Evaluating the Potential Safety Benefits of Electronic Hours-of-Service Recorders Final Report

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

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FOREWORD

The purpose of the current study was to assess the safety and hours-of-service (HOS) violations benefits of electronic HOS recorders (EHSRs) installed on Class 7 and 8 trucks as they operated during normal revenue-producing deliveries. Data were obtained through a third-party vendor that compiled previously-generated compliance data regarding participating motor carriers. The data collected from participating carriers were used to answer five specific research questions:

- Do commercial motor vehicles (CMVs) equipped with EHSRs have a significantly lower total crash rate than CMVs without EHSRs?
- Do CMVs equipped with EHSRs have a significantly lower U.S. Department of Transportation (USDOT)-recordable crash rate than CMVs without EHSRs?
- Do CMVs equipped with EHSRs have a significantly lower "preventable" crash rate than CMVs without EHSRs?
- Do CMVs equipped with EHSRs have a significantly lower rate of fatigue-related crashes than CMVs without EHSRs?
- Is there a difference in the HOS violation rates between CMVs with EHSRs and CMVs without EHSRs?

NOTICE

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16. Abstract

The purpose of the current study was to assess the benefits of installed electronic hours-of-service recorders (EHSRs) on safety and hours-of-service (HOS) violations related to Class 7 and 8 trucks as they operated during normal revenue service. Data were obtained through a third-party vendor that compiled previously-generated compliance data regarding participating motor carriers. Although the final data sets included data from 11 carriers representing small, medium, and large carriers (including a total of 82,943 crashes, 970 HOS violations, and 224,034 truck-years that drove a total of 15.6 billion miles), the data set in the current study was skewed toward larger, for-hire carriers and may not represent the overall U.S. trucking population. After controlling for calendar year, carriers in the data set, onboard safety system (OBSS) status, and long-haul/regional indicator, EHSR-equipped trucks had a significantly lower total crash rate (11.7 percent reduction) and a significantly lower preventable crash rate (5.1 percent reduction) than trucks not equipped with an EHSR. Small sample sizes limited the power to detect a significant difference between the EHSR cohort and the non-EHSR cohort for U.S. Department of Transportation (USDOT)-recordable and fatigue-related crashes. This result is primarily attributed to the lack of sufficient data (in terms of the number of these types of crashes) to be able to detect safety benefits with statistical significance at the observed level. After controlling for year, carrier index, OBSS status, and long-haul/regional indicator, EHSR-equipped trucks had a 53 percent lower driving-related HOS violation rate and a 49 percent lower non-driving-related HOS violation rate than trucks not equipped with EHSRs. The results show a clear safety benefit, in terms of crash and HOS violation reductions, for trucks equipped with EHSRs.

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SI* (MODERN METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units

Symbol	When You Know	Multiply By	To Find	Symbol
		Length		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		Area		
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
ac	Acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
		Volume (volumes greater than 1,000L shall be shown in m³)		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³
		Mass		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		Temperature (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		Illumination		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m²	cd/m²
		Force and Pressure or Stress		
lbf	poundforce	4.45	newtons	N
lbf/in²	poundforce per square inch	6.89	kilopascals	kPa

Approximate Conversions from SI Units

Symbol	When You Know	Multiply By	To Find	Symbol
		Length		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		Area		
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
Ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
		Volume		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m³	cubic meters	35.314	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
		Mass		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		Temperature (exact degrees)		
°C	Celsius	1.8c+32	Fahrenheit	°F
		Illumination		
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
		Force and Pressure or Stress		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in²

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003, Section 508-accessible version September 2009).

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ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Acronym	Definition
AOBRD	automatic onboard recording device
ATA	American Trucking Associations
ATRI	American Transportation Research Institute
CI	confidence interval
CMV	commercial motor vehicle
CRR	crash rate ratio
CSA	Compliance, Safety, and Accountability
EDPS	European Data Protection Supervisor
EHSR	electronic hours-of-service recorder
EOBR	electronic onboard recorder
EU	European Union
EWD	electronic work diaries
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FMCSR	Federal Motor Carrier Safety Regulation
GES	General Estimates System
GPS	Global Positioning System
HOS	hours-of-service
ID	identification
IIHS	Insurance Institute for Highway Safety
IRB	Institutional Review Board
MOU	memorandum of understanding

Acronym	Definition
MPG	miles per gallon
MVMT	million vehicle miles traveled
NHTSA	National Highway Traffic Safety Administration
NB	negative binominal
NDA	non-disclosure agreement
NPRM	notice of proposed rulemaking
NTC	National Transport Commission
NTSB	National Transportation Safety Board
OBSS	onboard safety system
OOIDA	Owner-Operator Independent Drivers Association
OOS	out-of-service
OV	other vehicles
RODS	record of duty status
SAFER	Safety and Fitness Electronic Records
SMS	Safety Management System
UMTRI	University of Michigan Transportation Research Institute
USDOT	U.S. Department of Transportation
VIN	vehicle identification number
Werner	Werner Enterprises, Inc.

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EXECUTIVE SUMMARY

INTRODUCTION

The Federal Motor Carrier Safety Administration (FMCSA) regulates the interstate commercial motor vehicle (CMV) industry with the primary goal of reducing crashes, injuries, and fatalities involving CMVs. One of the key regulations that FMCSA enforces is prescriptive hours-of-service (HOS) regulations, which ensure that CMV drivers have adequate time to obtain rest by limiting the number of hours per day and week they can drive/work.[(1)] FMCSA estimates that the revised HOS regulations (with a compliance date of July 1, 2013) will be beneficial to the trucking industry by reducing fatigue and increasing opportunities for sleep, thereby reducing associated crashes and improving CMV driver health and wellness. However, CMV drivers may violate HOS limits and falsify their paper records of duty status (RODS).[(2)] Therefore, to increase compliance with HOS regulations, FMCSA proposed the mandatory introduction of electronic logs, also known as electronic HOS recorders (EHSRs) in CMVs.

There have been many variations of EHSRs over the years, such as automatic onboard recording devices (AOBRDs), electronic onboard recorders (EOBRs), and functions included in fleet management systems. Each of these devices has specific functionality that may or may not be embodied by the term EHSR. For this report, the research team actively collected data on basic EHSRs. However, studies and other documents referenced throughout the report specifically address EOBRs. Thus, both terms will be used throughout the document, as appropriate.

On April 5, 2010, FMCSA published a Final Rule on EOBRs specifying their technical requirements and mandating their installation and use in CMVs manufactured on or after June 4, 2012. As explained below, FMCSA's April 2010 Final Rule on EOBRs was invalidated by the U.S. Court of Appeals for the Seventh Circuit; however, the description remains useful for purposes of our discussion. For CMVs manufactured prior to this date, the Final Rule mandated that these motor carriers may install an electronic device to record HOS if the device meets the requirements of either Section 395.16 (the new standards) or Section 395.15 (the old standards). The new rule also called for mandatory installation of EOBRs meeting the new performance standards in CMVs operated by motor carriers deemed to have serious HOS noncompliance (e.g., those found in a compliance review to have a 10 percent or greater violation rate).[(3)]

However, on August 8, 2011, the U.S. Court of Appeals for the Seventh Circuit vacated FMCSA's April 2010 Final Rule on the use of electronic logs for HOS compliance. Of particular concern to the court was FMCSA's failure to address the issue of driver harassment—including how EOBRs could potentially be used to harass drivers—and ways to ensure that EOBRs were not used to harass drivers. The court also noted that FMCSA had not estimated the safety benefits of EOBRs currently in use and how much EOBRs increased compliance.[(4)] The basis for the court's decision was that FMCSA's electronic log rule did not directly address a statutory requirement in 49 U.S.C. Section 31137(a) relating to the use of monitoring devices. Regulation Section 395.16 has since been removed from the Federal Motor Carrier Safety Regulations (FMCSRs) and is no longer mandated or enforced.

The purpose of this project was to conduct a literature synthesis on EHSRs and an effectiveness evaluation on EHSRs with data collected. For this project, EHSRs were defined as any device that electronically records drivers' HOS. The data collected from participating carriers were used to answer specific research questions:

1. Do individual CMVs equipped with EHSRs have a significantly lower total crash rate than CMVs without EHSRs?
2. Do individual CMVs equipped with EHSRs have a significantly lower U.S. Department of Transportation (USDOT)-recordable crash rate than CMVs without EHSRs?
3. Do individual CMVs equipped with EHSRs have a significantly lower "preventable" crash rate than CMVs without EHSRs?
4. Do individual CMVs equipped with EHSRs have a significantly lower rate of fatigue-related crashes than CMVs without EHSRs?
5. Is there a significant difference in the HOS violation rates between CMVs with EHSRs and CMVs without EHSRs?

RESEARCH APPROACH AND ANALYSIS

The study design determined the overall structure of the research and guided data collection and analyses. The main objective of the study was to quantitatively evaluate the safety impacts and the impact on HOS violations for EHSRs, that is, whether trucks equipped with EHSRs have a lower (or higher) crash and HOS violation risk than those without EHSRs. The safety benefits of EHSRs were quantitatively evaluated by comparing the crash risk for two exposure groups (i.e., EHSRs were considered to improve safety if the trucks with EHSRs showed a lower crash risk than trucks without EHSRs). Due to the lack of control for exposure (with EHSRs or without) by the research team, the study followed principles from epidemiology studies. Two alternative study designs—the retrospective cohort and before-and-after approaches—were conducted. The primary response variable for risk assessment was crash frequency. Correspondingly, the count-based Poisson regression model was used to model the crash count data. This model framework was able to accommodate complex data that were collected in this study. Other safety equipment in use, such as forward collision warning systems and lane departure warning systems, can impact the safety performance (e.g., crashes) of a CMV and can be confounded with the effect of EHSRs. To adjust for the potential confounding effects, these factors were factored as covariates in the same model. The output of this model was the effect of EHSRs adjusted for other factors.

RESULTS

Twelve carriers provided all the required data for this study (i.e., data on CMV crashes, vehicles, HOS violations, and carrier demographics). However, the research team determined the data from Carrier K were systematically biased. Carrier K was the only carrier that systematically targeted particular drivers (new drivers) with EHSR installation. For this reason, Carrier K was excluded from all analyses. Thus, all results are based on data from 11 of the 12 participating carriers.

The final data sets included a total of 224,034 truck-years that drove a total of 15.6 billion miles and had 82,943 crashes and 970 HOS violations. Truck-years do not reflect the number of mutually exclusive trucks over the 5 calendar years (e.g., as the same truck could be counted in each of the 5 calendar years that would be 5 truck-years for that specific truck), but rather the total number of trucks over the 5 years of data collection. The average mileage per truck per year was approximately 69,600 miles. Although this mileage may seem somewhat low, trucks that were taken off the road mid-year (such as those destroyed in a crash) counted toward this average involved in crashes.

Safety Benefits of EHSRs

Formal statistical inference was conducted using the above-described Poisson regression model. All models included potential effect modifiers, including year, carrier index, onboard safety system (OBSS) status, and long-haul/regional indicator. The effect of EHSRs was measured by the crash rate ratio (CRR) between non-EHSR- and EHSR-equipped trucks. The crash rate ratio was the exponent of the Poisson regression coefficient. A ratio smaller than 1 indicated the EHSR cohort had a lower crash rate than the non-EHSR cohort.

Overall, there were two statistically significant findings. EHSR-equipped trucks had an 11.7 percent significantly lower total crash rate than non-equipped trucks for all crash types ($p < 0.001$) and a 5.1 percent significantly lower crash risk than non-equipped trucks for preventable crashes ($p = 0.001$).
Similar analyses were conducted for HOS violation risk. Two types of HOS violations were evaluated, including driving-related HOS violations and non-driving-related HOS violations. All models included potential effect modifiers, including year, carrier index, OBSS status, and long-haul/regional indicator. EHSR-equipped trucks had a 53 percent significantly lower driving-related HOS violation risk than non-equipped trucks ($p = 0.01$) and a 49 percent significantly lower non-driving-related HOS violation risk than non-equipped trucks ($p < 0.001$).

DISCUSSION

The current study assessed the safety benefits of EHSRs installed on Class 7 and 8 trucks as they operated during normal revenue-producing deliveries. The approach used in this research went far beyond any previous study in this domain. First, the current study used actual motor carrier data previously compiled from participating carriers; thus, the resultant data set used in the analyses contained a broad spectrum of crashes (some of these crashes were not required to be reported to State or Federal agencies). Second, the research team collected detailed information on the trucks and the participating carriers, thereby allowing the research team to identify trucks with and without an EHSR and to control for variables that may have influenced the crash rate. Third, the research team collected mileage information from each truck to control for differences in exposure. Finally, the research team reviewed each crash file to determine if the crash was considered a “claim only” crash and if fatigue may have been a contributing factor.

Trucks equipped with EHSRs had total crash and preventable crash rates (per MVMT) that were significantly lower than the rates for non-equipped trucks (e.g., trucks equipped with EHSRs had a 11.7 percent lower total crash rate and a 5.1 percent lower preventable crash rate than trucks not equipped with EHSRs). Small sample sizes (in terms of the number of these types of crashes) limited the power to detect significant differences between the EHSR cohort and the non-EHSR cohort for USDOT-recordable and fatigue-related crash rates. In terms of HOS violations, trucks equipped with EHSRs had driving-related and non-driving-related HOS violation rates (per MVMT) that were significantly lower than the rates for trucks not equipped with EHSRs (e.g., trucks equipped with EHSRs had a 53 percent lower driving-related HOS violation risk and a 49 percent lower non-driving-related HOS violation risk than non-equipped trucks).

Results from this study support the assertions of proponents of EHSRs that there are safety and compliance benefits of EHSRs (see endnotes 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, and 16). Although these proponents asserted that EHSRs had safety or HOS compliance benefits, no quantitative data were provided to support their statements. Results from this study are in the middle of the range (12–70 percent) of potential HOS violation reduction.[17,18,19] One study completed in 2009 estimated a 15.6 percent and 12.4 percent reduction in crashes and HOS violations, respectively, with 100 percent EHSR adoption using a survey approach combined with national crash and HOS data.[20] The current study found similar reductions in the crash rate, but a far greater reduction in HOS violations (both driving-related and non-driving-related). The 2009 study included a far more representative sample of carriers than the current study; however, the authors were not able to include exposure, nor could they identify which trucks had an EHSR. Although the current study was able to precisely identify trucks equipped with an EHSR and include the specific yearly mileage for each truck, the results were skewed toward larger, for-hire carriers and may not reflect the general carrier population. Taken together, the current study and the above-referenced 2009 study clearly show a safety benefit for EHSRs with respect to crashes and HOS violations.

1. INTRODUCTION

1.1 BACKGROUND

The commercial trucking industry plays a vital role in America's economy and standard of living. Consumers, businesses, and industries rely heavily on the trucking industry for deliveries, with around 70 percent of goods being delivered by truck, which equates to an annual value of just over eight trillion dollars.(21,22) The U.S. freight volume is expected to increase by as much as 20 percent over the next decade, to 16.6 billion tons in 2023.(23) As stated by Knipling, "If you've got it, chances are a truck brought it." (24) In addition, the livelihoods of millions of Americans depend on trucking, with the industry employing over 5.5 million commercial motor vehicle (CMV) drivers, as well as administrative staff, managers, technicians, mechanics, depot workers, and dispatchers. Clearly, the safety, efficiency, and reliability of an industry that forms such an integral part of society should be of the utmost importance.(25)

Given that the CMV population shares the road with millions of other vehicles, the safety of the trucking industry—and its drivers—is often under the spotlight. CMVs have a much lower annual crash rate than light vehicles (112.8 crashes per 100 million vehicle miles traveled [MVMT] versus 186.4 crashes per 100 MVMT, respectively); however, CMVs have a higher fatal crash involvement rate than do light vehicles (1.1 fatal crashes per 100 MVMT versus 0.9 fatal crashes per 100 MVMT, respectively).(26) This is presumably due to the much greater forces at play when a large truck is involved in a crash. Indeed, traffic safety data from the National Highway Traffic Safety Administration (NHTSA) in 2010 shows that 76 percent of the fatalities in crashes involving large trucks were occupants of other vehicles.(27) However, the number of fatality- and injury-inducing CMV crashes has decreased substantially in recent years. The number of fatal CMV crashes declined from 4,472 in 2007 to 3,608 in 2011, and the number of CMV crashes involving an injury declined from 82,000 in 2007 to 63,000 in 2011.(28) Decreases in fatal and injury crashes were seen for all types of vehicle crashes across that same time period, but CMV mileage has risen faster than other vehicle types; therefore, the decrease in the crash and fatal crash involvement rates has been much greater for CMVs than for other vehicle types.(29) However, CMV crashes are still an economic burden, costing around $50 billion a year.(30)

The Federal Motor Carrier Safety Administration (FMCSA) regulates the interstate CMV industry with the primary goal of reducing crashes, injuries, and fatalities involving CMVs. One of the key regulations that FMCSA enforces is a prescriptive hours-of-service (HOS) restriction, which ensures that CMV drivers have adequate time to obtain rest by limiting the number of hours per day and week a driver can drive/work.(31) FMCSA estimates that the revised HOS regulations (with a compliance date of July 1, 2013) will be beneficial to the trucking industry by reducing fatigue and increasing opportunities for sleep, thereby reducing associated crashes and improving CMV driver health and wellness. However, CMV drivers may violate HOS limits and falsify their paper records of duty status (RODS).(32) Therefore, to increase compliance with HOS regulations, FMCSA proposed the mandatory introduction of electronic logs, also known as electronic HOS recorders (EHSRs), in CMVs.

There have been many variations of EHSRs over the years, such as automatic on-board recording devices (AOBRDs), electronic on-board recorders (EOBRs), and functions included in fleet management systems. Each of these devices has specific functionality that may or may not be embodied by the term EHSR. For this report, the research team actively collected data on basic EHSRs, defined for this study as any device that electronically records drivers' HOS. However, studies referenced in the literature review and in the discussion section of this report specifically address EOBRs. As such, the term EOBR will be used as appropriate throughout Sections 1 (Introduction) and 4 (Discussion), while the term EHSR will be used in Sections 2 (Methods and Approach) and 3 (Results), unless a specific reference calls for more precise terminology.

On April 5, 2010, FMCSA published a Final Rule on EOBRs specifying their technical requirements and mandating their installation and use in CMVs manufactured on or after June 4, 2012. For CMVs manufactured prior to this date, the Final Rule mandated that these motor carriers may install an electronic device to record HOS if the device meets the requirements of either Section 395.16 (the new standards) or Section 395.15 (the old standards). The new rule also called for mandatory installation of EOBRs meeting the new performance standards in CMVs operated by motor carriers deemed to have serious HOS noncompliance (e.g., those found in a compliance review to have a 10 percent or greater violation rate).(33)

However, on August 8, 2011, the U.S. Court of Appeals for the Seventh Circuit vacated FMCSA's April 2010 Final Rule on the use of electronic logs for HOS compliance. Of particular concern to the court was FMCSA's failure to address the issue of driver harassment—including how EOBRs could potentially be used to harass drivers—and ways to ensure that EOBRs were not used to harass drivers. The court also noted that FMCSA had not estimated the safety benefits of EOBRs currently in use and how much EOBRs increased compliance.(34) The basis for the court's decision was that FMCSA's electronic log rule did not directly address a statutory requirement in 49 U.S.C. Section 31137(a) relating to the use of monitoring devices. Regulation Section 395.16 has since been removed from the Federal Motor Carrier Safety Regulations (FMCSRs) and is no longer mandated or enforced.

