Economic Implications of the Use of Technology in Commercial Vehicle Operations

Kelly A. Pitera

A dissertation
submitted in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy

University of Washington
2012

Reading Committee:
Anne Goodchild, Chair
Linda Ng Boyle, Chair
Edward McCormack

Program Authorized to Offer Degree:
Civil and Environmental Engineering

University of Washington

Abstract

Economic Implications of the Use of Technology in Commercial Vehicle Operations

Kelly A. Pitera

Co-Chairs of the Supervisory Committee:
Associate Professor Linda Ng Boyle
Industrial & Systems Engineering and Civil & Environmental Engineering
Associate Professor Anne V. Goodchild
Civil & Environmental Engineering

The effective and efficient movement of freight is essential to the economic well-being of our country but freight transport also adversely impacts our society by contributing to a large number of crashes, including those resulting in injuries and fatalities. Technology has been used increasingly to facilitate safety and operational improvements within commercial vehicle operations, but motor carriers operate on small profit margins, limiting their ability to make large investments without also seeing an economic benefit from such technologies. This dissertation explores the economic implications associated with using on-board monitoring systems to enhance safety in commercial vehicle operations.

First, to better understand how electronic on-board systems work, paper-based methods of recording driver hour of service are compared to automated (or electronically recorded) hours of service for three motor carriers using process analysis. This analysis addressed the differences between manual (paper-based) and electronic methods of recording hours of service. Specifically as it relates to the frequencies and magnitude of the errors. Potential errors are categorized by operations within an information-based process and the findings suggest that a reduction of errors can be achieved with an electronic system.

A benefit-cost analysis provides a better understanding of the economic implications of on-board monitoring systems from the perspective of the carrier. In addition to the benefits of reduced crashes, benefits associated with electronic recording of hours of service, reduced mileage, and reduced fuel costs are considered. A sensitivity analysis is used and demonstrates that on-board monitoring systems are economically viable under a wide range of conditions. Results indicate that, for some fleet types, reducing crashes and improving hours of service recording, provides a net benefit of close to $300,000 over the five-year expected lifespan of the system. Furthermore, when exploring additional benefits such as reduced fuel consumption and reduced vehicle miles, benefits can be upwards of seven times more than safety-related benefits. This research also shows that net positive benefits are possible in large and small sized fleets. Results can be used to inform policies for motivating or mandating carriers to use such systems, and to inform carriers regarding the value of system investment.

TABLE OF CONTENTS

Page

List of Figures iiiii

List of Tables iiv

1. Introduction 1

   1.1. Motivation 1

   1.2. The Use of Technology within the Transportation Sector 3

   1.3. On-board Monitoring Systems 5

   1.4. Research overview and objectives 7

   1.5. Organization 9

2. Process Comparison of Hours of Service Recording and the Impact of Electronic On-board Recorders 11

   2.1. Problem Description and Background 11

   2.2. Recording Hours of Service 15

   2.3. Process Analysis of Hours of Service Recording 17

      2.3.1. Paper-based Methods of Recording HOS 18

      2.3.2. Electronic On-Board Recorder Based Methods of Recording HOS 23

   2.4. Potential Sources of Error within HOS Recording Process Flows 25

      2.4.1. Driver Error 25

      2.4.2. Transmission Error 25

      2.4.3. Data Entry Error 26

      2.4.4. EOBR Error 26

   2.5. Quantifying Error within HOS Recording Systems 26

   2.6. Discussion 29

   2.7. Summary 31

3. An economic analysis of on-board monitoring systems in commercial vehicles: a benefit-cost analysis 33

   3.1. Problem Description and Analysis Overview 33

   3.2. Literature Review 37

   3.3. Methodology 40

      3.3.1. Benefits 41

3.3.2. Costs 71
3.3.3. Metrics 73
3.4. Results 75
3.4.1. Safety-related benefits 76
3.4.2. Non-safety-related benefits 80
3.5. Sensitivity Analysis 82
3.5.1. Fleet variations 82
3.5.2. Crash reduction benefit uncertainty 85
3.5.3. HOS violation reduction benefit uncertainty 90
3.5.4. Fuel reduction benefit uncertainty 92
3.5.5. Mileage reduction benefit uncertainty 94
3.5.6. Summary 94
3.6. Discussion 95
3.7. Summary 97
4. An economic analysis of on-board monitoring systems in commercial vehicles: a regression analysis 99
4.1. Problem Description 99
4.2. Methodology 100
4.2.1. Data 101
4.2.2. Models 105
4.3. Regression Results 106
4.4. Regression Discussion 107
4.4.1. Comparing Models 108
4.5. Conclusions 111
5. Conclusions 112
References 119
Appendix A: Carrier Interview Notes 132
Appendix B: BCA Results 142
Appendix C: Regression analysis data and Results 144

LIST OF FIGURES

Figure Number Page

1. In-vehicle OBMS Displays (Transecurity, 2012) 6
2. Example of Driver's Daily Log (FMCSA, 2011c) 16
3. Paper-based HOS Recording Systems Flow for Carrier 20
4. HOS Recording Systems Flow for EOBR Systems 24
5. Combinations of Crash Reduction Rates and HOS Violation reduction rates 79
6. Impact of Fleet Size on NPV (100,000 VMT/vehicle/year) 84
7. Impact of VMT on NPV 85
8. Sample Distributions 103

LIST OF TABLES

Table Number Page

1. Operations within an Information-Based Process 19
2. Sources of Error within HOS Recording Systems 27
3. Crash Reduction Rates from Existing Literature 49
4. Crash Benefit Values Summary 51
5. Cost Data 73
6. BCA Base Case Inputs for Safety-related Benefits 77
7. Safety-related Benefit Results Summary 78
8. BCA Base Case Inputs for Non-safety-related Benefits 81
9. Non-safety-related and Total Benefit Results Summary 81
10. Sensitivity Analysis, Fleet Variation Results 83
11. Crash Costs 86
12. Results from Crash Cost Sensitivity Analysis 87
13. Results from Crash Reduction Rate Sensitivity Analysis 89
14. Summary of Benefit Sensitivity Analysis 95
15. Stratified Sample Selection 102
16. Descriptive Statistics 105
17. Regression Results, Carrier Specific Model 106
18. Regression Results, Average Value Model 106
19. Average Crash and HOS Violation Rates 109

ACKNOWLEDGEMENTS

Many people had a hand in helping me complete both this dissertation and my Ph.D. degree. First, I would like to thank the members of my dissertation committee: Linda Ng Boyle, Anne V. Goodchild, Edward D. McCormack, and Jennifer Turns, for their support, advice, wisdom, and gentle critiques of my work. I greatly appreciate their roles within this process.

My time at the University of Washington would not have been what it was without the camaraderie of and learning environment supported by my research group, the Goods Movement Collaborative. Together we have become better researchers, learned to express our ideas and insights, pursued our interests, and shared many laughs. I would not be where I am without all of you. I cannot give enough thanks for the support you have provided me over the years.

I would also like to thank my family – for providing me with the opportunities that I have lead me to where I am today, for teaching me the value of working hard to achieve my goals, and for supporting me in this endeavor.

Finally, I must thank the U.S. DOT Federal Motor Carrier Administration, as well as the Valle Scholarship and Scandinavia Exchange Program at the University of Washington for their generous funding of my work.

1. Introduction

The freight transportation system is an important part of our society. The movement of goods allows for fully stocked shelves at our local stores, overnight deliveries of our internet orders, and even the regular removal of garbage; all things we often take for granted. The trade associated with freight transportation provides jobs and builds the economy, further benefiting society. But these benefits do not come without a cost. The same trucks that supply our stores, deliver our packages, and haul away our garbage also adversely impact society and the environment. Commercial vehicles contribute to emissions and air pollution problems, increase congestion, and impact safety. Increasing trade volumes and growing energy concerns only intensify the issues. Sustainability within freight transportation is multi-faceted and a balance between environmental, societal, and economic sustainability must be considered when addressing freight issues. Technology has been used increasingly to facilitate safety and operational improvements within commercial vehicle operations, but motor carriers operate on small profit margins, limiting their ability to make large investments without also seeing an economic benefit from such technologies. This dissertation explores the economic implications associated with using on-board monitoring systems (OBMS) to enhance safety in commercial vehicle operations.

1.1. Motivation

While truck vehicle miles travelled (VMT) make up a small percentage (approximately 7%) of total VMT (Sedor and Caldwell, 2002), the effective and efficient movement of freight is essential to the economic well-being of our country. In 2007, the U.S. transportation system moved almost 18.6 billion tons of goods worth $16.5 trillion (FHWA, 2010). The freight demand is expected to grow dramatically, doubling from today's demand to 30 billion tons by 2050, with U.S. imports and exports growing at an annual rate of 4.2% and 5.8% respectively (AASHTO, 2010). Additionally, more than 10 million jobs in the U.S. are related to the freight industry (AASHTO, 2010). Despite the measureable economic benefits of goods movement, aspects of the freight transportation sector are also a detriment to society and on-going sustainability movements. In 2008, large truck crashes contributed to 4,229 deaths and 90,000 injuries in the U.S. (FMCSA, 2010a). While the number of fatalities and injuries associated with large vehicle crashes has decreased over the past ten years, they still represent a public health risk.

The Framework for a National Freight Policy (U.S. DOT, 2008a) attempts to align all stakeholders within the freight transportation system around a common vision:

> *"The United States freight transportation system will ensure the efficient, reliable, safe and secure movement of goods and support the nation's economic growth while improving environmental quality."*

Among others, the Framework for a National Freight Policy lists objectives such as better aligning costs and benefits for all stakeholders, reducing barriers to improved freight performance, maximizing safety, and better managing environment impacts on communities. The Framework for a National Freight Policy also highlights the importance of achieving a balance between the public and private sectors. One of the overarching themes of the framework is that it is a "national" policy, not a "federal" policy, emphasizing the collaboration between many public and private organizations and institutions. While public sector motivations may be focused on policies and programs which benefit society, private sector cooperation is required to make these policies and programs successful. Systems such as OBMS can be used to enhance the safety of commercial vehicle operations but carrier support and adoption of these systems is necessary and affected by the economic feasibility of their use.

1.2. The Use of Technology within the Transportation Sector

The use of technology to improve systems within the transportation sector has been around for many decades and has influenced the way we travel. Intelligent transportation systems (ITS) support and improve aspects of transportation systems such as safety, performance and productivity. These systems typically involve information collection and dissemination related to vehicles, infrastructure, or system users (FHWA, 1998). ITS applications include variable speed limits, variable message signs, electronic tolling, and ramp metering. The above mentioned ITS applications impact both personal vehicle and commercial vehicle operations, but some ITS technologies are specifically designed for commercial vehicles applications. For example, the Automated Commercial Environment (ACE) Truck e-Manifest system allows commercial vehicles to submit electronic paperwork for customs inspection prior to vehicle arrival at international borders. This system, which replaces a paper-based system, is intended to result in decreased wait and processing times at the border and facilitate pre-screening of commercial vehicles. A study of the system (Shackelford, Short and Murray, 2007) has indicated that the border crossing process is more efficient but workload and costs associated with start-up of the system have increased. The study suggests that there may be potential savings and net operational benefit in the long-term for medium and large carriers, but less so for smaller carriers. Technologies that facilitate activities such as safety information exchanges, electronic screening, and handling of electronic credentials and taxes have also been implemented within the freight transportation sector under the Commercial Vehicle Information Systems and Networks (CVISN) program. A study of these programs recommend further deployment of these initiatives based on benefit/cost analysis that show all stakeholders can receive significant benefits (Brand et al., 2004). Although some motor carriers are slow to adopt such technologies, drivers that have experience with these systems have generally positive responses (FMCSA, 2002).

As will be further described within this dissertation, technology has also been used to improve commercial vehicle operations. Many studies (Knipling, 2011; McKinnon, 2010; Baumgartner, Leonardi and Krusch, 2008; Steffansson and Woxenius, 2007; Hubbard, 1998) enumerate on the ways information technology can improve operational efficiencies. GPS units, along with fleet management systems, can allow for increased visibility and management oversight of operations, resulting in potential benefits including better real-time dispatching, increased productivity, improved HOS compliance, decreased overtime, lower fuel use, improved customer service, lower insurance costs, and decreased driver speeding. Communication between vehicles (and drivers) and terminals is also improved, and information such as weather, road conditions, navigation and dynamic route optimization can be easily passed onto the driver. Fleet management systems can also address the issue of empty truck miles by providing information to facilitate load matching or trip chaining. Case studies identify ways that carriers are currently using management systems and information provided by GPS devices to improve operations (Knipling, 2011). These include computerized mapping and routing directions to get origin to destination in the quickest, safest and most efficient manner, reducing the time drivers spend searching for shippers' docks, especially in remote locations or congested industrial areas, load and schedule planning and truck tracking, and use of truck-specific GPS navigation systems. The integration of all of these technologies have been considered in an on-board system that can help monitor a driver's progress and help support ways to enhance driving performance.

1.3. On-board Monitoring Systems

The use of on-board monitoring systems (OBMS) within commercial vehicle operations is a potential means of reducing risky driving behavior and improving driver safety performance. Previous research has shown that targeted driver feedback is effective at reducing driver-related crash risk factors (Donmez, Boyle and Lee, 2008a; Donmez, Boyle and Lee, 2008b; McGehee et al., 2007). On-board monitoring systems can objectively measure driving performance, inform commercial drivers of safety critical situations, provide feedback, and record trip information. On-board monitoring system functions can include forward collision warnings, lane departure warnings, electronic logbooks, driver behavior monitoring and drowsy driver detection. Additional information is also available within trip files including GPS coordinates, fuel economy, and time and miles spent driving. The information gathered by OBMS units cab used to monitor performance and provide feedback to drivers. Research indicates that larger carriers with broad geographic service areas are more likely to use OBMS (Cantor, Corsi and Grimm, 2008). OBMS often have a system component to record HOS, specifically known as an electronic on-board recorder (EOBR). These devices track driving, on-duty, off-duty, and sleeper berth time, store HOS records in the vehicle, as well as transmit records to carrier terminals.

The system considered within this research gathers information from a variety of sensors, including video, to monitor and evaluate driving behavior. The system supports forward crash warning, lane departure warning, drowsy driver detection, and driver monitoring, and provides real-time feedback and event based data collection to be used as both feedback and training. As seen in Figure 1, the in-vehicle display provides status information to drivers including current trips statistics (time and miles travelled), current fuel economy, and information regarding remaining hours of service (a). The display provides real-time warning information (audio and visual) if the event of a safety critical occurrence (b). Data regarding such safety critical events is also recorded and transmitted to the carrier to be used in future coaching sessions (c). The OBMS considered within this study also has EOBR capabilities (d). Data is transmitted wirelessly from the unit to carrier via the system manager.

Figure 1 In-vehicle OBMS Displays (Transecurity, 2012)

1.4. Research overview and objectives

This dissertation addresses the economic implications of increased technology intervention, namely on-board monitoring systems (OBMS) for commercial vehicle operations. On-board monitoring systems can be used in commercial vehicle operations to monitor driving behavior, with the goal of enhancing safety. While it is known that improved safety will produce an economic benefit to carriers, understanding how this benefit compares to system costs is an important factor for carrier acceptance. Understanding the economic effects of such systems in important in informing both carriers and policy makers, who are making decisions regarding their use.

Before the economic feasibility or OBMS is considered, a deeper understanding of how electronic on-board systems work is helpful to inform the remainder of the research. Electronic on-board recorders (EOBR) are a component of many OBMS and are used to monitor drivers' hours-of-service (HOS). As a contained element of OBMS with a specific objective, EOBR can be studied and compared to existing, paper-based means of recording HOS. A systematic process analysis and comparison allows for a greater insight into how electronic systems collect and monitor information differently than existing, manual systems. Within the comparison of the two methods, potential errors are categorized by operations within an information-based process and results demonstrate that a reduction of errors can be achieved with an electronic system. This awareness can not only inform policymakers who are considering revisions to HOS documentation procedures, but also increase shed light on issues related to the costs and benefits of system use.

The core component of the dissertation is centered on a benefit cost analysis (BCA) of OBMS in commercial vehicle operations. The BCA provides a better understanding of the economic implications of system use. This understanding is important for several reasons. First, policy makers and regulatory agencies have an interest in improving safety of commercial vehicle operations, thus an interest in the use of OBMS. Increased insight into the economic feasibility of these systems allows for improved decision-making regarding their use, including how to mandate and/or motivate their use. Second, as mentioned previously, carrier acceptance is important to successfully implement system use. While carriers value improved safety within operations, investment decisions are based on added profit which these systems generate. Numerous studies (Shackelford, Short and Murray, 2007; Hickman and Hanowski, 2011; Kavalaris and Sinha, 1994; Hall and Itihar, 1997; McCallum and Lee, 1993) have noted that economic benefit is a motivating factor in carrier acceptance regarding technology adoption. Having a greater understanding of the economic implications for both the carrier and society will allow for a more successful decision-making and implementation of such systems that will both improve safety and increases sustainability within commercial vehicle operations.

The BCA considers traditional, or safety-related, benefits of OBMS-use, including reduced crashes, reduced HOS violations, and improved HOS recording processes. In addition, non-safety-related benefits are also incorporated into the analysis. These benefits capitalize on additional components of OBMS which can improve operations, such as the ability to monitor fuel consumption or improve vehicle routing efficiency. As part of the BCA process, a sensitivity analysis addresses uncertainty and elasticity within the BCA. Beyond the BCA, a regression analysis serves as another means of considering the economic implications of on-board monitoring system (OBMS) use and to illustrate the relationship between variables within the BCA. The regression model results in a single equation showing the relationships between variables within the model.

The objective of this study is to better understand the economic implications of on-board monitoring systems and the following research questions are examined:

1. What differences, specifically related to error frequencies and magnitudes, are observed between manual (paper-based) and electronic methods of recording hours of service?

2. From a carrier perspective, what are the benefits and costs associated with using on-board monitoring systems within commercial vehicle operations, and under what circumstances is system use is economically feasible?

3. What relationships exist between fleet characteristics and economic feasibility of OMBS?

1.5. Organization

The remainder of this dissertation is organized as follows:

Chapter two compares the use of paper-based and automated (or electronically recorded) hours of service for three motor carriers using process analysis. Potential errors are categorized by operations within an information-based process and compared between processes. The study provides a systematic and structured comparison of the two methods, highlighting the error types that occur in both.

Chapter three develops a benefit-cost methodology to examine the economic feasibility of OBMS in commercial vehicles. Benefits and costs associated with system use are identified and quantified. The BCA determines economic feasibility of OBMS use for a given fleet of vehicles within a base case. A sensitivity analysis is used to generalize the BCA and examine uncertainty and elasticity within components of the analysis. The circumstances under which system use is economically feasible are discussed.

Chapter four builds on the BCA, performing a regression analysis as a means of illustrating the results of the BCA in an alternative form. The regression model takes the form of a single equation, allowing the relationships between fleet characteristics and economic feasibility to be identified and discussed.

The final chapter summarizes key findings, highlights the scientific contributions of this research, and discusses areas for future research.

2. Process Comparison of Hours of Service Recording and the Impact of Electronic On-board Recorders

This chapter compares the use of paper-based and automated (or electronically recorded) hours of service for three motor carriers using process analysis, addressing the differences, specifically related to error frequencies and magnitudes, that are observed between manual (paper-based) and electronic methods of recording hours of service. It specifically addresses the research question:

> *What differences, specifically related to error frequencies and magnitudes, are observed between manual (paper-based) and electronic methods of recording hours of service?*

Potential errors are categorized by operations within an information-based process and results demonstrate that a reduction of errors can be achieved with an electronic system.

2.1. Problem Description and Background

In the U.S. in 2008, large truck crashes contributed to 4,229 deaths and 90,000 injuries (FMCSA, 2010a). While the number of fatalities and injuries associated with large vehicle crashes has decreased over the past ten years, they still represent a public health risk. Drowsiness and inattention represent a significant portion of truck-related crashes (NHTSA, 2003) and as such, the U.S. DOT - Federal Motor Carrier Safety Administration (FMCSA) has set regulations regarding the limits for when and how long commercial motor vehicle drivers may operate a vehicle (CFR 49, 395). These Hours of Service (HOS) regulations require drivers to record their work hours in a logbook that is then stored for a specified amount of time. Enforcement of regulations is conducted by the FMCSA, often via state officials, through either roadside inspections or carrier safety reviews. However, this process does not ensure the accuracy of records because there are no measures to validate that the hours logged by a driver correspond with the true hours of driving.

There were 3.1 million roadside driver inspections conducted in the U.S. in 2010, resulting in almost 1.2 million driver violations. Of these violations, over 600,000 (52%) were related to HOS regulations. Twenty-four percent of these drivers were placed out of service due to these violations (FMCSA, 2011a). Additionally, carrier safety reviews, where FMCSA inspectors visit carriers to examine safety and HOS records, resulted in almost 14,000 critical violations in 2010. Approximately 4,200 (30%) of these violations were related to HOS regulations (FMCSA, 2011b). The violations, found during both roadside inspections and carrier safety reviews, include exceeding the allocated time spent driving, and failing to retain seven days' worth of previous logs. Prior research (Hertz, 1991; Braver, 1992; Beilock, 1995) has also identified the prevalence of HOS rule violations based on objective (trip distances and travel times) and subjective (driver surveys and interviews) measures. While many of the above studies cite driver error as the catalyst for violations, not all of these actions are intentional. The logbooks contain a great deal of detail and complexity, and are therefore, prone to errors.

Another challenge to developing a true understanding of HOS compliance is the sensitive nature of the topic and the lack of openness among drivers to discuss the issues. Carriers and drivers are not likely to voluntarily disclose non-compliance thus, while some violations will be identified by the FMCSA during inspections and reviews, many others will go undetected. As explained in more detail within the forthcoming benefit-cost analysis, FMCSA-detected violations from both roadside inspections and carrier reviews provide the closest estimate of the number of drivers operating out of service based on the limited information available regarding true HOS violations. A previous study by the FMCSA (2010b) also notes the complexity of the issue.

The excess of HOS violations indicate that the current processes used to record and maintain HOS information is flawed in that it fails to meet the objectives of the regulations intended to limit driving to safe levels. While most carriers currently use paper-based methods to record HOS, improvements in technology, namely Global Positioning Systems (GPS), have resulted in the ability to develop systems that can automatically record the amount of time that a vehicle is operating. The use of Automatic On-Board Recording Devices (AOBRDs) has been allowed in the U.S. since 1988, but it is estimated that only 10 percent of carriers within the U.S. currently utilize electronic HOS recording (FMCSA, 2010b). More recently Electronic On-Board Recorders (EOBRs) have been introduced, with higher technical requirements than their predecessors, as a means of recording HOS. Recent regulations may mandate EOBR-use for all carriers, as the FMCSA maintains that EOBRs “systematically and effectively monitor” drivers’ HOS compliance (Federal Register, 2011). Cantor, Corsi and Grimm (2009) assessed how EOBRs contribute to safety, Focusing on the link between electronic log adoption and carrier safety performance, the results show statistical evidence that electronic logbook adoption does contribute to a reduction in hours of service violations and that the use of EOBRs will have a larger impact on hours of service violations for motor carriers with a below average safety performance record. This study makes the assumption that electronic logbooks reduce error, and does not investigate the specific ways that electronic logbooks are implemented by firms.

An area that is not as well understood is how information errors occur in the documentation of hours of service and how errors may differ between the manual and electronic documentation processes. The goal of this study is provide insights into the differences in errors that can occur between manual and automated documentation of hours of service. Within the context of this research, errors refer to situations when the HOS documentation does not reflect the actual driving performed and to situations where HOS regulations are not met. These errors may occur when the driver or the carrier controls the records, or when records are transferred between these entities.

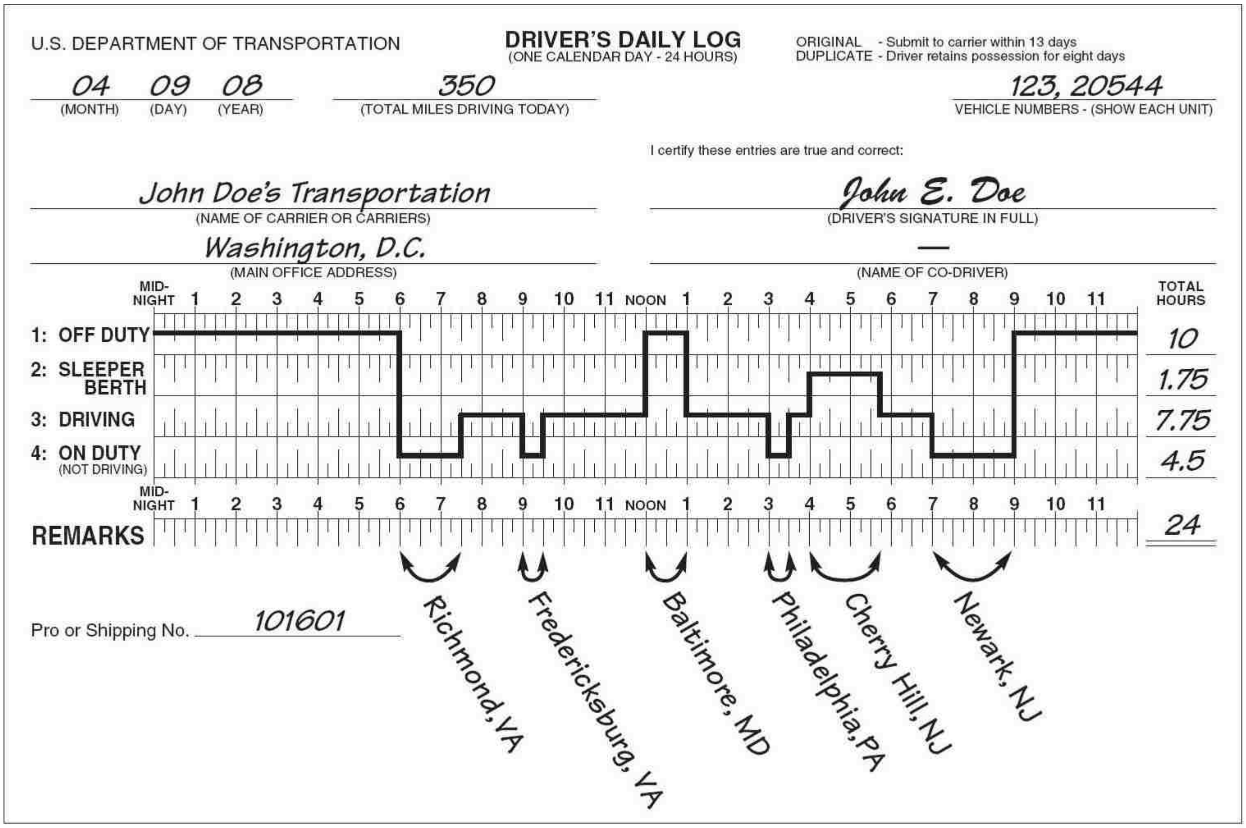
This work described in this study centers on the impact to U.S. regulations. However, similar hours of service regulations exist in other parts of the world, including Canada (Minister of Justice, 2005), the European Union (The European Parliament and the Council of the European Union, 2006), and parts of Australia (NSW Government, 2005). Within the European Union (European Commissions, 2009) electronic monitoring devices are already mandated for HOS compliance, while in Canada (CCMTA, 2011; CCMTA, 2010) and Australia (NTC Australia, 2009), regulations are being considered but to date, have not been implemented. Proponents of EOBR usage assert that electronic HOS recording will reduce errors when compared to manual recording, however no comparison of these processes has been performed. This paper provides such a critique. It considers the process flows within commercial vehicle hours of service recorded using manual and electronic operations from three carriers to compare existing paper-based methods of HOS recording to EOBR systems. The possible reduction of errors with the introduction of an electronic system is examined to identify how such systems can improve recording of HOS information documentation.

