11,663,838	$ 10,894,682	$ 2,530,652	$ 2,363,771	$9,046,558	$ 8,449,995		$ -	$ 17,202,665	$ 16,068,259
2015	$1,246,571	$ 1,138,189	$ 14,038,735	$ 12,818,153	$ 3,235,089	$ 2,953,818	$11,859,365	$ 10,828,265		$ -	$ 17,202,665	$ 15,706,998
2016	$1,300,597	$ 1,160,820	$ 16,616,180	$ 14,830,405	$ 3,968,236	$ 3,541,761	$14,907,254	$ 13,305,141		$ -	$ 17,202,665	$ 15,353,860
2017	$1,630,258	$ 1,422,337	$ 19,790,149	$ 17,266,140	$ 5,877,481	$ 5,127,875	$22,611,749	$ 19,727,877		$ -	$ 17,202,665	$ 15,008,660
2018	$1,884,158	$ 1,606,896	$ 23,283,853	$ 19,857,539	$ 7,864,186	$ 6,706,939	$30,965,111	$ 26,408,468		$ -	$ 17,202,665	$ 14,671,222
2019	$122,072	$ 101,768	$ 27,113,777	$ 22,603,982	$ 9,928,350	$ 8,276,982	$39,987,057	$ 33,336,068		$ -	$ 17,202,665	$ 14,341,371
2020	$2,554,130	$ 2,081,433	$ 31,297,020	$ 25,504,821	$ 12,069,972	$ 9,836,160	$49,697,301	$ 40,499,727		$ -	$ 17,202,665	$ 14,018,935
2021	$2,823,816	$ 2,249,469	$ 35,851,313	$ 28,559,377	$ 14,289,054	$ 11,382,748	$60,115,558	$ 47,888,424		$ -	$ 17,202,665	$ 13,703,749
2022	$3,350,373	$ 2,608,923	$ 40,795,043	$ 31,766,943	$ 16,585,594	$ 12,915,139	$71,261,545	$ 55,491,091		$ -	$ 17,202,665	$ 13,395,649
2023	$3,876,930	$ 2,951,076	$ 47,010,760	$ 35,784,065	$ 20,522,377	$ 15,621,403	$90,009,192	$ 68,513,990		$ -	$ 17,202,665	$ 13,094,476
2024	$4,586,904	$ 3,413,001	$ 53,808,379	$ 40,037,474	$ 24,595,510	$ 18,300,906	$110,066,175	$ 81,897,498		$ -	$ 17,202,665	$ 12,800,074
2025	$5,296,201	$ 3,852,171	$ 61,218,012	$ 44,526,683	$ 28,804,993	$ 20,951,200	$131,467,199	$ 95,622,158		$ -	$ 17,202,665	$ 12,512,292
2026	$6,069,808	$ 4,315,593	$ 69,270,907	$ 49,251,149	$ 33,150,827	$ 23,570,015	$154,246,968	$ 109,668,558		$ -	$ 17,202,665	$ 12,230,979
2027	$6,862,296	$ 4,769,352	$ 77,999,478	$ 54,210,269	$ 37,633,012	$ 26,155,248	$178,440,186	$ 124,017,373		$ -	$ 17,202,665	$ 11,955,991
2028	$7,679,514	$ 5,217,326	$ 87,437,346	$ 59,403,385	$ 42,251,548	$ 28,704,954	$204,081,557	$ 138,649,398		$ -	$ 17,202,665	$ 11,687,186
2029	$8,659,891	$ 5,751,101	$ 98,222,702	$ 65,230,464	$ 47,769,863	$ 31,724,340	$234,960,785	$ 156,039,294		$ -	$ 17,202,665	$ 11,424,424
2030	$9,685,772	$ 6,287,778	$ 109,874,070	$ 71,327,692	$ 53,450,376	$ 34,698,741	$267,621,843	$ 173,733,879		$ -	$ 17,202,665	$ 11,167,570
2031	$10,726,291	$ 6,806,705	$ 122,433,979	$ 77,694,323	$ 59,293,086	$ 37,626,288	$302,106,014	$ 191,710,852		$ -	$ 17,202,665	$ 10,916,491
2032	$11,804,060	$ 7,322,226	$ 135,946,517	$ 84,329,549	$ 65,297,994	$ 40,505,270	$338,454,580	$ 209,948,167		$ -	$ 17,202,665	$ 10,671,057
2033	$12,913,153	$ 7,830,119	$ 150,457,385	$ 91,232,498	$ 71,465,099	$ 43,334,128	$376,708,824	$ 228,424,062		$ -	$ 17,202,665	$ 10,431,140
2034	$14,053,708	$ 8,330,122	$ 166,013,944	$ 98,402,242	$ 77,794,403	$ 46,111,450	$416,910,026	$ 247,117,080		$ -	$ 17,202,665	$ 10,196,618
2035	$16,250,738	$ 9,415,814	$ 188,671,097	$ 109,317,619	$ 89,981,076	$ 52,135,792	$490,120,683	$ 283,980,043		$ -	$ 17,202,665	$ 9,967,369
2036	$18,511,345	$ 10,484,486	$ 213,202,215	$ 120,753,818	$ 102,504,987	$ 58,056,942	$567,328,742	$ 321,324,577		$ -	$ 17,202,665	$ 9,743,273
2037	$20,833,581	$ 11,534,465	$ 239,700,846	$ 132,709,829	$ 115,366,135	$ 63,872,199	$648,620,037	$ 359,107,011		$ -	$ 17,202,665	$ 9,524,216
2038	$23,216,182	$ 12,564,601	$ 268,264,005	$ 145,184,514	$ 128,564,520	$ 69,579,134	$734,080,399	$ 397,284,405		$ -	$ 17,202,665	$ 9,310,085
2039	$25,660,335	$ 13,575,148	$ 298,992,285	$ 158,176,601	$ 142,100,141	$ 75,175,576	$823,795,659	$ 435,814,580		$ -	$ -	$ -
2040	$28,165,454	$ 14,565,432	$ 334,683,499	$ 173,077,623	$ 155,972,999	$ 80,659,597	$921,593,229	$ 476,591,067	$ (1,912,681,302)	$ (989,120,572)	$ -	$ -
SUM	$253,179,559	$ 154,676,877	$ 2,966,292,983	$ 1,816,797,573	$ 1,376,519,989	$ 833,431,177	$ 7,313,568,016	$ 4,367,504,075	$ 2,712,325,917	$ 3,635,886,647	$ 481,674,623	$ 343,155,677
	Total Benefits	$ 7,172,409,701		BCR	1.802546723							
	Total Costs	$ 3,979,042,323		NPV	$ 3,193,367,378							