1.1.1 Research Objectives

EHSRs were primarily designed to improve efficiency. However, a study published in 2009 used a survey, combined with State crash data from the FMCSA Safety and Fitness Electronic Records (SAFER) and HOS violations from the FMCSA Safety Management Measurement System (SMS), to model the potential impact of full electronic logbook adoption on crashes and HOS violations. In this 2009 study, researchers found that full electronic logbook adoption could potentially reduce HOS violations by 12.4 percent and total crashes by 15.6 percent.(35) Moreover, FMCSA estimated that EHSRs have the potential to reduce HOS violations by up to 40 percent.(36)

Although the above-mentioned 2009 study and other FMCSA studies were able to show that electronic logbooks could reduce HOS violations and crashes, these studies have several methodological limitations that reduce the validity and generalizations of their findings. For example, the 2009 study only used State crash data.(37) During an analysis of carrier-collected crash data, researchers found that almost 20 percent of crashes were not reported to the State in which the crash occurred (mainly because these were low severity crashes).(38) The 2009 study also did not include a measure of exposure (miles or driving hours) nor could the authors identify if the truck involved in a crash or HOS violation had an electronic logbook (for those carriers without full electronic logbook adoption). Thus, the estimates of electronic logbook effectiveness provided in the above-referenced 2009 study should be viewed with caution.

The current study will attempt to address several of the limitations of the previously mentioned studies. First, the current study used carrier-collected crash data to obtain a more representative picture of how EHSRs perform under real-word driving conditions. Second, the analysis was at the truck level; thus, trucks equipped with EHSRs are being compared to trucks without EHSRs. Third, a measure of exposure was calculated (vehicle miles traveled) at the truck level. Finally, although the sample of participating carriers in the current study was a convenience sample, every attempt was made to obtain a sample that was representative of the general CMV population.

The purpose of this project was to conduct a literature synthesis on EHSRs and an effectiveness evaluation on EHSRs with data collected. The data collected from participating carriers were used to answer specific research questions:

1. Do individual CMVs equipped with EHSRs have a significantly lower total crash rate than CMVs without EHSRs?
2. Do individual CMVs equipped with EHSRs have a significantly lower U.S. Department of Transportation (USDOT)-recordable crash rate than CMVs without EHSRs?
3. Do individual CMVs equipped with EHSRs have a significantly lower “preventable” crash rate than CMVs without EHSRs?
4. Do individual CMVs equipped with EHSRs have a significantly lower rate of fatigue-related crashes than CMVs without EHSRs?
5. Is there a significant difference in the HOS violation rates between CMVs with EHSRs and CMVs without EHSRs?

1.2 LITERATURE REVIEW SUMMARY

The current literature review focuses on economic and safety benefits and any stress or health-related issues associated with EHSRs. EHSRs have the potential for increased HOS compliance, improvements in safety, productivity gains, and more efficient operations. However, there are concerns related to the use of EHSRs, such as the costs associated with switching to an electronic system, using unproven technology, limited safety benefits, and the potential for driver harassment. Evidence relating to proposed economic and safety benefits, as well as a number of costs and drawbacks, were considered in the current literature review along with the link between EHSRs and HOS regulations. Although the primary focus of the literature review was domestic, international research was also considered. Key lessons can be drawn from other countries around the world that already use similar systems (i.e., countries in the European Union [EU]) or that are evaluating the introduction of similar systems (i.e., Australia and Canada) in their commercial trucking industries. Please note that driver harassment issues associated with EHSRs are being evaluated in another FMCSA-funded study; thus, these issues are not addressed in the current literature review.

1.2.1 HOS Regulations

Excessively long driving/work hours have been recognized as a factor that may increase CMV crash risk. The CMV industry has been subjected to limits on driver on-duty time as early as the 1930s, when the first HOS regulations were introduced (limiting drivers to an on-duty time of 15 hours in every 24-hour period). These regulations were updated in the 1960s with the inclusion of a minimum off-duty period of 8 hours after every 15-hour on-duty period.(39) However, after this minor change, the HOS regulations remained largely unchanged for the next 40 years.

In 2003, FMCSA published a new set of HOS regulations that attempted to rectify certain deficiencies in the old HOS rules that contradicted current knowledge of human sleep needs and 24-hour circadian rhythms. The revised 2003 HOS regulations aimed to improve the regularity of daily work-rest cycles and to promote greater daily sleep. The main changes in the HOS rules included increasing the minimum off-duty requirement to 10 hours (up from 8 hours); increasing the maximum hours of driving to 11 hours (up from 10 hours); decreasing the maximum on-duty period to 14 hours (down from 15 hours); and increasing the total of split sleeper-berth off-duty periods to 10 hours (up from 8 hours). The revised 2003 rules also introduced a "restart" provision, permitting drivers to restart a 7- or 8-day consecutive period after 34 hours off duty.(40) Despite being well received by the trucking industry, the U.S. Court of Appeals vacated the revised 2003 rules after a number of safety advocacy groups filed a petition to have them reviewed. Of particular concern to the court was the lack of justification for the increase in driving time from 10 hours to 11 hours, the 34-hour restart provision, and the split sleeper-berth provision. Thus, FMCSA gathered more evidence to support the revised 2003 HOS regulations and in 2005 released a new version of revised HOS regulations with minor adjustments to the split sleeper-berth provision.(41)

In 2011, FMCSA revised the 2005 HOS regulations. The main focus of these revisions was the 34-hour restart provision, which was limited to one use every 168 hours with the 34-hour off-duty period comprising two periods that include 1:00 a.m. to 5:00 a.m. This change was made to limit drivers' ability to work the maximum number of allowable hours on a continuing basis, thereby reducing the possibility of driver fatigue. The 2011 HOS regulations also included a requirement for drivers to take a rest break of at least 30 minutes after a maximum of 8 hours of driving (or before, if they choose). Maximum daily and weekly driving limits remain unchanged in the current HOS regulations. Similar to earlier versions of the HOS rules, the 2011 HOS regulations were challenged by the American Trucking Associations (ATA); however, on August 2, 2013, the U.S. Court of Appeals found in favor of FMCSA on all of the provisions of the new 2011 HOS rules, with one exception. The court overturned the provision requiring a 30-minute break for short-haul drivers (i.e., local delivery drivers). All other provisions were allowed to stand, with the court stating, "Our decision today brings to an end much of the permanent warfare surrounding HOS rules." (42)

The purpose of the current HOS regulations is to reduce the likelihood of driver fatigue and fatigue-related crashes.(43) However, the link between HOS and fatigue is not so clear-cut. There are numerous factors that contribute to the development and experience of fatigue, such as circadian rhythms, inadequate sleep, and excessive time awake, none of which are directly impacted by HOS regulations.(44) Limiting the number of hours spent driving does not address circadian factors because the hours spent driving can be at any time of the day, including during circadian lows. Inadequate sleep is only indirectly addressed in that the 10-hour off-duty period that drivers are required to take creates a greater opportunity for rest and recuperation between shifts. Excessive time awake is also only indirectly addressed in that the limit of a maximum 14-hour on-duty period follows a minimum off-duty period of 10 hours in which the driver has the opportunity to sleep, thereby potentially reducing the amount of time a driver has been awake.

The key issue with relying on the off-duty period to promote greater daily sleep is the assumption that the driver is going to use that time to get an adequate amount of sleep. The mandatory 8-hour off-duty period in the pre-2003 HOS regulations was increased to a 10-hour off-duty period in the 2003 HOS regulations to allow drivers to complete other day-to-day activities besides sleeping.(45) However, once activities—such as commute time to and from work, eating, spending time with family, and so on—are taken into account, drivers may find they have less than the 7 or 8 hours of sleep that most people need in order to be rested. The key concept in reducing fatigue is the length of the sleep period, not the off-duty period.

In a separate study published in 2008, researchers interviewed almost 2,000 long-distance truck drivers before and after the introduction of the revised 2003 HOS rule.(46) They found that reported daily off-duty and sleep times increased after the introduction of the revised 2003 HOS rule. Similarly, the results of a focus group study published in 2006 revealed a positive aspect of the revised 2003 HOS rule change.(47) The general consensus was that "drivers are more rested and relaxed under the new rules, primarily because of the combined effects of 10-h (sic) off duty and the maximum 14-h (sic) daily tour of duty." In addition to focus groups, researchers who completed the 2006 study also conducted a survey of 996 CMV drivers and found that 46 percent of drivers reported feeling less fatigued since the new rule went into effect, with 23 percent reporting no change in their fatigue level. Analysis of actigraphy data from a naturalistic driving study published in 2007 led researchers to conclude that CMV drivers may be getting more sleep under the revised 2003 HOS regulations compared to the old regulations.(48) While prior research conducted when the old (pre-2003) HOS regulations were in place found that drivers averaged around 5 hours of sleep per day, the researchers who completed the 2007 study found that drivers slept an average of 6.28 hours per night, indicating that the "new regulations may be working as anticipated by providing additional opportunities for drivers to get sleep."(49,50) They also observed that drivers obtained significantly less sleep in the 24-hour period prior to the occurrence of a critical incident, which suggests that fatigue may have played a role in those critical incidents. This highlights the importance of the mandatory 10-hour off-duty period, as this aspect of the current HOS regulations provides drivers with a greater opportunity to get adequate sleep before they get out on the road.

1.2.2 Electronic Logs

EHSRs in CMVs are not a new concept. The National Transportation Safety Board (NTSB) issued its first recommendation for the use of electronic logbooks in CMVs more than 30 years ago. In addition, a number of highway safety and advocacy groups have petitioned FMCSA in recent years to require the mandatory installation and use of EOBRs in all trucks that are subject to HOS regulations.(51) The Insurance Institute for Highway Safety (IIHS), in particular, has submitted multiple petitions to U.S. Government agencies over the last 25 years outlining the potential benefits of EOBRs and urging the government to issue legislation that encompasses all carriers, rather than allowing some carriers to be exempt or excluded.(52) The primary argument they present for the mandatory introduction of EOBRs revolves around increasing compliance with HOS regulations. They see the current system of manual logbooks, also known as RODS, as being too vulnerable to tampering and falsification, which subsequently undermines the ability to enforce HOS regulations, thereby nullifying the benefits of these regulations for the public and for truck drivers.(53)

In 1998, the Federal Highway Administration (FHWA) announced a voluntary program whereby motor carriers using global positioning systems (GPSs) and related safety management computer systems could enter into an agreement with the Agency to use the systems in lieu of handwritten RODS or a conventional AOBRD. This program was offered as a pilot demonstration project consistent with the President's initiatives on reinventing government and regulatory reform. The ultimate goal of this initial pilot program was to “demonstrate that the motor carrier industry can use this technology to improve compliance with the hours-of-service requirements in a manner which promotes safety and operational efficiency while reducing paperwork.”(54) In June 1998, Werner Enterprises, Inc. (Werner) entered into a memorandum of understanding (MOU) with the Agency to test the use of its system under such a pilot project. At the time FHWA entered into the MOU with Werner, certain features of GPS technology, wireless communications, and related computer systems were not readily adaptable to the provisions of Section 395.15. However, the GPS-based systems that Werner proposed to pilot had other capabilities that would satisfy or go beyond these requirements. One notable difference was that, rather than being integrally linked to the vehicle to record driving time, the GPS system software employed algorithms that set on-duty and off-duty times using preprogrammed assumptions.

In 1999, however, FHWA was alerted to the fact that Werner’s system did not appear to provide an accurate accounting of drivers’ duty status under certain conditions, such as prolonged low speeds in traffic congestion. After an in-depth assessment, the Agency concluded that under certain conditions the Werner system indeed failed to provide an accurate reporting of duty status or times; thus, Werner was required to modify its GPS tracking and recording systems to ensure accurate documentation of drivers’ duty status as mandated by 49 CFR Part 395. In March 2002, FMCSA revised its MOU with Werner to address recording methods and the use of algorithms in the recording and reporting processes. Werner’s GPS-based (point-to-point) methodology was found to consistently understate the distance traveled; therefore, it was deemed an unacceptable methodology for recording mileage. As a result, within 120 days of signing the revised MOU, Werner was required to identify and implement an accurate means of determining distance traveled. In effect, the revised MOU required Werner to obtain engine data through the tractor’s electronic communications network in order to provide an “integral synchronization” with the vehicle's operation. In December 2003, FMCSA published a notice of intent to grant an exemption to Werner, thereby allowing the carrier to use GPS technology and complementary computer software programs to monitor and record its drivers’ hours of service.(55) The terms and conditions for the proposed exemption were the same as those of the revised MOU for the Werner pilot demonstration project, with a few exceptions. The need to rely on an exemption to allow Werner’s use of these advanced technologies for RODS purposes underscored the importance of aligning EOBR performance specifications with state-of-the-art technologies.

Thus, Werner became the first and only carrier in the U.S. to be formally granted an exemption from FMCSA to discontinue the use of paper logbooks and rely on an electronic GPS tracking system to log drivers’ HOS. Werner makes a number of claims on their corporate Web site regarding the system.[56] They assert that drivers are better able to focus on driving as they no longer have to deal with the hassle of paper logbooks, staff are able to monitor the paperless log system records in real-time (which allows them to identify problems and gives them better control of deliveries), and the company is better able to manage deliveries according to drivers' schedules and work hours. Thus, their drivers are more compliant with HOS regulations. They also believe the GPS-based paperless log system they use produces results comparable to the traditional RODs, and the reduction in paperwork enables their drivers to be more efficient and productive. Unfortunately, no official results or findings have been published on this study by FMCSA, so it is not possible to validate the company's claims. However, the experience of this carrier does highlight the numerous "secondary" benefits in using an EHSR system. Thus, rather than viewing EHSRs as strictly HOS record-keeping devices, the additional functionalities and benefits of these devices should be acknowledged and explored.

1.2.2.1 Link to HOS Regulations and Compliance

In the Final Rule on EOBRs for HOS compliance, FMCSA stated that EOBRs that are "properly designed, used, and maintained will enable motor carriers to track their drivers' on-duty driving hours accurately, thus minimizing regulatory violations or excessive driving, and schedule vehicle and driver operations more efficiently."[57] Many high-profile organizations and individuals within the trucking industry support the use of EOBRs as a way to improve HOS compliance without citing any evidence to support their assertions. For example, Qualcomm promotes the use of EOBRs for improved compliance, stating on their Web site that compliance performance significantly improves with the use of electronic logs.[58] Similarly, in a recent article in "Transport Topics," the ATA stated that EOBRs "are the best option to improve hours-of-service compliance…"[59] The ATA also reported that EOBRs "enhance compliance for those operators who may be fudging around the edges by not accurately filling out their log books."[60] In addition, eight organizations, including the ATA, the International Brotherhood of Teamsters, and the Commercial Vehicle Safety Alliance and Truck Safety Coalition, recently sent a letter to the House and to the Senate detailing their argument in favor of a mandate that would require EOBRs to track HOS, stating that it is essential for improving HOS compliance and to assist law enforcement in verifying compliance with HOS regulations.[61]

The majority of the evidence relating EHSR use to HOS compliance is anecdotal from companies that either supply EHSR devices and services, or that have installed EHSRs in their fleet and are promoting the benefits they have experienced. For example, XRS Corporation is a supplier of a variety of trucking technology solutions, including EOBRs. They cite an Aberdeen Group study showing that drivers routinely using EOBRs increase regulatory compliance by 27.9 percent.[62] Further details of the study are unavailable as the study was conducted by a private consulting company. A case study published in "FleetOwner" magazine presents the outcomes of one particular company's experience with installing EOBRs in its fleet. Shaw Industries, which is the world's largest producer of carpets and has one of the largest private fleets in the United States, saw a 53 percent reduction in HOS violations per month from March 2004 to March 2007 as a result of switching to EOBRs from paper logbooks. They also found a 72 percent reduction in their drivers' out-of-service (OOS) rates and a 47 percent reduction in driver OOS inspections.[63] Clearly, there are companies that have had positive experiences with the use of EHSRs and have witnessed the beneficial impact these devices can have on HOS compliance;

however, this is an area that needs to be addressed more systematically to determine if EHSR use actually does impact HOS compliance.

There is a small amount of quantitative evidence to support the link between the use of EHSRs and HOS compliance. In a 2008 study, more than half of CMV drivers surveyed said that an EOBR requirement would increase drivers' compliance with the HOS regulations.(64) However, the data collected in this study is based on drivers' opinions rather than actual HOS violations. A 2009 study referenced earlier in this report(65) is one of only two studies that used HOS violations data to link the use of electronic logbooks with HOS compliance. The researchers who conducted the 2009 study conducted a national survey of large motor carriers (n = 386) in the United States. In conjunction with the survey data, they also collected safety performance data from each carrier, including crash and HOS violations data. Using Poisson regression models, they found that full adoption of electronic logbooks by a carrier could result in a 12.4 percent reduction in HOS violations. FMCSA believes the magnitude of this estimate is much smaller than one would anticipate from mandating EOBR use.(66) The Agency points out that the carriers used in the 2009 study all adopted the electronic logbook technology voluntarily, which indicates a proactive attitude towards safety and HOS compliance, whereas industry-wide implementation of EOBRs would also include unwilling carriers. In a 2011 notice of proposed rulemaking (NPRM) on EOBRs and HOS, FMCSA included supporting documents related to the effectiveness of EOBRs in reducing HOS violations.(67) It focused on a number of carriers (n = 869) who entered an agreement with FMCSA to install EOBRs with enhanced functionality that would allow FMCSA to evaluate the effectiveness of the devices at reducing HOS violations. Analysis of the roadside inspection HOS violation data revealed that the overall OOS HOS violation rate fell 70 percent in these carriers; however, the majority of the violations eliminated were those for missing and improper RODS. Further analysis of the data specific to driving and on-duty time violations resulted in an estimated reduction of 40 percent for the remaining OOS HOS violations. Therefore, while the evidence points to a positive link between EOBR use and HOS compliance, this issue needs to be investigated further.

Despite the requirement for CMV drivers to keep logbooks showing they are in compliance with HOS regulations, HOS violations are still common. In 2011, Federal and State inspectors conducted around 3.5 million roadside inspections, resulting in 1.2 million citations for driver violations of safety regulations. Forty-eight percent of these violations, or 576,000, were related to non-compliance with HOS or logbook maintenance, including exceeding daily and weekly driving limits, false logs, "no log" violations, form and manner violations, and non-current logs.(68) Clearly, the current system of requiring drivers to manually record their HOS is not ideal, and the high number of violations is cause for concern. A report from the USDOT Office of the Inspector General stated that:

> *Driver hours-of-service violations and falsified driver logs continue to pose significant safety concerns. * * * During roadside safety inspections, the most frequent violation cited for removing a driver from operation is exceeding allowed hours of service. Use of electronic recorders and other technologies to manage hours-of-service requirements has significant safety value.* (69)

The use of EHSRs may help to reduce or eliminate many possible HOS violations due to an improvement in the accuracy and reliability of HOS records. In a 2002 FHWA-sponsored study on onboard recorders, researchers found that nearly 40 percent of OOS violations can be attributed to the driver either not having his/her logbook or the logbook not being current.(70) These types of infractions would be completely eliminated with the use of EHSRs, resulting in a drastic reduction in the number of OOS violations. EHSRs could also potentially reduce deliberate HOS violations by making it more difficult, if not impossible, to falsify driver RODS.