2.2. Recording Hours of Service

In the U.S., the procedure for documenting hours of service (by the driver and carrier) is laid out by the U.S. Department of Transportation regardless of whether a manual or automated process is used. Drivers are required to keep a “record of duty status” (or driving log) of their last 7 (or 8, depending on driving schedule) days of travel (FMCSA, 2011c). These logs must be kept in written form unless the log information is recorded electronically. Log entries must be true and correct, be made by the driver, account for every day (even days off), and cover all 24 hours of the day. As seen in Figure 2, the daily logs require detailed information regarding the daily operations of the vehicle.

Drivers must keep the original and a copy of their log and be able to present it to authorized inspectors at any time. Drivers may take up to 13 days to transfer the original logbook entries to their carrier, although their carrier may require it sooner. Carriers are then required to keep HOS records for each driver for a period of six months and will, in most cases, dispose of these records after the six month period. When a crash investigation is pending, records may be kept for longer.

The Hours of Service (HOS) regulations within the U.S. are complex and can make driver compliance difficult. Drivers are required to know three separate maximum duty limits, be able to distinguish between tasks that contribute to these limits, and interpret daily records to ensure compliance. FMCSA officials conduct enforcement to ensure that written HOS records comply with regulations but do not have provisions for ensuring the accuracy of these records. Instead, this burden falls on the carrier who is tasked with auditing the driver's HOS records using information such as mileage, fuel, and toll receipts, but even this action does not fully ensure accuracy.



U.S. DEPARTMENT OF TRANSPORTATION

DRIVER'S DAILY LOG
(ONE CALENDAR DAY - 24 HOURS)

ORIGINAL - Submit to carrier within 13 days
DUPLICATE - Driver retains possession for eight days

04 (MONTH) 09 (DAY) 08 (YEAR)
350 (TOTAL MILES DRIVING TODAY)
123, 20544 VEHICLE NUMBERS - (SHOW EACH UNIT)

I certify these entries are true and correct:

John Doe's Transportation (NAME OF CARRIER OR CARRIERS)
John E. Doe (DRIVER'S SIGNATURE IN FULL)
Washington, D.C. (MAIN OFFICE ADDRESS)
— (NAME OF CO-DRIVER)

	TOTAL HOURS
1: OFF DUTY	10
2: SLEEPER BERTH	1.75
3: DRIVING	7.75
4: ON DUTY (NOT DRIVING)	4.5
	24

REMARKS

Pro or Shipping No. 101601

Figure 2 Example of Driver's Daily Log (FMCSA, 2011c)

Within the current HOS recording process, there are errors that can occur specifically due to the manual nature of the process. With respect to manual recording processes, human errors include omission, repetition, and substitution of data, and issues with data sequencing (Haight and Kecojevic, 2005; Rasmussen, 1982; Shaw et al., 1999). Studies have shown that while keyed data error rates are small and hard to compare (Shaw et al., 1999; Biemer and Lyberg, 2003), they are not negligible. Errors increase as more processing steps are added and when variables become more sophisticated and detailed.

Automatic recording can result in simplified record keeping by removing the manual documentation of hours driven, easing data transfer, and automatically auditing information. It can also make it easier to identify potential regulation violations if HOS data is stored in one repository, with available driving hours automatically calculated for each driver. Hence, there are benefits for both the driver and the carrier (Kraft, 2006). EOBRs provide some level of automation on HOS while still engaging the driver in compliance and review.

Despite the benefits of EOBR use, electronic HOS recordings systems are not fail-safe. Previous research has noted disadvantages to EOBR systems such as its inability to record driver activity when the truck is not in operation. This includes time when a driver is waiting, sleeping, and loading or unloading a vehicle (Belzer, 2002). Additionally, EOBRs do not guarantee federal compliance. Carrier management is still needed to validate the information generated (Campbell et al., 1998). A better understanding of the sources of error within both manual and electronic HOS recording will allow for insights on how the objectives of HOS regulations can be better met.

2.3. Process Analysis of Hours of Service Recording

Process analysis provides information related to the flow of a process in a sequential manner. Examples of process analysis techniques include value stream maps, critical path methods, and workflow analysis (Martin, 1997; Rother et al., 1999; Madison, 2005). Process analysis is applicable for examining HOS documentation where gaps in the process and HOS information flow can be identified and errors can be quantified.

Recording and collecting commercial vehicle hours of service is an information-based process (Darnton and Darnton, 1997) that involves collection, storage, and processing of information to ensure that hours of service regulations are satisfied. Based on Darnton (1997), the general operations and corresponding description of the information-based processes are shown in Table 1. The last column of this table shows the relationship of each operation to hours of service. For example, the origination operation refers to the production of information, which occurs when drivers complete their log books within the HOS process. The operations do not necessarily occur in the same order as shown in Table 1 and some carrier-specific processes do not include all operations. Each carrier in this study is examined within the context of these information-based process operations.

2.3.1. Paper-based Methods of Recording HOS

One terminal from each of three carriers was examined for hours of service documentation. The research team interviewed the management at each carrier using a semi-structured set of questions. Notes from the interviews can be found in Appendix A. It was noted that each carrier had a process flow that includes many operations described in Table 1. There were differences in operating characteristics among carriers and this does impact the details of each HOS recording process flow as shown in Figure 3. The numbering and title for each box within the process flow corresponds to the operations in Table 1.

Table 1 Operations within an Information-Based Process

Operation	Description	Within Hours of Service
1. Origination	initial production of information	completion of hours of service logbooks by drivers
2. Collection	gathering the information	collection of logbooks by carrier (via dispatcher or vendor)
3. Storage	keeping information in a secure location	storing hours of service information for 7/8 days or for 6 months per U.S. DOT regulations
4. Processing	transforming the data into a usable form	entering hours of service information into computer
5. Interpretation	understanding implications of information	auditing logbooks to determine drivers' driving eligibility (hours left) and compliance status
6. Application	using information	using hours of service information to commend, reprimand, or assign drivers
7. Retrieval	retrieving previously stored information	providing past hours of service information to management or authorities
8. Communication	transferring information from one location to another	transferring information between drivers, dispatchers, carriers and/or vendors
9. Dissemination	distributing information to stakeholders within the system or process	informing management of hours of service violations
10. Decision making	using information to make choices within the system or process	using the hours of service information to make driver routing decisions

Carrier 1

Commercial Operations

Carrier 1 provides general truckload transportation services, predominately serving a single region of the country. The terminal being evaluated for this study also transports high value goods which require heightened security. Drivers spend weekdays on the road, and most return home for the weekend. The terminal is considered midsize with 100 to 150 vehicles.

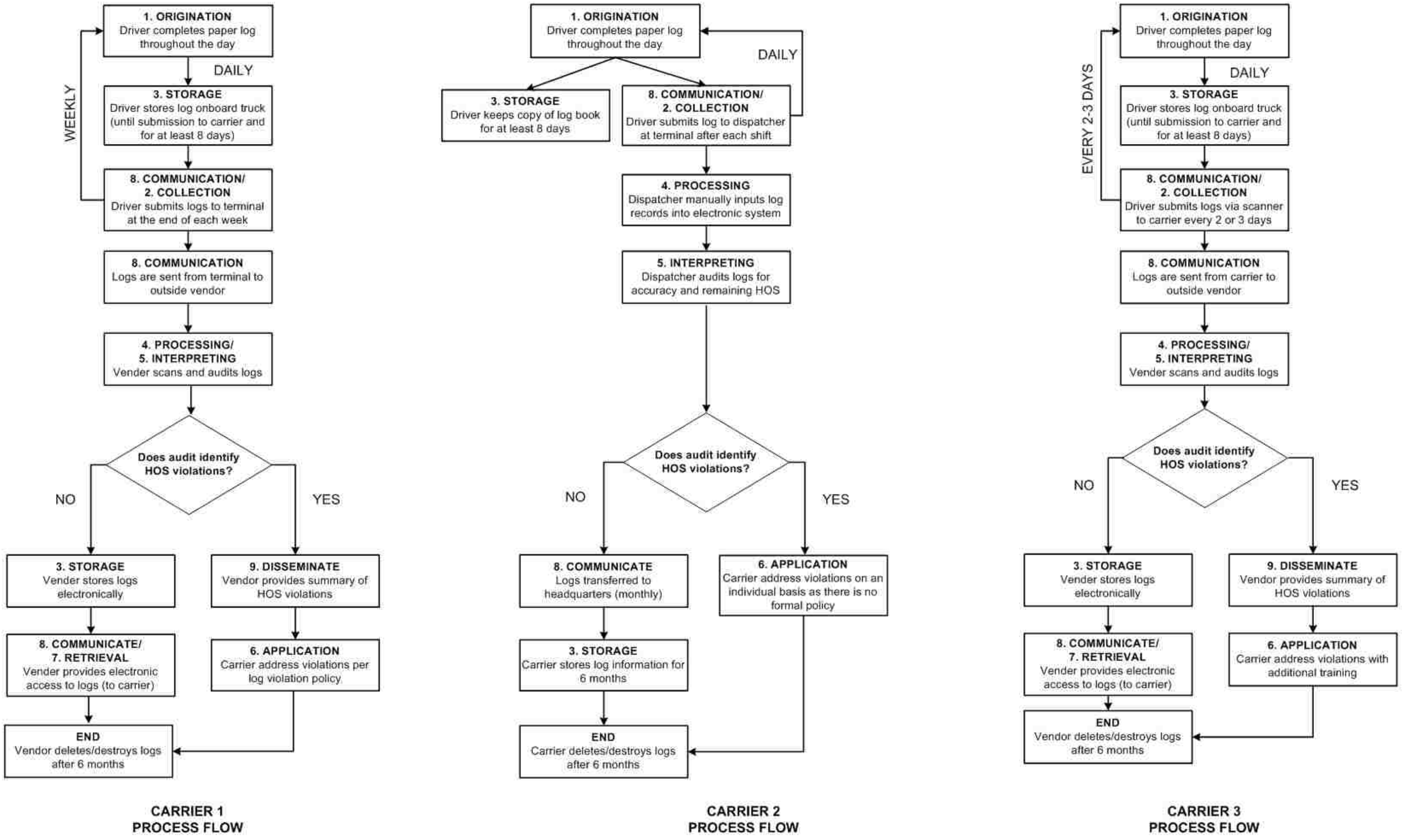


Figure 3 Paper-based HOS Recording Systems Flow for Carrier

Process flow for current HOS recording

Currently, drivers for Carrier 1 use paper logs to record HOS. Because drivers are typically away from the terminal for several consecutive days, drivers store daily logs onboard their truck and then submit logs to their terminals each week. Typically, logs are delivered in person, but drivers also have the option to mail logs to the terminal. Terminals send the completed logs to an outside vendor on a weekly basis. The vendor then scans each log, providing electronic access to the carrier, and audits the logs, checking for accuracy, compliance, and completeness. Logs are stored, both electronically and in hardcopy, by the vendor for the required six months. After six months (with the exception of logs involving accidents), logs are deleted and destroyed. In the cases where the vendor detects HOS violations for a driver, this information is passed onto the carrier. The carrier addresses violations per the provisions of the company log violation policy.

Carrier 2

Commercial Operations

Carrier 2 serves the eastern portion of the country and provides transport services for petroleum product distribution. The products transported by Carrier 2 are considered hazardous materials. Drivers work a split shift and return to the terminal each day. The terminal is considered midsize with 50 –100 vehicles.

Process flow for current HOS recording

Carrier 2 currently uses paper logs to record HOS. Logs are submitted to the dispatcher each day as drivers return to the terminal. The dispatcher manually inputs log information into an electronic system, and then checks each log for accuracy. The remaining HOS are calculated for use on the next day's dispatch. If the dispatcher notices a more serious violation when manually entering HOS information, the driver is called in for clarification and on occasion, the terminal manager is also involved. The Field Safety Coordinators and District Operations Managers audit approximately 50% of driver logs each month. Hence, these employees are intimately familiar with the regulations and check each other's work. At the end of each month, both the paper and electronic files are transferred to headquarters for storage for an additional five months. That is, HOS records are kept for a total of six months, and immediately after, are destroyed or deleted from the system.

The routing and scheduling system within Carrier 2 (split-shift driving) results in minimal HOS non-compliance issues; therefore Carrier 2 does not have a formalized procedure to handle violations. When violations do occur, they are handled on a case-by-case basis and repercussions include verbal reprimand, re-training on HOS regulations, and possible suspension for a day or more. No driver is to be dispatched if logs are not current to their last working day.

Carrier 3

Commercial Operations

Carrier 3 provides several types of trucking services including long haul services and dedicated contract services throughout the U.S., Canada, and Mexico. Carrier 3 carries containerized goods for a diverse customer base. The length of time drivers spend on the road before returning to their terminal varies, but many travel for an extended period of time. The terminal is considered midsize with 50 –100 vehicles.

Process flow for current HOS recording

Like the previous carriers, Carrier 3 uses a paper-based system to record HOS. The carrier encourages drivers to submit HOS logs two or three times a week. The drivers can scan logs in at any of Carrier 3's terminals or at numerous trucks stops that have the required scanner. The logs are sent directly to Carrier 3 but then immediately forwarded to an outside vendor. At the end of each week, the carrier performs a check for missing logs among all drivers. The vendor then scans each log and provides electronic access to the carrier. The vendor uses additional information from onboard computers to audit logbooks. Violations are reported to the carrier and, in most situations, violators also receive additional training. Consistent with the other carriers, logs are stored, by the vendor, for the required six months.

2.3.2. Electronic On-Board Recorder Based Methods of Recording HOS

There are numerous electronic recording systems that can record hours of service information. Although there are slight differences in recording techniques, there is still a general process flow shared among all systems due to federal standards and compliance, as shown in Figure 4.

Drivers log into the electronic systems at the start of their day using both a driver ID number and password. The system will automatically start recording if the vehicle begins moving, or drivers can manually select their duty status, including entering on duty/not driving time. Throughout the day, drivers can manually update their duty status. Many systems also automatically record an off-duty status when the vehicle is turned off or is idling for an extended period of time. The in-vehicle unit communicates the real-time status of drivers over a wireless connection. The system automatically records and reports drivers' HOS violations and availability to the carrier. HOS logs are stored within the system and the carrier is able to access them electronically.

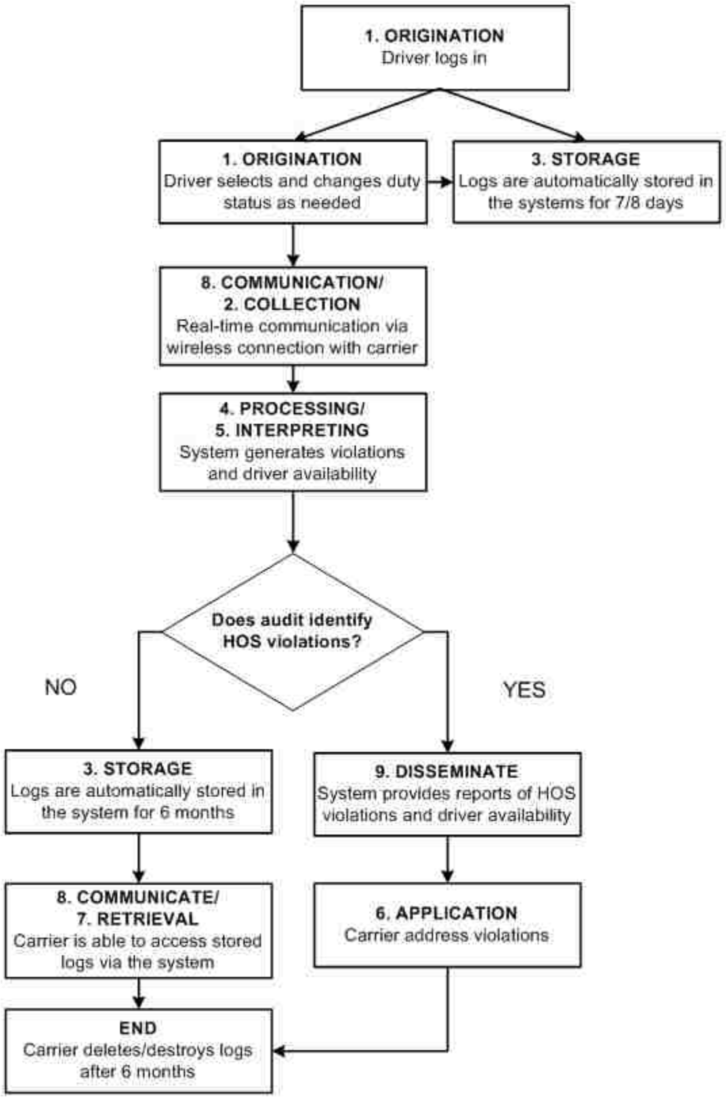


Figure 4 HOS Recording Systems Flow for EOBR Systems

2.4. Potential Sources of Error within HOS Recording Process Flows

Based on an examination of the process flow of the three carriers, several common sources of potential errors were observed in recording, auditing, and storing HOS information manually. Often these errors relate to the driver, the transferring of data, and entering of information into a database.

2.4.1. Driver Error

Driver errors are most common at the beginning of the process flow. There is a high likelihood that the driver may not remember specific aspects of the trip if the driver does not complete the logs in real-time, increasing the opportunity for error. Specific sources of error many include incomplete logs (e.g. missing signature, missing hours, missing destinations, missing mileage), unclear distinctions between off-duty, sleeper berth, driving, and on-duty status, and inaccuracies due to issues such as changing of time zones during trip and rounding to the nearest 15 minutes.

2.4.2. Transmission Error

There are also opportunities for errors when data is transferred between the driver and carrier and/or vendor. While drivers are tasked with submitting logs to the proper personnel (dispatchers, terminals or vendors), logs are occasionally lost prior to or during submission, requiring extra work by all parties involved. In fact, each time the logs are moved from one location to another, there is a potential for the logs to become lost. There is less potential to lose logs for Carrier 2 since drivers return to the terminal each night. For Carrier 2, logs are not transferred to a vendor for auditing and storage, thus removing the errors associated with the use of vendors.

2.4.3. Data Entry Error

Logs for those carriers who use vendors are electronically entered into the system. Carrier 2 manually enters HOS information into the carrier's computer system at each terminal. Manual entry generates more opportunities for errors. The carriers and outside vendors typically complete auditing manually. Hence, errors can be observed for various trip information including fuel stops, driving distances, tolls, and arrival times. Because Carrier 1 and Carrier 3 use a vendor to audit and store logs, the carriers has less control over the auditing and storage process. Additionally, there is the potential of not being properly notified of non-compliant logs or having problems accessing electronic logs.

2.4.4. EOBR Error

While EOBR systems are expected to reduce error within the HOS recording process, these systems are not expected to be error free. Even though the in-vehicle interface automates many driver inputs, the driver still needs to enter the on-duty and non-driving time manually, which can lead to some inaccuracies. Additionally, none of the recording systems (paper or electronic) require carriers to address log violations and regulations non-compliance.

2.5. Quantifying Error within HOS Recording Systems

Errors can be categorized using the information-based process operations described earlier. In the errors described in this section, a minimal or no risk of technology failure is assumed for the paper-based and electronic recording systems. Table 2 provides a comprehensive list of the sources of error within each case study and with EOBRs.

Table 2 Sources of Error within HOS Recording Systems

Sources of Error	Carrier 1	Carrier 2	Carrier 3	EOBR
1. Origination				
Drivers do not fill out logbook completely	✓	✓	✓	
Drivers do not fill out logbook accurately	✓	✓	✓	✓
2. Collection				
Driver does not submit log on time/at all	✓	✓	✓	
3. Storage				
Driver loses log before submitting to carrier	✓		✓	
Driver does not keep copy of log in truck for 7/8 days	✓	✓	✓	
4. Processing				
Logs are manually input incorrectly		✓		
Logs are scanned incorrectly	✓		✓	
5. Interpretation				
Logs are audited incorrectly	✓	✓	✓	
6. Application				
Carrier does not address violations/non-compliance	✓	✓	✓	✓
7. Retrieval				
Carrier has issues with outside electronic access to logs	✓		✓	
8. Communication				
Logs are lost during transport from driver to carrier/dispatch	✓	✓		
Logs are lost during transport from driver to vendor			✓	
Logs are lost during transport from carrier/dispatch to vendor	✓			
9. Dissemination				
Carrier is not notified by vendor about non-compliant logs	✓		✓	
TOTAL Sources of Error	12	8	11	2

A comparison between paper-based and electronic recording (in Table 2) shows that EOBR usage reduces the number of potential error types within the process. Opportunities for errors are reduced during collection, storage, processing, interpretation, and communication operations. As noted in previous studies (Belzer 2002; Campbell et al. 1998), errors associated with EOBRs occur because the system cannot guarantee that logbooks are completed accurately, especially during on-duty/non-driving times. Regardless, EOBRs do provide more oversight than previous methods, especially for automatically identifying when the vehicle is in motion. Additionally, EOBR systems do not force action by the carrier in response to violations. As with hand-written logs, carriers must address compliance on their own accord.

Table 2 also highlights the differences in potential errors between carrier processes. When another player or step is added to the process (i.e., use of a vendor by Carriers 1 and 3 to audit and store records), the potential for errors increase. There is potential error introduced with additional information transfer (communication) as well as the retrieval and dissemination of information that is not under the direct control of the carrier. Despite this, vendors may offer unique abilities to make them suitable for use in current HOS recording process.

While it is difficult to assign quantitative values to the impact of each error type, qualitative assessments can be made dependent on when and how the errors are identified, and by the consequences of these identifications. Errors can be identified by the carrier as logs are returned to the terminal, as they are audited, or by the DOT during either roadside inspections or carrier audits. While errors identified by the carrier are not without consequence, errors identified by the DOT often have larger repercussions such as drivers being placed out of service (OOS) or fined.

When the carrier discovers errors, either when logs are returned to the terminal or during an audit, the carrier typical follows a standard protocol to address the errors. Errors that are identified immediately (e.g., incomplete logbooks) can be corrected quickly and without serious consequence. Other errors, such as an inaccurate logbook, can be discovered during internal audits and may result in additional training and/or a driving suspension. Both of these consequences result in added cost and lost productivity for the carrier, but are not guaranteed to result in more severe repercussions from the DOT. One of the two types of errors not eliminated by EOBR-use, inaccurate logs (1b from Table 2), can be considered a HOS error with a great impact for the carrier. The second error that an EOBR does not eliminate is the failure of the carrier to address non-compliant logs (6a from Table 2). While this error does not directly impose a cost or penalty on the carrier, it may perpetuate a culture of disregard for HOS regulations within the company, which could result in indirect costs due to future violations. Additionally, there is a cost associated with the health and safety concerns of non-compliance.

2.6. Discussion

Current processes for recording HOS at three carrier sites were analyzed to understand how and where errors within the process could occur. Many carriers still use paper-based methods, but recent U.S. regulations may require carriers to begin recording HOS records in an electronic format, prompting the need for understanding the differences between the two methods. Although the use of electronic systems for recording HOS is still being validated, similar technology has been successfully used to monitor and record information to enhance system performance. The benefits of both the ACE Truck e-Manifest system (Shackelford, Short and Murray, 2007) and CVISN initiatives (Brand et al., 2004; FMCSA, 2002) help support the growing use of electronic systems to record and manage commercial vehicle data, such as the use of EOBRs to record HOS information.

This study examined the differences in processes and the potential for errors in three carriers using system flow diagrams. It is recognized that three carriers is not representative of all carriers in the U.S. Further, there may be other novel approaches to reduce errors that are not electronically based, such as modifications for internal use only for ease of recording. The comparison done in this study is one of the first and does provide a foundation for future research in analyzing the potential monetary savings/costs that may influence the increased adoption of recording-based technologies by the carrier industry.

Comparison of the paper-based and EOBR HOS recording processes revealed fewer error types (an average of 10 fewer within the carriers examined) with the electronic system. Error types are categorized by operations within an information-based process. With EOBR, improvements in the HOS recording process are observed for data collection, entry, and storage of data given fewer steps and less manual requirements.

Errors cannot be completely removed from the recording process. More specifically, EOBRs do not fully guarantee the accuracy of records or require carriers to act on non-compliance, but electronic systems do provide improvements for most current processes used by carriers. Examining the potential repercussions of the HOS recording errors can help reduce them and improve compliance. There is also a potential benefit for the carrier by reducing the costs related to these violations. The motor carriers represented in this study varied in size from mid to large. While it is expected that smaller carriers will also benefit from EOBR use, the cost of such units may be prohibitive. Further study is required to fully understand the economic feasibility of EOBR implementation.

As policymakers consider changes to current HOS regulations, a greater understanding of the documentation process is needed. This study identified where errors can occur in the HOS process and is a first step in understanding the full impact of EOBRs within HOS recordings. As carriers begin to implement EOBRs within their vehicle fleets, a quantitative assessment of the reductions in HOS violations can be completed. Additional issues may arise during implementation that may impact EOBR usage and the HOS recording process. Hence, empirical testing is needed to quantify the magnitude and frequency of these errors. Because, EOBR is not error free, it is unclear how drivers may actually compensate for these errors over extended period of use. A future area of research will need to examine whether drivers adapt to the system in ways not initially intended.

2.7. Summary

This chapter provides a systematic and structured comparison of paper-based and electronic methods of recording HOS, highlighting the error types that occur in both. The analysis shows that some of the errors that occur with paper-based systems still exist (e.g., verification of accurate records) with electronic recordings, and there are some additional minor errors. However, data collection, entry, and storage are improved, as the system requires fewer steps and less manual requirements within the process. Policymakers can consider this comparison when making recommended revisions to HOS documentation procedures. This chapter highlights the improvements made to the HOS recording processes through the use of technology and these insights help inform the benefit discussion within the next chapter. The work described in this chapter has already been presented at the Annual Meeting of the Transportation Research Board (in 2012) and has been accepted for publication in the ASCE Journal of Transportation.

3. An economic analysis of on-board monitoring systems in commercial vehicles: a benefit-cost analysis

This chapter develops a framework for a benefit-cost analysis (BCA) that not only analyzes benefits and costs associated with OBMS use, but also examines under which circumstances system use is economically feasible, the extent to which benefits can be quantified, and the uncertainty within such values. It specifically addresses the research question:

> *From a carrier perspective, what are the benefits and costs associated with using on-board monitoring systems within commercial vehicle operations, and under what circumstances is system use is economically feasible?*

In addition to the traditional benefits of improved safety from use of these systems, components in the system may allow for operational improvements that also result in economic benefits for the carriers. In order to better understand the economic implications of on-board monitoring systems, it is important to consider all such benefits, including reduction in crashes, reduction in hours of service violations and recording costs, reduction in fuel consumption, and reduction in miles travelled due to improved routing efficiency.

3.1. Problem Description and Analysis Overview

Technological advancements have improved monitoring and supporting the safety of commercial drivers. Some examples include lane departure warning systems (Orban et al., 2006), drowsy driver detection systems (Grace et al., 1998), and hours of service electronic on-board recorders (Cantor, Corsi and Grimm, 2009). These on-board monitoring systems (OBMS) are designed to monitor driving performance, inform commercial drivers of safety critical situations, provide feedback, and record trip information. Previous research (Donmez, Boyle and Lee, 2008a; Donmez, Boyle and Lee, 2008b) has shown that targeted driver feedback is effective at reducing driver-related crash risk factors and enhancing driver performance. However, there are costs to system implementation, and as expected, the systems' economic viability needs to be considered. As these systems become more prevalent and policies regarding the use of such system are considered, it is important to understand the value and economic sustainability of such systems. A framework for a benefit-cost analysis (BCA) is useful and considered in this paper for OBMS to examine both the safety-related and non-safety-related benefits. The BCA considers the uncertainty that exists with these benefits and the extent to which benefits can be quantified. This can then provide context for when the system is economically feasible.