Appendix 2D Summary of Benefits & Costs – Increase ITS Costs By 50%

	BENEFITS								COSTS			
Year	Pollutants		Travel Time Savings		Crashes		Operating Cost Savings		Capital Costs		O & M Costs	
	Value	Present Value	Value	Present Value	Value	Present Value	Value	Present Value	Value	Present Value	Value	Present Value
2011	$1,397,089	$ 1,397,089	$ 5,666,668	$ 5,666,668	$ 589,598	$ 589,598	$1,945,934	$ 1,945,934	$ 6,475,010,107	$ 6,475,010,107	$ 24,083,731	
2012	$879,054	$ 859,290	$ 7,486,391	$ 7,318,075	$ 1,207,906	$ 1,180,749	$4,096,960	$ 4,004,848		$ -	$ 24,083,731	$ 23,542,259
2013	$0	$ -	$ 9,482,589	$ 9,060,990	$ 1,854,924	$ 1,772,454	$6,461,525	$ 6,174,244		$ -	$ 24,083,731	$ 23,012,961
2014	$1,139,278	$ 1,064,150	$ 11,663,838	$ 10,894,682	$ 2,530,652	$ 2,363,771	$9,046,558	$ 8,449,995		$ -	$ 24,083,731	$ 22,495,563
2015	$1,246,571	$ 1,138,189	$ 14,038,735	$ 12,818,153	$ 3,235,089	$ 2,953,818	$11,859,365	$ 10,828,265		$ -	$ 24,083,731	$ 21,989,798
2016	$1,300,597	$ 1,160,820	$ 16,616,180	$ 14,830,405	$ 3,968,236	$ 3,541,761	$14,907,254	$ 13,305,141		$ -	$ 24,083,731	$ 21,495,403
2017	$1,630,258	$ 1,422,337	$ 19,790,149	$ 17,266,140	$ 5,877,481	$ 5,127,875	$22,611,749	$ 19,727,877		$ -	$ 24,083,731	$ 21,012,125
2018	$1,884,158	$ 1,606,896	$ 23,283,853	$ 19,857,539	$ 7,864,186	$ 6,706,939	$30,965,111	$ 26,408,468		$ -	$ 24,083,731	$ 20,539,711
2019	$122,072	$ 101,768	$ 27,113,777	$ 22,603,982	$ 9,928,350	$ 8,276,982	$39,987,057	$ 33,336,068		$ -	$ 24,083,731	$ 20,077,919
2020	$2,554,130	$ 2,081,433	$ 31,297,020	$ 25,504,821	$ 12,069,972	$ 9,836,160	$49,697,301	$ 40,499,727		$ -	$ 24,083,731	$ 19,626,509
2021	$2,823,816	$ 2,249,469	$ 35,851,313	$ 28,559,377	$ 14,289,054	$ 11,382,748	$60,115,558	$ 47,888,424		$ -	$ 24,083,731	$ 19,185,249
2022	$3,350,373	$ 2,608,923	$ 40,795,043	$ 31,766,943	$ 16,585,594	$ 12,915,139	$71,261,545	$ 55,491,091		$ -	$ 24,083,731	$ 18,753,909
2023	$3,876,930	$ 2,951,076	$ 47,010,760	$ 35,784,065	$ 20,522,377	$ 15,621,403	$90,009,192	$ 68,513,990		$ -	$ 24,083,731	$ 18,332,267
2024	$4,586,904	$ 3,413,001	$ 53,808,379	$ 40,037,474	$ 24,595,510	$ 18,300,906	$110,066,175	$ 81,897,498		$ -	$ 24,083,731	$ 17,920,104
2025	$5,296,201	$ 3,852,171	$ 61,218,012	$ 44,526,683	$ 28,804,993	$ 20,951,200	$131,467,199	$ 95,622,158		$ -	$ 24,083,731	$ 17,517,208
2026	$6,069,808	$ 4,315,593	$ 69,270,907	$ 49,251,149	$ 33,150,827	$ 23,570,015	$154,246,968	$ 109,668,558		$ -	$ 24,083,731	$ 17,123,371
2027	$6,862,296	$ 4,769,352	$ 77,999,478	$ 54,210,269	$ 37,633,012	$ 26,155,248	$178,440,186	$ 124,017,373		$ -	$ 24,083,731	$ 16,738,388
2028	$7,679,514	$ 5,217,326	$ 87,437,346	$ 59,403,385	$ 42,251,548	$ 28,704,954	$204,081,557	$ 138,649,398		$ -	$ 24,083,731	$ 16,362,061
2029	$8,659,891	$ 5,751,101	$ 98,222,702	$ 65,230,464	$ 47,769,863	$ 31,724,340	$234,960,785	$ 156,039,294		$ -	$ 24,083,731	$ 15,994,194
2030	$9,685,772	$ 6,287,778	$ 109,874,070	$ 71,327,692	$ 53,450,376	$ 34,698,741	$267,621,843	$ 173,733,879		$ -	$ 24,083,731	$ 15,634,598
2031	$10,726,291	$ 6,806,705	$ 122,433,979	$ 77,694,323	$ 59,293,086	$ 37,626,288	$302,106,014	$ 191,710,852		$ -	$ 24,083,731	$ 15,283,087
2032	$11,804,060	$ 7,322,226	$ 135,946,517	$ 84,329,549	$ 65,297,994	$ 40,505,270	$338,454,580	$ 209,948,167		$ -	$ 24,083,731	$ 14,939,479
2033	$12,913,153	$ 7,830,119	$ 150,457,385	$ 91,232,498	$ 71,465,099	$ 43,334,128	$376,708,824	$ 228,424,062		$ -	$ 24,083,731	$ 14,603,597
2034	$14,053,708	$ 8,330,122	$ 166,013,944	$ 98,402,242	$ 77,794,403	$ 46,111,450	$416,910,026	$ 247,117,080		$ -	$ 24,083,731	$ 14,275,266
2035	$16,250,738	$ 9,415,814	$ 188,671,097	$ 109,317,619	$ 89,981,076	$ 52,135,792	$490,120,683	$ 283,980,043		$ -	$ 24,083,731	$ 13,954,316
2036	$18,511,345	$ 10,484,486	$ 213,202,215	$ 120,753,818	$ 102,504,987	$ 58,056,942	$567,328,742	$ 321,324,577		$ -	$ 24,083,731	$ 13,640,583
2037	$20,833,581	$ 11,534,465	$ 239,700,846	$ 132,709,829	$ 115,366,135	$ 63,872,199	$648,620,037	$ 359,107,011		$ -	$ 24,083,731	$ 13,333,903
2038	$23,216,182	$ 12,564,601	$ 268,264,005	$ 145,184,514	$ 128,564,520	$ 69,579,134	$734,080,399	$ 397,284,405		$ -	$ 24,083,731	$ 13,034,118
2039	$25,660,335	$ 13,575,148	$ 298,992,285	$ 158,176,601	$ 142,100,141	$ 75,175,576	$823,795,659	$ 435,814,580		$ -	$ -	$ -
2040	$28,165,454	$ 14,565,432	$ 334,683,499	$ 173,077,623	$ 155,972,999	$ 80,659,597	$921,593,229	$ 476,591,067	$ (2,837,682,746)	$ (1,467,474,157)	$ -	$ -
SUM	$253,179,559	$ 154,676,877	$ 2,966,292,983	$ 1,816,797,573	$ 1,376,519,989	$ 833,431,177	$ 7,313,568,016	$ 4,367,504,075	$ 3,637,327,361	$ 5,007,535,949	$ 674,344,472	$ 480,417,947
	Total Benefits	$ 7,172,409,701		BCR	1.306936945							
	Total Costs	$ 5,487,953,896		NPV	$ 1,684,455,805							