1.2.2.2 Safety Benefits

Despite a lack of quantitative and statistically tested evidence, proponents of EHSRs argue that they are needed to improve safety, with improvements in safety coming via increases in HOS compliance. Figure 1 illustrates the individual components in the EHSR safety chain. The basic premise behind the safety claim is that EHSR use increases HOS compliance which, in turn, reduces driver fatigue, resulting in increased on-road safety. Unfortunately, the argument that EHSRs improve safety is based on a line of reasoning comprised of some issues that are far from resolved. For example, as outlined in the previous section, the evidence linking EHSRs with HOS compliance is relatively scarce. The link between HOS regulations and reductions in driver fatigue is still an issue of contention highlighted by FMCSA's frequent revision of HOS regulations due to numerous legal challenges. Ultimately, the motivation to implement industry-wide use of EHSRs is to improve on-road safety; however, the tenacity of the links inherent in the argument needs to be explored and strengthened with empirical data.

Figure 1. Flowchart. The components that make up the electronic log-to-safety continuum.
Diagram adapted from the American Transportation Research Institute (ATRI), 2006.(18)

In response to FMCSA's 2007 NPRM regarding EOBR use for HOS compliance, several commenters (including the International Brotherhood of Teamsters, the Truckload Carriers Association, the Specialized Carriers & Rigging Association, and the American Moving and Storage Association) criticized FMCSA for not providing any definitive evidence demonstrating the safety benefits of EOBRs. In fact, a number of studies that have attempted to identify the safety benefits associated with EOBRs have failed to show any safety benefit, although it should be noted that this was due to a lack of empirical data rather than an absence of safety benefits. The low response rate and small sample size in a study conducted by the University of Michigan Transportation Research Institute (UMTRI) prevented statistically significant conclusions regarding the relationship between EOBRs and safety.(71) ATRI surveyed a range of vendors and carriers to obtain insights into the benefits and concerns of EOBR usage.(72) Although they did not attempt to relate EOBRs to any safety outcomes, numerous respondents cited the need for further justification of this relationship, such that the authors concluded that "there is a significant need for, and interest in, research that scientifically documents the linear relationship between electronic on-board recorders, compliance, fatigue, and safety."

Opponents of EHSRs contend that these devices fail to enhance safety and are an unproven technology. A representative from the Owner-Operator Independent Drivers Association (OOIDA) stated that, "The correlation between usage and improved safety is poppycock," and that carriers that use EOBRs are not safer carriers and “in some instances they are far less safe than their peers.” [73] The vice president of research at ATRI also acknowledged that the correlation between EOBRs and safety is weak, citing a 2007 survey that showed fleets were more interested in adopting EOBRs technology as a compliance tool rather than for safety management.[74] In accordance with FMCSA requirements, EHSRs are strictly viewed as HOS record-keeping devices..

1.2.2.3 Economic Benefits

Proponents of EHSRs, such as ATA, cite a number of additional benefits, aside from safety and HOS compliance, that may entice carriers to adopt the technology voluntarily rather than through an industry-wide mandate. These benefits include increased productivity and efficiency, reduction in fuel consumption and cost, reduction in administrative time and effort, and improved communications between drivers and dispatchers. As with HOS compliance and safety benefits, much of the evidence supporting these benefits is anecdotal; thus, there is a need to empirically examine these secondary benefits.

Increased productivity and efficiency stems from the real-time connection between fleet management and fleet vehicles, thereby allowing fleet management to plan better routes, keep track of deliveries, and quickly assess how much on-duty driving time each driver has remaining. Large fleets, in particular, find this technology to be extremely beneficial. Some carriers have dozens of locations across the country that are controlled by a central organization; thus, more advanced routing and scheduling systems help the company manage the large number of inbound and outbound loads.[75] Other companies have reported a large reduction in idling time, from 50 percent to just 3 percent, as well as a 10- to 12-percent reduction in average route times against established route standards. This reportedly equated to an overall reduction in costs of 5.5 percent through a decrease in fuel consumption, idle time, and out-of-route miles.[76] Further support for the various benefits of EHSRs was provided in the aforementioned survey of EOBR users and non-users conducted by ATRI. Results from this survey revealed that over three-quarters of carriers that used EOBRs noted improved company productivity, a specific benefit of which was better coordination between drivers and loads.

Another benefit that has been shown to be associated with the use of EOBRs is a reduction in administration time and effort. A study by UMTRI (discussed above) demonstrated that drivers using EOBRs saved an average of 20 minutes per day compared with drivers who had to fill out paper logbooks. Administrative personnel also saved 20 minutes per driver per month using EOBRs, which reduced the time spent summarizing, storing, retrieving, and checking each driver’s HOS records. A case study focusing on the benefits that one of the largest private fleets in the United States experienced after switching to EOBRs revealed that they reduced document scanning costs by $18,000 per year.[77] The management of the company who participated in the initial pilot program of a paperless log system, Werner Enterprises, Inc., also claimed that eliminating paper logbooks from drivers’ daily tasks led to a reduction in time and money spent on administrative tasks, although this was not supported by any evidence.[78]

Not surprisingly, opinions of the mandatory introduction of EOBRs appear to be inextricably tied to carriers’ current adoption of EOBRs. Carriers that have already bought and installed EOBRs in their fleets tend to have a more favorable attitude towards an EOBRs mandate, and vice versa for carriers that have not installed EOBRs.[79] This highlights the need for further empirical examination on the benefits associated with using EHSRs rather than relying on subjective opinions and experiences and anecdotal information.

1.2.2.4 Stress or Health-Related Issues

There are potential stress- and health-related benefits associated with using EHSRs that require further investigation. The reduced administrative burden that accompanies the use of EHSRs may result in less stress for drivers who no longer have to invest the time and effort in ensuring their paper logbooks are accurate and up-to-date (there may also be less pressure to violate HOS regulations as dispatchers will see the drivers' HOS compliance status). Survey results from the aforementioned ATRI study revealed that 85 percent of EOBR users identified reductions in administrative burden as a specific benefit of EOBR use. The survey also showed that driver morale improved among EOBR users, with 76 percent of respondents reporting an improvement in driver morale and 16 percent indicating that EOBRs had no impact on morale. Other health-related benefits may stem from the use of EOBRs for HOS compliance. If EOBRs do improve HOS compliance, as claimed by their proponents, this should reduce fatigue and increase opportunities for sleep, thereby improving CMV driver health and wellness.(80)

In the April 2010 EOBR Final Rule, FMCSA concluded that an EOBR mandate would not result in negative impacts on driver health for two reasons. First, the Agency indicated that HOS is already monitored, albeit using paper logbooks, but HOS compliance was an existing requirement and EOBRs were just a new way to monitor compliance. Second, the requirement for EOBRs was to monitor safety, not workplace productivity. FMCSA is concerned with improving safety, which the Agency believes will occur as a result of increased HOS compliance due to EOBR use. (81)

Organizations, such as OOIDA, oppose the compulsory introduction of EOBRs for a number of reasons. Of particular concern is the issue of driver harassment, which was the reason the U.S. Court of Appeals for the Seventh Circuit decided to vacate FMCSA's April 2010 Final Rule on the use of electronic logs for HOS compliance. In the brief to the court, OOIDA and the plaintiff members argued that the use of EOBRs to enforce company policies and monitor drivers' behavior can constitute harassment and result in improper pressure on drivers. The brief states:

> *Carrier harassment includes the use of technology to interrupt a driver during an off-duty rest period. Carriers can contact the driver and pressure him to get back on the road to maximize his on-duty time. Such power usurps the driver's discretion to get rest, take a break or sleep when he believes it is necessary even when he or she has time left on the clock to drive or work.(82)*

There is a small amount of evidence to support this argument. OOIDA's Foundation conducted a survey with over 2,000 drivers and found that 54 percent of these drivers reported receiving instructions from their carriers to drive longer to use available hours, with some drivers reporting they were awakened from sleep to receive these instructions.(83) HOS regulations are in place to ensure that drivers get enough sleep and rest so they are not driving fatigued; therefore, if EOBRs are being used to encourage drivers to continue driving even if they are fatigued, this defeats the purpose of mandating their use. Ensuring compliance with HOS regulations is supposed to ultimately improve safety; however, the above-referenced ATRI report indicates there are concerns that strict compliance could have negative safety impacts. Drivers are worried that EOBRs will create a disincentive for drivers to rest when they are feeling fatigued, or that they create an incentive for drivers to speed, both of which could clearly impact the safety of the driver and other road users. As indicated above, the issue of driver harassment is being investigated in a separate FMCSA-funded study and will not be discussed here.

1.2.2.5 Other Costs and Drawbacks

Aside from the issue of driver harassment, opponents of EHSRs (e.g., OOIDA) focus on the costs associated with switching to an electronic system, using an unproven technology in regard to crash and HOS violation reductions, and driver retention and privacy. As with the other issues associated with EHSRs, there are conflicting points of view, and more scientific evidence is needed before any firm conclusions can be reached.

Despite being largely inconclusive due to low response rates and a small sample size, the 2002 UMTRI study (referenced above) determined that switching to EOBRs was not cost-effective for small carriers. The study found that the average cost of purchasing and installing an EOBR was $2,000 or less per vehicle, depending on the unit's level of functionality. This study was conducted over a decade ago; the technologies currently available are more cost-effective. The vice president of a current EOBR vendor says a standalone, self-contained EOBR unit that does nothing but track driver hours will cost less than $500(84) and stand-alone systems cost even less. There are systems available at the lower end which would be suitable and affordable for smaller carriers, and, once cost savings—such as the reduction/elimination of paperwork or fewer HOS violation-related fines—are taken into account, carriers and drivers will realize the significant value of EOBRs. A lack of adoption of EOBRs by small carriers and owner-operators makes it difficult to quantify the relevant costs and benefits for these smaller companies.

Driver retention is another frequently cited concern of those opposed to an EOBR mandate. ATRI highlights a clear contrast between the perceptions of EOBR non-users and the actual experiences of EOBR users regarding driver retention. The survey results revealed that driver retention was a major concern for 22 percent of EOBR non-users, whereas over 80 percent of carriers using EOBRs reported that driver retention was unaffected by EOBR use (with 19 percent indicating EOBRs actually improved driver retention). Anecdotal evidence suggests that some drivers who initially opposed the introduction of EOBRs may come to accept them and even prefer them to paper logbooks. The director of transportation for one motor carrier states, "I had a driver who swore he would never use an [onboard computer]. He threatened to quit. Now when I actually tried to take it away, this driver refused to drive until he got it back."(85)

Privacy concerns also need to be considered. The survey by ATRI revealed that data privacy/ownership/security was a major concern for 22 percent of EOBR non-users. Carriers were concerned that the data could be used against them and their drivers in litigation. Drivers are aware of their rights and obligations using the current paper logbook system, particularly in relation to inspections and crashes; however, electronic data may be viewed differently by drivers as they are not in possession of it (i.e., it is stored in a machine either in the truck or remotely at their depot), which may create a sense of distrust.(86) The lack of current standards and practices relating to EHSR data privacy and security clearly adds to the reluctance of many carriers to support a mandate for EHSR use.

1.2.3 International Context

Many other countries around the world regulate the driving and working hours of CMV drivers, some of which are already using, or currently investigating, EHSR systems for regulatory compliance purposes. The EU has required the use of tachographs since 1970 (and the use of digital tachographs—a different type of EHSR—since 2006) and the National Transport Commission (NTC) in Australia has enlisted Austroads to assess the effectiveness of EHSR systems in heavy vehicles to reduce driver fatigue and increase speed compliance. Transport Canada is also currently field-testing a range of EHSR systems in order to assess the use of these systems to improve regulatory compliance and road safety. Clearly, there are lessons to be learned from these countries, particularly those that have existing regulations and specifications regarding the use of EHSRs.

1.2.3.1 Europe

The EU regulations apply to vehicles in commercial use that are greater than 3.5 metric tons (7,716 lbs) and that are used to carry 10 or more persons. Earlier versions of the recording equipment used by CMV drivers were known as analog tachographs, which recorded drivers' periods of duty on a waxed paper disk called a tachograph chart. These devices are highly susceptible to tampering, and the charts are notoriously difficult to read; thus, they were never accepted as a possibility for use in the United States.(87) Advances in technology and digital electronics have resulted in the development of digital tachographs, which have been required in all new CMVs over 3.5 metric tons (except for those exempt) since May 2006. The new digital system was designed to overcome the frequent abuse of the analog system by introducing new "advanced recording equipment fitted with an electronic device for storing relevant information and a personal driver card, so ensuring that the data recorded are retrievable, intelligible when printed out, and reliable, and that they provide an indisputable record of the work done by both the driver over the last few days and by the vehicle over a period of several months."(88) Digital tachographs store data relating to driving time, rest, and break periods in their own memory and then record this data separately on the driver's own personal "driver card." The driver card is a small plastic card with a microchip in it that is personalized to the individual driver and that can store information for at least 28 days (as required by law). Only one card is issued per driver, and a driver is only authorized to use his/her own personalized card. This driver card must be presented to law enforcement officers upon request. This system is designed to minimize the possibility of tampering and to protect the integrity and confidentiality of the data.

A recent press release from the European Data Protection Supervisor (EDPS) raised concerns about data protection and driver privacy as EU legislation on digital tachographs has not kept up with new technological developments. The EDPS strongly recommends the inclusion of a specific provision on data protection in the EU legislation, along with additional data protection safeguards and security requirements. They also recommend that any new technological updates be supported by privacy impact assessments to assess the privacy risks to drivers that accompany these updates and advances. Privacy concerns stem from the fact that, although not required in the current regulation, newer digital tachographs use geolocation equipment and remote communication, which allows for the constant monitoring of drivers' locations.(89) The European Commission acknowledged that the security of the tachograph system is crucial; however, they were concerned with preventing fraud and unlawful manipulation of the driver data rather than privacy. They also recognize that security levels and security mechanisms required by the current tachograph legislation will need to be updated with new advances in technology and cryptography; otherwise, the vulnerability of the system will increase each year.[90]

Despite having mandated digital tachographs in new vehicles from May 2006, the European Commission has not been able to assess the benefits associated with the new system as the technology has not filtered down far enough through the industry due to the long lifetime of vehicles. They foresee the positive effect of digital systems on HOS compliance as being gradual, the result of which would be a more level playing field in the industry due to a reduction in the number of non-compliant drivers gaining a competitive advantage by not adhering to the EU legislation. The European Commission also believes that the benefits of reduced administrative burden far outweigh the cost of introducing the more advanced digital tachograph system. They also highlight that enhanced compliance with legislation will improve working conditions, health, and lifestyle for professional drivers via shorter working and driving times. Again, due to lack of available evidence, it is not possible to quantify the exact impact of the introduction of the digital tachograph system, possibly due to the range of enforcement programs across the EU; however, the expectations are high that there will be industry-wide benefits that gradually increase as more fleets adopt the technology. The EU is now considering updates to technical requirements for digital tachographs, including (among many other things) remote communications to the tachograph and automated location reporting.[91]

1.2.3.2 Australia

In July 2009, Transport for New South Wales implemented the "Operational Pilot of Electronic Work Diaries (EWDs) and Speed Monitoring Systems." The pilot study is running for 3 years, from 2010 to 2013. The major objective of this pilot study is to evaluate how EWD systems operate under working conditions. As is the case in the United States, many transport companies in Australia are already using in-vehicle EHSR systems to monitor work and rest hours, which help drivers to comply with HOS regulations and operators to manage their fleets more efficiently. These Australian drivers are still required to carry complete written records (i.e., paper logbooks) of their work and rest hours, despite the fact that this information is generally captured by the EHSR. This duplication of information in both the EHSR and paper logbooks is cumbersome and inefficient. It also creates the possibility of conflicts between what is written in the paper logbooks and what is recorded by the electronic system, which could be incriminating for the driver and operator.[92]

The current legislative environment in Australia requires guidelines in relation to electronic diaries approved by the Australian Transport Council; however, at this stage, there are no guidelines available approving the use of EWDs for managing fatigue and speeding compliance. There is also an absence of guidelines on the sanctions that may be imposed by the courts for failure to comply with fatigue and speeding regulations. There is an apparent need for guidelines to provide minimum specifications and procedures to allow for the approval of EWDs to be used for compliance purposes. Guidelines ensure consistency and certainty in what is required for a device to be deemed acceptable for use as a compliance monitoring tool. The results of the pilot study will provide recommendations on these issues to assist with the finalization of technical specifications, guidelines, and policy.[93]

The NTC promotes in-vehicle telematics, such as EWDs, as beneficial to the road freight sector via safety, operational, and environmental improvements. Similar to FMCSA and the European

Commission, they link safety improvements resulting from the use of EWDs to improved compliance and more effective compliance monitoring. Operational improvements stem from improved fleet management and coordination of deliveries. Environmental improvements are related to operational efficiency, as more efficient fleet management optimizes movement of freight, resulting in lower fuel consumption and vehicle emissions.(94) However, as is the case in the EU and the United States, there is very little data available to support these assumptions, hence the need for the Transport for New South Wales pilot study that is currently underway.

1.2.3.3 Canada

In June 2001, Transport Canada's Transportation Development Centre began a multi-phase project entitled "Field Testing of On-Board Recorder, Smart Card and Digital Signature Technologies." Phase 1 was a preliminary study on existing types of equipment and their functionalities. The analysis of the available technologies revealed that many of the onboard systems in Canada had been customized to specific company requirements, with very few centered on regulatory compliance (due to being more focused on logistics and fleet management). Thus, many of these devices did not meet regulatory requirements and were not suited for use as compliance auditing tools.(95) Phase 2 in this project was to conduct a feasibility study to finalize the field test procedures that would be used in Phase 3, which is the pilot study. Phase 2 used a limited number of onboard recording systems to develop and validate the procedures for gathering, transmitting, processing, and analyzing data in the next phase. Phase 2 also involved identifying and recruiting carriers and equipment suppliers to participate in the pilot study. The results of the Phase 2 study led the study authors to conclude that onboard recorder and smart card systems could be used to improve the regulatory compliance of drivers and operators, and that installation of the technology is economically and financially cost-effective for carriers. The study authors noted that the use of onboard technologies will not guarantee total regulatory compliance, but will help disclose undesirable, abusive, or recurrent behavior to improve the regulatory compliance of carriers. They recommend commencing the actual Phase 3 field testing of the relevant onboard technologies as quickly as possible.(96) Results of the field tests are not yet available.

1.3 CONCLUSIONS

This literature review brought together information from many different sources, including the U.S. Government, industry groups, and academic journals, along with anecdotal evidence reported by carriers to industry magazines. The primary focus was on economic and safety benefits and any stress- or health-related issues, as well as a number of costs and drawbacks associated with using EHSRs. Although the focus was on domestic research, international research was also considered from countries that already use similar systems or are evaluating the use of similar systems in their commercial trucking industries.