While safety of operations is important to carriers, it is also imperative to recognize that most investment decisions are related to the added profit that can be generated. While larger carriers are more likely to incorporate technological and/or safety systems into their operations, all carriers, regardless of size operate within low margins, thus both initial and recurring costs of these systems must be compared to the safety benefits and efficiencies gained from them (Shackelford, Short and Murray, 2007). A previous study on OBMS usage (Hickman and Hanowski, 2011) recommended further study of carrier return on investment as it was felt to be a motivating factor in carrier acceptance. Additional studies (Kavalaris and Sinha, 1995; Hall and Itihar, 1997; McCallum and Lee, 1993) related to technology adoption within freight transportation also highlight carriers' expectations to benefit economical from technology implementations. Thus it is important to quantify the benefits within a benefit-cost analysis

(BCA) from the perspective of individual carriers to underscore the potential economic benefits related to system usage.

The objective of a BCA is to determine the net economic benefit of a new program or project. Benefit-cost analyses are common within the transportation sector and many are focused on programs that incorporate technology into operations and/or which improve safety. Existing research, industry knowledge, and carrier consultation was used to develop the basis for a BCA regarding the use of OBMS. The safety benefits of using OBMS are to reduce crashes and HOS violations. It is beneficial to also consider non-safety related factors such as reduction in fuel consumption, and improved routing as these have to potential to provide significant economic benefit. Although BCAs have previously been used to study the economic impacts of other onboard safety systems (Orban et al., 2006; Battelle, 2007; Battelle, 2003; Houser et al., 2009; Murray, Shackelford and Houser, 2009a; Murray, Shackelford and Houser, 2009b; Flintsch et al., 2012; Campbell et al., 1998), most studies center on the safety benefits of these systems, and have very few to no factors related to the non-safety related benefits, which can have a larger impact on carrier costs.

Using a five year technology lifespan, as is common with such systems, several measures are considered in the BCA: net present value (NPV), benefit-cost ratio (BCR), and payback period (PBP). Any one of these metrics is not meant to provide a conclusive decision, but instead should be considered in making recommendations about OBMS usage. Net present value is traditionally the most used BCA metric because it straightforward and consistent results. All three metrics are calculated within the analysis and are explained in further detail within the methodology, but NPV is most frequently used in analysis discussions.

Within this research, as in most BCAs, a sensitivity analysis is necessary to address uncertainty and generalize the BCA. In the base BCA, benefit and cost data comes from carrier and system provider consultation, as well as from average nationwide values. The analysis considers input data specific to a given fleet of vehicles (for example, number of vehicles and average annual vehicle miles travelled) as well as variable inputs regarding the effectiveness of the system and level of carrier engagement (for example, crashes reduced and fuel consumption reduced). In order to capture the effects of both fleet characteristics and uncertainty in system effectiveness, a sensitivity analysis will examine the impact of changes to input components of the analysis. This allows for insight into how variables and changes to variables are related to the analysis output, and which variables have the largest impact on economic viability of OBMS. Details and results of the sensitivity analysis are explained in greater detail later in this study.

This BCA examines the economic implications of OBMS usage in commercial vehicle fleets from the carrier perspective. The initial and ongoing costs of such systems are compared to the benefits of OBMS use to better understand the economic implications of installing OBMS in a fleet of vehicles. While BCAs are often used within the transportation field and have previously been used to study the economic impacts of other onboard safety systems, most studies only consider the safety-related benefits (reduced crashes and/or reduced HOS violations) of these systems, and neglect to capture the additional benefits (reduced fuel use and/or reduced mileage) which fleets may be able to capitalize on. This study examines both sets of benefits, specifically looking at the extent to which benefits can quantified and under what conditions OBMS use is feasible, and aims to provide both carriers and regulatory agencies with insight into the economic impacts of OBMS usage.

3.2. Literature Review

Benefit-cost analysis is an economic decision making approach which calculates and compares expected benefits and expected costs of a proposed project or program (Boardman et al., 1996; Dasgupta and Pearce, 1972; Gramlich, 1981; Sassone and Schaffer, 1978). Formally BCAs are used to describe societal analyses which allow for fair and efficient allocation of resources. Benefit-cost analyses are often used by policy makers as part of the decisions making process within government. Conceptually, BCAs consist of the following nine steps (Boardman et al., 1996):

1. Determine the prospective of the analysis (global, national, state, local, individual)
2. Determine alternatives to be analyzed (often to implement the program or to not implement)
3. Catalogue the impacts and select metrics
4. Determine the quantitative impacts over the life of the project
5. Monetize all impacts
6. Discount for time to find present value
7. Sum up all benefits and costs
8. Perform sensitivity analysis
9. Recommend the alternative with larger net benefit

As expected, many benefit-cost analyses have been performed within the transportation sector, and many are focused on programs which incorporate technology into operations and/or which improve safety. Within these analyses programs are often examined from a carrier perspective because they require "buy-in" from the carriers who make decisions based on economic conditions. The existing literature on BCAs takes one of two perspectives within the analysis, focusing on either the individual (carrier) perspective, or the societal perspective. Regardless of the perspective taken, many of these studies conclude that the incorporation of technology into operations has a net positive economic benefit. Several of these studies specifically related to onboard safety systems are described in more detail below, with specific aspects explored even further within the study methodology.

As part of studies examining the efficacy of specific in-vehicle (or on-board) systems (Orban et al., 2006; Battelle, 2007; Battelle, 2003), high-level benefit cost analyses compared system deployment costs to the societal benefits of system use, focusing on the reduction of crashes. These field operations tests and simulator studies on lane departure warning systems, forward collision warning systems, and roll stability control systems aggregated safety benefit data to represent the national fleet of commercial vehicles by scaling the results to consider estimated nationwide truck populations. While the results of the efficacy studies (described in further detail in the methodology discussion) indicated that the system improved driving performance and reduced crashes, conclusions regarding the economic impact of use of such technology was mixed. Each study looked at multiple scenarios within the analysis, considering combinations of truck type, system cost category, conflict thresholds and system efficacy. The studies identified benefit costs ratios between -0.05 and 5.11 (where ratios greater than one are economically beneficial) and of the 64 scenarios considered between the 3 studies, only 25 were determined to have benefit cost ratios over one, thus considered economically viable. System cost and fleet type and size were key components in determining if a scenario was considered to be beneficial.

Following up on the above studies, a series of BCAs (Houser et al., 2009; Murray, Shackelford and Houser, 2009a; Murray, Shackelford and Houser, 2009b) examined the economic impact of electronic safety systems (lane departure warning systems, forward collision warning systems, and roll stability control systems) in commercial vehicles. These studies used, in part, efficacy results from the prior studies within their analysis. In all three studies the CBAs examine the systems from the carriers' perspective and use similar methodology. Within the analyses, the benefit was defined as crash avoidance. Cost data was provided by carriers through surveys and included purchase, installation and operations costs of the safety systems. The BCAs indicated positive returns on carrier investments in all three cases. These studies do not look at benefits beyond reduction in crashes.

Flintsch et al. (2012) further expanded on the above research to examine the economic effectiveness of onboard systems. This research differed from previous efforts in that data regarding crashes was gathered directly from carriers and each crash was reviewed to determine if the use of onboard safety systems (lane departure warning systems, forward collision warning systems, and roll stability control systems) could have prevented the crash. The benefit cost analyses presented in the research examine each safety system independently and examine the benefits and costs from both a carrier and societal perspective. The analysis considered both net present value and benefit cost ratios, and considered different levels of exposure (varying vehicle miles travelled). In most cases, the analysis indicated the benefits outweighed costs, the exception being within the forward collision warning scenario for trucks with high annual vehicle miles travelled.

Related to hours of service as discussed earlier and to be included within this BCA, Campbell (1998) performed an informal BCA of EOBR usage. The analysis was performed using input from carrier responses to a survey. The analysis was limited to the benefits resulting from reduced time required by both drivers and managers to record and manage HOS records. Results of the analysis indicated that carriers recovered their investment in 3 years and savings for use of EOBR systems include approximately 20 minutes per driver per day to record hours of service, and 20 minutes per vehicle per month for administrative time. Carriers indicated that they foresaw no adverse operations effects from the use of EOBRs but also felt that use of the devices would have little effect on commercial vehicle safety.

3.3. Methodology

Using the standard methodology described earlier as a basis for the BCA methodology within this research, the following steps are used:

1. Determine the benefits due to OBMS implementation
2. Determine to costs associated with the OBMS implementation
3. Calculate the net present value (NPV), benefit cost ratio, and payback period
4. Perform a sensitivity analysis to address uncertainty and generalize the BCA

While the BCA methodology developed within this research could be used to analysis the economic impact of OBMS usage in any given fleet, the fleet described below is used as a base case for comparison and discussion regarding the analysis. Aspects of one of the carriers (Carrier

2) previously studied with regards to HOS recording procedures were used as a base case for the BCA, specifically looking at one terminal consisting of a fleet of 62 vehicles. The carrier has indicated that there is one safety manager per approximately 20 drivers. Within the base case the terminal fleet travels approximately 7,900,000 miles per year, or approximately 127,500 miles per year per vehicle. This value of vehicle miles travelled (VMT) is within the range of typical VMT per vehicle. It is assumed that each terminal acts independently with regards to the benefits and costs associated with OBMS usage and that the base case terminal is representative of the carriers overall fleet. This fleet is used as a base case for comparison and discussion.

3.3.1. Benefits

While the primary motivation and largest benefit of OBMS usage is to reduce crashes, this is not the only potential benefit of system use to be realized by carriers. The EOBR components of the system also have the potential to reduce HOS violations and the costs associated with HOS recording. Due to improvements in driving behavior and improved operational efficiencies, the systems also have the potential of reducing fuel costs and improving routing, thus reducing mileage. Benefits are realized as cost reductions and discussed in greater detail below.

Benefits associated with reduced crashes

The monetary benefit of crash reduction due to monitored driving behavior is determined using the number of crashes that occur before OBMS use, the estimated crash reduction rate due to system use, and the cost of such crashes.

Number of crashes

Data from the National Highway Traffic Safety Administration (NHTSA, 2009), compiled from both the Fatality Analysis Reporting System (FARS) and the General Estimates System (GES) provide statistics on crash trends and involvement rates per vehicle miles of travel for specific classes of vehicles including large trucks (single-unit trucks and truck tractors with a gross vehicle weight rating greater than 10,000 pounds). Looking at 10 years of data (2000-2009), it was determined that large trucks are involved in crashes at the following rates: 138.8 property-damage-only (PDO) crashes per 100 million VMT, 35.4 injury crashes per 100 million VMT, and 1.96 fatality crashes per 100 million VMT. For the fleet examined as part of the base case (with a VMT of 7.9 million miles), this would result in 11 property-damage-only crashes, 3 injury crashes, and no fatality crashes. Comparing these numbers to the carrier provided information on past crashes (41 property-damage-only crashes, 3 injury crashes, and no fatality crashes), the injury and fatality crashes compare well, but there are significantly more carrier reported property-damage-only crashes reported. This is due to the fact that the NHTSA data only considers DOT-reported crashes, while the carrier data includes both DOT-reported and non-reported crashes. Some carriers are inherently safer than others, and more notably, larger fleets (thus those with greater vehicle miles of travel) are often safer (Knipling, 2011; Corsi and Barnard, 2003; Stock, 2001). Within the base BCA the crash rates from the NHTSA data is used. Varying crash rates will be considered within the sensitivity analysis and will address the concerns above.

Crash reduction rate

To determine a crash reduction rate due to OBMS implementation for use in the BCA, numerous existing studies were examined. A proxy measure is used to estimate the number of crashes avoided by onboard safety systems. The scopes and methodologies of such studies vary and some are more relevant than others. The most relevant studies involve commercial vehicles, consider multiple types of safety critical events, and/or examine the impact of both real-time and post event feedback. While studies of similar systems in passenger vehicles have been conducted (Toledo, Musicant and Lotan, 2008; Najm et al., 2006), results of these studies are not considered in this research given the differences in operations between passenger vehicles and commercial vehicles. All of the existing studies indicate that OBMS reduce crashes, but to varying degrees and with varying levels of comprehensiveness. The methodologies and results of these studies are examined in detail below.

Orban et al. (2006) evaluated a lane departure warning system for commercial vehicles using a field operational test. The system uses forward-looking videos to identify lane boundaries and determine the position of the vehicle within the boundaries. The system provides a warning to drivers when the vehicle drifts from the lane. Feedback was limited to this real-time feedback and there was not feedback regarding critical events after they occurred. While data was gathered from only 6 drivers (due in part to equipment malfunctions), the study was conducted over a 12 month period and included baseline, active and post-active periods. Two measures were considered: the exposure of a vehicle to driving conflicts which could lead to crashes, and the prevention of crashes when a vehicle is in a driving conflict. Driving conflicts served as a surrogate safety measure. Reductions in exposure of vehicles to driving conflicts was directly determined from the field operational test data, while the prevention of crashes was estimated using historical data and simulations developed using onboard truck information to determine if conflicts would result in crashes (based on vehicle trajectories and driver recovery maneuvers). The crash reduction ratio takes into account both the exposure ratio as well as the prevention ratio. The benefit of the LWDS related to the number of single vehicle road departure crashes avoided was estimated to be between 21.2% and 23.5%, while, the percentage of rollover crashes avoided was estimated to be between 17.4% or 23.9%.

Similar to the above study, Battelle (2007) evaluated the impact of forward collision warning systems on commercial vehicle safety in a field operational test. The forward collision warning system uses forward radar sensors to measure the distance between vehicles. The system provides both a visual and audible warning if vehicles are too close together and a potential crash is detected but there was no feedback or review of safety critical events after their occurrence. Data was collected for almost three years on 100 vehicles (high driver turnover resulted in over 1000 drivers). As above, two measures were considered: the exposure of a vehicle to driving conflicts which could lead to crashes and the prevention of crashes when a vehicle is in a driving conflict. Reductions in exposure of vehicles to driving conflicts was directly determined from the field operational test data, where driving conflicts included evasive maneuvers, hard brake applications and system alerts. The crash reduction rate was estimated by a kinematic analysis of field operational test conflicts to determine lag time of reaction and thus severity of conflict. Comparing crash rates for drivers that used the system to drivers that did not across all conflict types (constant speed, slowing, and lane change), it is estimated that the systems help reduce the total number of truck-initiated rear-end crashes by 21 to 28%.

In a third study based on a field operational test, Battelle (2003) examines the safety impacts of a roll advisor and controller on-board safety system. This system includes two major components. First, a roll stability advisor informs drivers when they are at a high risk of rollover due to speed on a curve. This includes visual and audible alerts which occur after the incident to advisor the driver that the previous maneuver was risky and recommend a lower speed for future curves. The roll stability control component initiates vehicle braking to prevent a rollover, specifically as a result of excessive speed in a curve. An alert is provided when this occurs. Rollover risk is determined by comparing the vehicle's rollover threshold to the effective lateral forces on the vehicle given speed and vehicle path. Data was gathered from six drivers in tanker trucks (the study assumed that potential benefits due to system could be found in all heavy vehicles) over a 15-month period and included baseline and active periods. Similar to the two previous studies, both the exposure of a vehicle to driving conflicts (which could lead to crashes), and the prevention of crashes when a vehicle is in a driving conflict were examined. Exposure ratios were determined from the field operational test data and prevention ratios were determined from simulations examining the forces existing in conflicts. The field operational test did not provide evidence of the roll stability control activating to prevent a crash; therefore it was not possible to determine the contribution of this system in the overall safety benefit estimate and the estimated crash reduction rate is assumed to be due to the roll stability component of the system. This aspect of the results makes the crash reduction rates more relevant for use in the BCA given that the OBMS being studied only provides warnings, not physical reactions to the vehicle's operations. It is estimated that the systems help reduce the total number of crashes by 20% to 33%.

An improved braking system was examined, by Houser, Pope & McMillan (2006), that included roll stability advisor and controller. This braking system was improved since the field operational test but this time, a computer simulation was used to model the new system and predict reactions based on the previous test results. Crash reduction rates of 53% to 69% were observed, but are based on both the roll stability advisor and the roll stability control, the later includes a mechanism to physically impact vehicle operations (i.e. to brake). For the dissertation and study, only the roll stability advisor is used in this calculation (i.e., crash reduction rates of 20% to 33%) as they are the more relevant to this study.

Three similar studies (Houser et al., 2009; Murray, Shackelford and Houser, 2009a; Murray, Shackelford and Houser, 2009b) developed a benefit-cost analysis for individual OBMS components: lane departure warning systems, forward collision warning systems, and roll stability control systems, respectively. All three of these studies use, in part, conclusions from the previously described research. These studies are primarily focused on evaluating the benefits and costs of safety systems within the trucking industry and estimate crash reductions based on previous studies and information gathered from motor carriers. Houser et al. (2009) use system efficacy values ranging from 23% to 53%, depending on crash type prevented. The value on the low end of the range is based on field operational test results (Orban et al., 2006) discussed earlier, while the values on the high end of the range are based on motor carrier estimations of crashes prevented within their own fleets. Murray, Shackelford and Houser (2009a) use crash reduction rates ranging from 21% to 44%. The value on the low end of the range is based on field operational test results (Battelle, 2007) also discussed earlier, while the values on the high end of the range are based on motor carrier estimations of crashes prevented within their own fleets. Finally, Murray, Shackelford and Houser (2009b) use crash reduction rates ranging from 37% to 53%. The value on the low end of the range is based on a motor carrier estimations of crashes prevented within their own fleets, while the values on the high end of the range are based on a simulation study (Houser, Pope and McMillan, 2006) discussed earlier. As noted previously, the results from the simulation study are considered to be higher than the crash reduction rates expected in the studied OBMS due to the automatic braking system being analyzed in the simulation.

Hickman & Hanowski (2011) used commercial vehicle drivers, employed by two separate carriers, and trucks equipped with onboard monitoring systems to evaluate the efficacy of such systems. Using cameras and accelerometers, safety critical events such as hard cornering, hard braking, hard acceleration, collision, and driving on rough or uneven surfaces were identified and recorded by the system. After a 4-week baseline phase, drivers received both immediate feedback and safety coaching sessions if necessary for a 13-week intervention phase. Both safety-related events and “severe” safety-related events (where the event was determined to be above a certain safety threshold) were identified for each stage of the experiment to determine if onboard safety monitoring systems would reduce such events. For both carriers the mean rate of safety-related events per 10,000 miles traveled was reduced by 37% and 52.2% and considered statistically significant. Considering severed safety-related events, while the findings were not considered statistically significant, there was a substantial reduction in the mean rate of severe safety-related events/10,000 miles (59.1% and 44.4%).

Based on the premise that drivers who know they are being monitored may adjust their driving behavior, and that data recording will enable feedback to drivers after specific driving events, Wouters and Bos (2000) examined seven different vehicle fleets (including heavy trucks, medium trucks, buses, taxis, vans, and company cars) to better understand the impact of monitoring driver behavior on safety. The onboard monitoring systems used within this study did not provide real-time feedback. Feedback was provided by fleet owners and managers after safety critical events, but the methods of feedback were not specified or controlled for within the study and varied amongst fleets. Reductions in crash rates were determined by comparing actual crash rates both before and after the intervention, and also between and experimental fleets and a comparable control fleet. This was possible due to the large number of vehicles observed (840 total with 270 equipped with a recorder) and the duration of the observation period (approximately 3100 vehicle years). Study results indicate an overall accident rate reduction between control vehicles and experimental vehicles of 20% and an overall accident rate reduction between pre-intervention and post-intervention within a fleet of 31%.

Table 3 summarizes the results of previous research on the estimated crash reduction rates due to onboard safety system (note that the results from the study by Houser, Pope and Millan was not included because it was determined that the results of the study were not relevant to this research). Given the range in both methodology and conclusions on crash rate reductions seen in previous research, a crash reduction rate of 21%, which corresponds to the first quartile of these reduction rates, is used within this analysis. Given the uncertainty of this value, other crash reduction rates will be examined within the sensitivity analysis. This crash reduction is applied to the number of yearly crashes, calculated using the crash rate and annual VMT of a fleet, to determine the number of crashes reduced by system use.

Table 3 Crash Reduction Rates from Existing Literature

Existing Literature	Crash Reduction Rate	System Description
Orban et el (2006)	17% to 23%	Lane departure warning system
Battelle (2007)	21% to 28%	Forward collision warning system
Battelle (2003)	20% to 33%	Roll stability control systems
Houser et al. (2009)	23% to 53%	Lane departure warning system
Murray, Shackelford and Houser (2009a)	21% to 44%	Forward collision warning system
Murray, Shackelford and Houser (2009b)	37% to 53%	Roll stability control system
Hickman and Hanowski (2011)	37% to 52%	On-board safety system considering hard cornering/braking/acceleration, collision, and rough/uneven surface
Wooters and Bos (2000)	20% to 31%	On-board data recording system (type of data recorded and feedback received varied among fleets in study)

Crash costs

The cost of a crash varies can be considered from several points of view including from the carrier and from society. Within this BCA, crash cost refers to the costs assumed by the carrier. This analysis assumes that all carriers are self-insured and are therefore, liable for the true cost of the crash. While this is likely not the case for small carriers, carrier crash costs are more difficult to determine if a carrier is not self-insured because crashes often result in increased future insurance premiums. It is assumed that while the direct costs of a crash may be less for a small carrier than the costs used in this analysis, these costs also account for the unknown additional indirect costs.

Within the base analysis, several sources were considered when during crash cost. The study carrier provided crash cost data for the time period from September 2009 to November 2011. Cost data was provided from carrier records for individual crashes and represent the true cost of each crash. These cost values only considered direct costs including liability, cargo and collision costs. The cost of PDO crashes vary between $0 (for not at fault crashes) and $8,500 per crash, and injury crashes vary between $50,000 and $81,000 per crash. There are no costs provided for fatality crashes given that no fatality crashes occurred within the analysis time frame. Additional cost information was gathered from existing literature. Several studies sponsored by the FMCSA (Houser et al., 2009; Murray, Shackelford and Houser, 2009a; Murray, Shackelford and Houser, 2009b) identify the following crash cost ranges (in 2008 dollars): $100,000 to $197,000 per crash for PDO crashes, $135,000 to $462,000 per crash for injury crashes, and $885,000 to $1,253,000 per crash for fatality crashes. These costs are from a carrier perspective and include many indirect costs that were not reported in the carrier-provided costs. These indirect costs include replacement labor (recruitment, training, testing, hiring), worker's compensation, environmental cleanup, and labor costs. While it is not unreasonable to include these costs when including the monetary effects of a crash, it is believed that they may be overestimated given the nature of accidents typically reported by the carrier involved in this study. It is believed that the cost data provided by the carrier is on the low end of typical crash costs because it does not include indirect costs associated with crashes, and the crash data from the FMSCA is on the high end of typical crash costs due to the high indirect costs included in the calculations. To address this, the following mid-range crash costs, based on the information gathered from the carrier and direct costs noted in the FMCSA studies, will be used in the base case analysis: $5,000 per crash for PDO crashes $50,000 per crash for injury crashes, and $500,000 per crash for fatality crashes.

These costs are in accordance with other high-level BCAs completed in research reviewed (Battelle, 2007; Orban, 2006; Battelle, 2003). Other cost values will be examined within the sensitivity analysis.

Calculating the benefit

The monetary benefit from reduced crashes is determined as follows:

$$B_{crash} = \sum_{all\ crash\ types} base\ crash * crash\ reduction * \ crash\ cost$$

where B_{crash} = benefit from crash reduction, base crash = base number of crashes/year before OBMS use, crash reduction = crash reduction rate (%) from OBMS use, and crash cost = cost of crash ($/crash).

The table below summarizes the data used within this benefit calculation.

Table 4 Crash Benefit Values Summary

Crash Type	Base Crash Rate (crashes/ 100M mile/year)	Crash Reduction Rate	Crash Cost ($/crash)
Fatality	1.96	21%	$800,000
Injury	35.4	21%	$50,000
PDO	138.8	21%	$5,000

Benefits associated with electronic HOS recording

The OBMS examined within this study also has capabilities to electronically record HOS using electronic on-board recorders (EOBRs). This option is not a feature included as part of the other electronic safety systems discussed earlier (Orban et al., 2006; Battelle, 2007; Battelle, 2003; Houser et al., 2009; Murray, Shackelford and Houser, 2009a; Murray, Shackelford and Houser, 2009b; Flintsch et al., 2012), but there are several economic benefits. First, there is a benefit associated with the cost reductions attributed to electronic recording of HOS information as compared to paper recording (as described in section 2). Second, there are both internal (time and extra training) and external (fines and out of service penalties) cost reductions associated with HOS violation reductions. Third, there are potential benefits associated with fewer fatigue-related crashes with greater adherence to HOS regulations.

While it is relatively easy to quantify the benefit gained due to improved recording process efficiencies when switching from a paper-based recording system to an electronic one, there is more complexity associated with quantifying the benefits associated with reduced violations and reduced crashes due to improved compliance. Regarding the reduction in violations, it is not possible to establish the true compliance rate before system use. Carriers and drivers are not likely to voluntarily disclose non-compliance thus, while some violations will be identified by the FMCSA during inspections and reviews, many others will go undetected. As explained in more detail below, FMCSA-detected violations from both roadside inspections and carrier reviews provide the closest estimate of the number of drivers operating out of service based on the limited information available regarding true HOS violations. A previous study (FMCSA, 2010b) makes similar assumptions. Within the BCA, benefit is obtained when fewer violations result in fewer fines and less employee time for training and administrative work. Undetected violations do not directly result in costs for the carrier, thus basing carrier benefits on reductions of known violations is reasonable.

Similar to earlier discussions of crash reductions, it is also difficult to quantify the number of crashes avoided due to improved HOS compliance. It is not always clear that a crash is fatigue-related and that the fatigue is a result of HOS non-compliance. While police crash reports may indicate if a crash is fatigue related, these reports rarely provide information about HOS violation and it is difficult to attribute crashes directly to HOS violations or to determine a crash reduction benefit specific to using an electronic system. These difficulties are noted as part of Large Truck Crash Causation Study (FMCSA, 2006). It was previously estimated using historical crash data that fatigue is significant factor in approximately 25% of all truck-involved crashes where the truck driver is responsible and the likelihood of a crash increases as drivers work longer hours (FMCSA, 2005), but it is difficult to attribute crashes directly to HOS violations or to determine a crash reduction benefit specific to EOBR use. Given the challenges associated with estimating this crash reduction, this benefit is not quantified.

At the same time that there is expected benefit from EOBR use, there is also concern that the use of such devices can reduce productivity. Information gathered from case studies (Knipling, 2011) indicates that carriers do report decreased productivity but also note that operational managers receive improved data on driver hours and compliance which improves planning and dispatching. In fact, other carriers also noted the benefits of EOBRs beyond HOS recording, commenting that EOBRs give the carrier more knowledge of operations, improve the efficiency of management, help in making better use of available driver hours, and quickly highlight compliance problems. One carrier indicated that drivers in EOBR-equipped vehicles actually drive more miles because they are more efficient, which has also been noted in other research

(CCMTA, 2010; FMCSA, 2010b; Hubbard, 2003). Within this analysis, the reduction in productivity, due to stricter adherence to HOS regulations, is not captured.

Benefits from Recording Process

The benefits gained from switching from a paper-based HOS recording process to an electronic process come from reduced costs associated with employee time and materials. Using an electronic system to record HOS reduces the time required by both administrative personnel and drivers to record and store hours of service information. Previous research indicates that time required by administrative personnel for HOS related tasks can be reduced by 1 minute per day per driver, or 20 minutes per month per driver (FMCSA, 2010a; Campbell, 1998). Estimates for reduced driver time vary between 4.5 minutes per day (FMCSA, 2010b) and 20 minutes per day (Campbell, 1998), but it is assumed that drivers are paid by the mile or by the trip and the burden of time spent recording HOS falls on the driver. Hence, the carrier does not necessarily observe a benefit from the time reduced by the driver in this process. In addition to the time savings, there is also a savings gained from no longer using paper log books. The carrier consulted within this study indicated that log books cost approximately $2.20 and one a month is required for each driver.