Appendix 2E Summary of Benefits & Costs – Increase ITS Costs By 100%

Year	BENEFITS								COSTS			
	Pollutants		Travel Time Savings		Crashes		Operating Cost Savings		Capital Costs		O & M Costs	
	Value	Present Value	Value	Present Value	Value	Present Value	Value	Present Value	Value	Present Value	Value	Present Value
2011	$1,397,089	$ 1,397,089	$ 5,666,668	$ 5,666,668	$ 589,598	$ 589,598	$1,945,934	$ 1,945,934	$ 7,400,011,550	$ 7,400,011,550	$ 27,524,264	
2012	$879,054	$ 859,290	$ 7,486,391	$ 7,318,075	$ 1,207,906	$ 1,180,749	$4,096,960	$ 4,004,848		$ -	$ 27,524,264	$ 26,905,439
2013	$0	$ -	$ 9,482,589	$ 9,060,990	$ 1,854,924	$ 1,772,454	$6,461,525	$ 6,174,244		$ -	$ 27,524,264	$ 26,300,527
2014	$1,139,278	$ 1,064,150	$ 11,663,838	$ 10,894,682	$ 2,530,652	$ 2,363,771	$9,046,558	$ 8,449,995		$ -	$ 27,524,264	$ 25,709,215
2015	$1,246,571	$ 1,138,189	$ 14,038,735	$ 12,818,153	$ 3,235,089	$ 2,953,818	$11,859,365	$ 10,828,265		$ -	$ 27,524,264	$ 25,131,197
2016	$1,300,597	$ 1,160,820	$ 16,616,180	$ 14,830,405	$ 3,968,236	$ 3,541,761	$14,907,254	$ 13,305,141		$ -	$ 27,524,264	$ 24,566,175
2017	$1,630,258	$ 1,422,337	$ 19,790,149	$ 17,266,140	$ 5,877,481	$ 5,127,875	$22,611,749	$ 19,727,877		$ -	$ 27,524,264	$ 24,013,857
2018	$1,884,158	$ 1,606,896	$ 23,283,853	$ 19,857,539	$ 7,864,186	$ 6,706,939	$30,965,111	$ 26,408,468		$ -	$ 27,524,264	$ 23,473,956
2019	$122,072	$ 101,768	$ 27,113,777	$ 22,603,982	$ 9,928,350	$ 8,276,982	$39,987,057	$ 33,336,068		$ -	$ 27,524,264	$ 22,946,193
2020	$2,554,130	$ 2,081,433	$ 31,297,020	$ 25,504,821	$ 12,069,972	$ 9,836,160	$49,697,301	$ 40,499,727		$ -	$ 27,524,264	$ 22,430,296
2021	$2,823,816	$ 2,249,469	$ 35,851,313	$ 28,559,377	$ 14,289,054	$ 11,382,748	$60,115,558	$ 47,888,424		$ -	$ 27,524,264	$ 21,925,998
2022	$3,350,373	$ 2,608,923	$ 40,795,043	$ 31,766,943	$ 16,585,594	$ 12,915,139	$71,261,545	$ 55,491,091		$ -	$ 27,524,264	$ 21,433,039
2023	$3,876,930	$ 2,951,076	$ 47,010,760	$ 35,784,065	$ 20,522,377	$ 15,621,403	$90,009,192	$ 68,513,990		$ -	$ 27,524,264	$ 20,951,162
2024	$4,586,904	$ 3,413,001	$ 53,808,379	$ 40,037,474	$ 24,595,510	$ 18,300,906	$110,066,175	$ 81,897,498		$ -	$ 27,524,264	$ 20,480,119
2025	$5,296,201	$ 3,852,171	$ 61,218,012	$ 44,526,683	$ 28,804,993	$ 20,951,200	$131,467,199	$ 95,622,158		$ -	$ 27,524,264	$ 20,019,667
2026	$6,069,808	$ 4,315,593	$ 69,270,907	$ 49,251,149	$ 33,150,827	$ 23,570,015	$154,246,968	$ 109,668,558		$ -	$ 27,524,264	$ 19,569,567
2027	$6,862,296	$ 4,769,352	$ 77,999,478	$ 54,210,269	$ 37,633,012	$ 26,155,248	$178,440,186	$ 124,017,373		$ -	$ 27,524,264	$ 19,129,586
2028	$7,679,514	$ 5,217,326	$ 87,437,346	$ 59,403,385	$ 42,251,548	$ 28,704,954	$204,081,557	$ 138,649,398		$ -	$ 27,524,264	$ 18,699,498
2029	$8,659,891	$ 5,751,101	$ 98,222,702	$ 65,230,464	$ 47,769,863	$ 31,724,340	$234,960,785	$ 156,039,294		$ -	$ 27,524,264	$ 18,279,079
2030	$9,685,772	$ 6,287,778	$ 109,874,070	$ 71,327,692	$ 53,450,376	$ 34,698,741	$267,621,843	$ 173,733,879		$ -	$ 27,524,264	$ 17,868,112
2031	$10,726,291	$ 6,806,705	$ 122,433,979	$ 77,694,323	$ 59,293,086	$ 37,626,288	$302,106,014	$ 191,710,852		$ -	$ 27,524,264	$ 17,466,386
2032	$11,804,060	$ 7,322,226	$ 135,946,517	$ 84,329,549	$ 65,297,994	$ 40,505,270	$338,454,580	$ 209,948,167		$ -	$ 27,524,264	$ 17,073,691
2033	$12,913,153	$ 7,830,119	$ 150,457,385	$ 91,232,498	$ 71,465,099	$ 43,334,128	$376,708,824	$ 228,424,062		$ -	$ 27,524,264	$ 16,689,825
2034	$14,053,708	$ 8,330,122	$ 166,013,944	$ 98,402,242	$ 77,794,403	$ 46,111,450	$416,910,026	$ 247,117,080		$ -	$ 27,524,264	$ 16,314,589
2035	$16,250,738	$ 9,415,814	$ 188,671,097	$ 109,317,619	$ 89,981,076	$ 52,135,792	$490,120,683	$ 283,980,043		$ -	$ 27,524,264	$ 15,947,790
2036	$18,511,345	$ 10,484,486	$ 213,202,215	$ 120,753,818	$ 102,504,987	$ 58,056,942	$567,328,742	$ 321,324,577		$ -	$ 27,524,264	$ 15,589,238
2037	$20,833,581	$ 11,534,465	$ 239,700,846	$ 132,709,829	$ 115,366,135	$ 63,872,199	$648,620,037	$ 359,107,011		$ -	$ 27,524,264	$ 15,238,746
2038	$23,216,182	$ 12,564,601	$ 268,264,005	$ 145,184,514	$ 128,564,520	$ 69,579,134	$734,080,399	$ 397,284,405		$ -	$ 27,524,264	$ 14,896,135
2039	$25,660,335	$ 13,575,148	$ 298,992,285	$ 158,176,601	$ 142,100,141	$ 75,175,576	$823,795,659	$ 435,814,580		$ -	$ -	$ -
2040	$28,165,454	$ 14,565,432	$ 334,683,499	$ 173,077,623	$ 155,972,999	$ 80,659,597	$921,593,229	$ 476,591,067	$ (3,300,183,468)	$ (1,706,650,950)	$ -	$ -
SUM	$253,179,559	$ 154,676,877	$ 2,966,292,983	$ 1,816,797,573	$ 1,376,519,989	$ 833,431,177	$ 7,313,568,016	$ 4,367,504,075	$ 4,099,828,083	$ 5,693,360,601	$ 770,679,396	$ 549,049,082

Total Benefits	$ 7,172,409,701		BCR	1.148980933	
Total Costs	$ 6,242,409,683		NPV	$ 930,000,018	

Appendix 3 Original FAF Data

ID	LENGTH	DIR	RECTYPE	VERSION	STATE	STFIPS	CTFIPS	SIGN1
88943	2.81	0	L	2005.08	MO	29	19	I70
90737	2.38	0	L	2005.08	MO	29	95	I70
90734	0.95	0	L	2005.08	MO	29	95	I70
90731	1.25	0	L	2005.08	MO	29	95	I70
88372	0.37	0	L	2005.08	MO	29	95	I70
88376	0.26	0	L	2005.08	MO	29	95	I70
88377	0.25	0	L	2005.08	MO	29	95	I70
88375	0.38	0	L	2005.08	MO	29	95	I70
90733	0.27	0	L	2005.08	MO	29	95	I70
90732	0.24	0	L	2005.08	MO	29	95	I70
90735	0.27	0	L	2005.08	MO	29	95	I70
90736	0.26	0	L	2005.08	MO	29	95	I70
90055	15.40	0	L	2005.08	MO	29	195	I70
89027	19.93	0	L	2005.08	MO	29	107	I70
90741	2.75	0	L	2005.08	MO	29	95	I70
91065	4.43	0	L	2005.08	MO	29	95	I70
90739	0.23	0	L	2005.08	MO	29	95	I70
90740	0.29	0	L	2005.08	MO	29	95	I70
90743	0.21	0	L	2005.08	MO	29	95	I70
90742	0.19	0	L	2005.08	MO	29	95	I70
88926	4.30	0	L	2005.08	MO	29	95	I70
90228	0.89	0	L	2005.08	MO	29	95	I70
90229	0.25	0	L	2005.08	MO	29	95	I70
90231	0.20	0	L	2005.08	MO	29	95	I70
90232	0.22	0	L	2005.08	MO	29	95	I70
90045	8.58	0	L	2005.08	MO	29	107	I70
90040	0.34	0	L	2005.08	MO	29	107	I70
90042	0.29	0	L	2005.08	MO	29	107	I70
90044	3.71	0	L	2005.08	MO	29	107	I70
90048	0.27	0	L	2005.08	MO	29	107	I70
90047	0.30	0	L	2005.08	MO	29	107	I70
90059	2.81	0	L	2005.08	MO	29	53	I70
90050	8.32	0	L	2005.08	MO	29	195	I70
90053	0.22	0	L	2005.08	MO	29	195	I70
90054	0.21	0	L	2005.08	MO	29	195	I70
90058	11.04	0	L	2005.08	MO	29	53	I70
90061	0.25	0	L	2005.08	MO	29	53	I70
90062	0.25	0	L	2005.08	MO	29	53	I70
88280	6.07	0	L	2005.08	MO	29	19	I70
88253	10.83	0	L	2005.08	MO	29	53	I70