There is evidence to suggest that companies benefit from the use of EHSRs. Operational and productivity benefits associated with the use of EHSRs primarily stem from the real-time connection between fleet management and vehicles. Real-time connection allows fleet management to plan optimal routes and more easily keep track of deliveries, thereby reducing idle time and fuel consumption. These more advanced secondary functions of EHSRs can be extremely beneficial to large fleets that require more advanced routing and scheduling systems to enable them to manage their deliveries. A number of large carriers reported benefits that far outweighed the costs associated with switching to an EHSR system (e.g., the system paid for itself within the first 2 years after installation). Small carriers and owner-operators may not achieve great operational and productivity benefits as compared to larger carriers; however, further investigation of this issue is necessary with more current pricing information on the range of EHSR systems currently available. Unfortunately, not enough small carriers and owner-operators use EHSRs, which makes it difficult to properly assess the relevant costs and benefits.

In addition to the productivity and operational benefits mentioned above, evidence shows that EHSRs are associated with a reduction in administration time and effort. Drivers may save as much as 20 minutes per day using EHSRs, which may also result in less stress for drivers who no longer have to worry about ensuring that paper logbooks are accurate and up-to-date. Administrative personnel may also save up to 20 minutes per driver per month; thus, larger carriers that employ a high number of drivers would experience greater benefits from an administrative time-saving perspective. Further empirical examination of these secondary benefits is needed— the evidence of which may assist in creating a more favorable attitude toward EHSRs.

The primary argument for an EHSR mandate revolves around improved HOS compliance and safety. The line of reasoning behind the argument is that EHSR use increases HOS compliance which, in turn, reduces driver fatigue, resulting in increased on-road safety. Research studies and anecdotal evidence from carriers that have implemented electronic logbooks have shown support that electronic logbook use increases HOS compliance and reduces crashes. However, given the lack of scientific rigor, this evidence is mixed at best; thus, more meticulous investigation on this topic is needed to explore this link. The idea that EHSRs are linked to safety and HOS compliance has taken hold worldwide, with various EHSR devices being used or trialed in Europe, Australia, and Canada. However, more rigorous research, such as that completed for the current study, needs to be conducted to determine the real-world safety benefits of EHSRs and their effect on HOS compliance.

2. METHODS AND APPROACH

2.1 RESEARCH DESIGN

The main objective of the study was to quantitatively evaluate the safety impacts and the impact on HOS violations for EHSRs. Due to the lack of control for exposure (with EHSRs or not), the study followed principles from epidemiology studies. Two alternative study designs—the retrospective cohort and before-and-after approaches—were conducted. The retrospective cohort study is less prone to time-trend bias but may be subject to the bias caused by fleet or individual truck variations as indicated by the collected data.

2.1.1 Analyses by Crash Type and HOS Violation Type

Crash severity and crash type were available from most of the carrier crash datasets. One issue the research team experienced was that the criteria for recording crashes varied considerably among carriers. Some carriers recorded minor crashes (e.g., scratching the truck body in a parking lot) that were often omitted by other carriers. The inconsistency in recording standards could have led to severe bias in EHSR evaluation, especially when the EHSR market penetration rate differed among truck fleets with different crash-recording standards.

Thus, the research team pursued a more unified crash standard. Factors that were considered included:

- Consistency of crash definitions across carriers.
- The severity of crashes (severe crashes were of primary interest).
- The crash type (which should have reasonable causal connection with EHSRs).

Following the above criteria, the researchers considered the following crash types:

- USDOT-recordable.
- Preventable crashes (i.e., crashes in which the motor carrier determined that the truck driver was at fault).
- Combination of USDOT-recordable and preventable crashes.
- Fatigue-related crashes (see below for an operational definition of fatigue-related crashes).

HOS violations were also divided into different categories. Driving-related and non-driving-related violations were evaluated. The definition of the two violation types is as follows:

- Driving-related violations.
  - 11-hour rule violation.
  - 14-hour rule violation.
  - 16-hour rule violation.

  - 60/70-hour rule violation.
- Non-driving-related violations.
  - Driver’s RODS not current.
  - Log violation (general/form and manner).
  - Driver failing to retain previous 7 days of logs.
  - False report of driver’s RODS.
  - No driver’s RODS.
  - No log book.

The analyses for each crash and HOS violation type followed the same study design and procedure.

2.1.2 Retrospective Cohort Approach

The main objective of this study was to evaluate the safety benefit of EHSRs, that is, whether trucks with EHSRs have a lower (or higher) crash risk than those without. There were two levels of exposure status: trucks with EHSRs (yes) or without EHSRs (no). The safety outcomes were measured by the number of crashes that occurred for each cohort. The safety benefits of EHSRs were quantitatively evaluated by comparing the crash risk for two exposure groups (i.e., EHSRs were considered to improve safety if the trucks with EHSRs showed a lower crash risk than trucks without EHSRs). The crash frequency and mileage for each truck was collected in the study period. The safety effects of the EHSRs were evaluated by comparing the crash rate between cohorts. A schematic plot of the retrospective cohort study is shown in Figure 2.

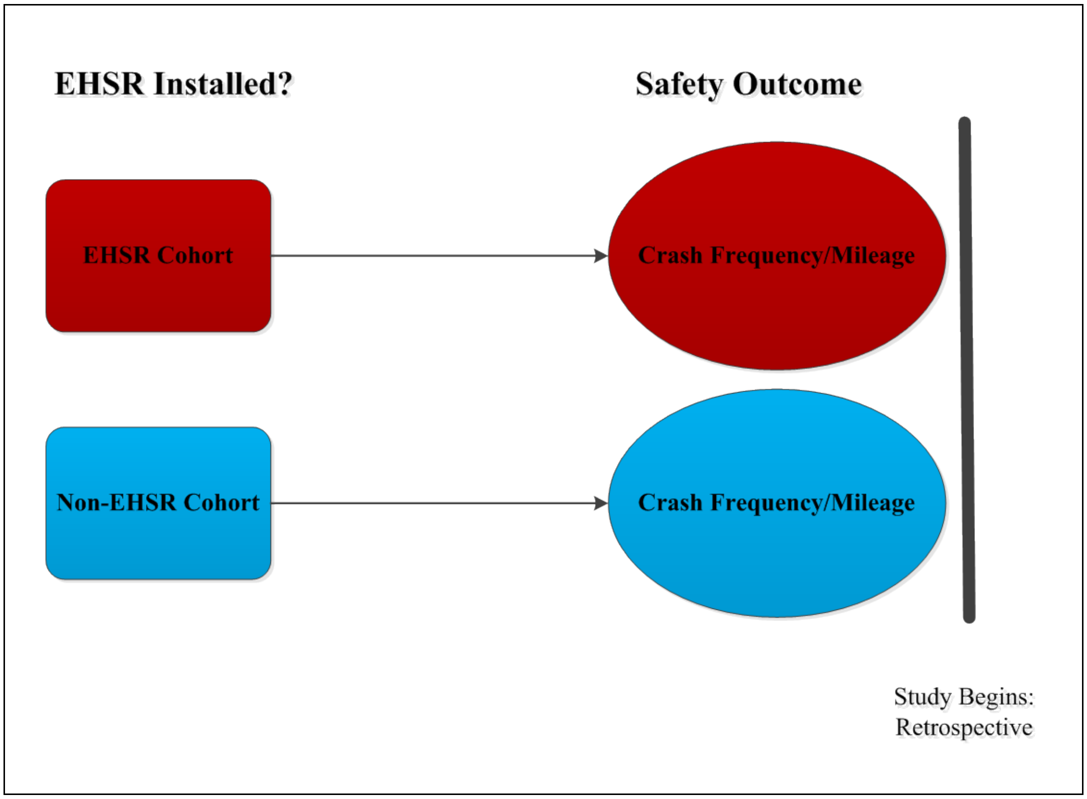

Figure 2. Schematic. Illustration of the retrospective cohort design.

The output of the retrospective cohort study is illustrated in Table 1. "A" represents the number of crashes for trucks without EHSRs in the study period, and "B" represents the number of crashes for trucks equipped with EHSRs. $E_{non\text{-}EHSR}$ and E_{EHSR} are the mileage traveled by each cohort. Note the table can be stratified by fleet or even by truck. The full statistical inference was based on Poisson or negative binomial models discussed in a later section.

Table 1. Output of retrospective cohort study.

Variable	Non-EHSR Cohort	Non-EHSR Cohort
Crash/HOS Violation Frequency	A	B
Mileage	$E_{non\text{-}EHSR}$	E_{EHSR}

2.2 STATISTICAL MODELS

The primary response variable for risk assessment was crash frequency. Correspondingly, the count-based Poisson regression model was used to model the crash count data. The model specification is discussed below.

The number of crashes for fleet *i*, truck *j*, Y_{ij} , was assumed to follow a Poisson distribution as shown in Figure 3:

$$Y_{ij} \sim \text{Poisson}(E_{ij}\lambda_{ij})$$

Figure 3. Equation. Poisson distribution.

where Y_{ij} is the number of crashes for Fleet *i*, Truck *j*, during the study period; E_{ij} is the mileage traveled for Truck j in Fleet i; and $Lambda_{ij}$ is the expected crash rate. The expected crash rate $Lambda_{ij}$ was the primary measure to evaluate the crash risk of a truck. A log link function was used to connect this crash rate to a set of independent variables, that is:

$$\text{Log}(\lambda_{ij}) = \beta_0 + \beta_1 X_{1ij} + \ldots + \beta_K X_{Kij}$$

Figure 4. Equation. Log link function.

Where X_{kij} is the variable based on a risk factor *k* for truck *j* in fleet *i* and $beta_k$ is the corresponding regression coefficient. The EHSR status of a truck was represented by a binary variable:

$$X_{EHSRij} = 1 \text{ if } \text{Truck}_{ij} \text{ is equipped with an EHSR or 0 if } \text{Truck}_{ij} \text{ is not equipped with an EHSR}$$

Figure 5. Equation. EHSR status using a binary variable.

The inference was conducted based on the corresponding regression coefficient $Beta_{EHSR}$. The research team conducted extensive testing and evaluation for Poisson models. There was no evidence of over-dispersion or lack of fit in the Poisson model (e.g., the deviance over degrees of freedom was smaller or close to "1.0," and fitting the Negative Binomial regression model indicated there was no need for an over-dispersion parameter). Therefore, the research team considered the Poisson model as appropriate and sufficient for the analysis**.**

This model framework was able to accommodate the complex data that were collected in this study. The safety equipment, such as forward collision warning systems and lane departure warning systems, can impact the safety and confound the effect of EHSRs. To adjust for the potential confounding effect, these factors were factored as covariates in the same model. The output of this model was the effect of EHSR adjusted for other factors.

The safety of a fleet is often affected by safety culture, safety management strategies, and nature of the business. As such, trucks in a same fleet are more likely to share similar risk profiles. The research team used a fixed-effect term to represent the base crash level for a carrier.

2.3 DATA COLLECTION PROCEDURES

The data collection effort of the current study involved the assemblage of existing carrier-owned data by the research team. This effort was designed to assess the potential safety benefits of EHSRs in reducing the frequency and severity of specific crashes (e.g., all crash types, USDOT-recordable, preventable, and fatigue-related) and HOS violations. These data included carrier, crash, HOS violation, vehicle, and driver information from calendar years 2008–2012. Below is a list of the necessary (or required) data elements included in the current study. Carriers that could not provide these data elements were excluded from participating.

- Carrier Variables.
  - Size (small, medium, large).
  - SafeStat/Compliance, Safety, Accountability (CSA) scores for corresponding calendar years.
  - Use of EHSRs to monitor HOS (e.g., if trucks have EHSRs installed, do the carriers use the EHSRs to monitor HOS?).
- Crash Variables.
  - Date.
  - Truck identification (ID) number/vehicle identification number (VIN).
  - Contributing factor (e.g., asleep, speeding, etc.).
  - Crash narrative (e.g., description of the crash circumstances).
  - Crash type (e.g., rear-end truck striking).
  - USDOT-recordable (yes or no).
  - Injury (yes or no).
  - Fatality (yes or no).
  - Preventable (yes or no).
- HOS Violation Variables.
  - Date.
  - VIN.
  - Type of HOS violation(s) (e.g., 11-hour rule).
- Vehicle Variables.

- VIN.
- Manufacture date.
- EHSR status (yes or no).
- Onboard safety systems (e.g., roll stability control).
- Mileage in calendar year.
- Operation type (e.g., tanker, dry bulk, intermodal).

- Driver Variables (if necessary; no personally identifiable information was requested).
  - Age.
  - Gender.

2.3.1 Carrier Recruitment

The research team recruited CMV carriers that had power units both with and without EHSRs. The only prerequisite for participating fleets was that they perform long-haul or regional operations and have the above-noted necessary data elements. Those vehicles that solely perform local, short-haul deliveries within a 150-air-mile radius were not included in the analyses. The research team has cultivated relationships with many CMV carriers. Researchers contacted these carriers via e-mail and/or telephone to request their participation in the study.

2.3.2 Carrier Data Collection

Collection of carrier data began after the non-disclosure agreement (NDA) was signed and returned by the participating carrier. After the NDA was returned, the research team worked with each carrier's representative to collect the necessary data. Specific carrier information was also gathered from these carrier representatives. This information included carrier demographic information and safety management techniques, and was crucial in controlling for differences between carriers.

After receiving HOS violation data from carriers, the research team determined that some carriers collected internal (not by an FMCSA roadside inspection) HOS violations, whereas others did not. Thus, HOS violation data for each carrier were collected via FMCSA's Safety Management System (SMS) online Web page, and these were the only HOS violations used in the data analyses. This ensured standard HOS violation data across all carriers and allowed comparisons with other studies using these data. However, the SMS Web site only provides data for 2 years prior to the date of retrieval. Thus, HOS violation data were only collected from a small portion of 2010, all of 2011, and 2012.

2.3.3 Data Merging/Reduction

As the data sets provided by each carrier were not identical, all data sets were merged and formatted into one large data set with common headings. Once this was complete, the project manager recoded each crash type, using the existing crash type and crash narrative, to a uniform list of crash types created by the research team. Table 2 displays the operational definitions for the uniform crash types created by the research team. The crash types coded by the project manager referred to the first impact or harmful event. For example, a vehicle that encroached on the truck's lane, thereby causing the truck driver to make an avoidance maneuver that resulted in the truck rear-ending another vehicle, would be coded as a rear-end collision.

Table 2. Operational definitions for the uniform crash types.

Crash Type	Operational Definition
Run Off Road	The truck ran off the road, and the road and/or surface caused the first damage to the truck.
Head-on	The truck had a front-end collision with another vehicle on the roadway.
Rear-end	The truck rear-ended another vehicle on the roadway.
Rear-ended	The truck was rear-ended by another vehicle on the roadway.
Sideswipe	The truck struck another vehicle/object traveling in the same direction on its side.
Opposite Sideswipe	The truck struck another vehicle traveling in the opposite direction on its side.
Backing	The truck backed up and struck another vehicle or object.
Parking Lot	The truck struck a fixed object or vehicle while maneuvering in a parking lot, dock, or truck stop.
Hit Object in Road	The truck hit an object in the roadway while driving.
Hit Animal	The truck struck an animal in the roadway.
Rollover	The truck rolled over, and the rollover was the first impact.
Jackknife	The truck jackknifed, and the jackknife was the first impact (loss of control of the trailer).
Parked	Another vehicle, person, or object damaged the truck while it was parked.
Roll Back	The truck rolled back into another vehicle or object after releasing the brake.
Roll Away	The truck rolled forward into another vehicle or object after releasing the brake.
Hit Fixed Object	The truck struck a fixed object not on the roadway.
Hit Pedestrian	The truck struck a person.
Overhead	The truck struck an overhead object (e.g., an overpass).
Mechanical	The truck experienced some sort of mechanical failure.
Hit by Other Vehicle (OV)	Another vehicle struck the truck, but there was not enough information to classify a specific crash type.
Truck Hit OV	The truck struck another vehicle, but there was not enough information to classify a specific crash type.
Broadside	The truck had a driver/passenger side impact with another vehicle, or the OV had a driver/passenger side impact with the truck.
Other	Miscellaneous crash circumstances that did not fit into other categories.
Non-contact	Any instance where there was not contact with another vehicle, object, or pedestrian (e.g., tire blowout).

The project manager also identified crashes where fatigue was a contributing factor. The individual crash files provided by the participating carriers included a primary contributing factor (i.e., the most likely reason for the crash). Therefore, all crashes containing the words "fatigue," "fatigued," "sleep," "asleep," "sleepy," "drowsy," "drowsiness," or "tired" as the primary contributing factor were identified as a fatigue-related crash. Additionally, a keyword search of the crash narratives for each crash was conducted. This keyword search filtered crash files containing the following keywords: fatigue, fatigued, sleep, asleep, sleepy, drowsy, drowsiness, tired, alertness, and inattention (or variations of these keywords). Furthermore, the project manager reviewed specific crash types that occurred during the circadian low between 2:00 a.m. and 6:00 a.m. These crash types included sideswipe, opposite sideswipe, run off road, head-on, rollover, jackknife, hit fixed object, and broadside. These crashes were reviewed by the project manager to determine if they were indeed fatigue-related. This process involved reading the crash narrative in each crash file identified during the keyword search to assess if the crash was fatigue-related.[97,98] However, critical information needed to asses if fatigue was a contributing factor was not provided by the participating carriers. These included hours slept prior to the crash, last rest period, and driving hours in current shift. As such, the frequency of fatigue-related crashes in the current report is likely to be underreported.

Additionally, the project manager reviewed each crash to determine if the crash was considered a "claim only" crash. Crashes that were considered "claim only" were curb strikes, mechanical failure, non-vehicle-to-vehicle crashes in a parking lot, non-contact, backing into a dock, parked, and vandalism. These crashes were excluded from all analyses.

3. RESULTS

3.1 OVERVIEW OF CARRIER DATA

Twelve carriers provided all required data for this study (including data on crashes, vehicles, HOS violations, and the carrier demographic and information sheet). Upon further examination, the research team determined that the data from Carrier K were systematically biased. Carrier K was the only carrier that systematically targeted particular drivers, operations, or locations with EHSR installation. More specifically, Carrier K tended to inadvertently target new drivers with EHSRs. For this reason, Carrier K was excluded from all analyses presented in this report.

3.1.1 Carrier Demographics

The carrier demographic data from the 11 participating carriers are presented in Table 3. Listed in Table 3 is a description of the carrier, including number of power units, number of full-time employees, and drivers' average number of years of driving experience for their fleet (carriers could provide more than one description for their fleet). As shown in Table 3, the majority of the carriers are large.

Table 3. Participating carriers' demographic information.