Reduction in HOS violations

In order to determine the direct economic benefit associated with a reduction of HOS violations, violations were categorized as either acute or critical violations. Acute violations are violations such as incomplete or unsigned logs. These violations can be easily identified by the carrier, addressed quickly, and rarely result in an external penalty (from the FMCSA). Critical violations are more serious violations where drivers are driving beyond the regulated hours and may result fines or drivers being placed out of service. These violations may be identified by either the carrier or by the FMCSA (or state officials) during roadside inspections. The reduction in violations is difficult to quantify because it is not possible to establish the true compliance rate before system use. Carriers and drivers are not likely to voluntarily disclose non-compliance. While FMCSA identifies some violations during inspections and reviews, many others go undetected. Hence, FMCSA-detected violations from roadside inspections and carrier reviews are used, and provide a conservative estimate of the number of drivers operating out-of-service, which is an assumption consistent with a previous FMCSA study (FMCSA, 2005).

Information provided by the FMCSA (FMCSA, 2012a) is used to determine average HOS violations rates with respect to vehicle miles travelled. Between 2008 and 2010, the FMCSA identified (through roadside inspections and carrier reviews) an average of 518,513 acute HOS violations and 168,170 critical HOS violations. Given an average annual commercial motor vehicles VMT of 295,090 million miles between 2008 and 2010 (FHWA, 2012), average violation rates are 1.76 acute violations per million VMT and 0.57 critical violations per million VMT. Constraints on data availability (HOS violation data is only available from 2008 onward and annual VMT information is currently only available prior to 2011) limits the number of years considered in the average violation rates. Similar to with crash rates, it is HOS violation rates may not be representative of the actual violation rates of a given fleet given that some carriers are inherently more compliant than others. Additionally, the statistics used to determine violation rates only account for the violations detected. It is assumed that a great number of violations go undetected, therefore this value in conservative. Within the base BCA the violation rates from above are used but varying rates will be considered within the sensitivity analysis to address the concerns above.

Within the FMCSA's Regulatory Impact Analysis of Electronic On-Board Recorders (FMCSA, 2010b), it is assumed, considering experiential knowledge, that a 50% reduction of HOS violations is reasonable. Industry studies (Cullen, 2007) have also verified this assumption to be sound. Varying reduction rates will be considered within the sensitivity analysis as well to address this uncertainty.

Violation costs

The cost savings associated with reduced violations is observed from reductions in time spent addressing violations (both administrative and driver time), time out-of-service, and fines. Undetected violations do not directly result in costs for the carrier, thus we base carrier benefits on reductions of known violations. It is assumed that the administrative time required to address HOS violations is 30 minute per acute violation and 2 hours per critical violation based on discussions with the carrier. The cost of remedial driver training, which is required by the carrier considered in the base case, when a critical violation takes place, is $27 per violation as provided by the carrier. It is more difficult to quantify the cost associated with the penalties associated with HOS violations because fines and out of service penalties can vary widely based on violation severity and past violation record. The HOS regulations state (FMCSA, 2012b) that carriers may be fined between $1,000 and $11,000 for violations. Due to the wide range of violations and the difficulties in determining the costs (both direct and indirect) associated with drivers being out of service, these penalties have been combined into one value. A penalty of

$6000 per critical violation will be considered in the base case with other penalty values considered in the sensitivity analysis.

Calculating the benefit

The monetary benefit from the use of EOBR as part of the OBMS is determined as follows:

$$B_{HOS} = B_{recording} + B_{violation}$$

where:

$$B_{recording} = \$2.20 * 12\, months * no.drivers + 20\frac{min}{month} * 12\, months * no.drivers * \$20/hr$$

$$B_{violations} = \sum_{all\ violation\ types} base\ violations * violation\ reduction * cost\ violation$$

where B_{HOS} = benefit from HOS improvements, $B_{recording}$ = benefit from improved HOS recording, $B_{violation}$ = benefit from HOS violation reduction, base violations = base number of violations/year before OBMS use, violation reduction = violation reduction rate (%) from OBMS use, and violation cost = cost of violation ($/violation).

Benefits associated with changes in fuel economy

OBMS have the potential to reduce fuel consumption by supporting more fuel efficient driving. Additionally, this potential can be further increased if carriers effectively use information gathered by OBMS to monitor fuel consumption. It is assumed that OBMS usage will impact the fuel economy of the vehicles within this study thus resulting in fuel cost savings.

Changes to driver behavior

Changes to fuel economy result from changes to speed and driving behavior associated with improved safety (Knipling, 2011; af Wåhlberg, 2007; Haworth and Symmons, 2001). Again, because there is not direct measure of improved fuel economy from OBMS usage within this study, existing research was used to determine an improved fuel economy. As pointed out in much of the research, it is difficult to determine a universal effect of driving behavior on fuel reduction for several reasons. First, research has shown (Beusen et al., 2009; Vangi and Virga, 2003; Haworth and Symmons, 2001) that there is wide variability, sometimes up to 20 to 30% between fuel reduction rates of individual drivers subject to the same training and feedback. Secondly, fuel consumption is also related to fleet characteristics such as operations (long haul versus delivery, environment (rural versus urban), and grade (flat versus hilly) and certain fleets may have greater opportunities to reduce fuel consumption by improved driving behavior, while others may be more limited. Additionally, it is difficult to isolate and measure changes in fuel consumption due to driver behavior. Because of this, the impacts of fuel reduction will be examined in the BCA as a range of potential reductions which may realized if OBMS are used in carrier operations.

While there exists limited literature that focuses directly on the fuel economy impacts of safer driving due to OBMS usage, literature regarding ecodriving was examined to consider its relevance. Ecodriving initiatives, which focus on improving fuel economy and reducing fuel consumption to reduce emissions, suggest behavioral improvements such as maintaining a steady speed, accelerating/decelerating smoothly, and anticipating traffic flow also contribute to (or result from) safer driving (Austrian Energy Agency, 2012). Thus, while the mechanism and motivation behind the behavioral change differs between OBMS usage and ecodriving, similar fuel economy improvement results can be expected. These driving tactics are also representative of more defensive driving styles where potential conflicts are anticipated, resulting in safer driving (Knipling, 2011). Several industry and governmental groups have made claims regarding the impact of improved driving behavior on fuel reduction, including both the EPA (U.S. Department of Energy, 2012) and SAFED (2012) indicating a 10% reduction, ecodrive.org reporting 20% reductions in fuel use immediately after training and 5% reductions in the long term, and a 2% - 5% reduction claim by Energy Savings Trust (2012).

Studies, to be described in further detail below, have looked at fuel savings from driving behavior training in passenger vehicle, buses and trucks, and have considered both short-term and long-term effects. As mentioned previously, results of such research varies greatly both between and within studies. Methodologies also vary with few studies being naturalistic in nature, and research conclusions often suggest further study.

Several studies consider heavy vehicle drivers including research by Symmons and Rose (2009), who looked at the impact of an ecodriving course on commercial vehicle drivers. Driver performance was measured while drivers drove a 30 kilometer circuit in a suburban environment both before and after classroom training. Drivers did not receive feedback while driving or have the ability to see their rate of fuel consumption. Focusing on drivers who completed the training, a 27% decrease in fuel consumption was seen immediately after completion of the training and maintained at the 6 and 12 week data collections. Comparing drivers who attended an ecodriving training session to those who did not, the similar decreases in fuel consumption were seen 6 weeks out from training.

Similarly to the study above, Zarkadoula, Zoidis and Tritopoulou (2007) also measured changes to fuel economy while drivers drove a predetermined route (15 kilometers) but instead focused on bus drivers in an urban environment. The sample size was small (three drivers) and all drivers were subject to classroom training. The average decrease in fuel consumption for all bus drivers was 10.2% directly after training and 4.35% during a two month period after the training.

Also considering buses, af Wåhlberg (2007) specifically examines the long term effects of ecodriving training. The study used several years of existing fuel consumption data to compare with fuel consumption in vehicles after drivers underwent ecodriving training. Some drivers also received in-vehicle feedback. The post-training data collection lasted for approximately one year, occurred in an urban environment, and examined nearly 400 drivers. Examining the differences between fuel consumption before and after ecodriving training, reductions of 1.8% were identified. Comparing the fuel consumption of drivers who received ongoing feedback regarding driving behavior to those who did not (where all drivers received one time training), it appears that feedback reduces fuel consumption by an additional 2%.

The impacts of ecodriving and related training are also examined in passenger vehicles. Beusen et al. (2009) study 10 passenger vehicles for 10 months, including time before and after a course on fuel efficient driving. Drivers did not receive ongoing feedback of driving behavior during the study. Analysis of the data indicates an average 5.8% reduction in fuel consumption, but there was a wide variation amongst individual drivers (between a 12% reduction and 3% increase in fuel consumption). Other studies have examined the impact of real-time feedback alone (with no formal training) on fuel consumption within passenger vehicles. Barth and Boriboonsomsin (2009) developed a dynamic ecodriving algorithm used to provide suggested speed information to drivers in an attempt to reduce fuel consumption. Using both simulation and real-world experimentation, the developed ecodriving strategy was employed to determine its impact on fuel consumption. Reductions between 10% and 20% were identified. Similarly, 20 vehicles were examined in a study (Boriboonsomsin, Barth and Vu; 2011) which provided information regarding current fuel consumption and fuel economy to determine the impact of such information on driver behavior. Again, as with many other studies, results varied dramatically amongst drivers. Fuel economy improved by an average of 6% for city driving, with variations between a 5% reduction and 24% improvement. In highway driving scenarios, the fuel economy only improved and average of 1%, with variations between a 12% reduction and 13% improvement.

Within the results discussed above, fuel reductions of up to 30% due to changes in driving behavior have been seen, with many results between 5% and 15%. Combined with the impact from fuel monitoring, described below, fuel reductions within this range will be considered within the BCA. The existing literature notes the variations between short and long-term results from ecodriving training. More specifically, training provides greater initial fuel reductions in the short term, but this may decrease over time if drivers are not provided refresher courses on a periodic basis and/or the feedback is removed. If carriers use OBMS to provide continuous feedback with respect to driving behavior, it is expected that fuel reductions will resemble those found in short-term results. If feedback is used to train drivers and then removed, fuel reductions are likely to resemble long-term results from existing literature.

Fuel consumption monitoring

In addition to changing driving behavior, thus reducing fuel consumption, OBMS can also provide carriers with information needed to monitor fuel consumption. Research has indicated that fuel monitoring also results in reductions in fuel consumption, although most of the evidence is anecdotal (Knipling, 2011; Shackelford and Murray, 2006). Carriers examined in case studies indicated fuel economy improvements of 1 to 2 miles per gallon, with at least one carrier indicating that monitoring of individual driver fuel use was motivated primarily by cost savings (Knipling, 2011). At an existing average fuel economy of 5 miles per gallon, a 1 mpg fuel economy improvement is equal to a 16.7% fuel reduction.

In order to realize this benefit due to OBMS, carriers must utilize the information provided by the system to encourage and assist drivers in improving fuel economy. As shown above, some carriers are already monitoring fuel consumption and thus OBMS would not provide additional benefits to them in this capacity. Due to the lack of quantitative evidence regarding the reduction in fuel consumption due to monitoring, the impact due to fuel monitoring will also be considered within a range of fuel reductions as indicated above.

Calculating the benefit

To determine the fuel savings in the BCA, an average fuel price of $3.84 (average cost of diesel fuel in the United States in 2011) (U.S. EIA, 2012) was considered. Carriers often buy fuel in bulk from cardlock facilities at a discount. It is estimated that these carriers receive a four to five cent per gallon reduction on fuel. Data provided by the carrier consulted within this BCA indicated an average fuel economy of 5.75 mpg for the fleet prior to OBMS installation, which is consistent with other reports of commercial vehicle fuel economy.

The monetary benefit from reduced fuel use is determined as follows:

$$B_{fuel} = \frac{VMT}{base\ fuel} * fuel\ cost * fuel\ reduction_{behavior}$$

where B_{fuel} = benefit from fuel savings, base fuel = base fuel economy (mpg), VMT = annual fleet VMT (miles), fuel cost = cost of fuel (\$/gal), fuel reduction $_{behavior}$ = reduced fuel due to improved driving behavior (%).

If a fleet is not currently monitoring fuel consumption, an additional benefit is also considered:

$$B_{fuel} = \frac{VMT}{base\ fuel} * fuel\ cost * fuel\ reduction_{monitoring}$$

where B_{fuel} = benefit from fuel savings, base fuel = base fuel economy (mpg), VMT = annual fleet VMT (miles), fuel cost = cost of fuel (\$/gal), fuel reduction $_{monitoring}$ = reduced fuel due to fuel monitoring (%).

Benefits associated with improved routing and operational efficiency

Efficient route planning within trucking has become more difficult in light of concerns such as HOS regulations, environmental sustainability, increasing fuel prices, and increasing congestion. What could once be done manually has become more complicated and additional resources are needed to support and maintain operational efficiency within fleet routing. Many on-board monitoring systems also have fleet management systems and GPS capabilities which provide information on truck status and location. These GPS capabilities provide information which, when used to its full advantage, allows for increased efficiencies such as the reduction of empty trips, reduced wait times during loading and unloading, optimizing routings, and avoiding congestion. Reducing unnecessary miles improves the efficiency of operations which reduces costs borne to carriers. Information provided by fleet management systems increases the visibility of operations and provides metrics to measure, compare, and improve on. Operations management systems within OBMS can monitor, record, and report fleet performance, and provide means of enhancing fleet productivity and efficiency. Improved efficiency results in a time savings for a given task or demand, and often that time saved is used to serve additional demand at additional profit. The benefits and costs associated with the additional service which a fleet can provide due to more efficient routing is not considered within this analysis.

As part of the Commercial Truck and Bus Safety and Synthesis Program, the connection between safety and operational efficiencies has been examined (Knipling, 2011). Knipling focused on identifying operational efficiency measures which also have potential safety implications when implemented successfully, noting that operational policies often improve safety via risk avoidance (as opposed to direct risk reduction) by reducing the exposure of vehicles to potential crashes through optimized routing which reduces VMT and/or avoids risky routes. It was concluded that efficient carriers were often safer carriers because they had the resources (both monetary and time) to invest in better safety equipment and processes. Corsi et al. (2002) examine the relationship between carrier financial performance and safety and concluded that companies with higher safety ratings had higher profits than those with lower ratings. While profitability is not a measure of efficiency it is assumed that there is a relationship between the two. The relationship between safety and efficiency can also move in the other direction where the operational policies and efficiency improvements noted in this study can be realized through the use of primarily safety-focused OBMS.

Improved efficiency

Quantifying the benefits associated with improved routing and operational efficiency due to OBMS usage is difficult. First, there are multiple components to the benefit. Not only does reducing miles travelled (for a given demand) reduce direct costs such as fuel and wages for the carrier, but also impacts society resulting in less emissions, fewer accidents, reduced use of limited resources, and reduced congestions. These additional societal impacts also reduce indirect costs for carriers. Second, it can be difficult to isolate and measure the benefit that can be attributed to such systems. Existing literature, as described below, uses numerous different metrics to measure improvements to efficiency, making it difficult to compare study results. Additionally, the potential for benefits is not constant over all carriers and fleet operations. Some carriers operate on networks which may provide as many opportunities for improvement as other. For example, a carrier whose trucks predominately travel between warehouse areas on the outskirts of urban areas has less potential to improve operations than a carrier whose vehicles travel to destinations within urban areas. Similar to the previous discussion regarding fuel monitoring, providing the carrier with information regarding fleet operations does not automatically result in efficiency benefits. The level of benefits seen is related to the carrier's motivation and ability to use the provided information to improve routing and efficiency.

Given the challenges identified above, benefits (for the BCA) will be associated with improvements to routing and efficiency will be considered as reductions to vehicles miles travelled. As with the benefits associated with fuel reduction, existing literature described below will be used to provide a basis for a range of efficiency benefits to be considered in the analysis. The operational benefit associated with OBMS use are only realized in fleets who do not currently use another system for fleet management and GPS routing, as these fleets are not likely to receive any additional operational benefits from OBMS use. There exists literature on improving commercial vehicle operational efficiencies and the use of information technology within motor carrier operations, but there is limited quantitative data about the impact of information technology on commercial vehicles operations. This makes determining the benefits to improved logistics and routing is difficult (McKinnon, 2010).

The Motor Carrier Efficiency Study (Belella et al., 2009) examines how technology can be used to improve inefficiencies within commercial vehicle operations. Phase I of this project attempted to identify inefficiencies and high-level potential uses of technology to improve operations with input from carrier stakeholders. A methodology for a BCA was also developed and applied to generic representations of supply chains (based on discussions with stakeholders that occurred within the study) and results provide a baseline for feasibility analysis. Inefficiencies identified in the study include equipment/asset utilization, fuel economy and fuel waste, loss and theft, safety, maintenance inefficiencies, data and information inefficiencies, business and driver management inefficiencies. With regards to equipment utilization, delays from loading/unloading, empty miles, equipment repositioning, lack of optimized routing, congestion, and travel time reliability are noted as concerns. Within the study benefit cost analysis, looking at specific inefficiencies for a generic trucking firm, benefit-cost ratios of 1.96 and 8.92 were identified for implementing systems to address incident-related congestion and empty trips, respectively. The study concluded that inefficiencies can be mitigated by improving the quality, accuracy and transfer of information regarding operations. It is recommended that Phase II of the study focus on several pilot demonstration projects, specifically looking at information technology capabilities and economic implications of such systems.

Research which attempts to quantify efficiency improvements was examined to provide a basis of efficiency improvements for use in the BCA. The existing research considered examined improvements in efficiency due to improved routing both with and without the use of onboard computers. While studies of efficiency improvements using onboard computers are more directly relevant to this research, studies which examine static routing improvements are also relevant as they provide information regarding the potential improvements which can be achieved. As previously mentioned, the metrics used to describe efficiency vary between the existing studies.

In a study which directly addresses the quantitative impact of information technology systems used to improve efficiency, Hubbard (2003) examines the effect of on-board computers on truck productivity, specifically capacity and loaded miles. Using data from the 1992 and 1997 Truck

Inventory and Use Survey, the study examines the impact of a specific type of onboard computer, electronic vehicle management systems (EVMS) which provide real-time or close to real-time data connections, on loaded miles driven by vehicles. The study analysis shows that increased EVMS adoption contributed to increases capacity utilization and that the average capacity utilization among EVMS adopters is 13%. The onboard computer systems can allow for better communication between dispatchers and drivers which allow dispatchers and drivers to keep trucks on the road and loaded more. While Hubbard’s study is significant for this study in that it provides quantitative data relating on-board computer usage and operational efficiency, it should be noted that the data used within the study is from the 1990’s and there have been many significant changes and improvements to onboard computers over the past 15 to 20 years. These changes are not likely to affect the general conclusions that onboard computers improve truck productivity, but may impact to what degree.

Barla et al. (2010) performed a study similar to Hubbard’s, utilizing data from Canada’s 1999 National Roadside Survey. The study examined the impact of electronic vehicle management systems on heavy vehicle capacity utilization and differs from previous work in that it examines capacity on specific trips, which allows for insight into how these management systems impact efficiency on different trip types. The systems studied can provide real-time information and communication of vehicle locations, which can be used to coordinate vehicle activities in more efficiently and increase vehicles’ load factors. In the analysis, existing data is used to determine when load matching is possible based on vehicles’ status and location. The analysis indicated that electronic vehicle management systems could increase the load factor on backhaul trips by an average of 16%, although the load factor for front haul trips decreased by almost 8% at the same time. Regardless, the net impact is positive.

Examining a courier company, Button, Doyle and Stough (2001) consider the impact of company proprietary routing software on deliveries per driver hours. Advanced routing and decision-making algorithms are used by dispatchers to manage deliveries. While dispatchers are able to sort, group and assign jobs to drivers, and send updated delivery information to drivers in real-time via two-way radios or pagers, the vehicle itself is not providing status and location information to the dispatchers. Examining operations both before and after implementation of the software, productivity (deliveries per driver hour) increased by 24%.

Barcos et al. (2010) develops a methodology based on Ant Colony Optimization techniques to examine route optimization within less-than-truckload carriers. The optimization attempts to ensure a certain level of service (a high percent of delivery within 24 hours with the remainder in 48 hours) while also reducing cost per unit transported. In addition to development of the methodology, the study is applied to a real case of a LTL fleet operating in Spain and Portugal (49 terminals and 2352 origin-destination pairs). The algorithm solution values were compared to the current routes, which were established based on years of experience. Costs, which include a distance component plus a fixed cost associated with stops and a handling cost per unit of freight, were compared and the best salutation resulted in cost savings of 10.8% with 87% of shipments being delivered in 24 hours. The study notes that the algorithm is highly sensitive to speed. The above results occur at 80 km/hr (approximately 50 mph) but slight decreases in speed resulted in considerably less cost savings. If service requirements were relaxed, cost savings of

8.3% could be seen at lower speeds (75 km/h). The results of this study indicate that improvements to efficiency of routing are possible when applying the methodology to an existing set of conditions but does not address the effectiveness of the method when considering dynamic decision making.

Work by Pitera, Sandoval and Goodchild (2011) examines the impact of operational changes on cost, service quality, and emissions within a heterogeneous fleet of vehicles. Considering static improvements to vehicle routing using a metaheuristic model, emissions could be reduced by an average of almost 6%, while also reducing costs by an average of 9%. Within this formulation, emissions and distance travelled were directly related and it can be assumed that distance travelled by the fleet could also be reduced by an average of close to 6%.

There is also industry data on the use of technology to improve efficiency and routing. For example Bennett (2008) provides insight into a small fleet of 27 vehicles (vans) where it is estimated that the use route optimization software to improve operations reduces company mileage by 5% to 10%, or 25,000 to 50,000 annual miles. Route optimization also provided fuel savings and the elimination of the manual task of route planning for the trucks. Results of a survey (Fleming, 2008) indicate that carriers who use GPS technologies reduce mileage by an average of 231 miles per week, which results in approximately $52,000 in yearly fuel savings.

As mentioned previously, within the BCA in this study, improved efficiency will be considered as reduced vehicle miles. Given that the studies above measure efficiency improvements in different ways and improvements to efficiency are dependent on carrier operations and network, a range of mileage reductions between 0% and 25% will be considered within the BCA. The operational scenarios expected to results in such reductions will be further described in the results section.

Calculating the benefit

A reduction in miles travelled impacts the other components of the BCA as crash rates, HOS violation rates, and fuel consumption rates are related to the VMT of a fleet. The benefit is only realized if a carrier is not currently using GPS or fleet management systems to route and schedule vehicles.

The monetary benefit from reduced mileage is determined as follows:

$$B_{routing} = \frac{VMT}{base\ fuel} * fuel\ cost * mileage\ reduction + \ (B_{crash} + B_{violation}) * mileage\ reduction$$

where $B_{routing}$ = benefit from routing improvements, base fuel = base fuel economy (mpg), VMT = annual fleet VMT (miles), fuel cost = cost of fuel ($/gal), mileage reduction = reduced miles traveled due to improved routing (%), B_{crash} = benefit from crash reduction, and $B_{violation}$ = benefit from HOS violation reduction.

3.3.2. Costs

There are costs associated with OBMS implementation, including equipment purchase, installation, and training. Cost data has been supplied by the equipment provider consulted on this study and is consistent with other similar studies (Flintsch, 2012; Houser et al., 2009;

Murray, Shackelford and Houser, 2009a; Murray, Shackelford and Houser, 2009b). The standard OBMS unit within this study cost \$3500 per vehicle. This unit supports forward collision warning, lane departure warning, electronic on-board recording, drowsy driver detection, and driver monitoring, in addition to having GPS capabilities, and provides real time feedback and event based data collection. Installations are estimated at: \$100 per vehicle as reported by equipment provider. The unit will be warrantied for a year and given the five year expected life of the unit, it is assumed in the base case that yearly unit maintenance is small (5% of unit cost). The potential need to replacement systems within the expected lifespan of the system is not considered in the analysis.

It is assumed that training for the OBMS is in addition to the safety training drivers already receive and there is no overlap with existing training. Driver training is two hours with an average driver wage being \$18 per hour. Safety manager training requires a trainer to be brought onsite at the cost of \$1500 per terminal and requires eight hours of training at an average wage of \$33 per hour for each manager. It is assumed that there is approximately 1 manager for every 20 drivers. Training durations are provided by the equipment provider and hourly wages are provided by the carrier.

The monetary cost from OBMS implementation is determined as follows:

$$\begin{aligned} Cost = {} & (equiptment + installation) * no.vehicles + trainer\ cost + drivers\ training\ cost * no.drivers \\ & + manager\ training\ cost * no.managers \end{aligned}$$

The table below summarizes the data used within this cost calculation.

Table 5 Cost Data

Component	Costs used in study	Costs used in previous studies
Equipment cost ($/vehicle)	$3,500	$1000-$2,500*
Installation cost ($/vehicle)	$100	Incl. in above cost
Maintenance cost ($/vehicle/yr)	$175	Negligible
Training cost ($/terminal)	$1,500	Not considered
Cost of training per driver	$36	$23
Cost of training per manager	$264	Not considered

* *Single function systems (do not have all the capabilities of system used in study)*

3.3.3. Metrics

The BCA included the net present value (NPV), benefit cost ratio, and payback period. These values serve as metrics used to understand the factors and conditions that impact the economic sustainability of OBMS usage. The analysis period and expected life of the system, as suggested by the unit provider and validated by previous BCAs (Flintsch, 2012; Houser et al., 2009; Murray, Shackelford and Houser, 2009a; Murray, Shackelford and Houser, 2009b) is 5 years. The analysis will consider discount rates of 3% and 7% to calculate the present value of both benefits and costs in 2011 dollars. A 3 percent discount rate is recommended by economists in both the public and private sector for such analyses and represents the social discount rate, or rate of return at which society is indifferent between a benefit now and a greater benefit in a future year (US OMB, 2000). A 7 percent discount rate is more conservative and is required to be considered by the U.S. Office of Management and Budget (U.S. OMB, 1992). This rate is an estimate of the after- tax rate of return to private capital. Costs and benefits resulting from reductions in cost were adjusted for inflation. A 3% per year inflation rate was assumed.

Net present value

The following formula is used to determine the net present value (NPV) within the BCA:

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t};$$

where B_t = total benefits arising in year t (t=0,1,2,…T) and C_t = total costs arising in year t (t=0,1,2,…T).

This methodology will use 2011 as the base year for comparison, where t=0 designates the beginning of 2011 when startup costs occur and t=1 occurs at the end of 2011. As mention previously, the lifespan of the project (T) is 5 years and discount rates (r) of 3% and 7% are considered. A positive NPV indicates that the project/program results in beneficial economic conditions.

Benefit cost ratio

The following formula is used to determine the benefit cost ratio within the BCA:

$$BCR = \frac{\sum_{t=0}^{T} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}};$$

again where B_t = total benefits arising in year t (t=0,1,2,…T) and C_t = total costs arising in year t (t=0,1,2,…T).

This methodology will use 2011 as the base year for comparison, where t=0 designates the beginning of 2011 when startup costs occur and t=1 occurs at the end of 2011. As was above, the analysis will examine a lifespan (T) of 5 years and discount rates (r) of 3% and 7%. A BCR greater than 1 indicate that the project results in beneficial economic conditions.

Payback period

The following formula is used to determine the payback period within the BCA:

$$PBP = \frac{investment\ cost}{annual\ benefits};$$

where the investment costs occurs in the first year (2011) and benefits are assumed to be constant over the life of the project. The payback period is calculated in years and shorter periods are considered preferable.