90063	1.80	0	L	2005.08	MO	29	53	I70
90065	0.44	0	L	2005.08	MO	29	53	I70
90066	0.29	0	L	2005.08	MO	29	53	I70
90069	0.30	0	L	2005.08	MO	29	53	I70
88279	1.23	0	L	2005.08	MO	29	19	I70
88282	0.37	0	L	2005.08	MO	29	19	I70
88283	0.38	0	L	2005.08	MO	29	19	I70
88619	0.58	0	L	2005.08	MO	29	19	I70
90465	0.27	0	L	2005.08	MO	29	19	I70
90464	1.38	0	L	2005.08	MO	29	19	I70
88616	0.66	0	L	2005.08	MO	29	19	I70
90466	0.29	0	L	2005.08	MO	29	19	I70
88618	0.22	0	L	2005.08	MO	29	19	I70
88617	0.22	0	L	2005.08	MO	29	19	I70
88941	0.76	0	L	2005.08	MO	29	19	I70
88939	0.23	0	L	2005.08	MO	29	19	I70
88620	0.22	0	L	2005.08	MO	29	19	I70
88621	0.23	0	L	2005.08	MO	29	19	I70
88940	0.21	0	L	2005.08	MO	29	19	I70
88938	0.02	0	L	2005.08	MO	29	19	I70
88944	0.18	0	L	2005.08	MO	29	19	I70
89049	0.49	0	L	2005.08	MO	29	19	I70
88942	0.37	0	L	2005.08	MO	29	19	I70
88945	0.08	0	L	2005.08	MO	29	19	I70
90088	7.14	0	L	2005.08	MO	29	219	I70
91014	16.55	0	L	2005.08	MO	29	27	I70
90073	11.11	0	L	2005.08	MO	29	27	I70
89097	4.11	0	L	2005.08	MO	29	19	I70
89092	0.54	0	L	2005.08	MO	29	19	I70
90075	0.25	0	L	2005.08	MO	29	27	I70
90077	0.26	0	L	2005.08	MO	29	27	I70
90081	9.93	0	L	2005.08	MO	29	139	I70
90079	10.84	0	L	2005.08	MO	29	139	I70
90083	0.29	0	L	2005.08	MO	29	139	I70
90085	0.29	0	L	2005.08	MO	29	139	I70
90087	9.61	0	L	2005.08	MO	29	219	I70
90090	0.26	0	L	2005.08	MO	29	219	I70
90092	0.25	0	L	2005.08	MO	29	219	I70
89133	3.12	0	L	2005.08	MO	29	183	I70
89131	1.25	0	L	2005.08	MO	29	183	I70
88946	1.96	0	L	2005.08	MO	29	183	I70
88948	0.71	0	L	2005.08	MO	29	183	I70

ID	SIGNT1	SIGNN1	SIGNQ1	SIGN2	SIGNT2	SIGNN2	SIGNQ2	SIGN3
88943	I	70						
90737	I	70						
90734	I	70						
90731	I	70						
88372	I	70						
88376	I	70						
88377	I	70						
88375	I	70						
90733	I	70						
90732	I	70						
90735	I	70						
90736	I	70						
90055	I	70		U40	U	40		
89027	I	70		U40	U	40		
90741	I	70						
91065	I	70						
90739	I	70						
90740	I	70						
90743	I	70						
90742	I	70						
88926	I	70		U40	U	40		
90228	I	70						
90229	I	70		U40	U	40		
90231	I	70						
90232	I	70		U40	U	40		
90045	I	70		U40	U	40		
90040	I	70		U40	U	40		
90042	I	70		U40	U	40		
90044	I	70		U40	U	40		
90048	I	70		U40	U	40		
90047	I	70		U40	U	40		
90059	I	70		U40	U	40		
90050	I	70		U40	U	40		
90053	I	70		U40	U	40		
90054	I	70		U40	U	40		U65
90058	I	70		U40	U	40		
90061	I	70		U40	U	40		
90062	I	70		U40	U	40		
88280	I	70						
88253	I	70						
90063	I	70						
90065	I	70		U40	U	40		
90066	I	70		U40	U	40		

90069	I	70		U40	U	40		
88279	I	70		U40	U	40		
88282	I	70		U40	U	40		
88283	I	70						
88619	I	70						
90465	I	70						
90464	I	70						
88616	I	70						
90466	I	70						
88618	I	70						
88617	I	70						
88941	I	70						
88939	I	70						
88620	I	70						
88621	I	70						
88940	I	70						
88938	I	70						
88944	I	70						
89049	I	70						
88942	I	70						
88945	I	70						
90088	I	70		U40	U	40		
91014	I	70		U40	U	40		
90073	I	70		U40	U	40		
89097	I	70		U40	U	40		
89092	I	70		U40	U	40		
90075	I	70		U40	U	40		
90077	I	70		U40	U	40		
90081	I	70		U40	U	40		
90079	I	70		U40	U	40		
90083	I	70		U40	U	40		
90085	I	70		U40	U	40		
90087	I	70		U40	U	40		
90090	I	70		U40	U	40		
90092	I	70		U40	U	40		
89133	I	70		U40	U	40		
89131	I	70		U40	U	40		
88946	I	70						
88948	I	70						

ID	SIGNT3	SIGNN3	SIGNQ3	LNAME	MILES	KM	FCLASS	RUCODE
88943					2.8150	4.504	11	3
90737					2.3827	3.812	11	4
90734					0.9537	1.526	11	4
90731					1.2545	2.007	11	4
88372					0.3662	0.586	11	4
88376					0.2558	0.409	11	4
88377					0.2489	0.398	11	4
88375					0.3813	0.610	11	4
90733					0.2685	0.430	11	4
90732					0.2437	0.390	11	4
90735					0.2720	0.435	11	4
90736					0.2648	0.424	11	4
90055					15.4042	24.647	1	1
89027					19.9257	31.881	1	1
90741					2.7482	4.397	11	4
91065					4.4279	7.085	11	4
90739					0.2276	0.364	11	4
90740					0.2899	0.464	11	4
90743					0.2095	0.335	11	4
90742					0.1851	0.296	11	4
88926					4.3021	6.883	1	1
90228					0.8920	1.427	1	4
90229					0.2520	0.403	1	4
90231					0.2040	0.326	1	4
90232					0.2173	0.348	1	4
90045					8.5783	13.725	1	1
90040					0.3378	0.540	1	1
90042					0.2929	0.469	1	1
90044					3.7091	5.935	1	1
90048					0.2712	0.434	1	1
90047					0.3032	0.485	1	1
90059					2.8064	4.490	1	1
90050					8.3235	13.318	1	1
90053					0.2184	0.349	1	1
90054	U	65			0.2106	0.337	1	1
90058					11.0357	17.657	1	1
90061					0.2477	0.396	1	1
90062					0.2481	0.397	1	1
88280					6.0710	9.714	1	1
88253					10.8311	17.330	1	1
90063					1.8026	2.884	11	1
90065					0.4427	0.708	11	1
90066					0.2945	0.471	11	1

90069					0.3016	0.483	11	1
88279					1.2260	1.962	1	3
88282					0.3670	0.587	1	1
88283					0.3818	0.611	1	1
88619					0.5767	0.923	11	3
90465					0.2659	0.425	11	3
90464					1.3831	2.213	11	3
88616					0.6608	1.057	11	3
90466					0.2895	0.463	11	3
88618					0.2192	0.351	11	3
88617					0.2166	0.347	11	3
88941					0.7626	1.220	11	3
88939					0.2317	0.371	11	3
88620					0.2214	0.354	11	3
88621					0.2311	0.370	11	3
88940					0.2103	0.336	11	3
88938					0.0211	0.034	11	3
88944					0.2368	0.379	11	3
89049					0.3115	0.498	11	3
88942					0.3703	0.593	11	3
88945					0.2083	0.333	11	3
90088					7.1356	11.417	1	1
91014					16.5520	26.483	1	1
90073					11.1068	17.771	1	1
89097					4.1113	6.578	1	1
89092					0.5362	0.858	1	3
90075					0.2491	0.399	1	1
90077					0.2594	0.415	1	1
90081					9.9329	15.893	1	1
90079					10.8437	17.350	1	1
90083					0.2922	0.468	1	1
90085					0.2941	0.471	1	1
90087					9.6142	15.383	1	1
90090					0.2623	0.420	1	1
90092					0.2509	0.402	1	1
89133					3.1239	4.998	1	4
89131					1.2483	1.997	1	4
88946					1.9627	3.140	11	4
88948					0.7141	1.143	11	4