Carrier ID	Carrier Description	Number of Power Units	Number of Full-time Employees	Average Total Driving Experience
A	For hire: truckload Other: temperature controlled	1,001 or more	1,001–5,000	5.5 years
B	For hire: truckload	1,001 or more	1,001–5,000	45% = 1 year 16% = 2 years 17% = 5 years 22% = 5+ years
C	For hire: truckload Private: less-than-truckload For hire: regional Other: company drivers and owner-operators	1,001 or more	5,001 or more	4.4 years
D	For hire: less-than-truckload	1,001 or more	5,001 or more	20 years
E	Private: truckload Private: regional	1,001 or more	5,001 or more	Data not available
F	For hire: truckload For hire: less-than-truckload For hire: regional Owner-operator	101–500	101–500	14.5 years
G	For hire: less-than-truckload	1,001 or more	5,001 or more	8.87 years
H	For hire: less-than-truckload	101–500	1,001–5000	9 years
I	For hire: truckload For hire: regional	1,001 or more	5,001 or more	4.33 years
J	For hire: truckload	1,001 or more	5,001 or more	Unknown
L	Private: regional Private: less-than-truckload	1,001 or more	5,001 or more	10.16 years

3.1.2 Carrier Safety Management Techniques

Table 4 lists the safety management techniques and 2011 CSA Behavior Analysis and Safety Improvement Category scores employed at each carrier. CSA uses available Federal motor carrier safety data to measure the relative safety status of motor carriers in six areas: unsafe driving, HOS compliance, driver fitness, controlled substances and alcohol, vehicle maintenance, and hazardous materials compliance.

Table 4. Participating carriers' safety management techniques and 2011 CSA Scores.

C[redacted]	Safety Management Techniques	Unsafe Driving CSA	HOS Compliance CSA	Driver Fitness CSA	Controlled Substances CSA	Vehicle Maintenance CSA	Hazardous Materials CSA	Crash Indicator CSA
A	[redacted] TR, SI, FB, DDT, FCT, RA, SC, HWP, and [redacted] ty monitoring program	15.60	33.40	25.60	47.00	21.00	NA	NA
B	[redacted], FB, FCT, and SC	26.10	31.20	9.80	NA	34.80	NA	5.00
C	[redacted] TR, HMDP, SI, FB, DDT, FCT, RA, SC, HWP, quarterly driver training, post-incident performance enhancement training, and truck technology applications training	19.70	15.80	39.80	11.70	64.70	38.20	4.70
D	DFP, YTR, SI, DDT, FCT, RA, and SC	6.90	20.50	23.80	0.00	44.40	NA	35.30
E	YTR, RA, SC, new hire training on HOS, defensive driving, vehicle inspection, drugs and alcohol, CSA, coupling and uncoupling, etc.	0.00	9.35	53.40	0.00	33.80	16.10	0.35
F	YTR, HMDP, SI, FB, DDT, FCT, and HWP	1.90	23.70	0.00	0.00	21.60	NA	7.70
G	DFP, YTR, SI, DDT, and HWP	3.40	21.10	32.90	0.90	27.00	NA	36.30
H	YTR, SI, DDT, FCT, RA, SC, and HWP	4.00	15.50	29.80	NA	35.30	70.40	95.90
I	YTR, HMDP, SI, FB, DDT, FCT, RA, SC, and HWP	13.90	34.20	55.90	0.00	31.00	NA	23.40
J	YTR, HMDP, SI, FB, DDT, FCT, SP, HWP	78.00	16.00	86.00	24.00	44.00	55.00	88.00
L	SI and DDT	1.92	3.54	5.45	0.38	26.23	NA	NA
Average	NA	15.98	21.07	32.90	9.47	35.19	44.93	32.75

Safety Management Techniques Key: DFP = Driver Finishing Program; YTR = Yearly Training/Retraining (general); HMDP = How's My Driving Placards; SI = Safety Incentives; FB = Fuel Bonus; DDT = Defensive Driving Training; FCT = Fatigue Countermeasures Training; RA = Ride Alongs; SC = Spot Checks; HWP = Health and Wellness Program

3.1.3 Data Filtering

Data were collected from 12 carriers and included a total of 253,227 truck-years, 180,023 crashes, and 1,889 HOS violations. Truck-years do not reflect the number of mutually exclusive trucks over the 5 calendar years (as the same truck could be counted in each year), but rather the number of trucks over the 5 years of data collection. Portions of the data set were excluded from the analyses due to data quality issues. Excluded data are as follows:

- Yearly mileage not provided.
- Yearly mileage less than 200 miles.
- Yearly mileage more than 300,000 miles.
- All data from Carrier K.
- Truck ID number or VIN not provided or unable to match to vehicle data set.

As a result, 29,193 truck-years, 97,080 crashes (excluding those determined to be “claim only”), and 919 HOS violations were excluded from data set. The final data set included data from 11 carriers with 224,034 truck-years, 82,943 crashes, and 970 HOS violations. These trucks drove a total of 15.6 billion miles. Truck-years do not reflect the number of mutually exclusive trucks over the 5 calendar years (e.g., as the same truck could be counted in each of the 5 calendar years that would be 5 truck-years for that specific truck), but rather the number of trucks over the 5 years of data collection. The average mileage per truck per year was 69,654 miles.

Data analyses required that all crashes and HOS violations match a vehicle ID or VIN from the vehicle dataset. This allowed the research team to identify those crashes and HOS violations that involved an EHSR-equipped truck or a non-EHSR-equipped truck. Table 22 in Appendix A presents the percentage of crashes that matched a vehicle ID or VIN from the vehicle dataset.

3.1.4 Carrier EHSR Penetration

As shown in Table 5, eight carriers had an EHSR in a portion of their fleets at some time during the study period. Of these carriers, six used EHSRs to record drivers’ logs and used a third-party monitoring vendor. As noted in Table 5, Carrier E does not use EHSRs to record drivers’ logs. Thus, Carrier E’s data was grouped with the non-EHSR cohort in all data analyses.

Table 5. Participating carriers' EHSR use.

Carrier ID	Electronic Hours-of-Service Recorder Use	Electronic Hours-of-Service Recorder Used to Record Logs	Third-party Monitoring Vendor
A	Yes	Yes	RAIR
B	Yes	Yes	RAIR
C	Yes	Yes	Qualcomm RAIR
D	No	No	NA
E	Yes	No	NA
F	No	No	NA
G	No	No	NA
H	No	No	NA
I	Yes	Yes	People Net Qualcomm RAIR
J	Yes	Yes	Eclipse Software
L	Yes	Yes	XATA

Table 6 shows the number and percentage of truck-years with an EHSR. The percentage of trucks equipped with an EHSR was calculated by dividing the number of trucks equipped with an EHSR by the total number of trucks. For example, in 2008, 4 percent of the trucks had EHSRs, or 1,170 trucks out of 29,013 trucks.

Table 6. Number and percentage of truck-years with EHSRs.

Year	Number of Truck Years with Electronic Hours-of-Service Recorders (A)	Number of Truck Years without Electronic Hours-of-Service Recorders (B)	Percentage of Truck Years with Electronic Hours-of-Service Recorders [(A/A+B)*100]	Total
2008	1,170	27,843	4.0%	29,013
2009	3,210	37,102	8.0%	40,312
2010	15,864	26,358	37.6%	42,222
2011	27,774	24,458	53.2%	52,232
2012	35,147	25,108	58.3%	60,255
TOTAL	**83,165**	**140,869**	**37.1%**	**224,034**

Table 7 shows the distribution of truck-years with EHSRs across each carrier. The numbers listed in each cell in Table 7 indicate truck-years.

Table 7. Number of truck-years with EHSRs by carrier.

Carrier ID	EHSR
A	2,096
B	5,369
C	37,764
D	0
E	0
F	0
G	0
H	0
I	3,746
J	14,083
L	20,107

3.1.5 Yearly Crash, Non-crash, HOS Violation, and Mileage Data

Table 8 shows the years of data, truck-years, MVMT, number of crashes, the total crash rate, number of HOS violations, and the HOS violation rate. As shown in Table 8, there are different mileages for crashes and HOS violations. This is because HOS violations were only collected from 2 years prior to data collection. Furthermore, HOS violations were not collected from Carriers F and G. Carrier F only provided data for calendar years 2008 and 2009; thus, HOS data were not available for those years. Carrier G HOS violation data were not included because there were issues matching the VINs to the vehicle data set.

The crash rate was defined as the number of crashes (i.e., total number of crashes) divided by MVMT. Similarly, the HOS violation rate was defined as the number of HOS violations (i.e., total number of HOS violations) divided by MVMT. As shown in Table 8, the MVMT, crash rate, and HOS violation rate varied substantially among carriers.

Table 8. Years of data, truck-years, MVMT, number of crashes, total crash rate, number of HOS violations, and HOS violation rate by carrier.

Carrier ID	Years with Data	Truck-years	Crash MVMT (B)	Number of Crashes (A)	Crash Rate (A/B)	Number of HOS Violations (C)	HOS Violation MVMT (D)	HOS Violation Rate (C/D)
A	5	8,359	671	2,870	4.28	134	441	0.30
B	5	9,965	1,136	2,732	2.41	35	889	0.04
C	5	61,678	5,347	33,840	6.33	85	3,172	0.03
D	5	6,585	659	4,376	6.65	102	400	0.26
E	2	16,559	363	2,192	6.04	19	364	0.05
F	2	418	40	35	0.88	N/A	N/A	N/A
G	5	42,361	2,773	15,336	5.53	N/A	N/A	N/A
H	3	1,306	84	132	1.57	14	84	0.17
I	5	20,234	1,355	8,196	6.05	330	1,168	0.28
J	5	23,463	1,981	10,915	5.51	201	1,223	0.16
L	4	33,106	1,197	2,319	1.94	50	932	0.05
TOTAL	**N/A**	**224,034**	**15,606**	**82,943**	**5.32**	**970**	**8,673**	**0.11**

3.2 CRASH AND HOS VIOLATION RATES

This section describes the following crash rates: total, USDOT-recordable, preventable, and fatigue-related. HOS violation rates are also presented at the end of this section. Appendix B provides bar graphs for each of the following crash rates.

3.2.1 Crash Rates

Table 9 shows the crash type, MVMT, and the crash rate for each cohort. Preventable, DOT-recordable, and fatigue-related crashes were not mutually exclusive (thus, the total crash rate is not the sum of preventable, USDOT-recordable, and fatigue-related crashes).

Table 9. Crash rates by EHSR cohort.

Crash Type	EHSR Cohort Crash Count (A)	EHSR Cohort MVMT (B)	EHSR Cohort Crash Rate (A/B)	Non-EHSR Cohort Crash Count (C)	Non-EHSR Cohort MVMT (D)	Non-EHSR Cohort Crash Rate (C/D)
Preventable	14,537	6,048	2.40	24,985	9,555	2.61
USDOT-recordable	3,197	6,052	0.53	5,729	9,543	0.60
Fatigue-related	328	6,054	0.05	659	9,540	0.07
Total Crashes	29,093	6,046	4.81	53,850	9,559	5.63

Figure 6 shows a bar graph for total, preventable, USDOT-recordable, and fatigue-related crash rates by EHSR status. The blue bar shows the crash rate for the EHSR cohort and the black bar shows the crash rate for the non-EHSR cohort.

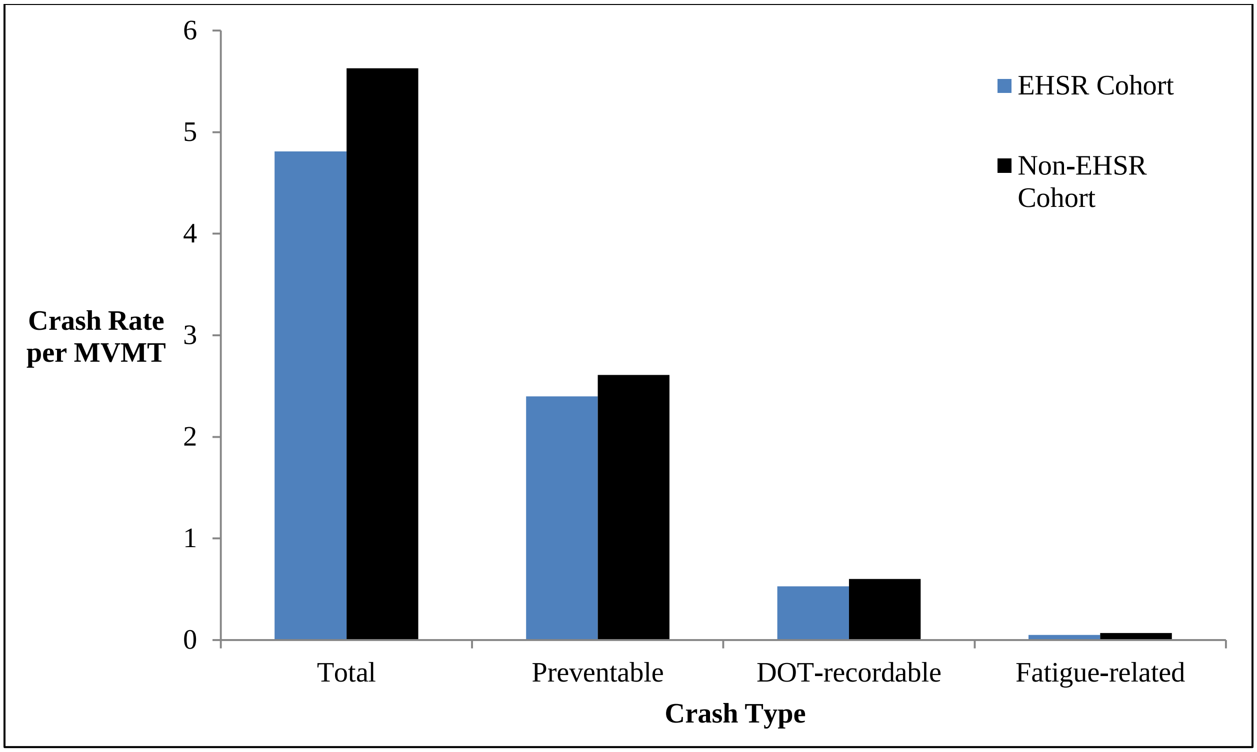

Figure 6. Bar graph. Crash rates by EHSR cohort.

The following tables show the total crash rates by carrier. These data were used in the Poisson regression to assess the safety benefits of EHSRs.

Table 10 shows the crash rates by EHSR cohort across all carriers. Figure 8 in Appendix B shows a bar graph of the crash rate by EHSR cohort across all carriers. The blue bars show the crash rate for the EHSR cohort and the black bars show the crash rate for the non-EHSR cohort.

Table 10. Total crash rate by EHSR cohort across carrier.

Carrier ID	EHSR Cohort Crash Count (A)	EHSR Cohort MVMT (B)	EHSR Cohort Crash Rate (A/B)	Non- EHSR Cohort Crash Count (C)	Non- EHSR Cohort MVMT (D)	Non- EHSR Cohort Crash Rate (C/D)
A	686	150	4.57	2,184	522	4.18
B	1,145	644	1.78	1,587	492	3.23
C	16,769	3,171	5.29	17,071	2,176	7.85
D	N/A	N/A	N/A	4,376	659	6.65
E	N/A	N/A	N/A	2,192	363	6.04
F	N/A	N/A	N/A	35	40	0.88
G	N/A	N/A	N/A	15,336	2,773	5.53
H	N/A	N/A	N/A	132	84	1.57
I	1,186	183	6.48	7,010	1,172	5.98
J	7,925	1,180	6.72	2,990	801	3.73
L	1,382	719	1.92	937	479	1.96
TOTAL	**29,093**	**6,047**	**4.81**	**53,850**	**9,561**	**5.63**

Table 11 shows the preventable crash rates by EHSR cohort across all carriers. Figure 9 in Appendix B shows a bar graph of the preventable crash rate by EHSR cohort across all carriers.

Table 11. Preventable crash rate by EHSR cohort across carrier.

Carrier ID	EHSR Cohort Preventable Crashes (A)	EHSR Cohort MVMT (B)	EHSR Cohort Preventable Crash Rate (A/B)	Non-EHSR Cohort Preventable Crashes (C)	Non-EHSR Cohort MVMT (D)	Non- EHSR Cohort Preventable Crash Rate (C/D)
A	498	150	3.32	1,576	522	3.02
B	509	644	0.79	627	492	1.27
C	7,691	3,171	2.43	8,137	2,175	3.74
D	N/A	N/A	N/A	2,286	659	3.47
E	N/A	N/A	N/A	0	364	0.00
F	N/A	N/A	N/A	24	40	0.60
G	N/A	N/A	N/A	5,896	2,773	2.13
H	N/A	N/A	N/A	45	84	0.54
I	728	184	3.96	4,506	1,170	3.85
J	5,111	1,181	4.33	1,890	798	2.37
L	0	719	0.00	0	479	0.00
TOTAL	**14,537**	**6,049**	**2.40**	**24,987**	**9,556**	**2.61**

Table 12 shows the USDOT-recordable crash rates by EHSR cohort across all carriers. Figure 10 in Appendix B shows a bar graph of the USDOT-recordable crash rate by EHSR cohort across all carriers.

Table 12. USDOT-recordable crash rate by EHSR cohort across carrier.

Carrier ID	EHSR Cohort USDOT-recordable Crashes (A)	EHSR Cohort MVMT (B)	EHSR Cohort USDOT-recordable Crash Rate (A/B)	Non-EHSR Cohort USDOT-recordable Crashes (C)	Non-EHSR Cohort MVMT (D)	Non-EHSR Cohort USDOT-recordable Crash Rate (C/D)
A	64	150	0.43	180	522	0.35
B	97	644	0.15	166	492	0.34
C	1,943	3,172	0.61	1,601	2,175	0.74
D	N/A	N/A	N/A	903	659	1.37
E	N/A	N/A	N/A	107	364	0.29
F	N/A	N/A	N/A	14	40	0.35
G	N/A	N/A	N/A	1,558	2,773	0.56
H	N/A	N/A	N/A	60	84	0.71
I	98	186	0.53	644	1,163	0.55
J	975	1,182	0.82	401	794	0.51
L	20	719	0.03	95	479	0.20
TOTAL	**3,197**	**6,053**	**0.53**	**5,729**	**9,545**	**0.60**

Table 13 shows the fatigue-related crash rates by EHSR cohort across all carriers. Figure 11 in Appendix B shows a bar graph of the fatigue-related crash rate by EHSR cohort across all carriers.

Table 13. Fatigue-related crash rate by EHSR cohort across carrier.

Carrier ID	EHSR Cohort Fatigue-related Crashes (A)	EHSR Cohort MVMT (B)	EHSR Cohort Fatigue-related Crash Rate (A/B)	Non-EHSR Cohort Fatigue-related Crashes (C)	Non-EHSR Cohort MVMT (D)	Non-EHSR Cohort Fatigue-related Crash Rate (C/D)
A	8	150	0.05	17	522	0.03
B	9	644	0.01	10	492	0.02
C	153	3,172	0.05	196	2,175	0.09
D	N/A	N/A	N/A	80	659	0.12
E	N/A	N/A	N/A	9	364	0.02
F	N/A	N/A	N/A	0	40	0.00
G	N/A	N/A	N/A	251	2,773	0.09
H	N/A	N/A	N/A	2	84	0.02
I	14	187	0.07	36	1,162	0.03
J	132	1,183	0.11	51	792	0.06
L	12	719	0.02	7	479	0.01
TOTAL	**328**	**6,055**	**0.05**	**659**	**9,542**	**0.07**

3.2.2 HOS Violation Rates

HOS violations were separated into driving-related and non-driving-related violations. The HOS violation rates are presented below. Appendix C provides bar graphs for each of the following HOS violation rates. Table 14 shows the HOS violation type, MVMT, and the HOS violation rate.