3.4. Results

The benefit cost analysis was performed to provide insight into how factors such as fleet characteristics, carrier operations, and use of the system impact the economic viability of on-board monitoring systems. The subsequent sensitivity analysis also investigates the impact of uncertainty which is found within many of the system benefits. The analysis separates the benefits into two categories, safety-related and non-safety-related benefits. Safety-related benefits include benefits stemming from a reduction in crashes, a reduction in HOS recording costs, and a reduction in HOS violations (the latter two being considered together). These are benefits the OBMS with an EOBR are designed and intended to produce. Additionally, OBMS can impact driving behavior and contain features which can be utilized to produce further benefits. These non-safety-related benefits include reduced fuel consumption due to improved driving behavior and the capability to monitor fuel consumption, and reduced mileage due to using GPS and fleet monitoring systems to improved efficiency of operations. While the reduction in fuel consumption due to changes in driving behavior is likely to occur if the OBMS improve safety, other non-safety-related benefits will only be realized if (1) the carriers is not currently monitoring fuel consumption, encouraging fuel efficient driving, and/or using GPS and fleet management systems, and (2) the carrier is proactive in capitalizing on additional information provided by the OBMS. The types of operations and services provided by carriers may also affect the level of non-safety-related benefit seen.

Considering a base case as described previously and summarized below, a BCA is performed to establish comparison values of the economic metrics. Considering the benefit components separately and then collectively allows for insight into the role which each component plays in the overall benefit. Examining the uncertainty found within each benefit component further identifies the relationships and impacts within factors of the benefit components. These results and the conclusions which can be drawn from them are described further below.

3.4.1. Safety-related benefits

In order to fully understand the implications of OBMS usage, components of the BCA were examined both independently and in conjunction with one another. First, the safety-related benefits of reduced crashes and reduced HOS violations were examined. As previously mentioned, discount rates of both 3% and 7% were considered in the analysis. Within the results presented and discussed, a 3% discount rate is used. Results using a 7% discount rate are included in Appendix B. The inputs for the BCA base-case are shown in Table 6.

Table 6 BCA Base Case Inputs for Safety-related Benefits

Input	Base Value
Base year	2011
Length of analysis	5 years
Number of vehicles/drivers	62
Number of managers	3
Vehicle miles travelled	7,900,000 miles/fleet/year
Number of crashes per year (fatality, injury, PDO)	0, 3, 11
Percent reduction in crashes due to OBMS	21%
Cost per crash (fatality, injury, PDO)	$800,000, $50,000, $5,000
Number of HOS violations (acute, critical)	5, 14
Percent reduction in HOS violations due to OBMS	50%
Cost associated with HOS violation (acute, critical)	$10, $107 + $6,000 fine
Cost reduction from converting to electronic recording	$6,597

The analysis indicates that OBMS can produce economic benefits due to a reduced number of commercial vehicle crashes that average approximately $71,000 per year, with initial system and training costs of approximately $228,000 (one time over the life of the system) and average maintenance costs of close to $12,000 per year. Considering solely the benefit due to a reduction in HOS recording costs and violations, the costs would remain the same, with an average yearly benefit of just under $50,000. Comparing benefits to costs using the metrics described earlier, results are summarized in Table 7.

Table 7 Safety-related Benefit Results Summary

BCA computation considering	Including (all in 2011$)		NPV	BCR	PBP
Crash Benefits Only	Benefit from crash reduction (over 5 years)	= $324,713	$54,853	1.29	3.40 years
	One-time equipment and training cost	= $227,724			
	Maintenance cost (over 5 years)	= $42,136			
HOS Only	Benefit from HOS improvements	= $226,772	($43,088)	0.90	4.64 years
	One-time equipment and training cost	= $227,724			
	Maintenance cost (over 5 years)	= $42,136			
Crash & HOS	Benefit from crash reduction (over 5 years)	= $324,713	$281,625	2.20	1.96 years
	Benefit from HOS improvements	= $226,772			
	One-time equipment and training cost	= $227,724			
	Maintenance cost (over 5 years)	= $42,136			

Considering reduced crashes alone, use of OBMS results in only minimal economic benefit (a NPV of $54,853). Within the sensitivity analysis varying values of crash cost, system cost, crash reduction rate, and base crash rates will be examined to better understand how this uncertainty affects the economic feasibility of the system. Results regarding benefits associated with a reduction in HOS recording costs and violations indicate that the system is not economically beneficial. These results indicate that given the inputs used in the base case, including a crash reduction rate of 21%, an OBMS has the potential to be economically beneficial to a carrier by providing benefits beyond the costs of the system. If only the benefits associated with HOS recording and violations were considered, the benefits of the system would not be greater than the costs. This is not unexpected as OBMS have many capabilities beyond those seen in EOBRs, which are traditionally used when looking to only record and monitor HOS information and are lower in cost.

When crash cost reduction and reduction in HOS recording and violation costs, are considered together, there is a much larger economic benefit to the carrier over the 5-year life span of the system. This indicates that if carriers (with characteristics similar to those within the base case) were to use OBMS within their fleet as a means of improving safety related to crashes and HOS, it would be possible, given certain conditions, to see an economic benefit from such systems. Figure 5 shows the combinations of crash reduction rates and HOS violation reduction rates for a fleet of 62 vehicles that result in conditions were OBMS are economically beneficial (NPV>0).

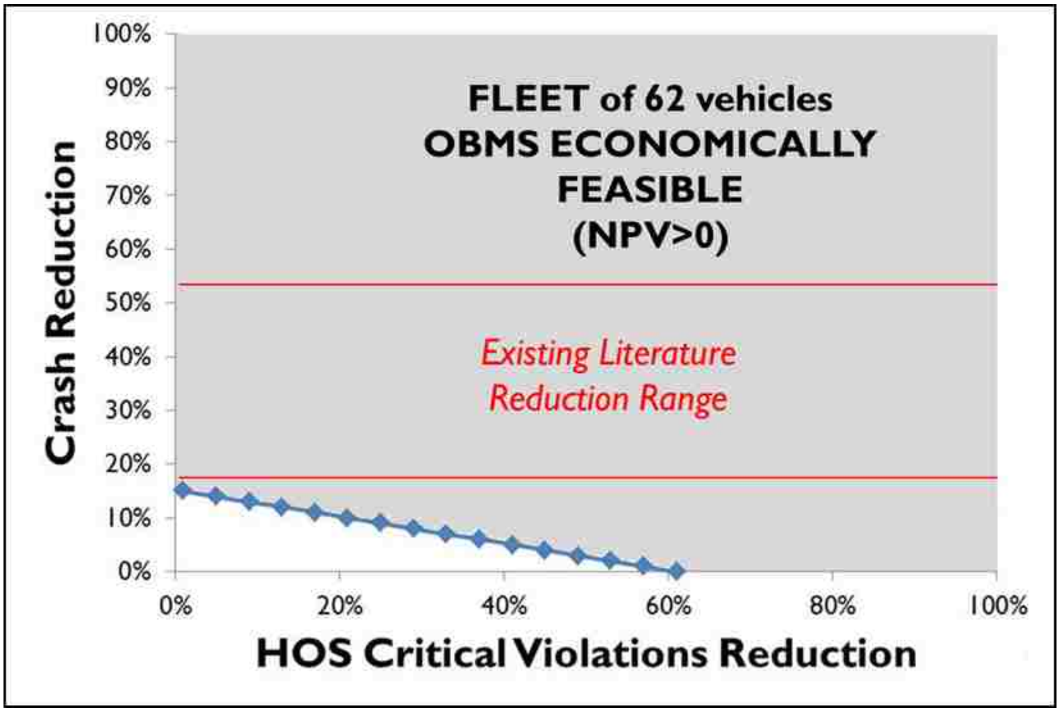


Figure 5 Combinations of Crash Reduction Rates and HOS Violation reduction rates

With a HOS violation reduction rate of zero, a crash reduction rate of 17% is required to make OBMS use economically feasible. Conversely, with a crash reduction rate of zero, a HOS violation reduction rate of 61% is required to make OBMS use economically feasible. As previously mentioned, existing research indicated crash reduction rates between 17% and 53%, thus even with greater uncertainty regarding HOS violation reduction rates, there is a high possibility for fleets to have crash and violation reduction rates fall within the economically feasible zone as shown in Figure 5.

While these results show the potential benefits of OBMS use, they are specific to one set of conditions and the economic impact cannot be generalized to all system users and context. Performing a sensitivity analysis to better understand the effects of fleet characteristics and uncertainty within these calculations will provide more depth to the discussion regarding their value to other carriers.

3.4.2. Non-safety-related benefits

While not the intent of OBMS, additional information provided by these systems can result in additional economic benefit if capitalized on by the carrier. Most notably, these include reductions in fuel use due to changes in driver behavior and the ability to monitor fuel and reductions in mileage due to improved routing efficiency. The level of such benefit is dependent on both existing operational strategies of the carrier and particular fleet operations. This results in a much greater uncertainty in the analysis. Like with the safety-related OBMS benefits, the non-safety-related benefits will be examined both independently and in conjunction with other benefits. In addition to the analysis inputs included in Table 6, the following additional information, in Table 8, was used in the base analysis.

Table 8 BCA Base Case Inputs for Non-safety-related Benefits

Input	Base Value
Base fuel economy	5.75 mpg
Fuel reduction due to improved driving behavior	15%
Fuel reduction due to fuel monitoring	15% (1 mpg reduction in base case)
Price of fuel	$3.79
Reduction in miles travelled	15%

When considering both fuel use reductions and reduced mileage, it is immediately evident that these two benefit components can have a significant impact on the analysis. Comparing the economic implications of individual components of the non-safety-related benefits (including considering reductions to fuel use due to changes in driving behavior both individually and also with reductions due to fuel monitoring), we can see (in Table 9 below) that the NPVs are several orders of magnitude larger than those seem with the safety-related benefits.

Table 9 Non-safety-related and Total Benefit Results Summary

Analysis considering:	NPV	BCR	PBP
Reduced fuel use due to driving behavior (only)	$3,474,930	14.92	0.30 years
Reduced fuel use due to driving behavior & fuel monitoring (only)	$7,266,530	30.03	0.15 years
Reduced mileage (only)	$3,521,740	15.11	0.29 years
All benefits (safety-related and non-safety-related)	$11,687,806	17.64	0.09 years

In a scenario where a fleet would see all safety-related and non-safety-related benefits, a potential net present value of over $11.5 million could be realized in given conditions, although it is acknowledged that this scenario is likely to represent a best-case scenario. As with the safety-related benefits, these results only represent one scenario for OBMS use thus an analysis of variations in non-safety-related benefits due to fleet characteristics and uncertainty is needed to further understand the economic implications of non-safety-related benefits. Regardless, the results of the base case BCA indicate that if non-safety-related benefits can be capitalized on by a carrier, a significant benefit above that seen from safety-related benefits could be realized.

3.5. Sensitivity Analysis

The sensitivity analysis expands on the base analysis to provide generalization of the BCA for fleet variations and to address the uncertainty contained within the analysis. This allows for greater insights on the factors that may impact the economic benefits of OBMS. Unless otherwise specified, beyond the input being considered in a specific sensitivity analysis, the base case inputs are used.

3.5.1. Fleet variations

Within the base case BCA, a fleet of 62 vehicles and an average (fleet) VMT of 7,900,000 miles/year was analyzed. This represents a mid-sized fleet with mid-level utilization (mid-level VMT per vehicle). Fleet sizes can vary greatly with many fleets consisting of fewer than 10 vehicles and others consisting of thousands. In the base analysis, OBMS use in a mid-sized fleet was found to be economically feasible. With a constant VMT per vehicle, the relationship between NPV, or any of the economic metrics, and number of vehicles (or VMT per fleet) are directly related, thus all fleets larger than 62 vehicles would also consider OBMS usage to be economically feasible. Examining fleets smaller than 62 vehicles, the analysis indicates that, even for single truck fleets (owner- operated), OBMS is economically feasible at the reduction rates considered in the base analysis (Table 10).

Table 10 Sensitivity Analysis, Fleet Variation Results

Analysis considering:	**NPV**	**BCR**	**PBP**
Safety-related benefits with fleet size of 1	$2,821	1.58	2.89 years
Safety-related and non-safety-related benefits with fleet size of 1	$186,908	34.30	0.14 years

With all else remaining fixed, the NPV (considering safety-related benefits) for a fleet of one is $2,821, which is a smaller benefit than the per-vehicle NPV of $4542 for a fleet of 62. As fleet size increases, the per-fleet cost of training does not change and the per-vehicle share of this cost decreases. In other words, OBMS has greater economic benefits as fleet size increases, although this shared cost is quite small and has minimal impact when compared to mid or large fleet sizes. This is illustrated in Figure 6, where variations in fleet size are considered on a per vehicle basis (at a constant VMT of 100,000 miles per vehicle per year). Larger fleets see a greater per vehicle benefit than smaller fleets, but as fleet size increases, there is less incremental increase in per vehicle NPV.

Average vehicle VMT also varies greatly among fleets. Increasing mileage increases a vehicles exposure to crashes, potential for HOS violations, and use of fuel. Similar to other existing studies (Flintsch, 2012; Houser et al., 2009; Murray, Shackelford and Houser, 2009a; Murray, Shackelford and Houser, 2009b), VMTs of 60,000, 80,000, 100,000, 120,000, 140,000, 160,000, and 180,000 miles were considered in the sensitivity analysis. Similar to fleet size, there is a direct relationship between VMT and economic benefit. With the base fleet of 62 vehicles, NPV ranged from $6,771 (at 60,000 miles/vehicle/year) to $495,986 (at 180,000 miles/vehicle/year) when considering only safety-related benefits, and between $5,377926 (at 60,000 miles/vehicle/year) and $16,608,909 (at 180,000 miles/vehicle/year) when considering both safety-related and non-safety-related benefits. These results verify that economic benefit of OBMS use increases as VMT increases.

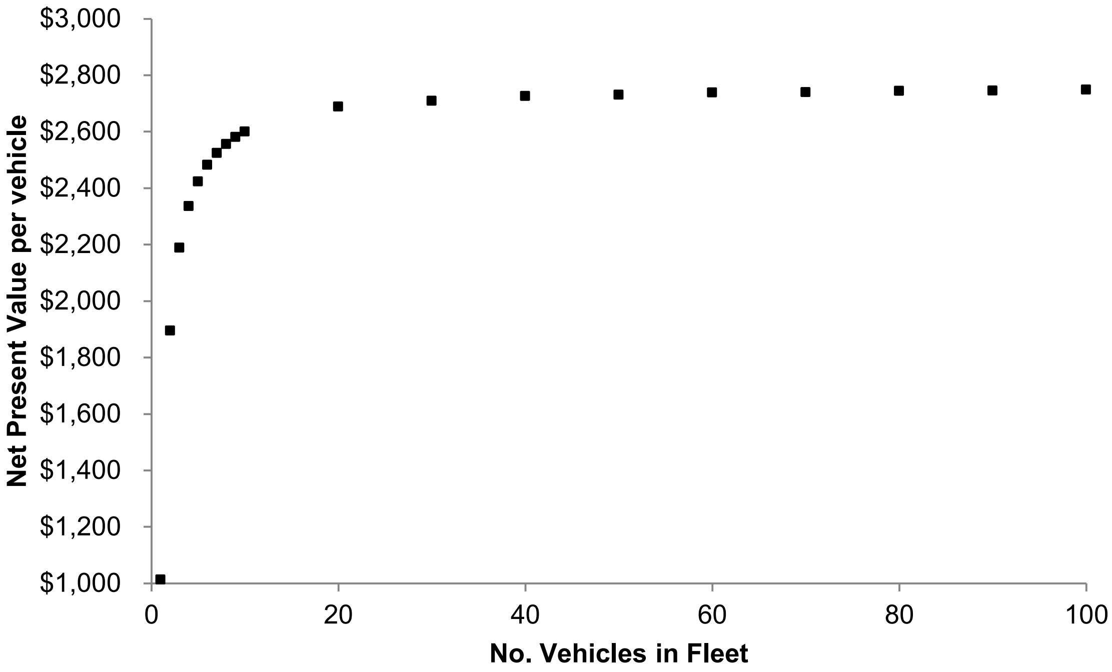


Figure 6 Impact of Fleet Size on NPV (100,000 VMT/vehicle/year)

Figure 7 illustrates the relationship of VMT on NPV. NPVs are shown on a per vehicle basis for a fleet of 62 vehicles. The figure not only shows the increase in NPV as VMT increases, but also the difference in benefit magnitude when considering only safety-related benefits as compared to total (safety-related and non-safety-related) benefits.

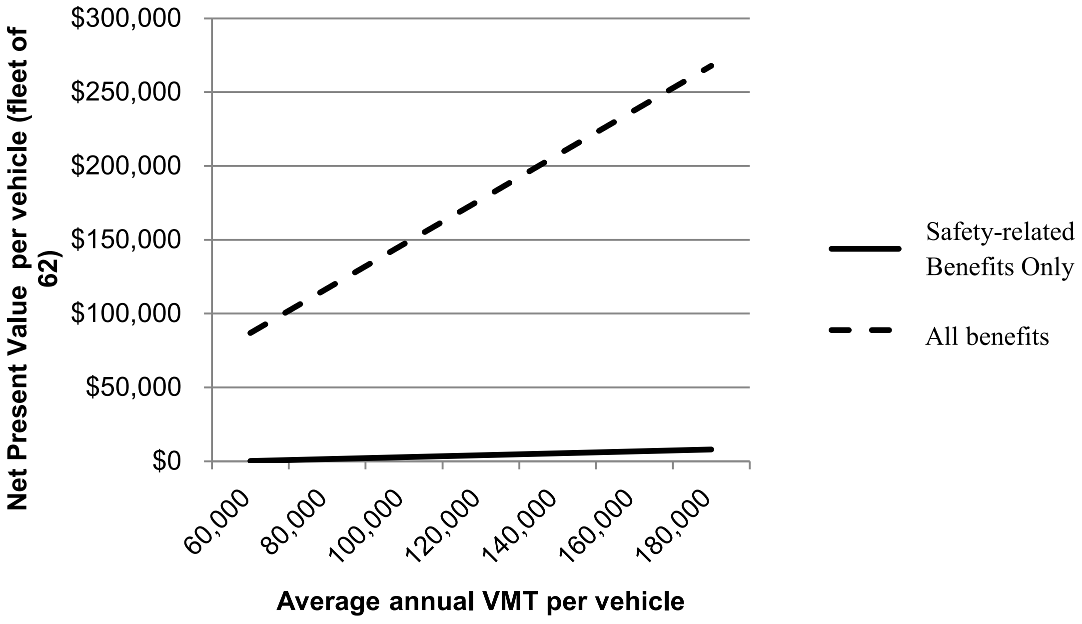


Figure 7 Impact of VMT on NPV

The sensitivity analysis indicates that as fleet size or average vehicle VMT increases, the economic benefit of OBMS usage also increases. When considering safety-related benefits only, OBMS use is economically beneficial for all fleet size and VMT combinations resulting in more than 84,604 vehicle miles per fleet per year. When non-safety-related benefits are also included, OBMS use is economically beneficial for all fleet size and VMT combinations resulting in more than 3,682 vehicle miles per fleet per year. Within the confines of the base case assumptions, OBMS use is generally considered to be economically beneficial, but as the annual fleet VMT decreases, the systems become less economically feasible, thus smaller fleet sizes will also be examined in more detail as the uncertainty within other components of the analysis is considered.

3.5.2. Crash reduction benefit uncertainty

In addition to variability to crash and system costs associated with the analysis, the greatest uncertainty exists within the determination of crash reduction, including both reduction rates and base crash levels. Because the base case BCA has shown OBMS use to be generally economically viable, the sensitivity analysis determines the limiting values of analysis components where the system use is no longer economically beneficial. Uncertainty and variation within the crash reduction benefit components is described in further detail below.

Crash cost

Variations on crash cost are considered in an effort to consider costs similar to previous research. Within the base analysis, a low-level crash cost was used. While these costs are conservative and thus will be used in the remainder of the sensitivity analysis, other crash cost levels were examined briefly. Table 11 differentiates between crash cost levels.

Table 11 Crash Costs

Cost Level/ Crash Type	Fatality	Injury	PDO
Base (low) level	$800,000	$50,000	$5,000
Mid-level	$800,000	$150,000	$40,000
High level	$1,250,000	$462,000	$200,000

Within the analysis, OBMS are economically viable at all crash cost levels examined, and as expected, the use of OBMS becomes more economically sustainable as crash cost increases. Table 12 illustrated the difference in economic metrics given varying crash cost levels, considering only crash reduction benefits. Similar increasing benefits would also be seen if safety-related benefits and total benefits were examined (other components of these benefits remain unchanged).

Table 12 Results from Crash Cost Sensitivity Analysis

Crash Cost Level	NPV	BCA	PBP
Base (low) level	$54,853	1.29	3.4
Mid-level	$731,177	3.99	1.1
High level	$3,480,189	14.94	0.3

While the BCA analysis examines the economic viability of OBMS in a specific set of carrier parameters, the results of the sensitivity analysis indicate that OBMS are economically beneficial at a wide range of carrier-borne crash costs.

Cost of system

A supplier of a mid-level option was consulted for this study to obtain the system cost in the base case. The base analysis indicated that systems lower in cost (less than $3,500) would also be economically feasible. A sensitivity analysis was performed to determine the highest cost at which an OBMS would still be economically feasible. Considering only safety-related benefits, at a system cost of $7,304, the NPV of the BCA is equal to zero, indicating this is an upper limit on possible system cost. This is more than double the current system cost and it is believed that if onboard monitoring systems were to increase in cost to this level, they would include additional features within the system would also increase carrier benefit.

Crash reduction rate

The crash reduction rate used in the base analysis, 21%, was determined by examining existing literature that has quantified the impact of onboard safety systems (Orban et al., 2006; Battelle, 2007; Battelle, 2003; Houser et al., 2009; Murray, Shackelford and Houser, 2009a; Murray, Shackelford and Houser, 2009b; Flintsch et al., 2012). In addition to the inherent difficulty in estimating the number of crashes that did not occur because of OBMS, it is difficult to determine a universal expected benefit as systems, operations, drivers and driving conditions vary, all impacting crash reduction. Both higher and lower rates of crash reduction due to OBMS use were considered. The highest crash reduction rate observed was 53% (Hickman and Hanowski, 2011; Houser et al., 2009; Murray, Shackelford and Houser, 2009b). While it is not likely that a crash reduction rate of this magnitude will occur, the results of this analysis provide insight into the benefits of onboard safety systems in ideal conditions. To determine the crash reduction rate on the low end of the range, the NPV was assumed to be zero and the smallest crash reduction rate was calculated, determining the smallest rate as which the analysis produced economically feasible. At a crash reduction rate of 53%, considering crash benefits only, the analysis shows that NPV = $549,654, BCR = 3.27, and PBP = 1.35, indicating the economic feasibly of OBMS increases as crash rate increases. More interesting is the analysis considering crash rates at the low end of the range. The lowest feasible crash reduction rate (where NPV = 0) for three benefit scenarios (crash reduction benefit only, safety-related benefits, and safety-related plus non-safety-related benefits) was determined, as shown in Table 13. These results follow the expected trend, as when further benefits are considered, without increasing costs, the minimum crash reduction rate required to make OBMS economically viable decreases. As noted earlier, the non-safety-related benefits are large enough to allow for economic viability of the system even with crash reduction rates of zero. These crash reduction rates are calculated considering base rates for other benefit components. Further sensitivity analysis will examine variations in all these reduction rates simultaneously.

Table 13 Results from Crash Reduction Rate Sensitivity Analysis

Benefits Considered	Minimum Crash Reduction Rate
Crash benefits only	17%
Safety-related benefits	3%
Safety-related and non-safety-related benefits	0%

Base crashes

In the base analysis, crash rates prior to OBMS use were determined from national average crash rates of vehicles, determined by VMT. As mentioned previously, crash rates are not uniform among all carriers. While not always the case, larger carriers tend to have lower crash rates per VMT than smaller carriers due to increased resources to promote safety. Based on the relationships used within the analysis, higher initial crash rates will increase the economic benefit of OBMS usage. In order to easily compare changes to the BCA with respect to changing base crashes, total crash cost, regardless of the combination of severity of crashes, is used. With a 21% crash reduction rate due to OBMS use and low level crash costs, a total of $66,891 (in 2011 dollars) in benefits per year are realized due to OBMS use within the base case analysis.

With existing fleet of 62, lowest base crash rates before OBMS use which produce an economic benefit result in a year cost reduction of $55,591, which is 17% (by total cost) less than the base case. While there are numerous combinations of base crash rates that can result in this outcome, one example is 0.13 fatality crashes, 2.24 injury crashes and 10.11 property damage only crashes per year before OBMS use, decreases of between 8% and 20% from base crash rates. While these results may prove useful when assessing a given fleet with specific crash rates, the variation in crash rates among fleets makes these results less useful in making overall conclusions.

If a fleet of one vehicle travelling an average of 127,500 miles per year (consistent with individual truck VMT in base case) is considered, only 1.19 property damage only crashes are required prior to OBMS use to result in an economic benefit from OBMS use. Given the assumption that smaller fleets are more likely to have higher crash rates and these results which indicate that minimal crashes are required to make the use of OBMS in small fleets economically feasible, it is likely that many small fleets could see economic benefit from the implementation of such safety systems.

3.5.3. HOS violation reduction benefit uncertainty

Within the base analysis, system use was not considered to be economically beneficial when considering benefits related to HOS alone. The sensitivity analyses performed was used to examine and understand this component in more detail. Economic benefits associated with the conversion from paper-based to electronic HOS recording are considered to be standard and not addressed in the sensitivity analysis. Similar to the sensitivity analysis concerning crash reductions, the greatest degree of uncertainty is contained within the determination of pre-OBMS violation rates and HOS violation reductions due to system use. Uncertainty and variation within the HOS violation reduction benefit components is described in further detail below.

Cost of system

The base analysis indicated if the OBMS were used solely to reduce costs associated with HOS recording and violations, the system would not be economically beneficial to the carrier. As previously mentioned, the system considered in the analysis provides capabilities beyond those related to HOS, thus it is not unexpected that system costs exceed isolated HOS-related benefits. Within the sensitivity analysis, it was determined that system costs less than $2,918 would result in an economic benefit. Past research (Campbell et al., 1998) has indicated median costs of EOBR systems (on-board safety systems that specifically record and monitor HOS) around $2,000, within the range of economically beneficial system costs.

Violation reduction

Similar to crash reductions, it is difficult to determine how many violations will be avoided due to system use. The base case considered violations reductions of 50%, based on previous estimations in the literature, but as previously stated, this violation reduction rate did not result in a large enough benefit to outweigh the cost of the system. Further analysis indicates that when keeping all other factors constant, a 61% HOS violation reduction rate is required for NPV of the BCA to be non-negative, indicating an economic benefit. More importantly, the sensitivity analysis also highlights that the impact of acute violations is generally negligible within the analysis, as compared to the economic impact from critical violations due to the wide variation in cost associated with each violation ($10 and $6,107, respectively). This is significant as it was previously determined that acute violations (those associated with collection, storage, and communication) may be more likely reduced than critical violations.

Base violations

Again, similar to crash rates, HOS violation rates prior to OBMS use were determined using national average violation rates per VMT, are likely to vary widely amongst carriers with smaller carriers often having higher violation rates. Additionally, many HOS violations go undetected and unreported, increasing the difficulty of determining a true value of violations within a fleet. As mentioned above, acute violations are considered negligible, thus only critical violations were considered within this aspect of the sensitivity analysis. Within the sensitivity analysis, it was determined that a pre-OBMS violation rate of 17 critical violations per year (given a fleet VMT of 7,900,000 miles) would result in benefits large enough to result in an overall economic benefit from using OBMS. This is an increase of 21% (3 violations) when compared to the base analysis. Because it is assumed that actual violation rates are higher than estimated in the base case analysis, it is also reasonable to assume that many carriers do have violation rates of this magnitude. Regardless, the benefit associated with HOS violation reductions only considered the reduction of detected violations, further complicating the understanding of the true benefits.