ID	STATUS	NHS	NN	TRK_TYPE	LCV_TYPE	OID_	ID_1	VERSION_1
88943	1	1	1	2	0	67303	88943	3.11
90737	1	1	1	2	0	75110	90737	3.11
90734	1	1	1	2	0	76269	90734	3.11
90731	1	1	1	2	0	76281	90731	3.11
88372	1	1	1	2	0	76294	88372	3.11
88376	1	1	1	2	0	76302	88376	3.11
88377	1	1	1	2	0	76303	88377	3.11
88375	1	1	1	2	0	76305	88375	3.11
90733	1	1	1	2	0	76308	90733	3.11
90732	1	1	1	2	0	76310	90732	3.11
90735	1	1	1	2	0	76320	90735	3.11
90736	1	1	1	2	0	76322	90736	3.11
90055	1	1	1	2	0	77731	90055	3.11
89027	1	1	1	2	0	77844	89027	3.11
90741	1	1	1	2	0	77853	90741	3.11
91065	1	1	1	2	0	77864	91065	3.11
90739	1	1	1	2	0	77883	90739	3.11
90740	1	1	1	2	0	77888	90740	3.11
90743	1	1	1	2	0	77893	90743	3.11
90742	1	1	1	2	0	77895	90742	3.11
88926	1	1	1	2	0	77898	88926	3.11
90228	1	1	1	2	0	77899	90228	3.11
90229	1	1	1	2	0	77901	90229	3.11
90231	1	1	1	2	0	77902	90231	3.11
90232	1	1	1	2	0	77904	90232	3.11
90045	1	1	1	2	0	77977	90045	3.11
90040	1	1	1	2	0	77979	90040	3.11
90042	1	1	1	2	0	77981	90042	3.11
90044	1	1	1	2	0	77983	90044	3.11
90048	1	1	1	2	0	77985	90048	3.11
90047	1	1	1	2	0	77986	90047	3.11
90059	1	1	1	2	0	78081	90059	3.11
90050	1	1	1	2	0	78085	90050	3.11
90053	1	1	1	2	0	78086	90053	3.11
90054	1	1	1	2	0	78089	90054	3.11
90058	1	1	1	2	0	78100	90058	3.11
90061	1	1	1	2	0	78102	90061	3.11
90062	1	1	1	2	0	78103	90062	3.11
88280	1	1	1	2	0	78114	88280	3.11
88253	1	1	1	2	0	78118	88253	3.11
90063	1	1	1	2	0	78123	90063	3.11
90065	1	1	1	2	0	78124	90065	3.11
90066	1	1	1	2	0	78125	90066	3.11

90069	1	1	1	2	0	78127	90069	3.11
88279	1	1	1	2	0	78134	88279	3.11
88282	1	1	1	2	0	78136	88282	3.11
88283	1	1	1	2	0	78138	88283	3.11
88619	1	1	1	2	0	78146	88619	3.11
90465	1	1	1	2	0	78148	90465	3.11
90464	1	1	1	2	0	78149	90464	3.11
88616	1	1	1	2	0	78150	88616	3.11
90466	1	1	1	2	0	78151	90466	3.11
88618	1	1	1	2	0	78154	88618	3.11
88617	1	1	1	2	0	78155	88617	3.11
88941	1	1	1	2	0	78158	88941	3.11
88939	1	1	1	2	0	78163	88939	3.11
88620	1	1	1	2	0	78165	88620	3.11
88621	1	1	1	2	0	78166	88621	3.11
88940	1	1	1	2	0	78171	88940	3.11
88938	1	1	1	2	0	78172	88938	3.11
88944	1	1	1	2	0	78175	88944	3.11
89049	1	1	1	2	0	78177	89049	3.11
88942	1	1	1	2	0	78178	88942	3.11
88945	1	1	1	2	0	78179	88945	3.11
90088	1	1	1	2	0	88695	90088	3.11
91014	1	1	1	2	0	88827	91014	3.11
90073	1	1	1	2	0	88830	90073	3.11
89097	1	1	1	2	0	88831	89097	3.11
89092	1	1	1	2	0	88832	89092	3.11
90075	1	1	1	2	0	88843	90075	3.11
90077	1	1	1	2	0	88844	90077	3.11
90081	1	1	1	2	0	88877	90081	3.11
90079	1	1	1	2	0	88881	90079	3.11
90083	1	1	1	2	0	88882	90083	3.11
90085	1	1	1	2	0	88885	90085	3.11
90087	1	1	1	2	0	89917	90087	3.11
90090	1	1	1	2	0	89921	90090	3.11
90092	1	1	1	2	0	89923	90092	3.11
89133	1	1	1	2	0	89928	89133	3.11
89131	1	1	1	2	0	89929	89131	3.11
88946	1	1	1	2	0	89930	88946	3.11
88948	1	1	1	2	0	89931	88948	3.11

ID	AADT07	AADTT07	FAF07	NONFAF07	AADT40	AADTT40	FAF40
88943	43295	12988	10423	2565	64269	23500	19688
90737	106500	12780	8897	3883	158095	22436	16426
90734	113286	13594	8976	4618	168168	23514	17197
90731	107732	12927	8976	3951	159923	22524	17197
88372	112564	13507	8976	4531	167096	23385	17197
88376	107732	12927	8976	3951	159923	22524	17197
88377	112564	13507	8976	4531	167096	23385	17197
88375	112564	13507	8976	4531	167096	23385	17197
90733	107732	12927	8976	3951	159923	22524	17197
90732	113286	13594	8976	4618	168168	23514	17197
90735	106500	12780	8897	3883	158095	22436	16426
90736	113286	13594	8976	4618	168168	23514	17197
90055	23938	6942	9265	0	35535	20752	17411
89027	35693	9994	9708	286	52984	18558	18038
90741	46330	11582	9708	1874	68775	20915	18038
91065	88987	17797	10407	7390	132097	30105	19045
90739	106500	12780	8897	3883	158095	22436	16426
90740	88987	17797	10407	7390	132097	30105	19045
90743	88987	17797	10407	7390	132097	30105	19045
90742	46330	11582	10444	1138	68775	20882	19108
88926	35693	9994	9708	286	52984	18558	18038
90228	46330	11582	9708	1874	68775	20915	18038
90229	35693	9994	9708	286	52984	18558	18038
90231	46330	11582	9708	1874	68775	20915	18038
90232	35693	9994	9708	286	52984	18558	18038
90045	19799	5939	9289	0	29390	22319	17447
90040	19799	5939	9289	0	29390	22319	17447
90042	35693	9994	9269	725	52984	18605	17387
90044	23938	6942	9265	0	35535	20752	17411
90048	19799	5939	9289	0	29390	22319	17447
90047	23938	6942	9265	0	35535	20752	17411
90059	28550	7994	10255	0	42381	22313	19114
90050	27898	7811	10255	0	41413	22585	19114
90053	27898	7811	10255	0	41413	22585	19114
90054	23938	6942	9265	0	35535	20752	17411
90058	27898	7811	10255	0	41413	22585	19114
90061	27898	7811	10255	0	41413	22585	19114
90062	28550	7994	10255	0	42381	22313	19114
88280	28461	7969	10125	0	42249	21950	18923
88253	28461	7969	10125	0	42249	21950	18923
90063	28461	7969	10169	0	42249	22066	18971
90065	28550	7994	10255	0	42381	22313	19114
90066	28461	7969	10169	0	42249	22066	18971