Table 14. HOS violation rates by EHSR cohort.

HOS Violation Type	EHSR Cohort (A)	EHSR Cohort MVMT (B)	EHSR Cohort HOS Violation Rate (A/B)	Non-EHSR Cohort HOS Violation Count (C)	Non-EHSR Cohort MVMT (D)	Non-EHSR Cohort HOS Violation Rate (C/D)
Driving	51	5,760	0.01	97	2,912	0.03
Non-driving	232	5,760	0.04	480	2,912	0.16

Figure 7 shows a bar graph for the driving-related and non-driving-related HOS violation rates by EHSR status. The blue bars show the crash rate for the EHSR cohort and the black bars show the crash rate for the non-EHSR cohort.

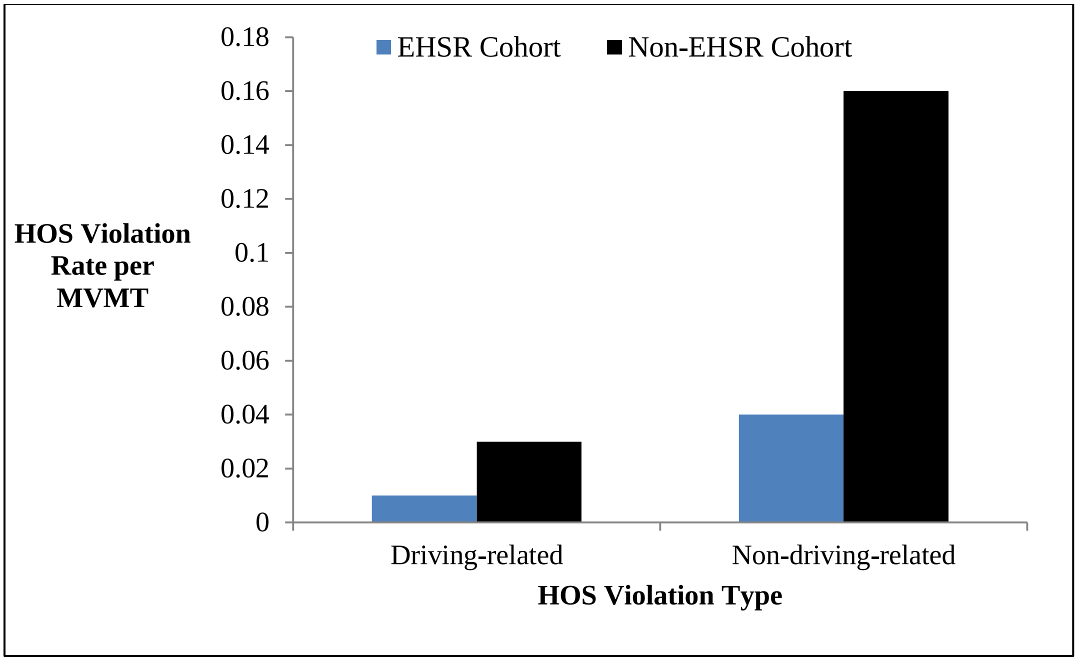

Figure 7. Bar graph. HOS violation rates by EHSR cohort.

Table 15 shows the driving-related HOS violation rates by EHSR cohort across all carriers. Figure 12 in Appendix C shows a bar graph of the driving-related HOS violation rate by EHSR cohort across all carriers. These data were used in the Poisson regression to assess the safety benefits of EHSRs.

Table 15. Driving-related HOS violation rate by EHSR cohort across carrier.

Carrier ID	EHSR Cohort Driving HOS Violations (A)	EHSR Cohort MVMT (B)	EHSR Cohort Driving HOS Violation Rate (A/B)	Non-EHSR Cohort Driving HOS Violations (C)	Non-EHSR Cohort MVMT (D)	Non-EHSR Cohort Driving HOS Violations Rate (C/D)
A	4	150	0.03	16	292	0.05
B	4	641	0.01	1	248	0.00
C	19	3,172	0.01	N/A	N/A	N/A
D	N/A	N/A	N/A	4	400	0.01
E	N/A	N/A	N/A	0	364	0.00
H	N/A	N/A	N/A	2	84	0.02
I	4	187	0.02	71	981	0.07
J	19	923	0.02	3	300	0.01
L	1	688	0.00	0	244	0.00
TOTAL	**51**	**5,761**	**0.01**	**97**	**2,913**	**0.03**

Table 16 shows the non-driving-related HOS violation rates by EHSR cohort across all carriers. Figure 13 in Appendix C shows a bar graph of the non-driving-related HOS violation rates by EHSR cohort across all carriers. These data were used in the Poisson regression to assess the safety benefits of EHSRs.

Table 16. Non-driving HOS violation rate by EHSR cohort across carrier.

Carrier ID	EHSR Cohort Non-driving HOS Violations (A)	EHSR Cohort MVMT (B)	EHSR Cohort Non-driving HOS Violation Rate (A/B)	Non-EHSR Cohort Non-driving HOS Violations (C)	Non-EHSR Cohort MVMT (D)	Non-EHSR Cohort Non-driving HOS Violations Rate (C/D)
A	23	150	0.15	83	292	0.28
B	24	641	0.04	1	248	0.00
C	61	3,172	0.02	N/A	N/A	N/A
D	N/A	N/A	N/A	94	400	0.24
E	N/A	N/A	N/A	18	364	0.05
H	N/A	N/A	N/A	13	84	0.15
I	17	187	0.09	234	981	0.24
J	95	923	0.10	37	300	0.12
L	12	688	0.02	0	244	0.00
TOTAL	**232**	**5,761**	**0.04**	**480**	**2,913**	**0.16**

3.3 STATISTICAL MODEL RESULTS

3.3.1 Crash Risk

Formal statistical inference was conducted using the above-described Poisson regression model. All models included potential effect modifiers, including year, carrier index, OBSS status, and long-haul/regional indicator. The effect of EHSRs was measured by the crash rate ratio (CRR) between EHSR- and non-EHSR-equipped trucks. The CRR was the exponent of the Poisson regression coefficient. A ratio smaller than 1 indicated the EHSR cohort had a lower crash rate than the non-EHSR cohort.

In addition to the total number of crashes, three specific crash types were evaluated. The three crash types included preventable, USDOT-recordable, and fatigue-related. Ten models were fitted by crash type. All models included potential effect modifiers including year, carrier index, onboard safety system (OBSS) status, and long-haul/regional indicator. The detailed model output is presented in Appendix D. The effect of EHSRs is summarized in Tables 19–22.

Table 17 shows the effects of EHSRs on crash risk across all carriers. As can be seen below, EHSR-equipped trucks had a 12 percent and 5 percent significantly lower crash rate than non-equipped trucks for total crashes ($p < 0.001$) and preventable crashes ($p = 0.001$), respectively. When the “operation variable” was included in the models in Table 17 and Table 18, the models failed to converge; thus, the effects of EHSRs could not be estimated. This was likely due to the multicollinearity issue caused by high correlation between the operation variable and other variables included in the model.

Table 17. Modeled effects of EHSR on crash rate.

Crash Type	Crash Rate Ratio (EHSR vs. Non-EHSR)	Estimated Crash Rate Reduction	95% Confidence Interval (CI) Lower Bound	95% CI Higher Bound	Chi-Square	p-Value
Preventable*	0.95	0.05	0.92	0.98	10.13	0.001
USDOT-recordable	0.99	0.01	0.92	1.06	0.08	0.781
Fatigue-related	0.99	0.01	0.80	1.22	0.01	0.926
Total Crashes	0.88	0.12	0.86	0.90	112.63	<0.001

*Operation variable (long, regional) was not included because of convergence issue.

3.3.2 HOS Violation Risk

Similar analyses were conducted for HOS violation risk. Two types of HOS violations were evaluated, including driving-related HOS violations and non-driving-related HOS violations. All models included potential effect modifiers, including year, carrier index, OBSS status, and long-haul/regional indicator. The detailed model output is presented in Appendix D. The effects of EHSRs on HOS violation risk is summarized in Table 18. As can be seen in Table 18, the EHSR cohort had 53 percent and 49 percent significantly lower driving-related ($p = 0.01$) and non-driving-related ($p < 0.001$) HOS violation rates than the non-EHSR cohort, respectively.

Table 18. HOS violation rate comparison between non-EHSR and EHSR cohorts.

HOS Violation Type	HOS Violation Rate Ratio (EHSR vs. Non-EHSR)	Estimated HOS Violation Rate Reduction	95% CI Lower Bound	95% CI Higher Bound	Chi-Square	p-Value
Driving-Related*	0.47	0.53	0.26	0.83	6.69	0.010
Non-driving-Related	0.51	0.49	0.39	0.66	24.71	<0.001

*Operation variable (long, regional) was not included because of convergence issue.

3.3.3 Case Study: Before/After Comparison

Only one carrier, Carrier B, had a clear-cut before-and-after period. The results of the before-and-after crash rate comparison are shown in Table 19. As can be seen in Table 19, there is a considerable drop in crash rates, varying from a 63 percent to a 31 percent reduction in the after period. It cannot be asserted that this drop was due the EHSRs because of time-related confounding factors, such as policy changes and a general drop in crash risk for the entire transportation system. Moreover, Carrier B indicated an increased focus on predictive analytical models during the time of EHSR installation. However, there is no evidence that EHSRs increased crash risk. A before-and-after analysis of Carrier B's HOS violations was not performed due to a small sample of HOS violations in the before period. Due to the constraints of FMCSA's SMS, only 1 month of HOS violations were collected in the before period.

Table 19. Before-and-after EHSR comparison for Carrier B.

Crash Type	EHSR Cohort Crash Count (A)	EHSR Cohort MVMT (B)	EHSR Cohort Crash Rate (A/B)	Non-EHSR Cohort Crash Count (C)	Non-EHSR Cohort MVMT (D)	Non-EHSR Cohort Crash Rate (C/D)
Preventable	509	644	0.79	627	492	1.28
DOT-recordable	97	644	0.15	166	492	0.34
Fatigue-related	9	644	0.01	10	492	0.02
Total Crashes	1,145	644	1.78	1,587	492	3.23

Table 20 shows the model's output for only Carrier B. (See Appendix E for the detailed model output.) The effect of EHSRs was measured by the CRR between non-EHSR-equipped trucks and EHSR-equipped trucks. The crash rate ratio was the exponent of the Poisson regression coefficient. A ratio smaller than 1 indicated the EHSR cohort had a lower crash rate than the non-EHSR cohort.

Table 20. Effects of EHSRs on crash rate for Carrier B.

Crash Type	Crash Rate Ratio (EHSR vs. Non-EHSR)	Estimated Crash Rate Reduction	95% CI Lower Bound	95% CI Higher Bound	Chi-Square	p-Value
Preventable	0.62	0.38	0.55	0.70	64.43	<0.001
DOT-recordable	0.45	0.55	0.35	0.57	39.94	<0.001
Fatigue-related	0.69	0.31	0.28	1.69	0.67	0.413
Total Crashes	0.55	0.45	0.51	0.59	236.93	<0.001

Overall, there were three statistically significant results supporting assertions that EHSRs have an impact on crash risk for Carrier B. More specifically, trucks with EHSRs had a significant 45 percent ($p < 0.001$) lower total crash rate, a 38 percent ($p < 0.001$) lower preventable crash rate, and a 55 percent ($p > 0.001$) lower USDOT-recordable crash rate than non-EHSR trucks. The only crash type that did not differ between the EHSR cohort and non-EHSR cohort was fatigue-related crashes ($p = 0.413$). This may be due to the small sample size of fatigue-related crashes.

4. DISCUSSION

The current study assessed the potential safety benefits of EHSRs installed on Class 7 and 8 trucks as they operated during normal revenue-producing deliveries. Whereas other studies addressed in the literature review assessed the potential safety benefits of EHSRs without a scientific study, with surveys, or crash rates obtained from large national or State crash databases, the current study used real-world data collected from carriers to determine the efficacy of EHSRs. Crash and HOS violation data were collected from 11 carriers representing small, medium, and large carriers hauling a variety of commodities. The data from these carriers included a total of 224,034 truck-years, 82,943 crashes, and 970 HOS violations. These trucks drove a total of 15.6 billion miles over a 5-year period from 2008–2012.

The approach used in this research went far beyond any previous study in this domain. First, the current study used motor carrier data from participating carriers; thus, the resultant data set used in the analyses contained a broad spectrum of crashes, many of which were not required to be reported to State or Federal agencies. Second, the research team collected detailed information on the trucks, thereby allowing the identification of trucks with and without an EHSR installed. Information on the safety management techniques at the participating carriers was also collected, which allowed the research team to control for variables that may have influenced the crash rate. Third, the research team collected mileage information from each truck to control for differences in exposure. Finally, the research team reviewed each crash file to determine if the crash was considered a “claim only” crash (and thus removed from analysis) and if fatigue may have been a contributing factor.

4.1 CONCLUSIONS

The primary safety analysis conducted in this study focused on the potential reduction in crashes for trucks equipped with EHSRs. The data used in the study were divided into two cohorts: trucks equipped with an EHSR and trucks not equipped with an EHSR. The crash data were arranged into four categories: total crashes, preventable crashes, USDOT-recordable crashes, and fatigue-related crashes. HOS violations were also arranged into two categories: driving-related HOS violations and non-driving-related HOS violations. The safety analyses included a Poisson regression model. The results across analyses indicated a strong, positive safety benefit for EHSRs in relation to total crashes, preventable crashes, driving-related HOS violations, and non-driving-related HOS violations.

Trucks equipped with EHSRs had total crash and preventable crash rates (per MVMT) that were significantly lower than the rates for trucks not equipped with EHSRs (e.g., trucks equipped with EHSRs had a 12 percent lower total crash rate and a 5 percent lower preventable crash rate than trucks not equipped with EHSRs). No differences were found between the EHSR cohort and the non-EHSR cohort for USDOT-recordable and fatigue-related crash rates. This result is primarily attributed to the lack of sufficient data (in terms of the number of these types of crashes) to be able to detect safety benefits with statistical significance at the observed level. And, for fatigue-related crashes, the research team was missing critical information (hours slept prior to the crash, last rest period, and driving hours in current shift) to asses if fatigue was a contributing factor.

In terms of HOS violations, trucks equipped with EHSRs had driving-related and non-driving-related HOS violation rates (per MVMT) that were significantly lower than the rates for non-equipped trucks (e.g., trucks equipped with EHSRs had a 53 percent lower driving-related HOS violation rate and a 49 percent lower non-driving-related HOS violation rate than non-equipped trucks).

Results from the current study support the assertions of proponents of EHSRs that there are safety and compliance benefits of EHSRs. Although these proponents asserted EHSRs had safety or HOS compliance benefits, little scientific data were provided to support their statements. See Table 21 for the three studies that provided specific numbers for reductions in crashes and/or HOS violations with the use of EHSRs.

Table 21. Studies with specific claims of reductions in crashes and HOS violations for EHSR-equipped trucks.

Study	Study Overview	Methodology	Results
Cantor, et al., 2009[99]	Examined potential effectiveness of EHSR in reducing HOS violations and number of crashes.	Survey of CMV carriers. Crash data from FMCSA's SAFER and SAFESTAT. Modeled 100% EHSR adoption.	Reduced HOS violations by 12.4%. Reduced total crashes by 15.6%.
XRS Corporation, 2012[100]	Private research on companies using EHSRs.	Methodology not published.	Increased HOS compliance by 27.9%.
Cullen, 2007[101]	Private carrier claims on the effectiveness of EHSRs in increasing HOS compliance.	Methodology not published.	53% reduction in HOS violations per month from 3/2004–3/2007. 72% reduction in OOS rate. 47% reduction in OOS inspections.
Current study	Examined effectiveness of EHSRs in reducing HOS violations and crashes.	Carrier-collected crash and vehicle data. HOS data from roadside inspections.	Significant 5% to 12% reduction in certain crash types. Significant 53% and 49% reduction in driving- and non-driving-related HOS violations, respectively.

Results from this study are in the middle of the range (12–70 percent) of potential HOS violation reduction. The study completed by Cantor, et al. estimated a 15.6 percent and 12.4 percent reduction in crashes and HOS violations, respectively, with 100 percent EHRS adoption using a survey approach combined with national crash and HOS data (as shown in Table 21). The current study found similar reductions in the crash rate, but a far greater reduction in HOS violations (both driving- and non-driving-related). The Cantor, et al. study included a far more representative sample of carriers than the current study; however, the authors were not able to include exposure, nor could they identify which trucks were equipped with an EHSR. Although the current study was able to precisely identify trucks equipped with an EHSR and include the specific yearly mileage for each truck, the results were skewed toward larger, for-hire carriers and may not reflect the general carrier population.

Results presented by the XRS Corporation article (see Table 21) cite an Aberdeen Group study of companies currently using EOBRs to record and manage drivers' HOS compliance. The Aberdeen Group asserts that companies using EOBRs experienced a 27.9 percent increase in HOS compliance. The current study also found that EHSRs reduce HOS violations; however, the current study found an even greater reduction in HOS violations than the XRS Corporation found. The XRS Corporation article did not provide the methodology or data from the Aberdeen Group study. Thus, it is impossible to validate the increase in HOS compliance.

The 2007 study completed by Cullen (see Table 21) presents Shaw Industries' experiences with EOBRs. Between March 2004 and March 2007, Shaw Industries experienced a 53 percent reduction in HOS violations per month with the use of EOBRs. Furthermore, Shaw Industries' out-of-service rates and driver out-of-service inspections were reduced 72 percent and 47 percent, respectively. The current study found similar reductions in HOS violations with EHRS use. Although the reductions presented in Cullen's study show reductions in HOS violations, the article does not present the methodology used to determine the effectiveness of EHSRs. Additionally, it is unknown if confounding factors were controlled in the analyses. Thus, the results presented in Cullen's study cannot be validated and may not reflect the true effects of EOBRs. The current study was able to control for confounding factors (i.e., exposure, OBSSs, operation type, and year) while comparing the crash and HOS violation rates of EHSR-equipped and non-EHSR-equipped trucks.

Taken together, the current study and the other three studies presented in Table 21 clearly show a safety benefit for EHSRs with respect to crashes and HOS violations.

4.2 LIMITATIONS

Although the data set used in the analyses to assess the potential safety benefits of EHSRs was comprehensive, there were several limitations:

- The crash files obtained from participating carriers may have contained errors that are inherent with retrospective crash reconstruction. In turn, these errors could have influenced the evaluation of EHSRs. There was no way to determine the veracity of the crash files.
- The data set in the current study was skewed toward larger, for-hire carriers (only two private fleets participated) and may not represent the overall U.S. trucking population.
- One factor that was not included was driver characteristics, which might affect the crash rate. Due to the high turnover rate in the truck industry, it was difficult to associate a particular truck with all its drivers. Therefore, the analysis was based on trucks and did not factor in driver characteristics.