3.5.4. Fuel reduction benefit uncertainty

The non-safety-related benefits of fuel reduction was considered as two components, first the reduction in fuel use due to safer driving, and second the reduction in fuel use due to the ability to monitor fuel use. Within the BCA, the highest level of uncertainty within this component is seen within the determination of the fuel consumption reduction. This will be examined further below. While there is uncertainty within the cost of fuel, increasing fuel prices improves economic benefit, and fuel would have to decrease to unreasonable levels (14 to 27 cents per gallon) to not be beneficial to the carrier if all other factors remain steady.

Fuel reduction due to driving behavior and fuel monitoring

The benefits associated with both components of fuel reduction are calculated as a percent reduction in fuel use for a given mileage and vehicle fuel economy. At the reduction rates assumed in the base analysis (15% for each component, 30% if both are considered), this benefit far surpasses the safety-related benefits and the BCA indicates that system use is highly beneficial if driving behavior changes, resulting in less fuel consumption, and carriers use OBMS to monitor fuel consumption. It is likely that these reductions overlap and a total fuel reduction of 30% is only likely to occur in the most ideal circumstances; therefore it is important to consider a conservative fuel reduction as well.

Assuming that a carrier already monitors fuel consumption, this there will be no additional benefit from OBMS use, only 1% total fuel reduction due to improved driving behavior is required to make systems economically beneficial when only considering benefits from fuel reduction. While results from existing literature vary, a 1% fuel reduction seems reasonably achievable within the confines of the existing research. As fleet size increases, this lower limit remains constant, but as fleet size decreases, the limit only increases to a small degree. Considering a fleet of 1, a 2% reduction in fuel is required to maintain economic feasibility. Within the base case analysis, considering safety-related benefits as well, a reduction of fuel is not required to result in the economically feasibility of OBMS use, thus any benefit seen from such reduction allows for more variability within other analysis components.

3.5.5. Mileage reduction benefit uncertainty

It is difficult to capture an accurate quantitative value of mileage reduced due to OBMS both because there is limited research on the subject and because it is related to existing fleet operations. A previously described in the methodology, a reduction in miles travelled reduces fuel use and also impacts crash and HOS violations rates, which are calculated based on VMT. The economic benefit of a 1% reduction in vehicle miles travelled ($52,496) is roughly equal to the economic benefit of a 1% reduction in fuel use ($52,071). Given the similarity to a reduction in fuel consumption, only a 1% reduction in miles travelled is required to make OBMS economically beneficial when only considering miles reduced.

3.5.6. Summary

Table 14 summarizes the results of the sensitivity analysis considering the benefits of OBMS. For the table, benefits are considered independently of one another. However, the relationship between crash reduction rate and HOS violation rate was examined previously and shown in Figure 5. The non-safety benefits are clearly immense and consideration within the analysis can only improve economic feasibility.

Table 14 Summary of Benefit Sensitivity Analysis

<table>
<tr><td colspan="2"></td><td>Base Case</td><td colspan="3">Sensitivity Analysis Summary</td></tr>
<tr><td colspan="2">Crash reduction rate[1]</td><td>21% reduction
NPV=$54,853</td><td colspan="2">16% reduction
NPV=$0</td><td>53% reduction
NPV=$549,654</td></tr>
<tr><td colspan="2">HOS violation reduction rate[2]</td><td>50% reduction
NPV = ($43,088)</td><td colspan="3">61% reduction
NPV=$0</td></tr>
<tr><td rowspan="2">Non-safety related benefits</td><td>Fuel reduction[3]</td><td>Not considered</td><td>1% reduction
NPV=$0</td><td>5% reduction
NPV=$994,007</td><td>15% reduction
NPV=$3,521,740</td></tr>
<tr><td>Mileage reduction[4]</td><td>Not considered</td><td>1% reduction
NPV=$0</td><td>5% reduction
NPV=$994,007</td><td>25% reduction
NPV=$6,049,473</td></tr>
</table>

[1] BCA considers crash benefits only
[2] BCA considers HOS benefits only
[3] BCA considers fuel reduction benefits only
[4] BCA considers mileage reduction benefits only

3.6. Discussion

The BCA shows that OBMSs can be economically viable under a wide range of circumstances. Given the fleet characteristics of the base case, we can determine that crash reduction rates as low as 16%, which is equivalent to the lowest crash reduction found within existing studies (Orban et al., 2006), could provide economic benefits to the carrier. While this crash reduction rate was determined for a specific fleet, it does not take into account any other benefits, such as those from electronic HOS recording or non-safety-related benefits. With the inclusion of these additional benefits, crash rates could decrease dramatically yet still provide economic benefits to a carrier. Benefits related to HOS recording are on the order of 70% of the magnitude of benefits from crash reduction. At a base cost of $3,500 OBMS are not economically feasible when benefits only related to HOS are considered. Systems costs of just under $3,000 are required for the system to be economically feasible when just used as an EOBR. When considering both crash and HOS benefits, at a crash reduction rate of 21% (from the base case), additional HOS benefits are not required to make system use economically feasible. When HOS violation reduction rates of 50% (from the base case) are considered, only a 3% crash reduction rate is necessary to make system use economically beneficial.

The base analysis used a fleet of 62 vehicles with an average vehicle VMT of 127,500 miles per year. Variation in fleet size and VMT were considered to observe the elasticity of NPV. While the economic benefit associated with OBMS use increases as fleet VMT (a function of fleet size and vehicle VMT) increases, smaller carriers can still gain economic benefits, in part due to limited fleet-shared costs. In fact, the only component of the BCA where a fleet of one vehicle did not result in an economic benefit was when HOS recording was the only factor being considered, but this outcome is also noted in the BCA regardless of fleet size. Smaller carriers may also benefit the most from non-safety-related benefits because they are less likely to be already monitoring fuel or using fleet management software (Campbell et al., 1998; Barla et al., 2010). Additionally, if small carriers are more likely to have higher initial crash and HOS violation rates (Monaco and Williams, 2000; Moses and Savage, 1994), these carriers can actually benefit more from OBMS than larger fleets on a per vehicles basis.

Much of the existing research on the economic impacts of onboard monitoring systems only consider the impact of safety-related benefits of reduced crashes or reduced HOS violations, and rarely are these considered together. This analysis moves beyond previous research efforts to also consider non-safety-related benefits such as reductions in fuel and mileage. While these benefits are fleet specific and subject to the existing operations of the carrier, these benefits are an orders of magnitude greater than safety-related benefits and should not be overlooked. Solely considering non-safety-related benefits, minimal “improvement” is required to result in benefits greater than system costs. While carriers who already promote fuel-efficient driving, monitor fuel, and/or use fleet management systems to improve efficiency within operations may not see added benefits from utilizing these capabilities within OBMS, they may be able to consolidate onboard management systems, which could result in additional benefits. Informing carriers of the potential of such benefits may provide additional incentive to implement OBMS use within fleets, because, for carriers who are committed to utilizing OBMS to capitalize on these components, significant benefits can be realized.

On-board monitoring systems are used to improve safety by promoting improved driving behavior. While there is a cost associated with such systems, this research has shown that the economic benefit from their use outweighs the costs in many operational circumstances. Beyond the traditional system benefits associated with improved safety, many carriers also have the ability to capitalize on other components of the system to improve operational efficiency and further increase benefits of system use.

3.7. Summary

The BCA and sensitivity analysis demonstrated that on-board monitoring systems are economically viable under a wide range of conditions. Results indicate that, for some fleet types, reducing crashes and improving HOS recording, provides a net benefit of close to $300,000 over the five-year expected lifespan of the system. Furthermore, when exploring additional benefits such as reduced fuel consumption and reduced vehicle miles, benefits can be upwards of seven times more than safety-related benefits. This research also shows that net positive benefits are possible in large and small sized fleets. Results can be used to inform policies for motivating or mandating carriers to use such systems, and to inform carriers regarding the value of system investment. These outcomes have been submitted for presentation and publication consideration at the Annual Meeting of the Transportation Research Board (2013).

4. An economic analysis of on-board monitoring systems in commercial vehicles: a regression analysis

This chapter describes a regression model developed to support the benefit cost analysis (BCA) in the previous chapter. While the BCA and subsequent discussion provides information on the economic feasibility of OBMS use, the model developed does not provide a simple and transparent way to understand relationships between input variables within the analysis. The regression analysis provides an alternative means of considering the economic implications OBMS use, illustrate the relationship between variables within the BCA, and allows individual carriers to estimate the economic benefits of OBMS, given the characteristics of their fleet. It specifically addresses the research question:

What relationships exist between fleet characteristics and economic feasibility of OMBS?

4.1. Problem Description

In addition to the benefit-cost analysis (BCA), a regression analysis was performed to serve as another means of considering the economic implications of on-board monitoring system (OBMS) use and to illustrate the relationship between variables within the BCA. The BCA was used to make general conclusions regarding OBMS use and to understand the uncertainty within the analysis, while the regression model allows individual carriers to estimate the economic benefits of OBMS, given the characteristics of their fleet. Because the regression model takes the form of a single equation, the relationships between variables and to net present value (NPV) are more easily seen than in the BCA, which consists of a series of calculations.

Within this research we are not examining economic efficacy of OBMS through experimental means, meaning we are not measuring the benefits and costs used to determine the NPV of system use. Instead, fleet characteristics are used to calculate and estimate of NPV using the previously developed BCA model. These fleet characteristics and the calculated NPV provide the basis for the regression model. A sample of carriers with known fleet size, VMT, initial crash rates, and initial HOS were considered in the regression analysis. Because it is not known whether the carriers in the sample already monitor fuel use and/or use GPS and fleet management systems to improve efficiency, non-safety-related benefits were not considered within the regression analysis. Safety benefits of reduced crashes and improved HOS recording, resulting in reduced HOS violations were examined assuming constant crash reduction rates of 21% and violation reduction rates of 50% as justified by previous research (further justification provided within the BCA methodology, section 3.3).

Within the benefit cost analysis it was noted that, despite uncertainty, OBMS have the potential to be economically viable in a wide range of circumstances. Results of the regression analysis will provide more insight into this conclusion and further the understanding of the economic implications of on-board monitoring system use for commercial vehicles.

4.2. Methodology

Two different models were developed based on varying levels of fleet information. The first model (Carrier Specific) requires the following fleet information, serving as independent variables:

- fleet size
- vehicle miles travelled (VMT)/year
- number of fatality crashes/year
- number of injury crashes/year
- number of property damage only (PDO) crashes/year
- number of acute hours of service (HOS) violations/year
- number of critical hours of service (HOS) violations/year

In the second model (Average Value), less fleet information is required, including:

- fleet size
- vehicle miles travelled (VMT)/year

The rationale behind the naming of the models will be explained within the data description. Both models use net present value (NPV) as the dependent variable. In the regression NPV is a calculated value, determined using the methodology developed within the BCA (refer back to that section in the BCA chapter). The regression models describe the relationship between variables in an alternative and simple way.

4.2.1. Data

The regression analysis considers data from 100 commercial vehicle fleets as further described below. The FMCSA Motor Carrier Census Information (FMCSA, 2012c), which contains a subset of registration data for all carriers operating within the United States, provided the population from which the data sample was taken. Among other information, the census provided carrier identification (including legal name and USDOT number), vehicle miles travelled as reported on Motor Carrier Identification Report (MCS-150), year in which latest VMT was reported, and number of power units reported. This data set was cleaned, removing incomplete, out of date, and unreasonable entries (e.g. VMT equal to zero), and the result population consisted of 120,870 motor carriers out of over 1.3 million registered carriers (as of March, 2012).

Proportionate allocation was used as indicated in Table 15 to select a random stratified sample of 100 carriers. Carriers were the selected from each fleet size grouping to form the sample. Within the nationwide fleet, the majority of carriers are small, with 10 or fewer vehicles. This translates into the sample used in the analysis, and results in a skewed distribution, as seen in Figure 8.

Table 15 Stratified Sample Selection

Fleet size	No. carriers in total population	Percentage of total population	No. carriers in sample population
1 vehicle	60,909	50%	50
2-10 vehicles	47,398	39%	39
11-25 vehicles	7,274	6%	6
26-100 vehicles	4,151	3%	3
101-500 vehicles	955	1%	1
500+ vehicles	183	<1%	1

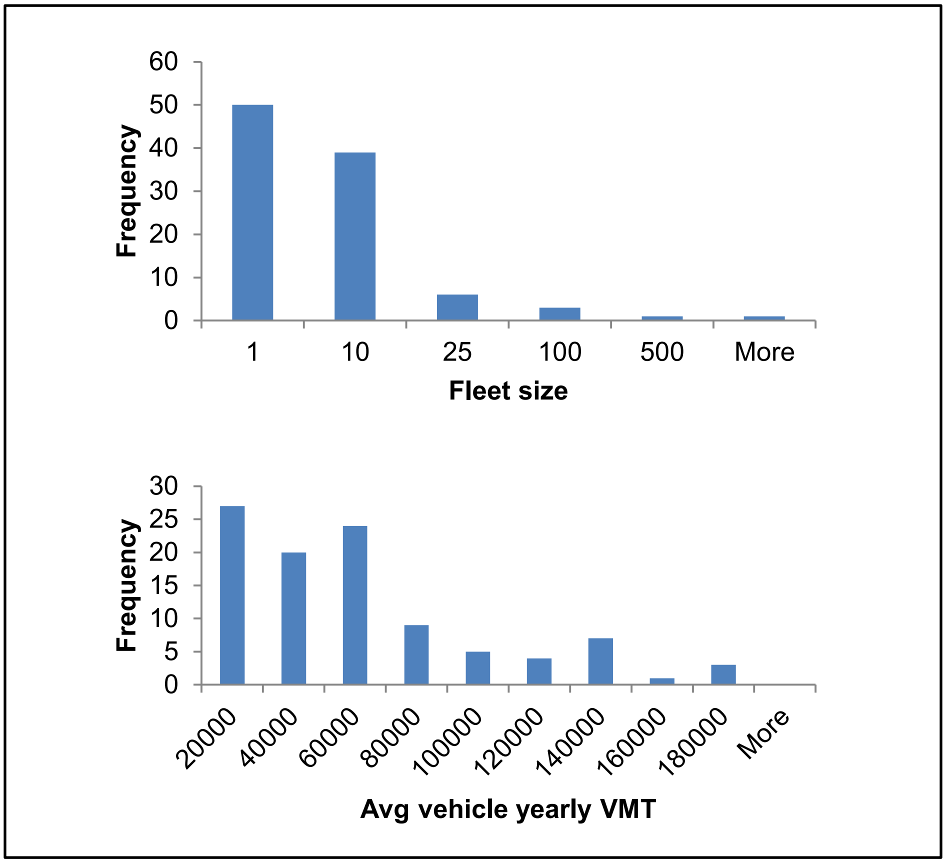


Figure 8 Sample Distributions

Carrier Specific Model

The FMCSA Motor Carrier Census Information (FMCSA, 2012c) provided fleet size and VMT values for each of the carriers within the sample. The FMCSA's Motor Carrier Management Information System (MCMIS) (FMCSA, 2012d) provided carrier specific data regarding crashes and HOS violations was gathered from the). Data from the two sources was matched by carriers' U.S. DOT numbers. The data gathered from the MCMIS systems included information on all crashes for given carriers in 2011, including the total number of crashes, number of fatality crashes, and number of injury crashes, and inspection violations for a given carriers in 2011, including violation type. Crash and HOS violation values are specific to each carrier, hence the name of the model. This data is used to calculate the net present value of OBMS use over a 5-year system life using the previously described BCA methodology (Section 3.3).

Average Values Model

The Average Values model considered the same values of fleet size and VMT as the model above. Because this model assumes that further information about carrier is not known, crash and HOS values are estimated using the value of VMT and nationwide average crash and violation rates. This method was used and described in detail in Section 3.3.1.1 and 3.3.1.2, and is the basis for the naming of the regression model. Crashes and HOS violations are not considered as independent variables in the Average Values model because there are directly determined from VMT. Fleet size and VMT values are used to calculate the net present value of OBMS use over a 5-year system life using the previously described BCA methodology (include section).

A summary of the variables along with descriptive statistics of the data sets are found in Table 16. These data sets will be compared in more detail in within the discussion.

Table 16 Descriptive Statistics

Carrier Specific (CS) data				
Variable	Obs.	Mean	Std. Dev	Min, Max
FLEET	100	12	54	1, 512
VMT	100	702,477	4,035,445	10,000, 39,583,312
FATALITY	100	0.02	0.14	0, 1
INJURY	100	0.09	0.53	0, 5
PDO	100	0.18	0.85	0, 7
ACUTE	100	0.58	2.80	0, 27
CRITICAL	100	1.46	5.39	0, 42
NPV_CS	100	-4,345	120,836	-560,561, 809,971
Average Values (AV) data				
Variable	Obs.	Mean	Std. Dev	Min, Max
FLEET	100	12	54	1, 512
VMT	100	702,477	4,035,445	10,000, 39,583,312
NPV_AV	100	-391	82,641	-386,705, 649,282

4.2.2. Models

Within the models, the net present value of OBMS-use (NPV) is the dependent variable. As presented in the tables above, the independent variables include fleet size (FLEET) and vehicles miles travelled per fleet per year (VMT) for both the Carrier Specific and Average Values models. The Carrier Specific model has addition independent variables of the number of fatality, injury and property damage only crashes per fleet per year (FATALITY, INJURY, and PDO, respectively), and the number of acute and critical HOS violations per fleet per year (ACUTE AND CRITICAL, respectively). The following two equations are used within the regressions:

$$\mathrm{NPV\_CS} = \beta_0 + \beta_1\mathrm{FLEET} + \beta_2\mathrm{VMT} + \beta_3\mathrm{FATALITY} + \beta_4\mathrm{INJURY} + \beta_5\mathrm{PDO} + \beta_6\mathrm{ACUTE} + \beta_7\mathrm{CRITICAL}$$

$$\mathrm{NPV\_AV} = \beta_8 + \beta_9\mathrm{FLEET} + \beta_{10}\mathrm{VMT}$$

4.3. Regression Results

Tables 17 and 18 summarize the results of the regression analysis. The implications of these results will be explored further below.

Table 17 Regression Results, Carrier Specific Model

	Coefficients	Standard Error	P-value	95% C.I.	
FLEET	-3,811	0.5595	< 2e-16	-3,812	-3,809
VMT	-7.971e-06	8.853e-06	0.37028	-2.555e-05	9.6012e-06
FATALITY	815,400	62.05	< 2e-16	815,316	815,562
INJURY	50,920	42.20	< 2e-16	50,838	51,006
PDO	5,086	28.45	< 2e-16	5,029	5,142
ACUTE	23.76	8.313	0.00528	7.25	40.27
CRITICAL	14,000	3.893	< 2e-16	13,991	14,007
Constant	-1,719	6.787	< 2e-16	-1,732	-1,705
Adjusted R2	1	-	-	-	

Table 18 Regression Results, Average Value Model

	Coefficients	Standard Error	P-value	95% C.I.	
FLEET	-3,811	47.09	< 2e-16	-3,812	-3,810
VMT	.06574	6.335e-06	< 2e-16	.06573	.06575
Constant	-1,719	6.512	< 2e-16	-1,732	-1,706
Adjusted R2	1	-	-	-	

Within the Carrier Specific model, all independent variables with the exception of VMT are significant. Fleet size and VMT are negatively related to NPV, while all other independent variables are positively related to NPV. Both independent variables in the Average Value model are statistically significant. Again, fleet size is negatively related to NPV, while VMT is positively related.

As previously mentioned, the objective of the regression analysis was to provide a simple way to express the relationships considered in the BCA. Using the equations below, a carrier with knowledge of a fleet could estimate the benefit associated with OBMS use. The choice of equation to use is dependent on the level of information the carrier has about the fleet.

$$\text{NPV\_CS} = -1{,}719 - 3{,}811 * \text{FLEET} + 815{,}400 * \text{FATALITY} + 50{,}920 * \text{INJURY} + 5{,}086 * \text{PDO} + 23.76 * \text{ACUTE} + 14{,}000 * \text{CRITICAL}$$

$$\text{NPV\_AV} = -1{,}719 - 3{,}811 * \text{FLEET} + 0.06574 * \text{VMT}$$

In the Carrier Specific model the variable VMT is dropped from the expression because it was determined to be insignificant. It should be noted that in the Average Value model while the coefficient for VMT is considerably smaller than the coefficient for FLEET, VMT values are several orders of magnitude larger than FLEET variables used within the analysis.

4.4. Regression Discussion

Examining the results of the regression analysis provides insight into the relationships between variables considered within the BCA. A comparison can also be made between the results of the two regression models. These results can be seen in Appendix C.

Results of the BCA (Section 3.4) and sensitivity analysis (Section 3.5) indicated that fleet size had less of an impact on economic feasible of OBMS despite initial assumptions that as fleet size increased, overall fleet VMT and exposure to crash and violation incidents were likely to increase as well. When considering fleet size as independent from other variables, as was done in the regression, results reveal that fleet size is actually negatively related to NPV. This result is supported by the understanding that larger fleets require greater costs to procure, install, train for, and maintain OMBS. The regression results further the argument that a small fleet size is not a limiting factor in the economic feasibility of OBMS use.

Within the Carrier Specific analysis, the positive relationships between crashes and HOS violations (both of any type) and NPV is easily understood as a greater initial crash and violation rates result in greater crash and violation reductions, which in turn result in an economic benefit to the carrier. As would be expected, as crash severity and thus respective crash costs increases, the impact of each crash type on the NPV (as indicated by the coefficients) increases. This means that the reduction of a fatality crash, which has a highest crash cost ($800,000 per crash), is more economical beneficial than the reduction of a PDO crash, with the lowest crash cost ($5,000 per crash). A similar relationship is seen with HOS violations.

4.4.1. Comparing Models

The data used in the Carrier Specific model is limiting because it only considers one year (2011) of data. The NPV calculations assume a 5-year system life, meaning that the crash and HOS violation trends from the one year of data are assumed to hold true over the 5-year period. While this is likely not to be the case for an individual carrier, it is more reasonable to assume that crash rates may be steady over a 5-year period if considering the whole 100 vehicle sample in aggregate. In contrast, crash rates and HOS violations rates in the Average Value model considers 10 years of data (2000-2009) and over 1.3 million fleets. This data is also limiting in that only aggregated nation-wide fleet information is available.

In theory, contribution of VMT to NPV in the Average Values model is equivalent to the combined contribution of FATALITY, INJURY, PDO, ACUTE, and CRITICAL to NPV in the Carrier Specific model (VMT is neglected because it was determined to be non-significant in the regression). This assumes that the rates of crashes and HOS violations in the Carrier Specific data are consistent with the nationwide crash and HOS violation rates used in the Average Value model. If a given fleet has crash and violation rates equal to that of the nationwide averages used in the Average Vales model, NPV_CS would be equivalent to the NPV_AV.

If the crashes and violations from the Carrier Specific dataset are translated into average crash/violations rates per year per VMT, the Carrier Specific dataset can be compared to the nationwide average rates of crash/violation used in the Average Value dataset and model. Table 19 compares the sample average rates (from the Carrier Specific dataset) to the nationwide average rates (used in the Average value dataset).

Table 19 Average Crash and HOS Violation Rates

Crashes or Violations per year per 100 million VMT	Carrier Specific Dataset	Average Value Dataset
FATALITY	2.85	1.96
INJURY	12.81	35.40
PDO	25.62	138.8
ACUTE	82.56	1.76
CRITICAL	207.84	0.57

Again, the rates in the Carrier Specific column are calculated using the data gathered from the FMCSA (FMCSA, 2012c; FMCSA, 2012d) on VMT, number of crashes (fatality, injury and PDO), and number of HOS violations (acute and critical) in 2011 for the 100 vehicle sample. The rates in the Average Value column were calculated from nationwide data as described previously (Sections 3.3.1.1 and 3.3.1.2). Comparing the two columns, the vehicles within the Carrier Specific dataset experience more fatality crashes and HOS violations (acute and critical) but fewer injury and PDO crashes. The rates in Table 19 illustrate that the sample population varies from the total population, thus for a given carrier within the sample, NPVs calculated from the two equations. This is verified within the regression datasets in Appendix C and is also seen in the descriptive statistics of the NPV variable in Table 16.

As larger sample sizes are considered in the Carrier Specific model, the sample average crash/violation rates would presumable move closer to the rates used in the Average Value model, converging as the sample size nears that of the entire population. At this point the contribution of VMT to NPV in the Average Values model is truly equal to the combined contribution of FATALITY, INJURY, PDO, ACUTE, and CRITICAL to NPV in the Carrier Specific model. With this understanding, it is evident that the regression model developed from the Average Value dataset is better suited than the Carrier Specific model to estimate the economic benefit of OBMSs for a fleet. This model only requires information about fleet size and fleet VMT. If a carrier has crash/violation rates greater than the nationwide average rates, the Average Value equation will underestimate the NPV of system use. If a carrier has crash/violation rates less than the nationwide average rates, the Average Value equation will overestimate the NPV of system use. If a carrier has both detailed information about crash and

HOS violation rates, along with access to the BCA model developed in chapter 3, the best estimate of the economic benefit of OBMS use would be calculated by the BCA model.

4.5. Conclusions

A regression analysis was used as a means of looking at the economic feasibility and benefit-cost analysis of on-board monitoring systems. Models for two different datasets were examined and it was determined that the following equation based on the Average Value model is best suited to estimate a carriers NPV of OMBS use:

$$NPV\_AV = -1{,}719 - 3{,}811*FLEET + 0.06574*VMT$$

This equation simplifies the series of calculations used in the BCA. Based on the relationships illustrated within regression equation and the assumption that crashes/violations increase with VMT, fleets with higher VMT/vehicle are more likely to see economic benefit from OBMS use are fleet size is negatively related to NPV and VMT is positively related to NPV. The both regression models show that fleets with higher rates of crashes/HOS violations have benefit more from OBMS use. The results of the regression analysis support the findings of the BCA.

5. Conclusions

This dissertation addressed the economic implications of the use of safety systems within commercial vehicle operations through process analysis, benefit-cost analysis, and regression analysis. On-board monitoring systems have been suggested within commercial vehicle operations as a means of reducing risky driving behavior and improving driver safety performance. A better understanding of processes associated with such systems, along with the economic feasibility of their use, can inform both carriers and policy makers when making decisions regarding the implementation of the systems.

The process comparison of HOS recording methods provides insight into the differences between methods used to gather and record HOS information, highlighting the benefits of electronic recording. Through process analysis, it was demonstrated that electronic HOS recording has the potential to minimize many error types due to fewer steps and less manual inputs. This finding suggests that the FMCSA's current policy attempts, to mandate EOBR use as a means of improving HOS compliance, have merit. In order to further build the case for mandated use of EOBR, additional insight is necessary. This includes a quantitative assessment of the reductions in HOS violations. As discussed within the BCA, this task is complex because of challenges in establishing the true compliance rate before system use. FMCSA-detected violations from both roadside inspections and carrier reviews provide the best estimate for the number of drivers operating out-of-service based on the limited information available regarding true HOS violations but these do not capture violations that go undetected. Carriers may have better insight into the true HOS violation rates but are typically hesitant to disclose this information.

Additionally, the FMCSA is more likely to target carriers with low safety ratings for inspections (FMCSA, 2010b), further skewing the data regarding violations. Without a true understanding of the number of existing HOS violations, it becomes more difficult to measure the violations reduced by EOBR use.

The method used within the BCA to determine the economic benefit of using an EOBR to record HOS provides a reasonable estimate of the benefit given the constraints, but improving on this estimate would make the policy argument for EOBR use more powerful. One method to do this would be to record HOS electronically in conjunction with drivers continuing to record HOS manually for a given fleet of vehicles/drivers. A comparison of the two sets records could provide data to make conclusions regarding the efficacy of EOBR in improving HOS compliance. While a study of this nature could improve the understanding of the impact of EOBR, it would be dependent on cooperation from both carriers and drivers and could be potentially biased if drivers have knowledge of electronic recordings.