90069	28550	7994	10255	0	42381	22313	19114
88279	45933	13320	10186	3134	68185	23773	19033
88282	45933	13320	10186	3134	68185	23773	19033
88283	28461	7969	10125	0	42249	21950	18923
88619	69669	20900	9642	11258	103420	34968	19218
90465	45933	13320	10253	3067	68185	23859	19218
90464	45933	13320	10253	3067	68185	23859	19218
88616	66107	19832	9642	10190	98133	33382	19218
90466	66107	19832	9642	10190	98133	33382	19218
88618	69669	20900	9642	11258	103420	34968	19218
88617	66107	19832	9642	10190	98133	33382	19218
88941	63750	19125	9412	9713	94634	32327	18882
88939	63750	19125	9412	9713	94634	32327	18882
88620	69669	20900	9642	11258	103420	34968	19218
88621	71923	21576	9642	11934	106766	35971	19218
88940	71923	21576	9642	11934	106766	35971	19218
88938	71923	21576	9642	11934	106766	35971	19218
88944	43295	12988	10423	2565	64269	23500	19688
89049	63490	19047	9412	9635	94248	32211	18882
88942	63750	19125	9412	9713	94634	32327	18882
88945	43295	12988	10423	2565	64269	23500	19688
90088	30464	8834	10720	0	45222	23012	20190
91014	26926	7808	9866	0	39970	22256	19188
90073	43295	12988	10013	2975	64269	23486	19087
89097	43295	12988	10013	2975	64269	23486	19087
89092	43295	12988	10013	2975	64269	23486	19087
90075	26926	7808	9866	0	39970	22256	19188
90077	43295	12988	10013	2975	64269	23486	19087
90081	26926	7808	9866	0	39970	22256	19188
90079	30464	8834	9758	0	45222	20370	18974
90083	30464	8834	9758	0	45222	20370	18974
90085	26926	7808	9845	0	39970	22043	19041
90087	57717	13274	10537	2737	85678	23852	19915
90090	57717	13274	10537	2737	85678	23852	19915
90092	30464	8834	10720	0	45222	23012	20190
89133	57717	13274	10537	2737	85678	23852	19915
89131	57717	13274	10537	2737	85678	23852	19915
88946	57717	13274	10537	2737	85678	23852	19915
88948	57717	13274	11905	1369	85678	23579	21646

ID	NONFAF40	CAP07	SF07	VCR07	SPEED07	DELAY07	CAP40
88943	3812	3509	1731	0.493	54.173	0.0000	3411
90737	6010	5827	5325	0.914	55.046	0.0002	5995
90734	6316	6057	5890	0.972	54.962	0.0001	6001
90731	5326	5976	5602	0.937	55.111	0.0001	5998
88372	6187	6057	5853	0.966	55.194	0.0000	6001
88376	5326	5976	5602	0.937	55.261	0.0000	5998
88377	6187	6057	5853	0.966	55.228	0.0000	6001
88375	6187	6057	5853	0.966	55.190	0.0000	6001
90733	5326	5976	5602	0.937	55.259	0.0000	5998
90732	6316	6057	5890	0.972	55.213	0.0000	6001
90735	6010	5942	5538	0.932	55.262	0.0000	5995
90736	6316	6057	5890	0.972	55.205	0.0000	6001
90055	3340	2869	1711	0.596	70.036	0.0092	2369
89027	519	2900	2227	0.768	65.601	0.0312	2914
90741	2876	3580	2455	0.686	53.743	0.0001	3690
91065	11060	5530	4627	0.837	55.072	0.0003	5764
90739	6010	5827	5325	0.914	55.276	0.0000	5995
90740	11060	5530	4449	0.805	55.288	0.0000	5764
90743	11060	5530	4894	0.885	55.284	0.0000	5764
90742	1774	3580	2455	0.686	53.796	0.0000	3691
88926	519	2900	2159	0.745	71.351	0.0014	2914
90228	2876	3580	2455	0.686	53.781	0.0000	3690
90229	519	3533	1784	0.505	53.798	0.0000	3428
90231	2876	3580	2455	0.686	53.796	0.0000	3690
90232	519	3533	1784	0.505	53.798	0.0000	3428
90045	4871	2840	1441	0.507	71.856	0.0020	2078
90040	4871	2840	1441	0.507	73.050	0.0000	2078
90042	1218	2900	2227	0.768	72.961	0.0000	2912
90044	3340	2869	1742	0.607	72.286	0.0006	2369
90048	4871	2840	1441	0.507	73.060	0.0000	2078
90047	3340	2869	1742	0.607	73.033	0.0000	2369
90059	3198	2900	1427	0.492	72.711	0.0002	2353
90050	3470	2900	1994	0.688	70.588	0.0041	2445
90053	3470	2900	1994	0.688	73.031	0.0000	2445
90054	3340	2869	1711	0.596	73.055	0.0000	2369
90058	3470	2900	1394	0.481	71.667	0.0030	2308
90061	3470	2900	1394	0.481	73.067	0.0000	2308
90062	3198	2900	1427	0.492	73.065	0.0000	2353
88280	3027	2900	1280	0.442	72.417	0.0008	2314
88253	3027	3612	1992	0.551	71.250	0.0038	3314
90063	3095	2900	996	0.343	72.965	0.0000	2309
90065	3198	2900	1427	0.492	73.038	0.0000	2353
90066	3095	2900	996	0.343	73.078	0.0000	2309

90069	3198	2900	1427	0.492	73.058	0.0000	2353
88279	4740	3524	2066	0.586	54.183	0.0000	3436
88282	4740	2869	2066	0.720	72.964	0.0000	2919
88283	3027	2900	1280	0.442	73.057	0.0000	2314
88619	15749	3509	3135	0.893	54.153	0.0000	3643
90465	4640	3524	2149	0.610	54.196	0.0000	3489
90464	4640	3524	2149	0.610	54.179	0.0000	3489
88616	14163	3509	2974	0.848	54.164	0.0000	3640
90466	14163	3509	2974	0.848	54.184	0.0000	3640
88618	15749	3509	3135	0.893	54.182	0.0000	3643
88617	14163	3509	2974	0.848	54.188	0.0000	3640
88941	13444	3509	2652	0.756	54.177	0.0000	3638
88939	13444	3509	2652	0.756	54.193	0.0000	3638
88620	15749	3509	3135	0.893	54.182	0.0000	3643
88621	16752	3552	3236	0.911	54.177	0.0000	3645
88940	16752	3509	2991	0.853	54.188	0.0000	3645
88938	16752	3552	3236	0.911	54.198	0.0000	3645
88944	3812	3509	1731	0.493	54.198	0.0000	3411
89049	13328	3509	2641	0.753	54.185	0.0000	3638
88942	13444	3509	2652	0.756	54.189	0.0000	3638
88945	3812	3509	1731	0.493	54.199	0.0000	3411
90088	2821	2869	1066	0.372	72.499	0.0008	2335
91014	3068	2869	1750	0.610	69.655	0.0112	2422
90073	4399	2840	1731	0.610	70.718	0.0051	2787
89097	4399	2840	1766	0.622	72.142	0.0007	2815
89092	4399	3509	1731	0.493	54.195	0.0000	3412
90075	3068	2869	1077	0.375	73.078	0.0000	2244
90077	4399	2840	1731	0.610	73.042	0.0000	2787
90081	3068	2869	1925	0.671	70.345	0.0053	2422
90079	1395	2869	2178	0.759	68.666	0.0096	2653
90083	1395	2869	2178	0.759	72.968	0.0000	2653
90085	3001	2869	1925	0.671	73.014	0.0000	2433
90087	3937	3693	2020	0.547	71.479	0.0030	3615
90090	3937	3062	2020	0.660	73.027	0.0000	3136
90092	2821	2869	1066	0.372	73.079	0.0000	2335
89133	3937	3612	3174	0.879	53.585	0.0002	3732
89131	3937	3612	3174	0.879	53.714	0.0000	3732
88946	3937	3612	2597	0.719	53.752	0.0000	3732
88948	1932	3612	2597	0.719	53.783	0.0000	3737