- Although the research team had no information on the functionality of each EHSR installed on a truck (i.e., the research team could not verify if the EHSR was malfunctioning), the team did assess whether the EHSRs were being used by each carrier to monitor drivers' HOS compliance.
- No driver information was used in the analyses; thus, it is possible that a few drivers were overrepresented in the crashes and the differences in the crash rates may have been the result of these drivers and not the EHSRs.
- Information about each carrier's approach to EHSR installation was collected to ensure data included in the analyses were not systematically biased. Data from Carrier K was excluded from all analyses because of this. However, it is possible, albeit unlikely, that other carriers systematically targeted problem drivers/operations with EHSR installation.
- The design was quasi-experimental and subject to many threats to inferential validity. The results in the current study could be confounded by factors that vary between carriers. Information on these factors was collected; however, it is possible that variables not collected may have confounded the results.
- HOS violation data was collected from FMCSA's SMS. During analyses it was determined that a large percentage of VINs did not match the VINs in the vehicle data set (most likely due to human error in recording the VIN). The non-matching trucks that had HOS violations could have impacted the HOS violation results (either supporting the current analyses or vice versa).

4.3 FUTURE RESEARCH

Although the current study involved the collection of comprehensive truck, carrier, crash, and HOS violation information, the carrier-collected data still rely on retrospective crash reconstruction. This information can be erroneous for a variety of reasons, such as eyewitness recall, limited pre-crash information, and unwillingness to report information for fear of prosecution, termination, or reprimand. A video-based naturalistic truck study would address these concerns. Many trucks would need to be involved to obtain the necessary number of crashes to assess the efficacy of EHSRs. The current study design could be expanded to include a larger, more representative sample. Although there were 224,034 truck-years, 82,943 crashes, and 970 HOS violations in the data set, the number of fatigue-related crashes represented a small portion of these (0.44 percent and 15.3 percent, respectively). Furthermore, analyses could be re-run using HOS violations over a longer period of time (as only the previous 2 years' worth of HOS violations were collected for the current study) using FMCSA's archived data. Future studies could also gather driver-based assessment of EHSRs through surveys or focus groups. Finally, the majority of participating carriers in the current study were large, for-hire carriers. An additional study with small-to-medium carriers (i.e., carriers with less than 250 power units) should be performed.

APPENDIX A: PERCENT OF CRASHES MATCHING A VEHICLE ID OR VIN FROM VEHICLE DATA SET

Table 22. Percent of matching VINs from vehicle data set.

Carrier ID	Percent of Matching Total Crashes	Percent of Matching Preventable Crashes	Percent of Matching USDOT-recordable Crashes	Percent of Matching Fatigue-related Crashes	Percent of Matching Preventable, USDOT-recordable Crashes	Percent of Matching HOS Violations
A	92%	94%	87%	100%	90%	81%
B	88%	90%	88%	90%	85%	78%
C	80%	90%	85%	90%	87%	65%
D	100%	100%	100%	100%	100%	55%
E	98%	NA	100%	100%	NA	59%
F	100%	100%	100%	100%	100%	NA
G	89%	85%	89%	94%	88%	0%
H	95%	94%	97%	100%	94%	93%
I	33%	32%	30%	30%	30%	50%
J	74%	74%	76%	73%	76%	83%
L	51%	NA	44%	45%	NA	48%

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APPENDIX B: FIGURES FOR CRASH RATES BY EHSR COHORT ACROSS CARRIERS

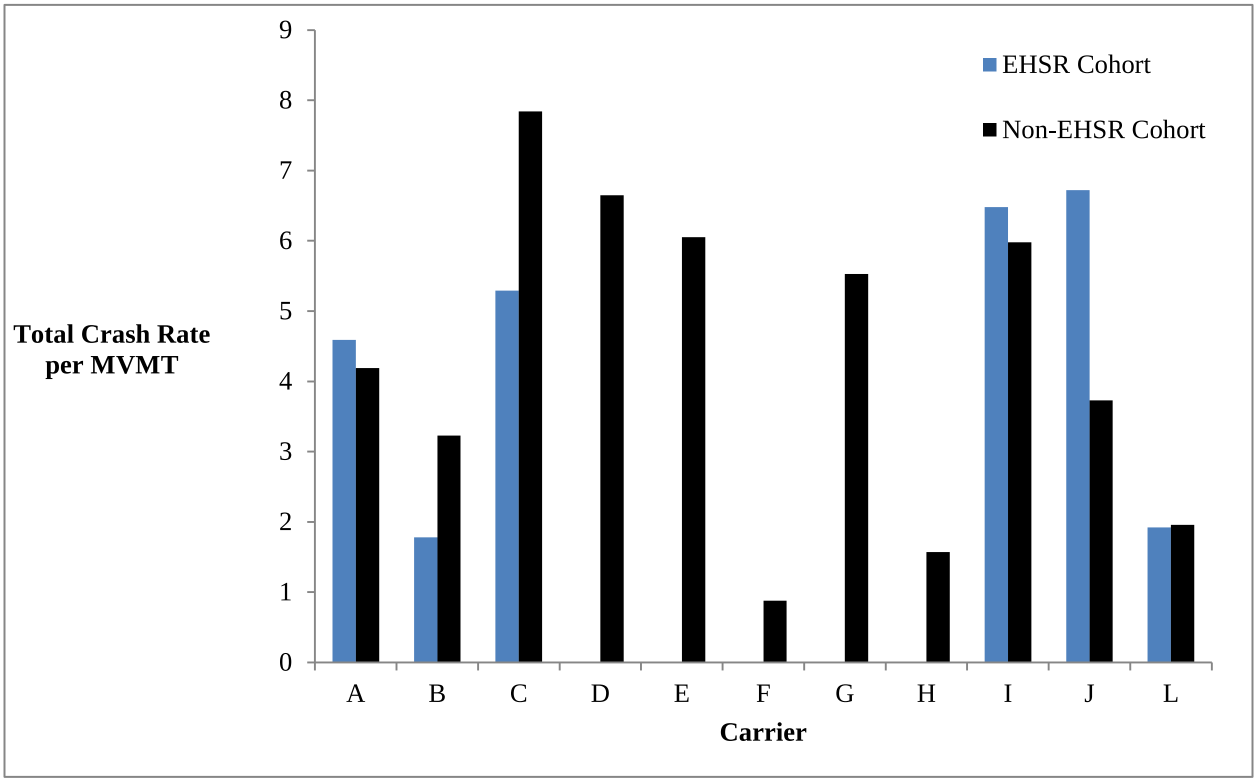

Figure 8. Bar graph. Total crash rate by EHSR cohort across carrier.

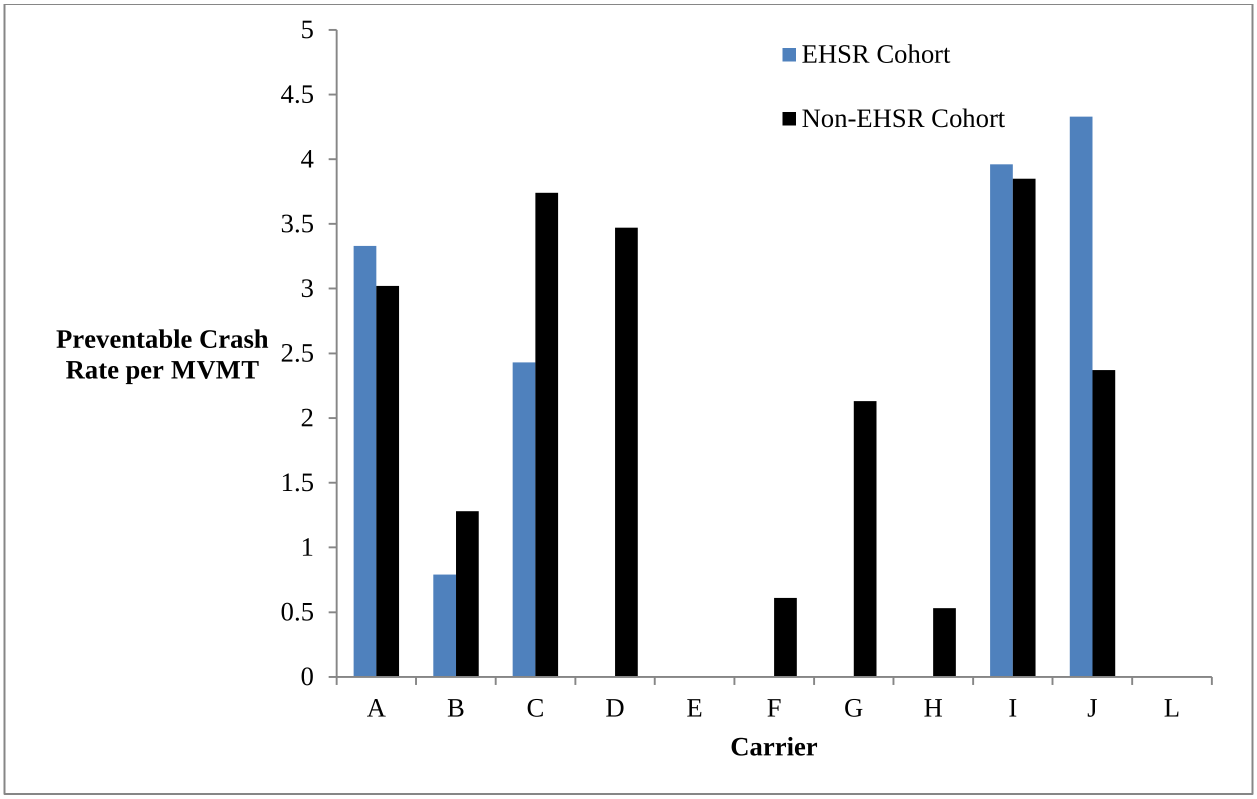

Figure 9. Bar graph. Preventable crash rate by EHSR cohort across carrier.

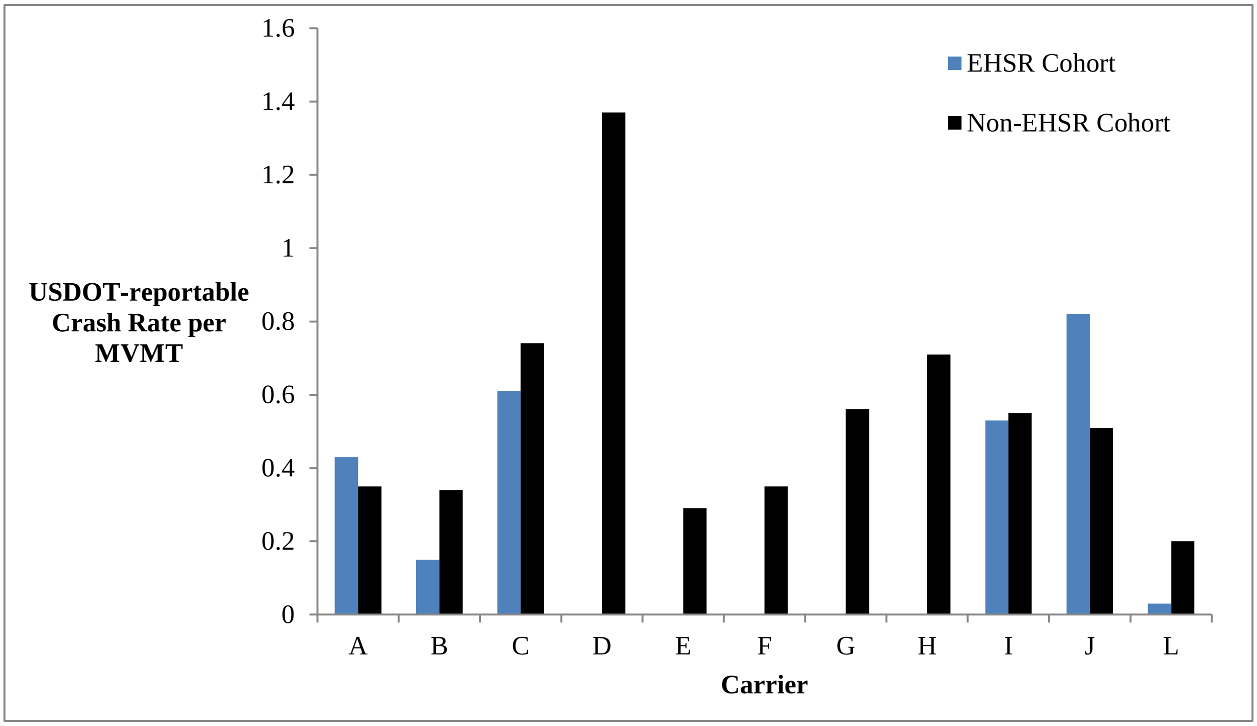

Figure 10. Bar graph. USDOT-recordable crash rate by EHSR across carrier.

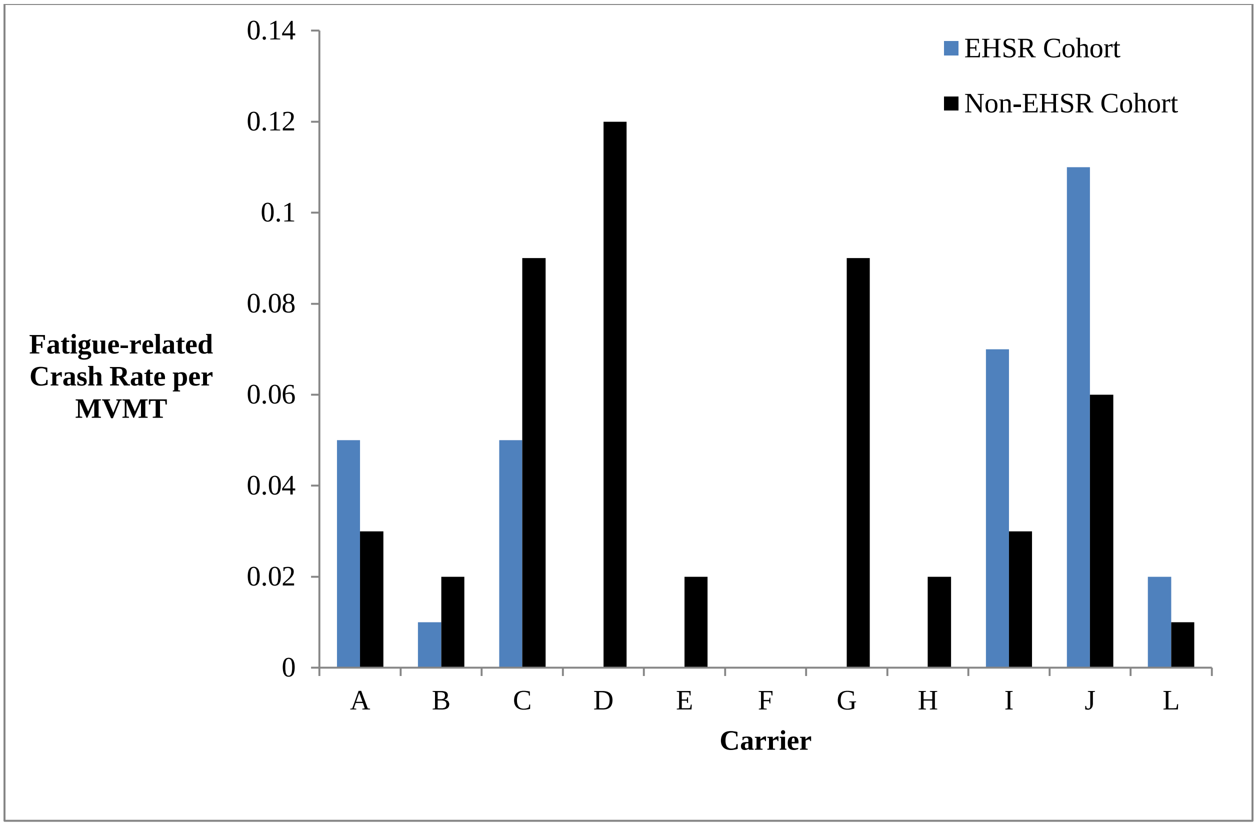

Figure 11. Bar graph. Fatigue-related crash rate by EHSR cohort across carrier.

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APPENDIX C: FIGURES FOR HOS VIOLATION RATES BY EHSR COHORT ACROSS CARRIERS

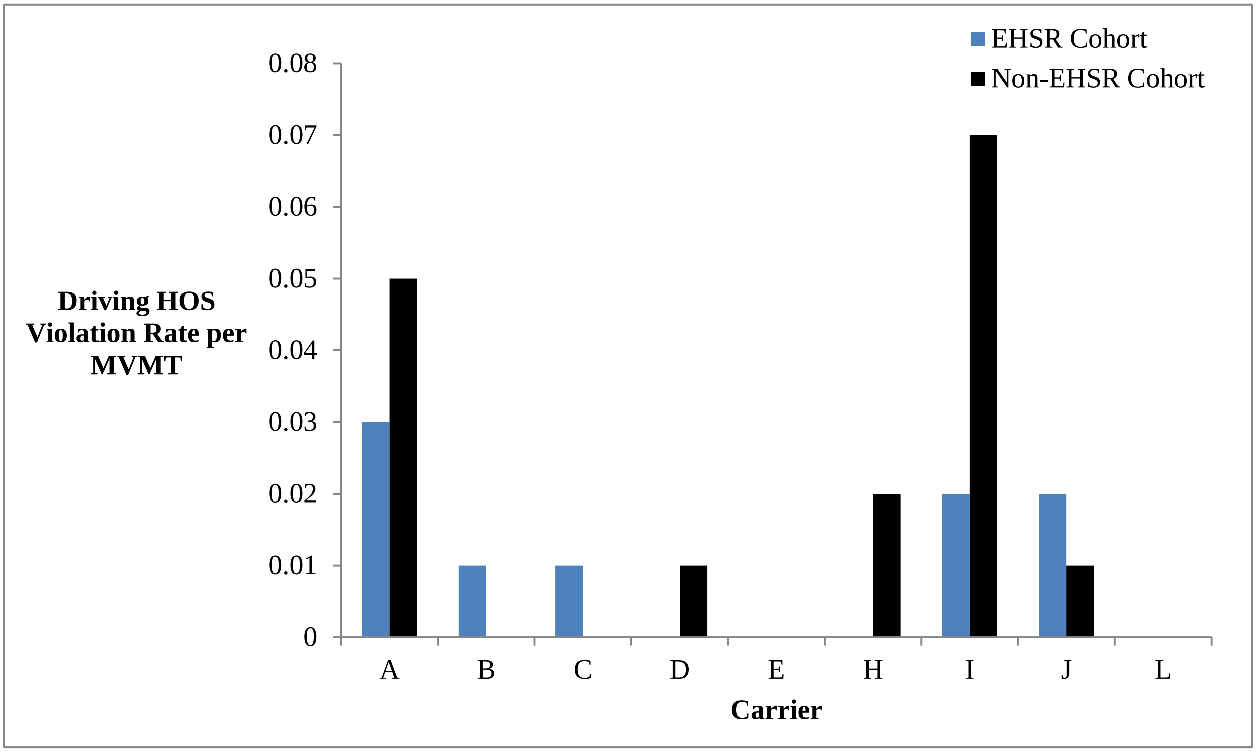

Figure 12. Bar graph. Driving-related HOS violation rate by EHSR cohort across carrier.