The BCA showed that OBMS have the potential to improve safety and reduce carrier costs. Considering the safety benefit of reduced crashes alone within the base case, a crash reduction rate of 16% is required for a net economic benefit. This rate is within the range of expected reduction rates seen in previous studies (Orban et al., 2006; Battelle, 2007; Battelle, 2003; Houser et al., 2009; Murray, Shackelford and Houser, 2009a; Murray, Shackelford and Houser, 2009b; Flintsch et al., 2012). When the benefits associated with electronic HOS recording as well as non-safety-related benefits are included within the analysis, a wider range of crash reduction rates and HOS reduction rates can be combined to result in economic feasible system use. At the initial system cost assumed within the analysis ($3,500), OBMS would not be economically feasible if only accounting for benefits associated with electronic HOS recording, but the sensitivity analysis indicated that at system costs below $2,918, the system would be economically feasible. This cost is within the range of typical sole-function EOBR costs.

Although non-safety-related benefits, such as reduced fuel consumption and vehicle miles traveled are of a magnitude greater than safety-related benefits in this analysis, the safety benefits should be overlooked. The sensitivity analysis further showed that positive benefits are possible for large and small sized fleets. The regression analysis provided an alternative means of examining the economic feasibility of OBMS and supports the findings of the BCA, that fleets with higher initial crash and HOS violation rates are more likely to see economic benefit with OBMS when compared to fleets with lower rates.

The insights gained from the BCA and subsequent regression analysis can be used to inform policies for motivating or mandating carriers to use such systems, and to inform carriers regarding the value of system investment. Focusing on the policy-maker's perspective, the analysis showed that OBMS can be used to improve safety without economically burdening carriers. This includes small carriers, who are often considered to be at a disadvantage when competing with larger carriers. The regression indicated that carriers with higher initial crash and HOS violation rates will see greater economic benefits from OBMS use than a carrier with lower initial crash and violation rates. This confirms the FMCSA's initial attempts to mandate on-board safety systems, specifically EOBR, as a remedial measure for carriers with low safety ratings (Federal Register, 2010). Carriers will likely see great safety and economic benefits with OBMS use. Despite this, it may be more effective from both a logistical and acceptability standpoint to mandate OBMS for all carriers, regardless of past safety performance. A general mandate removes the need for determining which carries should be subject to a targeted mandate. Additionally, if system use is mandated for all carriers, claims of discriminations against certain types of carriers will be minimized. Subsequent revisions of the above-mentioned EOBR policy have expanded that mandate to all carriers (Federal Register, 2011), indicating that a targeted mandate approach was not be well-received by motor carriers and drivers.

As noted by Hickman and Hanowski (2011), a BCA of OBMS use can determine the carrier return on investment, which can help encourage carriers to adopt such technologies. Because this analysis is from the carrier perspective, the BCA highlights the benefits of, along with providing quantitative evidence for, OBMS for carriers. If carriers understand the results of the BCA, they will be better poised to use these systems to their benefit. Several key conclusions from the analysis which are important for carriers to understand include the relationship between fleet size and economic benefit, and the potential contribution of non-safety-related benefits. The potential for insurance cost reductions is also an additional incentive of OBMS for carriers who are not self-insured (ATRI, 2007).

While it has been noted the OBMS have the potential to benefit carriers in a wide range of circumstances, there are conditions when system use may not be economically viable. Economic benefit is directly related to the number of crashes and HOS violations observed within a fleet prior to OBMS use, as seen within the regression analysis. Thus, a carrier with a consistently high safety rating has the potential to not see benefit from system use if only considering safety-related benefits. Additionally, while the five-year system life may indicate a short-term investment for larger carriers, many smaller carriers enter and exit the market in smaller time increments. The initial investment required for OBMS makes these systems impractical for fleets that will not remain in business for the duration of the life of the system

Issues beyond economic feasibility also factor into the successful implement of OBMS. As stated above, carrier buy-in of system use is important. At the same time, individual driver acceptance is of concern. While OBMS can benefit drivers by improving their personal safety and reducing the time required to record HOS, drivers are concerned about privacy and misuse of data (Roetting, et al., 2003; Sherry 2001). Preliminary findings from the larger study, of which this dissertation is a subset, indicate that driver acceptance of OBMS is low as evidenced by physical tampering of systems within fleet vehicles. While this outcome was not further explored within this dissertation (including not incorporating the cost of replacing systems which had been damaged into the BCA), it is important for policy-makers and carriers to consider when introducing OBMS into fleets. The above referenced research indicates that acceptance was a function of perceived benefit, thus carriers should focus on educating drivers on the use and benefit of OMBS. Concerns of driver acceptance also support the recommendation for a general mandate of OBMS. If drivers do not feel as if they are being singled out in being required to operate with OBMS, they made accept the systems more.

The BCA analysis performed for this dissertation only address the carrier benefits and costs of system use. A BCA considering the societal perspective of system use would be a natural extension to gain further insights into the feasibility and appropriate use of such systems on a larger scale. System use encompasses both safety-related and non-safety-related benefits to society. The benefit associated with reduced crashes would be determined using the same method as within the carrier BCA, with crash costs that are consistent with crash costs suggested by the U.S. DOT (2008b) for such studies. Societal benefits associated with HOS violation reduces could result from reductions in resources required to enforce regulations. Societal non-safety-related benefits include reductions in emissions and reductions on wear on pavements, associated with improved fuel economy and reduced vehicles miles travelled, that are considered in the carrier-perspective BCA.

While this dissertation addresses a specific type of technology and only one vendor, the results of this study can be expanded beyond on board safety systems. From a broader perspective, this study shows how commercial vehicle operations can have benefits beyond safety and that use of the technology will not place an economic burden on motor carriers. Results agree with previous studies (Houser et al., 2009; Murray, Shackelford and Houser, 2009a; Murray, Shackelford and Houser, 2009b; Flintsch et al., 2012) in concluding that various on-board safety systems are economically feasible for many reasons. The results also concur with other studies (Shackelford, Short and Murray, 2007, Brand et al., 2004) that consider the economic impacts of other technologies used to improve operations. While there are costs associated with the use of technology systems, in many cases, the benefits outweigh the costs.

Previous studies have shown that OBMS can enhance safety in commercial vehicle operations (Orban et al., 2006; Battelle, 2007; Battelle, 2003; Houser et al., 2009). This dissertation concludes that in many circumstances these safety improvements can be achieved with a net economic benefit to motor carriers. This research also shows that net positive benefits are possible in large and small sized fleets. Results can be used to inform policies for motivating or mandating carriers to use such systems, and to inform carriers regarding the value of system investment.

REFERENCES

af Wåhlberg, A.E. (2007). Long-term Effects of Training in Economical Driving: Fuel Consumption, Accidents, Driver Acceleration Behavior and Technical Feedback. *International Journal of Industrial Ergonomics*, 37, 333-343.

American Associations of State Highway and Transportation Officials (AASHTO) (2010). *Transportation Reboot: Restarting America's Most Essential Operating System*. Retrieved 18 August 2001 from http://expandingcapacity.transportation.org /unlocking_freight/images/ FreightReportFinal_7710.pdf

American Transportation Research Institute (ATRI), (2007). *Incentives for Deployment of Onboard Safety Systems, Final Report.* Report No. FMCSA RRT-007-031.

Austrian Energy Agency (2012). *Eco Will, ecodrive.org*. Retrieved 15 April 2012 from www.ecodrive.org

Barcos, L. V. Rodrigues, M.J. Alvarez, and F. Robuste (2010). Routing Design for Less-Than-Truckload Motor Carriers Using Ant Colony Optimization. *Transportation Research Part E*, 46, 367-383.

Barla, P., D. Bolduc, N. Boucher, J. Watters (2010). Information Technology and Efficiency in Trucking. *Canadian Journal of Economics/Revue canadienne d'Economique,* 43(1), 254-279.

Barth, B. and K. Boriboonsomsin (2009). Energy and Emissions Impacts of a Freeway-Based Dynamic Eco-Driving System. *Transportation Research Part D*, 14, 400–410.

Battelle (2007). *Evaluation of the Volvo Intelligent Vehicle Initiative Field Operational Test, Version 1.3, Final Report.* U.S. Department of Transportation.

Battelle (2003). *Evaluation of the Freightliner Intelligent Vehicle Initiative Field Operational Test, Final Report*. U.S. Department of Transportation.

Baumgaertner, M., J. Léonardi, and O. Krusch (2008). Improving Computerized Routing and Scheduling and Vehicle Telematics: a Qualitative Survey. *Transportation Research Part D*, 13, 377–382.

Beilock, R. (1995). Schedule-Induced Hours-of-Service and Speed Limit Violations Among Tractor-Trailer Drivers. *Accident Analysis and Prevention*, 27(1), 33-42.

Belella, P., et al. (2009). *Motor Carrier Efficiency Study Phase I.* Report No. FMCSA-RRT-09-015, Federal Motor Carrier Safety Administration, Washington, D.C.

Belzer, M.H. (2002). Technological Innovation and the Trucking Industry: Information Revolution and the Effects on the Work Process. *Journal of Labor Research*, 23(3), 375-395.

Bennett, S. (2008). Smart Routing to Save Fuel. *Transport Topics Online*. Retreived 2 May 2012 from www.ttnews.com/ articles/printnews. aspx?LMTID=232

Beusen, B. et al (2009). Using On-board Logging Devices to Study the Longer-term Impact of an Eco-driving Course. *Transportation Research Part D*, 14, 514–520.

Biemer, P. and L. Lyberg (2003). *Introduction to Survey Quality*. John Wiley and Sons, Hoboken, NJ.

Boardman, A.E., D.H. Greenberg, A.R. Vining, and D.L. Weimer (1996). *Cost-Benefit Analysis: Concepts and Practice.* Prentice Hall, Upper Saddle River, NJ.

Boriboonsomsin, K., M. Barth, A. Vu (2011). Evaluation of Driving Behavior and Attitude towards Eco- Driving: A Southern California Limited Case Study. *Proceedings of the TRB 90th Annual Meeting.* Washington, D.C.

Brand, D. T. Parody, J. Orban, and V. Brown (2004). A Benefit/Cost Analysis of the Commercial Vehicle Information Systems and Networks (CVISN) Program. *Research in Transportation Economics*, 8, 379-401.

Braver, E.R., et al. (1992). Long Hours and Fatigue: A Survey of Tractor-Trailer Drivers. *Journal of Public Health Policy*, 13(3), 341-366.

Button, K., E. Doyle, R. Stough (2001). Intelligent Transport Systems in Commercial Fleet Management: A Study of Short Term Economic Benefits. *Transportation Planning and Technology*, 24, 155-170.

Campbell, L., S.W. Lang, and M.C Smith (1998). *Electronic Recorder Study*. University of Michigan Transportation Research Institute for Federal Highway Administration.

Canadian Council of Motor Transport Administrators (CCMTA) (2011). *Request for Proposals Development of a Canadian National Standard for Electronic On-Board Recorder Use*. Ottawa, ON.

Canadian Council of Motor Transport Administrators (CCMTA) (2010). *Electronic On-Board Recorders: Discussion Paper*. Ottawa, ON.

Cantor, D.E., Corsi, T.M., Grimm, C.M. (2009). Do Electronic Logbooks Contribute to Motor Carrier Safety Performance? *Journal of Business Logistics*, 30 (1), 203-222.

Cantor, D.E., Corsi, T.M., Grimm, C.M. (2008). Determinants of Motor Carrier Safety Technology Adoption. *Transportation Research Part E: Logistics and Transportation Review*, 44 (1), 932-947.

Code of Federal Regulations (CFR). Title 49, Part 395. *Hours of Service of Drivers*.

Corsi, T. M. and R. E. Barnard (2003). *Best Highway Safety Practices: A Survey of the Safest Motor Carriers About Safety Management Practices, Final Report.* FMCSA Contract No. DTFH61-98-X-00006, Federal Motor Carrier Safety Administration, Washington, D.C.

Corsi, T. M., R. Barnard, and J. Gibney (2002). *Motor Carrier Industry Profile: Linkages Between Financial and Safety Performance Among Carriers in Major Industry Segments*. FMCSA Report No. FMCSA-RI-02-009, Federal Motor Carrier Safety Administration, Washington, D.C.

Cullen, D. (2007). A Positive Case Study Supports EOBRs. *Fleet Owner*. Retrieved 21 March 2012 from http://fleetowner.com/information_technology/truckcom/fleet_positive_case_study

Darnton, G., and Darnton, M. (1997). *Business Process Analysis*. International Thomson Business Press, London.

Dasgupta, A.K. and D.W. Pearce (1972). *Cost-Benefit Analysis, Theory and Practice.* Barnes and Noble Books, New York, NY.

Donmez, B., Boyle, L. N., & Lee, J. D. (2008a). Designing Feedback to Mitigate Distraction. In M. Regan, J. D. Lee & K. Young (Eds.), *Driver Distraction: Theory, Effects, and Mitigation.* CRC Press, Boca Raton, FL.

Donmez, B., Boyle, L. N., & Lee, J. D. (2008b). Mitigating Driver Distraction with Retrospective and Concurrent Feedback. *Accident Analysis and Prevention,* 40, 776-786.

Energy Saving Trust (2012). *Fuel-efficient Driving*. Retrieved 15 April 2012 from http://www.energysavingtrust.org.uk/Transport/Consumer/Fuel-efficient-driving.

European Commissions, Directorate-General for Energy and Transport (2009). *Background Information the Current Digital Tachograph Systems.* Retrieved 6 June 2011 from http://ec.europa.eu/transport/road/ consultations/doc/2010_03_ 01_ background_info.pdf

The European Parliament and the Council of the European Union (2006). *Regulation (EC) No. 531/2006, EUR-Lex, Access to European Law*. Retrieved 6 June 2011 from http://eur-lex. europa.eu/LexUriServ/ LexUriServ.do? uri=OJ:L:2006:102:0001:0013:EN:PDF

Federal Highway Administration (FHWA) (2012). *Roadway Extent, Characteristics, and Performance, Highway Statistics.* Policy Information, Highway Statistics Series. Retrieved 2 May 2012 from http://www.fhwa.dot.gov/policyinformation/statistics/

Federal Highway Administration (FHWA) (2010). *DOT Releases New Freight Transportation Data. FHWA 62-10.* Retrieved 23 June 2011 from http://www.fhwa.dot.gov/ pressroom/fhwa1062.htm

Federal Highway Administration (FHWA) (1998). *Intelligent Transportation Systems: real World Benefits*. Joint Program Office for Intelligent Transportation Systems, Washington, D.C.

Federal Motor Carrier Safety Administration (FMCSA) (2012a). *Roadside Inspections*. Analysis and Information Online. Retrieved 21 April 2012 from http://ai.fmcsa.dot.gov/SafetyProgram /RoadsideInspections.aspx

Federal Motor Carrier Safety Administration (FMCSA) (2012b). *HOS Frequently Asked Questions (FAQ)*. Retrieved 23 April 2012 from http://www. fmcsa.dot.gov/rules-regulations/ truck/driver/hos/hos-faqs.asp#_Toc111021228

Federal Motor Carrier Safety Administration (FMCSA) (2012c). *FMCSA A&I Online, Safety Measurement System*. Retrieved 22 May 2012 from http://ai.fmcsa.dot.gov/SMS/Data/ Downloads.aspx

Federal Motor Carrier Safety Administration (FMCSA) (2012d). *FMCSA Motor Carrier Management Information System*. Retrieved 22 May 2012 from http://mcmiscatalog.fmcsa. dot.gov/default.asp

Federal Motor Carrier Safety Administration (FMCSA) (2011a). *Roadside Inspections, Driver Violations*. Retrieved 21 April 2012 from http://ai.fmcsa.dot.gov/SafetyProgram/spViolation .aspx ?rpt=RDDV

Federal Motor Carrier Safety Administration (FMCSA) (2011b). *Reviews, Critical Violations.* Retrieved 21 April 2011 from http://ai.fmcsa.dot.gov/SafetyProgram/spViolation.aspx? rpt=CViol

Federal Motor Carrier Safety Administration (FMCSA) (2011c). *Interstate Truck Driver's Guide to Hours of Service*. Retrieved 19 May 2011 from http://www.fmcsa.dot.gov/rules-regulations/ truck/driver/hos/ fmcsa-guide-to-hos.pdf

Federal Motor Carrier Safety Administration (FMCSA), Analysis Division (2010a). *2008 Large Truck Crash Overview*. Publication No. FMCSA-RRA-10 004.

Federal Motor Carrier Safety Administration (FMCSA) (2010b). *Regulatory Impact Analysis of Electronic On-Board Recorders*.

Federal Motor Carrier Safety Administration (FMCSA) (2006). *Large Truck Crash Causation Study (LTCCS) Analysis Series: Using LTCCS Data for Statistical Analyses of Crash Risk.* Retrieved 2 July 2012 from http://www.fmcsa.dot.gov/facts-research/research-technology/ analysis/ltccs.htm#ISSUE7

Federal Motor Carrier Safety Administration (FMCSA) (2005). *Regulatory Impact Analysis and Small Business Analysis for Hours of Service Options.* Retrieved 2 July 2012 from http://www.fmcsa.dot.gov/rules-regulations/topics/hos/regulatory-impact.htm

Federal Motor Carrier Safety Administration (FMCSA) (2002). *Tech Brief: Evaluation of the Commercial Vehicle Information Systems and Networks (CVISN) Model Deployment Initiative*.

Federal Register (2011). *Notice of Proposed Rulemaking: Electronic On-Board Recorders and Hours of Service Supporting Documents*. 76(21) 5537-5555.

Federal Register (2010). *Electronic On-Board Recorders for Hours of Service Compliance; Final Rule.* 75(64) 17207-17252.

Fleming, B. (2008). Paving the Road to Savings with GPS. *IEEE Vehicular Technology Magazine.* December, 10-13.

Flintsch, A. M., et al. (2012). Benefit-Cost Analysis – Onboard Safety Systems Effectiveness Evaluation. *Proceedings of the TRB 91st Annual Meeting.* Washington, D.C.

Grace R. et al (1998). A Drowsy Driver Detection System for Heavy Vehicles. *Digital Avionics Systems Conference Proceedings.* 2, 1-8.

Gramlich, E.M. (1981). *Benefit-Cost Analysis of Government Programs*. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Haight, M. and V. Kecojevic (2005). Automation vs. human intervention: What is the best fit for the optimal system performance? *Process Safety Progress Journal*, 24(1), 45-51.

Hall, R.W., and C. Intihar (1997). *Commercial Vehicle Operations: Government Interfaces and Intelligent Transportation Systems.* California PATH Research Report UCB-ITS-PRR-97-12.

Haworth, N. and M. Symmonds (2001). *The Relationship Between Fuel Economy and Safety Outcomes*. Report No. 188, Monash University Accident Research Centre.

Hertz, Robin, P. (1991). Hours of service violations among tractor-trailer drivers. *Accident Analysis and Prevention*, 23(1), 29-36.

Hickman, J.S., and R.J. Hanowski (2011). Use of a Video Monitoring Approach to Reduce At-Risk Driving Behaviors in Commercial Vehicle Operations. *Transportation Research Part F*. 14, 189-198.

Houser, A., et al. (2009). *Analysis of Benefits and Costs of Lane Departure Warning Systems for the Trucking Industry*. Report No. FMCSA RRT 09 022. Federal Motor Carrier Safety Administration, U.S. Department of Transportation.

Houser, A., D. Pope, and N. McMillan (2006). *A Simulation Approach to Estimate the Efficacy Stability Control.* Report No. FMCSA MCRR 06 006. Federal Motor Carrier Safety Administration, U.S. Department of Transportation.

Hubbard, T.N. (2003). Information, Decisions, and Productivity: On-Board Computers and Capacity Utilization in Trucking. *The American Economic Review.* 93(4), 1328-1353.

Hubbard, T.N. (1998). Why Are Process Monitoring Technologies Valuable? The Use of On-Board Information Technology in the Trucking Industry. Working Paper 6482, *National Bureau of Economic Research*.

Kavalaris, J. G., and K.C. Sinha (1994). *Institutional Issues Related to the Application of Intelligent Vehicle Highway Systems Technologies to Commercial Vehicle Operations in Indiana*. Report No. FHWA/IN/JHRP-94/05. Indiana Department of Transportation and the Federal Highway Administration.

Knipling, R.R (2011). *Potential Safety Benefits of Motor Carrier Operational Efficiencies, A Synthesis of Safety Practice.* CTBSSP Synthesis 20. Federal Motor Carrier Safety Administration, U.S. Department of Transportation.

Kraft, D. (2006). Next-Generation EOBRs: The Issues Ahead. *American Trucking Association Technology and Maintenance Council.*

Madison, D. (2005) *Process Mapping, Process Improvement, and Process Management*. Paton Press, Chico, CA.

Martin, J. (1997) *Systems Engineering Guidebook: A process for developing systems and products*, CRC Press, Chantilly, VA.

McCallum, M.C., and J.D. Lee (1993). System Objectives and Performance Requirements of ATIS and Commercial Vehicle Components of IVHS. *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting,* Seattle, WA.

McGehee, D. V., M. Raby, C. Carney, J.D. Lee, and M.L. Reyes (2007). The Impact of an Event-Triggered Video Intervention on Rural Teenage Driving. *Proceedings of the 4th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*, Iowa City, IA.

McKinnon, A. (2010). *Green Logistics: Improving the Environmental Sustainability of Logistics*. Kogan Page Publishers, London.

Minister of Justice. (2005). *Commercial Vehicle Drivers Hours of Service Regulations (SOR/2005-313)*. Retrieved 6 June 2011 from http://laws-lois.justice.gc.ca/PDF/SOR-2005-313.pdf

Monaco, K. and E. Williams (2000). Assessing the Determinants of Safety in the Trucking industry. *Journal of Transportation and Statistics*. 3(1), 69-79.

Moses. L.N., and I. Savage (1994). The Effect of Firm Characteristics on Truck Accidents. *Accident Analysis and Prevention.* 26(2), 173-179.

Murray, D., S. Shackelford, A. Houser (2009a). *Analysis of Benefits and Costs of Forward Collision Warning Systems for the Trucking Industry*. Report No. FMCSA RRT 09 021. Federal Motor Carrier Safety Administration, U.S. Department of Transportation.

Murray, D., S. Shackelford, A. Houser (2009b). *Analysis of Benefits and Costs of Roll Stability Control Systems for the Trucking Industry*. Report No. FMCSA RRT 09 020. Federal Motor Carrier Safety Administration, U.S. Department of Transportation.

Najm, W. G., M. D. Stearns, H. Howarth, J. Koopmann, and J. Hitz (2006). *Evaluation of an Automotive Rear-end Collision Avoidance System.* Report No. DOT-VNTSC-NHTSA-06-01. HS-810 569. Research and Innovation Technology Administration, Volpe National Transportation Systems Center, National Highway Traffic Safety Administration.

National Highway Traffic Safety Administration (NHTSA) (2003). National Center for Statistics and Analysis - Mathematical Analysis Division. *An Analysis of Fatal Large Truck Crashes*. Report No. DOT HS 809 569. U.S. Department of Transportation.

National Highway Traffic Safety Administration (NHTSA) (2009). *Traffic Safety Facts 2009*. Report No. DOT HS 811 402. U.S. Department of Transportation.

National Transport Commission (NTC) Australia (2009). *Electronic Systems for heavy Vehicle Driver Fatigue and Speed Compliance: Draft Position Paper*. Melbourne, VIC.

New South Wales (NSW) Government. (2005). *Road Transport (General) Regulation*. 57-120.

Orban, J., J. Hadden, G. Stark, and V. Brown (2006). *Evaluation of the Mack Intelligent Vehicle Initiative Field Operational Test, Final Report*. Report No. FMCSA--06-016. Federal Motor Carrier Safety Administration, U.S. Department of Transportation.

Pitera, K., F. Sandoval, and A. Goodchild (2011). Evaluation of Emissions Reduction in Urban Pickup Systems. *Transportation Research Record: Journal of the Transportation Research Board*, 2224, 8-16.

Rasmussen, J. (1982). Human errors. A taxonomy for describing human malfunction in industrial installations. *Journal of Occupational Accidents*, 4, 311-333.

Roetting, M., Huang, Y-H., McDevitt, J.R. Melton, D. (2003). When technology tells you how you drive - truck drivers' attitudes towards feedback by technology. *Transportation Research Part F*, 6(4), 275-287.

Rother, M., Shook, J., Womack, J., and Jones, D. (1999). *Learning to see: Value stream mapping to add value and eliminate MUDA*, Lean Enterprise Institute.

SAFED, Safe and Fuel Efficient Driving (2012). Retrieved 15 May 2012 from http://uk-roadsafety.co.uk/safed.htm

Sassone, P.G., W.A. Schaffer (1978). *Cost-Benefit Analysis, A Handbook*. Academic Press, New York, NY.

Sedor, J. and H. Caldwell (2002). *The Freight Story: A National Perspective on Enhancing Freight Transportation*. Publication FHWA-OP-03-004. FHWA, U.S. Department of Transportation.

Shackelford, S. and D. MurrayD (2006). *Electronic On-Board Recorder Adoption in the Trucking Industry: Issues and Opportunities*. The American Transportation Research Institute, Alexandria, VA.

Shackelford, S., J. Short, and D. Murray (2007). *Assessing the Impact of the ACE Trucking e-Manifest System on Trucking Operations.* The American Transportation Research Institute, Alexandria, VA.

Shaw, R., J. Coia, and J. Michie (1999). Use of bar code readers and programmable keypads to improve the speed and accuracy of manual data entry in the clinical microbiology laboratory: experience of two laboratories. *Journal of Clinical Pathology*, 52, 54-60.

Sherry, P. (2001). *In-Vehicle Monitoring Technologies: Review of Current Use and Potential Enhancement through Behaviorally Based Safety Processes* (Report submitted to American Trucking Association Foundation). Denver, CO: University of Denver.

Symmons, M. S. and G. Rose (2009). Ecodrive Training Delivers Substantial Fuel Savings for Heavy Vehicle Drivers. *Driving Assessment 2009 Conference*, Big Sky, Montana.

Stefansson, G. and J. Woxenius (2007). The Concept of Smart Freight Transport Systems – The Road Haulier's Perspective. *Proceedings of the 19th Nordic Logistics Research Network (NOFOMA) Conference*, Reykjavik.

Stock, D. (2001). *I-95 Corridor Coalition Field Operational Test 10: Coordinated Safety Management; Volume I: Best Practices in Motor Carrier Safety Management*. PENNDOT Final Report, Pennsylvania Transportation Institute, University Park.

Toledo, T., O. Musicant, and T. Lotan (2008). In-Vehicle Data Recorders for Monitoring and Feedback on Drivers' Behaviour. *Transportation Research Part C*, 16, 320–331.

Transecurity (2012). http://www.transecurity.com/

U.S. Department of Energy (2012). *Driving More Efficiently*. Retrieved 15 April 2012 from http://www.fueleconomy.gov/ feg/driveHabits.shtml

U.S. Department of Transportation (U.S. DOT) (2008a). *Framework for a National Freight Policy*. Retrieved 23 June 2011 from http://www.freight. dot.gov/freight_framework/index.cfm

U.S. Department of Transportation (U.S. DOT) (2008b). *Treatment of the Economic Value of a Statistical Life in Department Analysis*. Washington, DC.

U.S. Energy Information Administration (U.S. EIA) (2012). *Independent Statistics and Analysis. Gasoline and Diesel Fuel Update*. Retrieved 30 April 2012 from http://www.eia.gov/petroleum/ gasdiesel/

U.S. Office of Management and Budget (U.S. OMB) (1992). *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*. U.S. Office of Management and Budget Circular A-94.