ID	SF40	VCR40	SPEED40	DELAY40
88943	2570	0.753	54.116	0.00008
90737	7904	1.318	6.589	0.31850
90734	8744	1.457	2.011	0.45711
90731	8315	1.386	3.067	0.38634
88372	8688	1.448	0.806	0.44790
88376	8315	1.386	0.654	0.38632
88377	8688	1.448	0.550	0.44789
88375	8688	1.448	0.838	0.44790
90733	8315	1.386	0.686	0.38632
90732	8744	1.457	0.528	0.45710
90735	8220	1.371	0.723	0.37116
90736	8744	1.457	0.573	0.45710
90055	2540	1.072	45.711	0.12626
89027	3306	1.134	42.514	0.19611
90741	3645	0.988	52.026	0.00174
91065	6869	1.192	16.271	0.19207
90739	7904	1.318	0.706	0.31842
90740	6604	1.146	1.919	0.14584
90743	7265	1.260	0.793	0.26042
90742	3645	0.987	53.662	0.00001
88926	3205	1.100	26.255	0.10501
90228	3645	0.988	53.141	0.00021
90229	2649	0.773	53.792	0.00000
90231	3645	0.988	53.645	0.00001
90232	2649	0.773	53.793	0.00000
90045	2139	1.029	47.779	0.06219
90040	2139	1.029	9.890	0.02953
90042	3306	1.135	2.102	0.13534
90044	2586	1.092	25.315	0.09578
90048	2139	1.029	8.169	0.02950
90047	2586	1.092	3.167	0.09159
90059	2119	0.900	69.695	0.00188
90050	2961	1.211	24.855	0.22102
90053	2961	1.211	1.021	0.21082
90054	2540	1.072	2.809	0.07208
90058	2070	0.897	63.344	0.02325
90061	2070	0.897	72.792	0.00001
90062	2119	0.900	72.780	0.00002
88280	1901	0.821	69.383	0.00445
88253	2957	0.892	63.746	0.02174
90063	1478	0.640	72.642	0.00016
90065	2119	0.900	72.531	0.00005
90066	1478	0.640	73.025	0.00000

90069	2119	0.900	72.711	0.00002
88279	3068	0.893	54.101	0.00004
88282	3068	1.051	6.535	0.05113
88283	1901	0.821	72.848	0.00002
88619	4653	1.277	2.003	0.27722
90465	3191	0.914	54.172	0.00000
90464	3191	0.914	54.057	0.00007
88616	4415	1.213	2.935	0.21299
90466	4415	1.213	1.326	0.21299
88618	4653	1.277	0.779	0.27722
88617	4415	1.213	0.998	0.21299
88941	3936	1.082	7.934	0.08204
88939	3936	1.082	2.685	0.08202
88620	4653	1.277	0.787	0.27722
88621	4804	1.318	0.717	0.31786
88940	4441	1.218	0.946	0.21829
88938	4804	1.318	0.066	0.31786
88944	2570	0.753	54.195	0.00000
89049	3920	1.078	5.653	0.07769
88942	3936	1.082	4.168	0.08202
88945	2570	0.753	54.198	0.00000
90088	1582	0.678	71.023	0.00285
91014	2598	1.072	46.152	0.13221
90073	2570	0.922	61.478	0.02872
89097	2622	0.931	66.377	0.00570
89092	2570	0.753	54.184	0.00000
90075	1598	0.712	73.011	0.00000
90077	2570	0.922	72.661	0.00002
90081	2857	1.180	29.959	0.19567
90079	3233	1.219	28.285	0.23504
90083	3233	1.219	1.312	0.21865
90085	2857	1.175	1.647	0.17455
90087	2998	0.829	67.297	0.01134
90090	2998	0.956	72.288	0.00004
90092	1582	0.678	73.024	0.00000
89133	4712	1.262	9.742	0.26261
89131	4712	1.262	4.370	0.26248
88946	3855	1.033	28.121	0.03331
88948	3855	1.031	15.939	0.03153

Bibliography

AASHTO. (2007). *America's Freight Challenge.* Washington, DC: American Association of State Highway and Transportation Officials.

AASHTO. (2011). *Estimating the Costs to State Governments Due to Highway-Related Fatal and Non-Fatal Injury Crashes.* Washington. D.C.: National Cooperative Highway Research Program.

Anderson, G. L., & Hadden, D. M. (2011). *Infrared Technology*. Retrieved May 2011, from Delphian Technology: http://www.delphian.com/infrared%20sensors.htm

Azcarate Lara, F. J. (2010). *Dualmode Transportation, Impact on the Electric Grid.* Texas A&M University.

Battelle, W., Mallett, W., Jones, C., Sedor, J., & Short, J. (2006). *Freight Performance Measurement: Travel Time in Freight-Significant Corridors.* Washington, D.C.: U.S. Department of Transportation.

Behroozi, M., & Arabi, S. (2010). Design of an Integrated Active Front Steering and Active Rear Differential Controller using Fuzzy Logic Control. *World Congress on Engineering 2010 Vol II.* London.

Belanovic, P., Valerio, D., Paier, A., Zemen, T., Ricciato, F., & Mecklenbrauker, C. (2010). On Wireless Links for Vehicle-to-Infrastructure Communications. *IEEE Transactions on Vehicular Technology, vol. 59, no. 1*, 269-282.

Bolger, J., & Kirsten, F. (1977). *Investigation of the Feasibility of a Dualmode Electric Transportation System.* Berkeley: Lawrence Berkeley Laboratory.

Bolger, J., Kirsten, F., & Ng, L. (1978). Inductive Power Coupling for an Electric Highway System. *Vehicular Technology Conference* (pp. 137-144). IEEE.

Boys, J., & Covic, G. (2010). *Inductive Power Transfer (IPT) - Powering Our Future.* Auckland, New Zealand: The University of Auckland.

Brown, M. (2010, May 12). *Can do CAN: A Simple Look at a Complex System*. Retrieved December 2010, from Brake & Front End: http://www.brakeandfrontend.com/Article/73701/can_do_can_a_simple_look_at_a_complex_system.aspx

CalTrans. (2007). *Types of Benefit-Cost Analysis*. Retrieved from California Department of Transportation: http://www.dot.ca.gov/hq/tpp/offices/ote/benefit_cost/calculations/types.html

CAN in Automation (CiA). (2011). *J1939-based higher-layer protocols*. Retrieved April 2011, from CiA Web site: http://www.can-cia.de/index.php?id=49

Carbaugh, J., Godbole, D., & Sengupta, R. (1998). Safety and capacity analysis of automated and manual highway systems. *Transportation Research Part C*, 69-99.

Ehlig-Economides, C., & Longbottom, J. (2008). *Dual Mode Vehicle and Infrastructure Alternatives Analysis.* College Station, TX: Texas Transportation Institute.

EIA. (2011, July). *State Total Electric Power Industry Net Generation, by Energy Source, 2005 - 2009 (Thousand MWh).* Retrieved October 2011, from Missouri Renewable Electricity Profile - US Energy Information Administration: http://www.eia.gov/cneaf/solar.renewables/page/state_profiles/missouri.html

EIA. (2011, September). *Weekly Retail Gasoline & Diesel Prices*. Retrieved from U.S. Energy Information Administration: http://www.eia.gov/dnav/pet/PET_PRI_GND_DCUS_R20_M.htm

Fancher, P. S., & Mathew, A. (1987). *A Vehicle Dynamics Handbook for Single-Unit and Articulated Heavy Trucks.* Washington, D.C.: NHTSA, U.S. DOT.

Ferlis, R. A. (2007, July/August). The Dream of an Automated Highway. *Public Roads*.