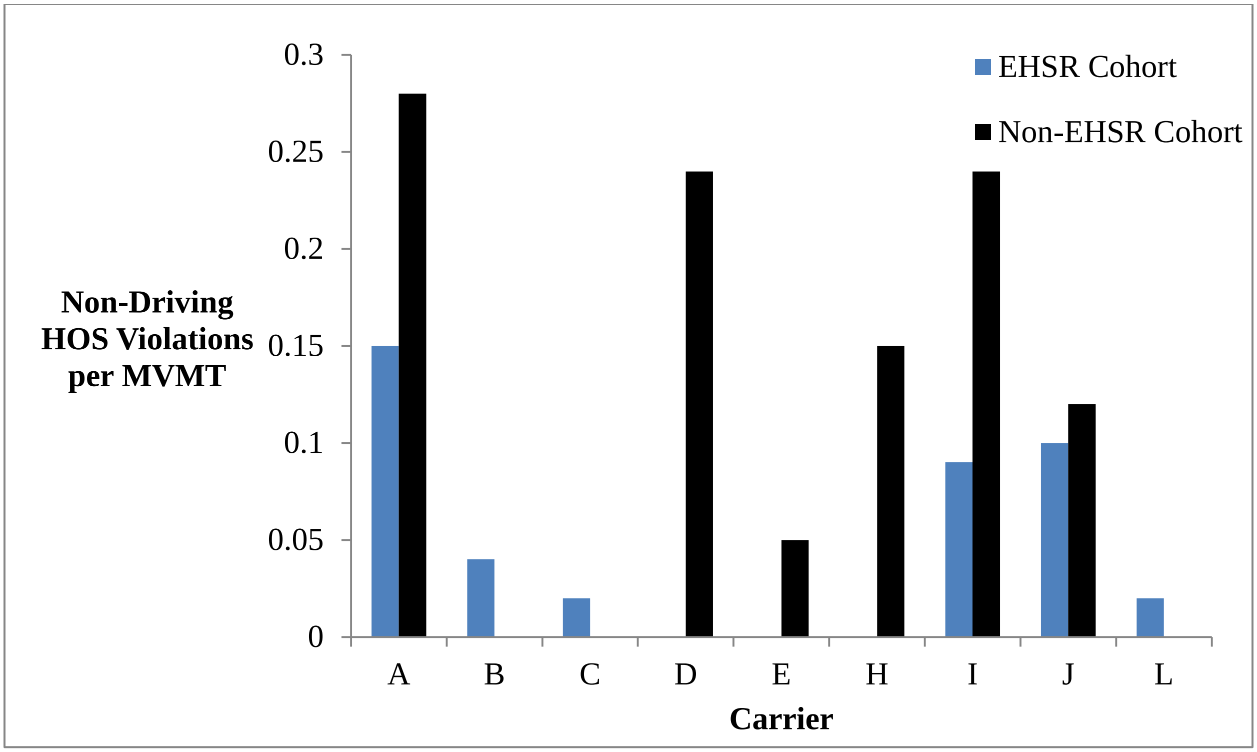

Figure 13. Bar graph. Non-driving-related HOS violation rate by EHSR cohort across carrier.

APPENDIX D: DETAILED CRASH RISK MODEL OUTPUTS

Table 23. Total crash rate detailed model output.

Model Parameter	Parameter Level	Degrees of Freedom	Crash Rate Ratio	Standard Error	95% CI Lower Bound	95% CI Upper Bound	Chi Square	p-Value
Intercept	N/A	1	-12.0411	0.1571	-12.3490	-11.7331	5873.51	<.0001
EHSR Status	No	1	0.1246	0.0117	0.1016	0.1477	112.63	<.0001
EHSR Status	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Year	2008	1	0.3133	0.0141	0.2857	0.3408	497.12	<.0001
Year	2009	1	0.0766	0.0139	0.0493	0.1038	30.34	<.0001
Year	2010	1	0.1897	0.0117	0.1668	0.2127	262.01	<.0001
Year	2011	1	0.1322	0.0109	0.1109	0.1536	147.99	<.0001
Year	2012	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Operation	Long	1	-1.1003	0.1550	-1.4041	-0.7965	50.38	<.0001
Operation	Regional	1	-1.0138	0.1550	-1.3177	-0.7099	42.75	<.0001
Operation	Unknown	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
OBSS?	No	1	-0.2522	0.0129	-0.2775	-0.2268	381.29	<.0001
OBSS?	Unknown	1	-0.3005	0.0222	-0.3441	-0.2569	182.56	<.0001
OBSS?	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Carrier ID	A	1	0.7227	0.0341	0.6558	0.7896	447.98	<.0001
Carrier ID	B	1	-1.0811	0.1582	-1.3912	-0.7711	46.72	<.0001
Carrier ID	C	1	0.1172	0.1566	-0.1897	0.4240	0.56	0.4541
Carrier ID	D	1	0.1526	0.1586	-0.1582	0.4634	0.93	0.3359
Carrier ID	E	1	1.1463	0.0325	1.0826	1.2101	1240.63	<.0001
Carrier ID	F	1	-1.9813	0.2304	-2.4328	-1.5297	73.96	<.0001
Carrier ID	G	1	-0.1141	0.1568	-0.4214	0.1933	0.53	0.4670

Model Parameter	Parameter Level	Degrees of Freedom	Crash Rate Ratio	Standard Error	95% CI Lower Bound	95% CI Upper Bound	Chi Square	p-Value
Carrier ID	H	1	-0.3011	0.0899	-0.4773	-0.1250	11.23	0.0008
Carrier ID	I	1	1.0930	0.0262	1.0417	1.1443	1742.57	<.0001
Carrier ID	J	1	1.0012	0.0304	0.9416	1.0607	1086.53	<.0001
Carrier ID	L	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Scale	N/A	0	1.0000	0.0000	1.0000	1.0000	N/A	N/A

Table 24. Preventable crash detailed model output (operation variable not included in the model).

Model Parameter	Parameter Level	DF	Crash Rate Ratio	Standard Error	95% CI Lower Bound	95% CI Upper Bound	Chi Square	p-Value
Intercept	N/A	1	-36.9282	0.0170	-36.9615	-36.8949	4727229	<.0001
EHSR Status	No	1	0.0524	0.0165	0.0201	0.0847	10.13	0.0015
EHSR Status	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Year	2008	1	0.3592	0.0197	0.3207	0.3978	333.55	<.0001
Year	2009	1	0.0371	0.0198	-0.0016	0.0759	3.53	0.0603
Year	2010	1	0.0367	0.0168	0.0037	0.0696	4.76	0.0291
Year	2011	1	0.0982	0.0157	0.0675	0.1290	39.11	<.0001
Year	2012	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
OBSS?	No	1	-0.2157	0.0178	-0.2505	-0.1809	147.28	<.0001
OBSS?	Unknown	1	0.0221	0.0312	-0.0390	0.0833	0.50	0.4781
OBSS?	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Carrier ID	A	1	24.1913	0.0265	24.1394	24.2432	833782	<.0001
Carrier ID	B	1	23.0033	0.0338	22.9369	23.0696	461869	<.0001
Carrier ID	C	1	24.2718	0.0155	24.2414	24.3023	2440097	<.0001
Carrier ID	D	1	24.1778	0.0371	24.1051	24.2505	425129	<.0001

Model Parameter	Parameter Level	DF	Crash Rate Ratio	Standard Error	95% CI Lower Bound	95% CI Upper Bound	Chi Square	p-Value
Carrier ID	E	1	0.6771	4140.063	-8113.70	8115.051	0.00	0.9999
Carrier ID	F	1	22.5526	0.2046	22.1515	22.9537	12144.3	<.0001
Carrier ID	G	1	23.8335	0.0205	23.7932	23.8737	1347786	<.0001
Carrier ID	H	1	22.6014	0.1503	22.3067	22.8961	22601.8	<.0001
Carrier ID	I	1	24.5510	0.0214	24.5090	24.5930	1314838	<.0001
Carrier ID	J	0	24.3849	0.0000	24.3849	24.3849	N/A	N/A
Carrier ID	L	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Scale	N/A	0	1.0000	0.0000	1.0000	1.0000	N/A	N/A

Table 25. USDOT-recordable detailed model output.

Model Parameter	Parameter Level	DF	Crash Rate Ratio	Standard Error	95% CI Lower Bound	95% CI Upper Bound	Chi Square	p-Value
Intercept	N/A	1	-15.6207	0.7166	-17.0251	-14.2162	475.19	<.0001
EHSR Status	No	1	0.0100	0.0358	-0.0602	0.0801	0.08	0.7806
EHSR Status	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Year	2008	1	0.4157	0.0419	0.3336	0.4978	98.38	<.0001
Year	2009	1	0.1108	0.0420	0.0285	0.1932	6.96	0.0084
Year	2010	1	0.2338	0.0356	0.1640	0.3036	43.09	<.0001
Year	2011	1	0.1979	0.0336	0.1322	0.2637	34.77	<.0001
Year	2012	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Operation	Long	1	-0.3987	0.7088	-1.7880	0.9905	0.32	0.5738
Operation	Regional	1	-0.4281	0.7091	-1.8179	0.9616	0.36	0.5460
Operation	Unknown	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
OBSS?	No	1	-0.2498	0.0394	-0.3270	-0.1725	40.17	<.0001

Model Parameter	Parameter Level	DF	Crash Rate Ratio	Standard Error	95% CI Lower Bound	95% CI Upper Bound	Chi Square	p-Value
OBSS?	Unknown	1	-0.1334	0.0681	-0.2669	0.0002	3.83	0.0503
OBSS?	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Carrier ID	A	1	1.1453	0.1322	0.8862	1.4044	75.06	<.0001
Carrier ID	B	1	0.1685	0.7190	-1.2407	1.5778	0.05	0.8147
Carrier ID	C	1	1.4375	0.7154	0.0353	2.8397	4.04	0.0445
Carrier ID	D	1	2.0507	0.7188	0.6418	3.4595	8.14	0.0043
Carrier ID	E	1	1.1422	0.1415	0.8650	1.4195	65.19	<.0001
Carrier ID	F	1	0.7193	0.7637	-0.7775	2.2161	0.89	0.3462
Carrier ID	G	1	1.2024	0.7160	-0.2010	2.6058	2.82	0.0931
Carrier ID	H	1	1.9759	0.1613	1.6597	2.2921	150.01	<.0001
Carrier ID	I	1	1.6897	0.1081	1.4778	1.9015	244.30	<.0001
Carrier ID	J	1	1.8058	0.1194	1.5718	2.0399	228.69	<.0001
Carrier ID	L	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Scale	N/A	0	1.0000	0.0000	1.0000	1.0000	N/A	N/A

Table 26. Fatigue-related crash detailed model output.

Model Parameter	Parameter Level	DF	Crash Rate Ratio	Standard Error	95% CI Lower Bound	95% CI Upper Bound	Chi Square	p-Value
Intercept	N/A	1	-34.8629	0.1319	-35.1214	-34.6043	69837.9	<.0001
EHSR Status	No	1	0.0099	0.1056	-0.1972	0.2169	0.01	0.9257
EHSR Status	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Year	2008	1	0.5960	0.1222	0.3565	0.8354	23.80	<.0001
Year	2009	1	0.2586	0.1227	0.0181	0.4991	4.44	0.0351
Year	2010	1	0.1014	0.1172	-0.1282	0.3311	0.75	0.3866

Model Parameter	Parameter Level	DF	Crash Rate Ratio	Standard Error	95% CI Lower Bound	95% CI Upper Bound	Chi Square	p-Value
Year	2011	1	0.3001	0.1019	0.1004	0.4998	8.68	0.0032
Year	2012	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Operation	Long	1	17.2678	0.3547	16.5726	17.9631	2369.69	<.0001
Operation	Regional	1	17.1010	0.2476	16.6158	17.5863	4771.06	<.0001
Operation	Unknown	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
OBSS?	No	1	-0.3678	0.1108	-0.5850	-0.1507	11.03	0.0009
OBSS?	Unknown	1	-0.4387	0.2013	-0.8333	-0.0442	4.75	0.0293
OBSS?	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Carrier ID	A	1	0.5003	0.3971	-0.2781	1.2786	1.59	0.2078
Carrier ID	B	1	16.7418	0.2556	16.2408	17.2428	4290.06	<.0001
Carrier ID	C	1	18.4031	0.1037	18.1997	18.6064	31467.6	<.0001
Carrier ID	D	1	19.1100	0.2001	18.7178	19.5022	9119.81	<.0001
Carrier ID	E	1	0.3742	0.4362	-0.4808	1.2292	0.74	0.3910
Carrier ID	F	1	-1.3291	10949.65	-21462.3	21459.59	0.00	0.9999
Carrier ID	G	0	18.6919	0.0000	18.6919	18.6919	N/A	N/A
Carrier ID	H	1	0.4154	0.7475	-1.0496	1.8805	0.31	0.5784
Carrier ID	I	1	0.7051	0.3118	0.0940	1.3162	5.11	0.0237
Carrier ID	J	1	1.3705	0.3552	0.6743	2.0666	14.89	0.0001
Carrier ID	L	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Scale	N/A	0	1.0000	0.0000	1.0000	1.0000	N/A	N/A

Table 27. Driving-related HOS violation detailed model output (operation variable not included in the model).

Model Parameter	Parameter Level	DF	Crash Rate Ratio	Standard Error	95% CI Lower Bound	95% CI Upper Bound	Chi Square	p-Value
Intercept	N/A	1	-20.1212	1.0358	-22.1514	-18.0910	377.34	<.0001
EHSR Status	No	1	0.7603	0.2940	0.1840	1.3366	6.69	0.0097
EHSR Status	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Year	2010	1	-1.8664	0.4067	-2.6635	-1.0694	21.06	<.0001
Year	2011	1	0.2573	0.1762	-0.0880	0.6027	2.13	0.1441
Year	2012	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
OBSS?	No	1	-0.4177	0.2845	-0.9753	0.1399	2.16	0.1420
OBSS?	Unknown	1	1.1114	0.5763	-0.0181	2.2408	3.72	0.0538
OBSS?	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Carrier ID	A	1	2.0984	1.1669	-0.1886	4.3854	3.23	0.0721
Carrier ID	B	1	1.2270	1.1310	-0.9897	3.4437	1.18	0.2780
Carrier ID	C	1	1.7558	1.0266	-0.2562	3.7678	2.93	0.0872
Carrier ID	D	0	0.0713	1.2986	-2.4739	2.6166	0.00	0.9562
Carrier ID	E	1	-20.7099	30569.92	-59936.6	59895.22	0.00	0.9995
Carrier ID	H	1	2.4521	1.2520	-0.0019	4.9060	3.84	0.0502
Carrier ID	I	1	3.3826	1.0373	1.3494	5.4157	10.63	0.0011
Carrier ID	J	1	2.4029	1.0438	0.3572	4.4486	5.30	0.0213
Carrier ID	L	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A

Table 28. Non-driving-related HOS violation detailed model output.

Model Parameter	Parameter Level	DF	Crash Rate Ratio	Standard Error	95% CI Lower Bound	95% CI Upper Bound	Chi Square	p-Value
Intercept	N/A	1	-35.5036	0.2560	-36.0054	-35.0018	19229.6	<.0001

Model Parameter	Parameter Level	DF	Crash Rate Ratio	Standard Error	95% CI Lower Bound	95% CI Upper Bound	Chi Square	p-Value
EHSR Status	No	1	0.6805	0.1369	0.4122	0.9488	24.71	<.0001
EHSR Status	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Year	2010	1	-1.3149	0.1475	-1.6040	-1.0258	79.46	<.0001
Year	2011	1	0.2391	0.0811	0.0801	0.3980	8.69	0.0032
Year	2012	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Operation	Long	1	18.0929	0.4197	17.2704	18.9154	1858.75	<.0001
Operation	Regional	1	17.8378	0.4089	17.0363	18.6392	1903.10	<.0001
Operation	Unknown	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
OBSS?	No	1	-0.4398	0.1363	-0.7069	-0.1727	10.41	0.0013
OBSS?	Unknown	1	0.8130	0.2282	0.3657	1.2604	12.69	0.0004
OBSS?	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Carrier ID	A	1	1.3505	0.3864	0.5930	2.1079	12.21	0.0005
Carrier ID	B	1	18.1666	0.3189	17.5416	18.7916	3245.33	<.0001
Carrier ID	C	1	18.2928	0.3200	17.6656	18.9199	3268.23	<.0001
Carrier ID	D	0	18.9466	0.0000	18.9466	18.9466	N/A	N/A
Carrier ID	E	1	0.3534	0.3945	-0.4198	1.1267	0.80	0.3703
Carrier ID	H	1	1.9296	0.4165	1.1133	2.7458	21.46	<.0001
Carrier ID	I	1	2.0558	0.3205	1.4276	2.6840	41.14	<.0001
Carrier ID	J	1	1.4910	0.3342	0.8360	2.1461	19.91	<.0001
Carrier ID	L	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Scale	N/A	0	1.0000	0.0000	1.0000	1.0000	N/A	N/A

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APPENDIX E: DETAILED CRASH RISK MODEL OUTPUT FOR BEFORE-AFTER COMPARISON FOR CARRIER B

Table 29. Total crash risk detailed model output for Carrier B.

Model Parameter	Parameter Level	DF	Crash Rate Ratio	Standard Error	95% CI Lower Bound	95% CI Upper Bound	Chi Square	p-Value
Intercept	-	1	-13.2404	0.0296	-13.2984	-13.1825	200729	<.0001
EHSR Status	No	1	0.5968	0.0388	0.5208	0.6728	236.93	<.0001
EHSR Status	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Scale	-	0	1.0000	0.0000	1.0000	1.0000	N/A	N/A

Table 30. Preventable crash risk detailed model output for Carrier B.

Model Parameter	Parameter Level	DF	Crash Rate Ratio	Standard Error	95% CI Lower Bound	95% CI Upper Bound	Chi Square	p-Value
Intercept	N/A-	1	-14.0511	0.0443	-14.1380	-13.9643	100494	<.0001
EHSR Status	No	1	0.4789	0.0597	0.3620	0.5958	64.43	<.0001
EHSR Status	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A	-
Scale	N/A	0	1.0000	0.0000	1.0000	1.0000	N/A	-

Table 31. USDOT-recordable crash risk detailed model output for Carrier B.

Model Parameter	Parameter Level	DF	Crash Rate Ratio	Standard Error	95% CI Lower Bound	95% CI Upper Bound	Chi Square	p-Value
Intercept	-	1	-15.7089	0.1015	-15.9079	-15.5099	23936.6	<.0001
EHSR Status	No	1	0.8077	0.1278	0.5572	1.0582	39.94	<.0001
EHSR Status	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A	N/A
Scale	N/A	0	1.0000	0.0000	1.0000	1.0000	N/A	N/A

Table 32. Fatigue-related crash risk detailed model output for Carrier B.

Model Parameter	Parameter Level	DF	Crash Rate Ratio	Standard Error	95% CI Lower Bound	95% CI Upper Bound	Chi Square	p-Value
Intercept	N/A	N/A	1	-18.0864	0.3333	-18.7397	-17.4330	2944.05
EHSR Status	No	No	1	0.3758	0.4595	-0.5248	1.2763	0.67
EHSR Status	Yes	Yes	0	0.0000	0.0000	0.0000	0.0000	N/A
Scale	N/A	N/A	1	-18.0864	0.3333	-18.7397	-17.4330	2944.05

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