U.S. Office of Management and Budget (U.S. OMB) (2000). *Guidelines to Standardize Measures of Costs and Benefits and the Format of Accounting Statements.*" U.S. Office of Management and Budget, Report M-00-08.

Vangi, D. and A. Virga (2003). Evaluation of Energy-Saving Driving Styles for Bus Drivers. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, 299-305.

Wouters, P.I.J., and J.M.J. Bos (2000). Traffic Accident Reduction by Monitoring Driver Behaviour with In-Car Data Recorders. *Accident Analysis and Prevention*, 32, 643-650.

Zarkadoula, M., G. Zoidis, and E. Tritopoulou (2007). Training Urban Bus Drivers to Promote Smart Driving: A Note on a Greek Eco-Driving Pilot Program. *Transportation Research Part D*, 12(6), 449–451.

APPENDIX A: CARRIER INTERVIEW NOTES

CARRIER 1 (7/27/2010)
CARRIER 2 (7/27/2010)
CARRIER 3 (12/14/2010)

Carrier 1 (7/27/2010)

General Information:

- Drivers are home every weekend (unless they don't want to be).
- Vehicle trade cycle – typically 4 years/500,000 miles.
- Cost of new trucks for 2011 - $125,000 (increase cost is supposed to be because of new fuel standards)
- Last time they bought trucks (2006), they cost $105,000
- Roughly 1200 miles on a tank of fuel

Questions regarding Hours of Service:

What method do drivers use to record hours of service?

Currently, all paper. Partner with Qualcom, and going to implement QHOS within next 6 months. It will take a while to get this working on trucks. It will make sense to not have them on the same trucks at the study system. Will need to know what trucks are using what system when we get started.

Do you use the standard US DOT form to record HOS?

Yes. They gave us a copy of a log book.

What other forms (in addition to the US DOT form) do you use?

Also use a time card for local drivers (those within 100 air-miles that don't need to fill out log books)

How frequently is the driver required to transfer HOS information to you?

Weekly.

Turn them in by either mail-in, or drop off at a terminal (most common). Also they are included in some trip packets. Can't scan them in (one reason is the additional cost)

About 85% of drivers turn in log books (the rest are within the 100 mile air radius)

For what period of time must the driver keep records of hours of service?

8 days (7+ the working day of)

How is HOS information filed and stored by the carrier?

A vendor scans and audits the logs (checks for accuracy, compliance, and completeness). Then carrier has access to them electronically.

Checks for fuel stops, tolls, arrival times, drug testing, collisions, HOS…

Is HOS information held by the terminals or at a centralized location (headquarters)?

At a centralized location (vendor), which carrier can access electronically.

How long does the carrier keep HOS information?

6 months (after – both paper and electronic copies are destroyed)

Carrier would keep them longer if there was an audit.

What incentives and/or penalties exist to encourage drivers to keep more accurate HOS records?

See Log Violation Policy. There are different penalties for different levels of violations and for number of violations.

When there is a 7 day suspension, there are lost revenue due to lost productivity on the truck.

There is no true incentive to keep more accurate HOS records, but if they have any HOS violations, they are taken out of the running for Top Achiever, which is highly regarded within carrier.

What procedures are in place for the carrier to verify drivers' HOS records and to ensure accuracy?

Every log is audited by vendor. We have a summary of violations.

How often have your drivers been asked to provide HOS records (to the FMCSA) this past year?

Only at roadside inspections (ask for the number of roadside inspections)

How often is the carrier asked to provide HOS records (to the FMCSA) this past year?

Zero. Last DOT audit was in August, 2002.

What challenges exist with the current HOS procedure (regulations/recording/ enforcement)?

Historically, education is a challenge – overcoming misinformation (things learned from truck stops and over CB radio).

With recording, mostly little things like didn't completely form fully.

Communication with dispatch – putting ownership of the HOS on the driver

Can you identify opportunities for improvement within the current HOS recording system?

Next big step is going paperless.

What is the cost of collecting and maintaining HOS records (e.g., storage space, date processing/staff time, computer equipment/hard driver/server, office space, drivers' time)?

Baseline cost – monthly $5000 for vendor. Also admin person, FedEx, driver manager time chasing missing logs, cost of log books.

Carrier 2 (7/28/2010)

General Information:

- Split-seat (is that the correct term?) Two drivers per truck (not at the same time) that each work 12 hour shifts. This doesn't really allow for non-compliance.
- While it is hard to measure fatigue, they think that there will be benefit from better enforcing of HOS in terms of loading/unloading fuel more correctly or safely (for example, sometimes a driver puts unleaded into a diesel tank. Then that fuel has to be pumped out and becomes the property of carrier and they have to try and sell it).
- Business is seasonal – for example, more drivers in the winter in Florida because there are more people down there in the winter months.

Questions regarding Hours of Service:

What method do drivers use to record hours of service?

Paper graph logs.

Carrier is trying to implement an e-log system (via Microlise), but only one truck instrumented and they are not getting quality performance so have not moved forward with it yet. They have not developed training materials for the e-logs at this point.

Do you use the standard US DOT form to record HOS?

Yes.

What other forms (in addition to the US DOT form) do you use?

None.

How frequently is the driver required to transfer HOS information to you?

Daily. Drivers physically hand-in log to dispatcher/clerk after each shift. The dispatcher/clerk checks for accuracy then calculate remaining HOS, so that next dispatcher knows if any remain to dispatch for next day.

For what period of time must the driver keep records of hours of service?

Last 8 days. But they recommend that the driver keeps copies for 30 days.

How is HOS information filed and stored by the carrier?

Logs are returned to the terminal daily. There is a person (approximately 10% of their time each day is spent doing this) who manually inputs the information into an electronic system and checks for accuracy. At the end of each month, these files (hard and electronic) are transferred to HQ for storage for 5 more months.

Is HOS information held by the terminals or at a centralized location (headquarters)?

Held at the terminal until the end of the month, and then transferred to HQ after.

How long does the carrier keep HOS information?

6 months. Also hold 30 days before and after crashes (until incident has been cleared)

What incentives and/or penalties exist to encourage drivers to keep more accurate HOS records?

No incentives directly related to HOS, but more for crashes. Considering looking at HOS for some sort of achievement metric, but not sure how to consider it yet.

No true penalties – instead they think of them as “learning opportunities.”

People don’t get suspended or fired for HOS non-compliance (probably because there are not many incidents of it). Instead, counseling with safety officer and/or online training.

What procedures are in place for the carrier to verify drivers’ HOS records and to ensure accuracy?

Driver is supposed to add up hours to make sure they are under the weekly limit. 100% checked daily by dispatcher /clerk when turned in. Drivers have to have the previous days log turned in before they are dispatched that day. The safety officer audits about 25% of the logs (matching times, hrs, speed versus miles).

Only about 1-2% are non-compliant (this includes minor issues like forgetting to sign the form).

How often have your drivers been asked to provide HOS records (to the FMCSA) this past year?
321 (company-wide) roadside inspections between 1/1/10 and 6/28/10.

How often is the carrier asked to provide HOS records (to the FMCSA) this past year?
None. Last compliance audit was in 1996.

What challenges exist with the current HOS procedure (regulations/recording/ enforcement)?
Prompt receipt of daily logs, lost logs.
Carrier typically only hire experienced drivers so they are more informed. Do 14-30 days of on the road training where they are filling out logs (with a trainer).
Dispatcher should already know how many hours are left, but drivers are supposed to check too.

Can you identify opportunities for improvement within the current HOS recording system?
Eliminate opportunities for falsification.

What is the cost of collecting and maintaining HOS records (e.g., storage space, date processing/staff time, computer equipment/hard driver/server, office space, drivers' time)?
Have never formally calculated this.
1-2 hours spent each day at each terminal (x21 terminals), mailing costs (USPS)
8 hours a month at HQ (collecting, storing, disposing), 10 feet of file cabinet space at HQ
Cost of logbook is rather significant – buy approximately 1000 log books per month (700 drivers + turnover). One book lasts one month. Approximately $2.20 each. Spend $20k to 30k a year.

Carrier 3 (12/14/2010)

General Information:

- Dedicated contract services
- 90 units at the terminal

Questions regarding Hours of Service:

What method do drivers use to record hours of service?

Paper based (the majority)

Do you use the standard US DOT form to record HOS?

No (see below)

What other forms (in addition to the US DOT form) do you use?

Carrier has their own log book form. It is similar to the US DOT forms.

How frequently is the driver required to transfer HOS information to you?

They encourage the drivers to submit forms 2 or 3 times a week. The drivers can scan them in at any of the carrier terminals or at numerous trucks stops (which have a particular scanner, they indicated that it was commonly found on the road). The logs are sent directly to carrier and then immediately forwarded to vendor.

For what period of time must the driver keep records of hours of service?

They are required to keep previous 7 days. Some keep for longer (a year) for tax records.

How is HOS information filed and stored by the carrier?

Vendor files and stores the logs for carrier.

Is HOS information held by the terminals or at a centralized location (headquarters)?

At an offsite centralized location (vendor).

How long does the carrier keep HOS information?

The required 6 months, although summarized HOS information is kept for longer.

What incentives and/or penalties exist to encourage drivers to keep more accurate HOS records?

No real incentives. When there are problems with HOS record keeping, they offer training to an extent. This is done on a case by case basis by safety and fleet managers. Determine if drivers are willing and able to keep accurate HOS records, if not, they may be terminated. Often though, it is a training issue. Rarely is it blatant falsification.
Drivers get "points" on their electric record of vendor finds problems with their logs

What procedures are in place for the carrier to verify drivers' HOS records and to ensure accuracy?

The logs are audited by vendor using the Qualcom locator records (which are also sent by carrier to vendor). They use some sort of an algorithm looking at miles driven, time, fuel used… to check logs.
On Fridays, a missing log report is file by fleet managers.

How often have your drivers been asked to provide HOS records (to the FMCSA) this past year?

To date this year 7050 roadside inspections (out of 10,000 units * 300 days a year – less than 1%)

How often is the carrier asked to provide HOS records (to the FMCSA) this past year?

Only a handful of time. This only happens for litigation purposes.

What challenges exist with the current HOS procedure (regulations/recording/ enforcement)?

The rules themselves. The 14 hour rule is the hardest to meet.

Can you identify opportunities for improvement within the current HOS recording system?

The form they use it good.

The biggest problem is behavioral – the rules are confusing, complication and head to learn.

The 34 hour reset is positive

New rules make it harder to meet every persons' sleep.

Don't teach split-sleeper procedures unless driver specifically asks about it.

What is the cost of collecting and maintaining HOS records (e.g., storage space, date processing/staff time, computer equipment/hard driver/server, office space, drivers' time)?

Carrier will provide

APPENDIX B: BCA RESULTS

BCA Results: 3% and 7% reduction rates

Scenario Description	*r = 3%*			*r = 7%*		
	NPV	***BCR***	***PBP***	***NPV***	***BCR***	***PBP***
Base case BCA considering only reduced crash benefits (Table 7)	$ 54,853	1.29	3.40	$ 25,429	1.29	3.40
Base case BCA considering only HOS benefits (Table 7)	$ (43,088)	0.9	4.64	$ (61,676)	0.9	4.64
Base case BCA considering both safety-related benefits (Table 7)	$ 281,625	2.20	1.96	$ 228,395	2.20	1.96
Base case BCA considering reduced fuel use benefit due to driving behavior only (Table 9)	$ 3,474,930	14.92	0.30	$ 3,080,536	14.92	0.30
Base case BCA considering reduced fuel use benefit due to both driving behavior and fuel monitoring (Table 9)	$ 7,266,530	30.03	0.15	$ 6,467,519	30.03	0.15
Base case BCA considering reduced miles travelled benefit only (Table 9)	$ 3,521,740	15.11	0.29	$ 3,122,350	15.11	0.29
Base case BCA considering all benefits (safety and non-safety-related) (Table 9)	$ 11,687,806	47.64	0.09	$ 10,417,416	47.64	0.09
BCA considering safety-related benefits with fleet size of 1 (Table 10)	$ 2,821	1.58	2.89	$ 1,961	1.58	2.89
BCA considering all benefits (safety and non-safety-related) with fleet size of 1 (Table 10)	$ 186,908	34.3	0.14	$ 166,405	34.3	0.14
BCA considering only reduced crash benefits with mid-level crash costs (Table 12)	$ 731,177	3.99	1.10	$ 629,580	3.99	1.10
BCA considering only reduced crash benefits with high-level crash costs (Table 12)	$ 3,480,189	14.94	0.29	$ 3,085,233	14.94	0.29

APPENDIX C: REGRESSION ANALYSIS DATA AND RESULTS

CARRIER SPECIFIC DATASET (DATA1)
AVERAGE VALUE DATASET (DATA2)
R CODE AND REGRESSION RESULTS

CARRIER SPECIFIC DATASET (DATA1)

sample no.	VMT	FLEET	FATALITY	INJURY	PDO	ACUTE	CRITICAL	NPV
1	860,000	17	0	1	0	3	2	12,693
2	374,102	8	0	0	0	0	0	(32,157)
3	350,000	8	0	0	0	0	0	(32,157)
4	10,000	1	0	0	0	0	0	(5,563)
5	1,200,000	48	0	0	1	0	0	(179,288)
6	3,800,046	81	0	0	1	0	0	(305,187)
7	390,000	3	0	0	0	1	3	28,859
8	75,000	1	0	0	0	0	0	(5,563)
9	290,000	4	0	0	0	2	1	(2,913)
10	700,000	5	0	0	0	0	1	(6,761)
11	4,000,000	170	0	1	2	0	2	(560,561)
12	873,061	14	0	0	0	2	5	15,091
13	25,000	2	0	0	0	0	0	(9,362)
14	47,000	1	0	0	0	0	0	(5,563)
15	322,463	22	0	0	0	1	5	(15,326)
16	10,000	1	0	0	0	0	0	(5,563)
17	101,000	4	0	0	0	0	0	(16,960)
18	86,000	2	0	0	0	0	0	(9,362)
19	10,000	1	0	0	0	0	0	(5,563)
20	90,000	2	0	0	0	0	0	(9,362)
21	7,550,000	57	0	1	1	0	0	(162,773)
22	200,000	8	0	0	0	1	0	(32,133)
23	250,000	16	0	0	0	0	0	(62,550)
24	165,000	1	0	0	0	0	0	(5,563)
25	70,000	1	0	0	0	0	0	(5,563)
26	39,583,312	512	1	5	7	27	42	(258,833)
27	100,000	2	0	0	0	0	0	(9,362)
28	55,000	1	0	0	0	0	0	(5,563)
29	30,000	1	0	0	0	0	0	(5,563)
30	38,961	3	0	0	0	0	0	(13,161)
31	17,000	1	0	0	0	0	0	(5,563)
32	10,000	1	0	0	0	0	0	(5,563)
33	50,000	2	0	0	0	0	0	(9,362)
34	100,000	5	0	0	0	0	0	(20,760)
35	129,558	1	0	0	0	0	1	8,436
36	50,000	1	0	0	0	1	0	(5,539)
37	150,000	5	0	0	0	0	7	77,232
38	32,966	3	0	0	0	0	0	(13,161)
39	35,000	1	0	0	0	0	0	(5,563)
40	30,000	1	0	0	0	0	0	(5,563)
41	60,000	2	0	0	0	0	0	(9,362)
42	724,152	11	0	0	0	1	2	(15,532)
43	109,000	4	0	0	0	0	0	(16,960)
44	104,680	1	0	0	0	0	0	(5,563)
45	200,000	8	0	0	0	0	0	(32,157)
46	82,000	5	0	0	0	0	0	(20,760)
47	100,000	3	0	0	0	0	0	(13,161)

48	120,000	1	0	0	0	0	0	(5,563)
49	80,000	2	0	0	0	0	0	(9,362)
50	100,000	6	0	0	0	6	4	31,582
51	250,036	4	0	0	0	0	1	(2,962)
52	50,658	1	0	0	0	0	0	(5,563)
53	60,000	1	0	0	0	0	0	(5,563)
54	100,000	1	0	0	0	0	0	(5,563)
55	827,250	5	0	0	0	0	0	(20,760)
56	89,897	1	0	0	0	0	0	(5,563)
57	123,000	1	0	0	0	0	0	(5,563)
58	252,321	2	0	0	0	0	0	(9,362)
59	50,000	1	0	0	0	0	0	(5,563)
60	65,000	4	0	0	0	0	1	(2,962)
61	70,072	1	0	0	0	0	0	(5,563)
62	50,000	1	0	0	0	0	1	8,436
63	70,000	3	0	0	0	0	0	(13,161)
64	130,000	1	0	0	0	0	0	(5,563)
65	10,000	1	0	0	0	0	0	(5,563)
66	50,000	1	0	0	0	0	0	(5,563)
67	95,535	1	0	0	0	0	0	(5,563)
68	104,352	1	0	0	0	0	0	(5,563)
69	148,025	1	0	0	0	0	2	22,435
70	47,127	1	0	0	0	0	1	8,436
71	520,000	6	0	0	1	3	8	92,602
72	388,725	7	0	0	0	1	0	(28,333)
73	37,000	1	1	0	0	0	0	809,971
74	50,000	1	0	0	0	0	0	(5,563)
75	825,605	15	0	0	0	2	5	11,292
76	30,000	2	0	0	0	1	2	18,660
77	10,000	1	0	0	0	0	0	(5,563)
78	355,667	4	0	0	1	1	1	2,160
79	245,817	9	0	0	0	0	0	(35,956)
80	34,000	1	0	0	0	0	0	(5,563)
81	60,000	1	0	0	0	0	1	8,436
82	10,000	1	0	0	0	0	1	8,436
83	86,558	2	0	0	0	2	10	130,675
84	14,500	1	0	0	0	0	0	(5,563)
85	10,000	1	0	0	0	0	0	(5,563)
86	50,000	1	0	0	0	0	0	(5,563)
87	100,000	7	0	0	0	0	0	(28,358)
88	86,937	2	0	0	0	1	4	46,657
89	46,425	1	0	0	0	0	2	22,435
90	37,000	1	0	1	0	0	0	45,408
91	21,000	1	0	0	4	2	31	448,838
92	15,600	1	0	0	0	0	0	(5,563)
93	120,000	1	0	0	0	0	0	(5,563)
94	156,678	2	0	0	0	0	0	(9,362)
95	35,000	2	0	0	0	0	0	(9,362)
96	105,000	7	0	0	0	0	0	(28,358)
97	10,000	1	0	0	0	0	0	(5,563)

98	10,000	1	0	0	0	0	0	(5,563)
99	15,000	1	0	0	0	0	0	(5,563)
100	177,640	1	0	0	0	0	0	(5,563)

AVERAGE VALUE DATA SET (DATA2)

sample no.	VMT	FLEET	NPV
1	860,000	17	(9,800)
2	374,102	8	(7,558)
3	350,000	8	(9,143)
4	10,000	1	(4,906)
5	1,200,000	48	(105,479)
6	3,800,046	81	(60,413)
7	390,000	3	12,483
8	75,000	1	(632)
9	290,000	4	2,108
10	700,000	5	25,269
11	4,000,000	170	(386,705)
12	873,061	14	2,456
13	25,000	2	(7,718)
14	47,000	1	(2,473)
15	322,463	22	(64,141)
16	10,000	1	(4,906)
17	101,000	4	(10,319)
18	86,000	2	(3,707)
19	10,000	1	(4,906)
20	90,000	2	(3,444)
21	7,550,000	57	277,607
22	200,000	8	(19,006)
23	250,000	16	(46,111)
24	165,000	1	5,286
25	70,000	1	(960)
26	39,583,312	512	649,282
27	100,000	2	(2,787)
28	55,000	1	(1,947)
29	30,000	1	(3,590)
30	38,961	3	(10,599)
31	17,000	1	(4,445)
32	10,000	1	(4,906)
33	50,000	2	(6,074)
34	100,000	5	(14,184)
35	129,558	1	2,956
36	50,000	1	(2,275)
37	150,000	5	(10,896)
38	32,966	3	(10,994)
39	35,000	1	(3,262)
40	30,000	1	(3,590)
41	60,000	2	(5,417)
42	724,152	11	4,062
43	109,000	4	(9,793)
44	104,680	1	1,320
45	200,000	8	(19,006)
46	82,000	5	(15,368)
47	100,000	3	(6,586)

48	120,000	1	2,327
49	80,000	2	(4,102)
50	100,000	6	(17,983)
51	250,036	4	(519)
52	50,658	1	(2,232)
53	60,000	1	(1,618)
54	100,000	1	1,012
55	827,250	5	33,636
56	89,897	1	348
57	123,000	1	2,525
58	252,321	2	7,229
59	50,000	1	(2,275)
60	65,000	4	(12,686)
61	70,072	1	(956)
62	50,000	1	(2,275)
63	70,000	3	(8,558)
64	130,000	1	2,985
65	10,000	1	(4,906)
66	50,000	1	(2,275)
67	95,535	1	719
68	104,352	1	1,299
69	148,025	1	4,170
70	47,127	1	(2,464)
71	520,000	6	9,634
72	388,725	7	(2,797)
73	37,000	1	(3,130)
74	50,000	1	(2,275)
75	825,605	15	(4,463)
76	30,000	2	(7,390)
77	10,000	1	(4,906)
78	355,667	4	6,426
79	245,817	9	(19,792)
80	34,000	1	(3,327)
81	60,000	1	(1,618)
82	10,000	1	(4,906)
83	86,558	2	(3,671)
84	14,500	1	(4,610)
85	10,000	1	(4,906)
86	50,000	1	(2,275)
87	100,000	7	(21,782)
88	86,937	2	(3,646)
89	46,425	1	(2,510)
90	37,000	1	(3,130)
91	21,000	1	(4,182)
92	15,600	1	(4,537)
93	120,000	1	2,327
94	156,678	2	940
95	35,000	2	(7,061)
96	105,000	7	(21,454)
97	10,000	1	(4,906)

98	10,000	1	(4,906)
99	15,000	1	(4,577)
100	177,640	1	6,118

R CODE AND RESULTS

```
R VERSION 2.15.1 (2012-06-22) -- "ROASTED MARSHMALLOWS"
COPYRIGHT (C) 2012 THE R FOUNDATION FOR STATISTICAL COMPUTING
ISBN 3-900051-07-0
PLATFORM: I386-PC-MINGW32/I386 (32-BIT)

R IS FREE SOFTWARE AND COMES WITH ABSOLUTELY NO WARRANTY.
YOU ARE WELCOME TO REDISTRIBUTE IT UNDER CERTAIN CONDITIONS.
TYPE 'LICENSE()' OR 'LICENCE()' FOR DISTRIBUTION DETAILS.

  NATURAL LANGUAGE SUPPORT BUT RUNNING IN AN ENGLISH LOCALE

R IS A COLLABORATIVE PROJECT WITH MANY CONTRIBUTORS.
TYPE 'CONTRIBUTORS()' FOR MORE INFORMATION AND
'CITATION()' ON HOW TO CITE R OR R PACKAGES IN PUBLICATIONS.

TYPE 'DEMO()' FOR SOME DEMOS, 'HELP()' FOR ON-LINE HELP, OR
'HELP.START()' FOR AN HTML BROWSER INTERFACE TO HELP.
TYPE 'Q()' TO QUIT R.

> DATA1 <- READ.CSV("FMCSA.CSV", HEADER = TRUE)
> LM(NPV~VMT+FLEET+FATALITY+INJURY+PDO+ACUTE+CRITICAL,DATA=DATA1)

CALL:
LM(FORMULA = NPV ~ VMT + FLEET + FATALITY + INJURY + PDO + ACUTE +
    CRITICAL, DATA = DATA1)

COEFFICIENTS:
(INTERCEPT)          VMT        FLEET     FATALITY       INJURY          PDO
 -1.719E+03   -7.971E-06   -3.811E+03    8.154E+05    5.092E+04    5.086E+03
      ACUTE     CRITICAL
  2.376E+01    1.400E+04

> > RESULT<-LM(FORMULA = NPV ~ VMT + FLEET + FATALITY + INJURY + PDO + ACUTE
+
+ +     CRITICAL, DATA = DATA1)
> SUMMARY(RESULT)

CALL:
LM(FORMULA = NPV ~ VMT + FLEET + FATALITY + INJURY + PDO + ACUTE +
    +CRITICAL, DATA = DATA1)

RESIDUALS:
    MIN      1Q  MEDIAN      3Q     MAX
-112.05  -33.43  -23.34   11.98  259.98

COEFFICIENTS:
              ESTIMATE STD. ERROR   T VALUE PR(>|T|)
(INTERCEPT) -1.719E+03  6.787E+00  -253.240  < 2E-16 ***
VMT         -7.971E-06  8.853E-06    -0.900  0.37028
FLEET       -3.811E+03  5.595E-01 -6810.374  < 2E-16 ***
FATALITY     8.154E+05  6.205E+01 13140.751  < 2E-16 ***
INJURY       5.092E+04  4.220E+01  1206.567  < 2E-16 ***
PDO          5.086E+03  2.845E+01   178.756  < 2E-16 ***
ACUTE        2.376E+01  8.313E+00     2.858  0.00528 **
CRITICAL     1.400E+04  3.893E+00  3595.921  < 2E-16 ***
---
SIGNIF. CODES:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

RESIDUAL STANDARD ERROR: 63.2 ON 92 DEGREES OF FREEDOM
MULTIPLE R-SQUARED:     1,      ADJUSTED R-SQUARED:     1
F-STATISTIC: 5.171E+07 ON 7 AND 92 DF,  P-VALUE: < 2.2E-16
```

```
> CONFINT(RESULT)
                    2.5 %        97.5 %
(INTERCEPT) -1.732131E+03 -1.705173E+03
VMT         -2.555368E-05  9.611959E-06
FLEET       -3.811639E+03 -3.809416E+03
FATALITY     8.153156E+05  8.155621E+05
INJURY       5.083800E+04  5.100564E+04
PDO          5.029045E+03  5.142052E+03
ACUTE        7.245429E+00  4.026526E+01
CRITICAL     1.399143E+04  1.400689E+04

> DATA2 <- READ.CSV("MODEL2.CSV", HEADER = TRUE)
> RESULT2<-LM(FORMULA = NPV ~ VMT + FLEET, DATA = DATA2)
> SUMMARY(RESULT2)

CALL:
LM(FORMULA = NPV ~ VMT + FLEET, DATA = DATA2)

RESIDUALS:
     MIN       1Q   MEDIAN       3Q      MAX
-120.287  -32.495  -31.031    6.174  267.680

COEFFICIENTS:
              ESTIMATE STD. ERROR T VALUE PR(>|T|)
(INTERCEPT) -1.719E+03  6.512E+00    -264   <2E-16 ***
VMT          6.574E-02  6.335E-06   10377   <2E-16 ***
FLEET       -3.811E+03  4.709E-01   -8093   <2E-16 ***
---
SIGNIF. CODES:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

RESIDUAL STANDARD ERROR: 62.99 ON 97 DEGREES OF FREEDOM
  (5 OBSERVATIONS DELETED DUE TO MISSINGNESS)
MULTIPLE R-SQUARED:     1,      ADJUSTED R-SQUARED:     1
F-STATISTIC: 8.521E+07 ON 2 AND 97 DF,  P-VALUE: < 2.2E-16

> CONFINT(RESULT2)
                    2.5 %        97.5 %
(INTERCEPT) -1.732037E+03 -1706.1881237
VMT          6.572595E-02     0.0657511
FLEET       -3.811639E+03 -3809.7696476
>
```

VITA

Kelly A. Pitera earned a Bachelor of Civil Engineering degree from Villanova University in 2001. She completed a Master of Civil Engineering with a focus in transportation engineering at the University of Washington in 2008. In 2012, Kelly earned a Doctor of Philosophy at the University of Washington in Civil Engineering with a focus in transportation engineering.