FHWA. (2010). *National Freight Transportation Trends and Emissions*. Retrieved January 2011, from Federal Highway Administration: http://www.fhwa.dot.gov/environment/freightaq/chapter2.htm

FHWA. (2011, July). *Appendix F: Procedures for Estimating Air Pollution Costs*. Retrieved from HERS-ST Highway Economic Requirements System - State Version: Technical Report: http://www.fhwa.dot.gov/asset/hersst/pubs/tech/tech14.cfm

FHWA. (2011, April). *CORRIDOR: Interstate 70 (I-70): Dedicated Truck Lanes - Missouri to Ohio.* Retrieved August 2011, from http://www.fhwa.dot.gov/pressroom/fsi70.htm

FHWA. (2011, April 7). *Economic Analysis Primer*. Retrieved October 2011, from Asset Management: http://www.fhwa.dot.gov/infrastructure/asstmgmt/primer05.cfm

FHWA. (2011, July). *Freight Analysis Framework*. Retrieved from Freight Management & Operations: http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm

Frank, R. (2007, February). *Power Conversion*. Retrieved May 2011, from Auto Electronics: http://autoelectronics.com/powertrain/hybrid_electric_vehicles/power_conversion-hybrid-electric-vehicles/

Gaj, S., & Sun, S. (2008, October 15). *Relationships Between Asset Management and Travel Demand: Findings and Recommendations from Four State DOT Site Visits*. Retrieved January 2011, from US DOT Federal Highway Administration: http://www.fhwa.dot.gov/infrastructure/asstmgmt/vmt02.cfm

Giler, E. (2009). Eric Giler demos wireless electricity. (TEDGlobal, Interviewer)

Hall, R. W. (1996, June 22). *Cost effectiveness of automated highway systems: a case study in engineering economic analysis of a new technology.* Retrieved December 2010, from AllBusiness: http://www.allbusiness.com/accounting-reporting/methods-standards-cost-accounting/590232-1.html

Heaslip, K., Womack, K. C., & Muhs, J. (2011, January 23-28). Automated Electric Transportation: A Way to Meet America's Critical Issues. *Leadership & Management in Engineering*.

Heddebaut, M., Rioult, J., Klingler, M., Menhaj, A., & Gransart, C. (2008). Microwave Radio Coverage for Vehicle-to-vehicle and In-vehicle Communication.

Hiemstra, G. (2000, September/October). Driving in 2020: Commuting Meets Computing. *The Futurist*.

Iteris. (2008). *Lane Departure Prevention (LDP).* Retrieved May 2011, from Lane Departure Warning System: http://www.iteris.com/upload/LDP.pdf

Konings, R., Priemus, H., & Nijkamp, P. (2005). *The Future of Automated Freight Transport: Concepts, Design and Implementation.* Northampton, MA: Edward Elgar Publishing, Inc.

Lank, C., Haberstroh, M., & Wille, M. (2010). Interaction Between Human, Machine, and Environment in Automated Driving Systems. *TRB 90th Annual Meeting Compendium of Papers DVD.* Washington, DC: Transportation Research Board.

Luo, J., & Hubaux, J.-P. (2004). *A Survey of Inter-Vehicle Communication.* Lausanne, Switzerland: School of Computer and Communication Sciences.

McNally, S. (2011, February 23). *Ohio Trucking Exec Says Traffic Congestion is Choking Nation's Economy*. Retrieved February 27, 2011, from American Trucking Association: http://www.truckline.com/pages/article.aspx?id=845%2F{8E1C7279-ED27-4C03-B189-CEEEE26BBB12}

Meins, J., Buhler, G., Czainski, R., & Turki, F. (2006). *Contactless Inductive Power Supply.*

Mescherin, I., Zhuravlev, D., Barsuk, S., & Izotov, N. (2008). *Research on Natural Gas Liquefaction in Russia and Former USSR. Methods to Reduce Overall Consumption of LNG Production Trains.* Paris: International Gas Union Research Conference.

MODOT. (2009, February). Retrieved January 2011, from Improve I-70: http://www.improvei70.org/

MODOT. (2009). *TIGER Discretionary Grant Application.* Retrieved September 2011, from Missouri Department of Transportation: http://www.modot.mo.gov/arra/tiger/index.htm

Moon, S., Moon, I., & Yi, K. (2009). Design, tuning, and evaluation of a full-range adaptive cruise control system with collision avoidance. *Control Engineering Practice 17*, 442-455.

Motavalli, J. (2011, November 5). WiTricity Plans to Harness Charges for Mitsubishi and Toyota E.V.'s From Thin Air. *The New York Times*.

National Transportation Research Center. (2011). *Vehicle Stability and Dynamics*. Retrieved April 2011, from NTRCI Web site: http://www.ntrci.org/areas_of_research/vehicle_stability_dynamics.aspx

National Weather Service. (2011, July). Retrieved from Weather Forecast Office: http://www.nws.noaa.gov/climate/index.php?wfo=lsx

NHTSA. (2009). *FARS Total Vehicle Trends*. Retrieved January 2011, from Fatality Analysis Reporting System Encyclopedia: http://www-fars.nhtsa.dot.gov/Vehicles/VehiclesAllVehicles.aspx

NSSGA. (2008). *Measuring Transportation's Share of GDP, Including Household Transportation Expenditures.* Alexandria, VA: National Stone, Sand, and Gravel Association.

RAND Corporation. (2009). *Modernizing the U.S. Freight Transportation System for Future Economic Growth.* Retrieved December 2010, from RAND Corportation: Supply Chain Policy Center: http://www.rand.org/pubs/research_briefs/RB9457-1/index1.html

Schonfeld, E. (2010, August 2). *Department of Outlandish Ideas: Build Solar Roadways*. Retrieved December 2010, from GreenTech: http://techcrunch.com/2010/08/02/solar-roadways/

Sinha, K., & Labi, S. (2007). *Transportation Decision Making: Prinicíples of Project Evaluation and Programming*. Hoboken, NJ: John Wiley & Sons, Inc.

Sullivan, C. R. (1999). Optimal Choice for Number of Strands in a Litz-Wire Transformer Winding. *IEEE Transactions on Power Electronics*, 283-291.

Technovelgy LLC. (2009, October 11). *In-Road Electric Vehicle Charger*. Retrieved January 2011, from Technovelgy.com: http://www.technovelgy.com/ct/Science-Fiction-News.asp?NewsNum=2591

The Trucker News Services. (2008, March 17). *ATA projects record-high fuel expenses for trucking in 2008* . Retrieved February 2011, from TheTrucker.com: http://www.thetrucker.com/News/Stories/2008/3/17/ATAprojectsrecord-highfuelexpensesfortruckingin2008.aspx

TRB Transportation Economics Committee. (2010). *Types of Measures*. Retrieved from Transportation Benefit-Cost Analysis: http://bca.transportationeconomics.org/types-of-measures

U.S. Census Bureau. (2004). *Vehicle Inventory and Use Survey.* Retrieved from U.S. Census Bureau: http://www.census.gov/svsd/www/vius/purpose.html

U.S. DOT. (2011, September). *The Value of Travel Time Savings: Departmental Guidance for Conducting Economic Evaluations, Revision 2*. Retrieved September 2011, from Office of the Assistant Secretary for Transportation Policy: http://ostpxweb.dot.gov/policy/reports.htm

U.S. EPA. (2002). *User's Guide to MOBILE6.0 Mobile Source Emission Factor Model.* Washington, DC.

U.S. EPA. (2003). *Automobiles and Carbon Monoxide.* Retrieved from U.S. EPA Office of Mobile Sources: http://www.epa.gov/oms/consumer/03-co.pdf

U.S. EPA. (2005, December). *Control of Air Pollution From New Motor Vehicles and New Motor Vehicle Engines; Modification of Federal On-Board Diagnostic Regulations for: Light-Duty Vehicles, Light-Duty Trucks, Medium Duty Passenger Vehicles, Complete Heavy Duty Vehicles and Engines I*. Retrieved June 2011, from Federal Register Environmental Documents: http://www.epa.gov/fedrgstr/EPA-AIR/2005/December/Day-20/a23669.htm

U.S. EPA. (2011, May 6). *AAD VMT Calculator HPMS.* Retrieved from U.S. EPA - Tools for MOVES (Motor Vehicle Emission Simulator): http://www.epa.gov/otaq/models/moves/tools.htm

U.S. EPA. (2011, October). *MOVES (Motor Vehicle Emission Simulator)*. Retrieved from Modeling and Inventories: http://www.epa.gov/otaq/models/moves/index.htm

USACE. (2011, September). Retrieved from Engineering and Design - Civil Works Construction Cost Index System (CWCCIS) : http://140.194.76.129/publications/eng-manuals/em1110-2-1304/EM_1110-2-1304_2011Sep.pdf

USOMB. (2010, December). *Discount Rates for Cost Effectiveness, Lease-Purchase, and Related Analyses.* Retrieved from Office of Management & Budget: http://www.whitehouse.gov/omb/circulars_a094/a94_appx-c

Williamson, S. (2008). *Annual Inflation Rates in the United States*. Retrieved from MeasuringWorth: http://www.measuringworth.com/inflation/